

EARLY SUBNEOLITHIC CERAMIC SEQUENCES IN EASTERN FENNOSCANDIA— A BAYESIAN APPROACH

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ABSTRACT. In this contribution, we establish a radiocarbon-based chronology of early ceramic sequences in eastern Fennoscandia utilizing a Bayesian approach. The data consist of 56 individual ¹⁴C dates from charred or fermented food remains (charred crust, food residue) and birch bark tar used to seal cracks in vessels. We present the results of the models, discuss the chronological boundaries obtained, and compare the outcome with contemporary archaeological knowledge of the Subneolithic in eastern Fennoscandia. We also look at the role of charred crust $\delta^{13}\text{C}$ values as indicators of reservoir effect present in the dates, perform some preliminary correction procedures for the dates, and discuss their effect on the chronologies.

INTRODUCTION

The chronology of the Subneolithic is still heavily laid on the foundation of artifact typology. In eastern Fennoscandia, as elsewhere, changes in the ornamentation and the technology of the ceramics have been considered as chronological boundaries. Furthermore, the regional variability of the ceramics is often interpreted to reflect cultural or technological boundaries between the regions (cf. Carpelan 1999; Pesonen and Leskinen 2009). Accelerator mass spectrometry (AMS) dating has provided a tool to date individual vessels, rendering absolute chronologies with better resolution possible (e.g. Carpelan 1999, 2002; Pesonen 1999a, 2004). Bayesian modeling, introduced into archaeology in the 1990s, allows integrating archaeological knowledge into natural scientific dates to define joint posteriors for the chronological boundaries.

In archaeology, the Bayesian approach has gained popularity during the recent decade, following the pioneering work carried out in 1990s, particularly in Britain (e.g. Buck et al. 1991; Bayliss 2009; Bronk Ramsey 2009a,b). In Finland, the use of the approach has, until recently, been limited to individual radiocarbon calibrations. One of the authors has pioneered the inclusion of stratigraphical information into model dates in Finland, in a project for the Middle Age museum Aboa Vetus in Turku (Oinonen et al. 2011). Within a broader context, the authors' Argeopop project has proceeded in spatiotemporal modeling of past human occupation in the area relying on ¹⁴C data to form a timeline for the study (Onkamo et al., these proceedings). In this work, and tightly related to the Argeopop efforts, we perform a Bayesian analysis of early ceramic phases in eastern Fennoscandia.

BACKGROUND: CHRONOLOGY OF SUBNEOLITHIC CERAMICS IN EASTERN FENNOSCANDIA

Populations in eastern Fennoscandia developed ceramic manufacturing skills under the influence of ceramic traditions in northwestern Russia, beginning about 5300–5200 cal BC. There does not seem to exist any pottery preforms in the region, which indicates that pottery was introduced here either as a ready-made product or as manufactured here by skilled potters. It is known that there were pottery traditions within hunter-gatherer populations in the Volga-Oka interfluvium and along the upper reaches of the Volga River already about 6500–6000 cal BC (e.g. Carpelan 1999; Dolukhanov et al. 2005; Tsetlin 2008). The latter has been seen as a source for the early production of ceramics in eastern Fennoscandia, as well (Carpelan 1999:253). From 5300–5200 cal BC onwards, ceramics have

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been manufactured almost continuously among the hunter-gatherer societies in the region. It should be stressed that in the northern boreal forest zone, the ceramics were not a part of the “Neolithic package,” where the agriculture plays a decisive role. Instead, the ceramics were adopted in Subneolithic societies in wide areas of Asia and eastern Europe (e.g. Jordan and Zvelebil 2009).

The wide distribution of ceramics among hunter-gatherer societies and the easily recognizable stylistic and technological changes in it have increased its potential as a chronological marker in archaeology. In Finland and the rest of eastern Fennoscandia, current Subneolithic chronology is strongly founded on the ceramic typology—almost all the phases are named according to ceramic styles. The postglacial uplift of Earth’s crust and the corresponding displacement of the shore level made it possible to date the shorebound settlement sites in relation to each other (Europaeus 1926; Europaeus-Äyräpää 1930; Äyräpää 1956). This way, the ceramic typology was linked to shoreline chronology almost 90 yr ago and the ^{14}C dating eventually gave the absolute timing for the periods (e.g. Siiriäinen 1970). The advent of the AMS technique finally provided a tool to directly date the artifacts, at least in special cases. The charred crust and birch bark tar on the pottery surface are such cases, and this possibility has been used widely in archaeology during the last decades in order to gain more accuracy in the dating of the periods. The current chronology of the Finnish Subneolithic is based on individual AMS datings (Carpelan 1999, 2002; Pesonen 1999a, 2004).

Although the ^{14}C methodologies are reasonably well established, systematic uncertainties may occur. Treating the dates among a typological sequence allows for investigating possible outliers. On the other hand, detailed archaeological *a priori* knowledge on the typological phases has been formed by the archaeological community during the last 100 yr. Bayesian modeling offers a possibility to include this invaluable information of successive typological phases into the actual computational analysis.

METHODOLOGY

Charred Crust and Birch Bark Tar AMS Radiocarbon Dates

The data of this study is composed of 55 AMS and 1 GPC dates performed on charred crust or birch bark tar adhered to the surface of Subneolithic pottery in eastern Fennoscandia. In terms of provenance, the study material comes mainly from Finland (38), with additional dates from Norway (10) and Russia (8) (Figure 1, Table 1). Charred crust is a general name for the charred or fermented food remains crusted on the vessel walls. Several studies show that the material most probably derives from a cooking or fermentation process connected with food preparation. The composition of the food ingredients can in some cases be deduced from the crust. The results have shown a great variability in the eating habits throughout the world (e.g. Arrhenius and Lidén 1989; Fischer and Heine-meier 2003; Hopia et al. 2003; Leskinen 2003; Craig et al. 2007 and references therein).

Birch bark tar is a distillation product, which derives from heating wood from birch trees (usually the outer bark) under reducing conditions. A number of uses have been suggested for this product including hafting stone and bone implements, waterproofing and caulking ceramic and other vessels and—because of the tooth marks often visible in the lumps—as a “chewing gum,” hence the often used name “chewing resin” (e.g. Pesonen 1999a; Leskinen 2003; Stern et al. 2006; Vahur et al. 2011). One of its uses in eastern Fennoscandia has been sealing the cracks in ceramic vessels, especially during the Typical Combed Ware period (~4000–3500 cal BC), though some earlier and later examples of birch bark tar use exist (e.g. Carpelan 2004; Leskinen and Pesonen 2005; Pesonen 1994, 1999a).

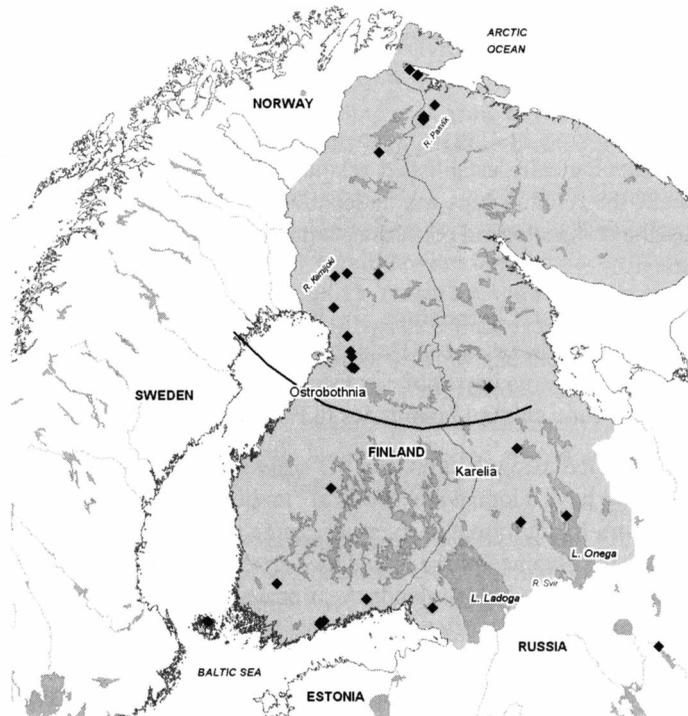


Figure 1 The distribution of Säräisniemi 1, Sperrings 1, and Sperrings 2 ceramic crust and birch bark tar dates in eastern Fennoscandia and the division of the study area into northern and southern areas. The study area comprises Finland without its northwestern arm, a small part of northern Norway east of the Tana River and Fiord, Murmansk Oblast, the Karelian Republic, and part of Leningrad Oblast of Russia. Also, a Sperrings 1 date from Veksa 3 site by Lake Kubana in Vologda Oblast, northwest Russia, has been included in the study.

Table 1 The number of dates on each studied ceramic style from different regions of eastern Fennoscandia.

Ceramic type	Norway	Finland	Russia	Total
Säräisniemi 1	10	10	2	22
Sperrings 1		22	6	28
Sperrings 2		6		6
Total	10	38	8	56

Most of the dates collected for this study have been published earlier and the use of a few unpublished ones has been consented by the original submitters. The data is included in the database of Finnish archaeological ¹⁴C dates, while the ones from the neighboring countries have been collected from the literature and included in the analysis since they were assessed to be representative for this study (e.g. Skandfer 2005, 2009; Hallgren 2008; Piezonka 2008; see Appendix 1 for the full reference list).

The study was restricted to the earliest ceramic styles present in eastern Fennoscandia, i.e. to the archaeological period commonly termed the “Early Combed Ware period.” These include Säräisniemi 1, Sperrings 1, and Sperrings 2 traditions. In addition, the early ceramic sequence of eastern

Fennoscandia includes other contemporary styles as well. These were excluded from this study due to their lack of ^{14}C dates (e.g. Early Asbestos Ware and Jäkärälä Ware; Edgren 1964; Pesonen 1996).

Models

We have performed the analyses in 2 ways: independently style-by-style (single-phase model) or by assuming certain archaeologically established relationships between the styles (2-phase model). Considering the latter, the relationships are understood as *a priori* information integrated in the model. This contains the archaeological consensus that has been formed during a century of research into Stone Age pottery.

Due to the limited number of dates in the study, it is not possible to trace the spatiotemporal rate for the spread of ceramic innovations (as in e.g. Dolukhanov et al. 2005). The only attempt in this sense has been to divide the research area into northern and southern sections. The boundaries were drawn between some distinct ceramic cultural boundaries in Finnish and northwest Russian prehistory.

The analyses were conducted using the OxCal v 4.1 software (Bronk Ramsey 2009a) with outlier detection. For outliers, we have adopted the “General” model with the basic settings recommended in Bronk Ramsey (2009b). In addition, the reservoir correction model was experimented for all the data sets. The results for the obtained phase boundaries are discussed as average values provided by the OxCal code. Typically, the posterior calendar year probability distributions for boundaries were reasonably normally distributed to justify this selection. In addition, the mean value is a convenient way to provide point estimates and uncertainties for comparing the posterior calendar year probability distributions. However, we have also given the 1σ and 2σ highest posterior density regions in Table 2. An example of the OxCal code is given in Appendix 2.

Table 2 Results of the analyses. The datings from literature in column 2 are from Carpelan (1999:273). The models used are single-phase models (individual, allows overlapping) except for the Sperrings 1 and 2 succession in the southern study area, where a 2-phase model with a transition boundary was used. The first and last values in the given cell are the start boundary and the end boundary, respectively. The boundaries between successive phases are marked with an asterisk (*).

Ceramic type, area	Literature (cal BC)	Without reservoir correction, mean value (cal BC)	Without reservoir correction, 68% HPD region (cal BC)	Without reservoir correction, 95% HPD region (cal BC)	With reservoir correction, mean value (cal BC)	With reservoir correction, 68% HPD region (cal BC)	With reservoir correction, 95% HPD region (cal BC)
Säräisniemi 1, North	5000 4500	5365 ± 145 4560 ± 85	5560–5220 4660–4505	5615–5085 4720–4395	5190 ± 100 4455 ± 110	5265–5075 4575–4350	5390–5010 4670–4260
Säräisniemi 1, South	NA	NA	NA	NA	NA	NA	NA
Sperrings 1, North	5100 4500	4880 ± 165 4500 ± 165	4970–4705 4685–4425	5210–4605 4765–4190	4860 ± 160 4505 ± 160	4950–4695 4685–4435	5175–4595 4760–4210
Sperrings 1, South	5100 4500	5165 ± 65 4365 ± 65	5215–5085 4430–4320	5300–5040 4485–4420	5155 ± 65 4360 ± 60	5205–5175 4430–4320	5295–5035 4460–4225
Sperrings 2, North	4500 4000	NA	NA	NA	NA	NA	NA
Sperrings 2, South	4500 4000	4410 ± 95 4185 ± 110	4470–4320 4315–4145	4595–4260 4330–3975	4365 ± 90 4170 ± 115	4400–4270 4305–4115	4555–4240 4325–3950
Sperrings 1→2, South	5100 4500* 4000	5150 ± 65 4375 ± 35* 4210 ± 85	5200–5075 4420–4340* 4315–4185	5285–5035 4450–4295* 4330–4035	5145 ± 65 4400 ± 30* 4175 ± 95	5195–5070 4430–4370* 4300–4130	5280–5030 4465–4335* 4325–3990

Stable Carbon Isotope Ratios and the Reservoir Effect

It has been known for a while that the ^{14}C contents of marine organisms differ from the contemporary atmospheric ^{14}C content, reflected by organisms in terrestrial environments. The discrepancy between the ^{14}C ages of the animal or human dieting on marine or terrestrial game is called the reservoir effect. The global average of the reservoir effect is close to 400 yr (Reimer et al. 2009).

Concerning the Arctic Sea, a full reservoir effect of $R_{\text{Arctic}} = 370 \pm 77$ yr can be adopted based on the average of the existing 10 measured values along with the coastline (<http://calib.qub.ac.uk/marine/>). On the other hand, the history of the Baltic Sea has been characterized by mixing of freshwater and saltwater sources (see e.g. Eronen 2005). Therefore, the size of the reservoir effect within the basin varies both geographically and temporally. The estimates vary depending e.g. on the influence of the Atlantic water masses and on the local topography and the bedrock around the basin (e.g. Olsson 1980, 1991, 1996; Lanting and van der Plicht 1998; Hedenström and Possnert 2001). For the full Baltic Sea reservoir effect, we adopt the average of the 8 measured values available: 279 ± 77 yr (<http://calib.qub.ac.uk/marine/>). To account for the suspected spatiotemporal variation, we introduce a slightly larger uncertainty: $R_{\text{Baltic}} = 279 \pm 100$ yr.

Obviously, the charred food remains crusted on the vessel walls may carry the reservoir effect within the ^{14}C samples, in particular, if the food ingredients were of marine origin. Albeit reservoir effects are mostly known from marine samples, they have also been reported due to freshwater (e.g. Fischer and Heinemeier 2003; Fischer et al. 2007; Olsen and Heinemeier 2007; Philippsen et al. 2010; however, cf. Hart and Lovis 2007). However, due to the lack of significant limestone reservoirs in eastern Fennoscandia, we assume the possible freshwater effect to be fairly limited.

To estimate the proportion of the marine carbon intake, we took a closer look at the $\delta^{13}\text{C}$ values included in the ^{14}C dates of the charred crust samples. Here, all the available prehistoric ceramic crust datings from eastern Fennoscandia were taken into account in order to get a more comprehensive picture of the phenomenon. The isotope values in the charred crust material vary from -19.3‰ to -32.9‰ (on average, $\delta^{13}\text{C}_{\text{crust}} = -26.1 \pm 2.3\text{‰}$), while in the purely terrestrial birch bark tar the deviation is clearly smaller, the average being $\delta^{13}\text{C}_{\text{birch bark tar}} = -27.8 \pm 1.0\text{‰}$ (Figure 2). The latter corresponds well to the average value of -27.9‰ obtained by Stern et al. (2006). Generally, the average value for terrestrial samples in the food residue is about -26‰ (Fischer and Heinemeier 2003:460–1).

It is reasonable to assume that all the isotopic values under -26‰ represent terrestrial/freshwater origin, while the values above it may be partly of marine origin. The most negative values are likely due to freshwater fish consumption (Fischer and Heinemeier 2003:463; cf. also Craig et al. 2007; Syväranta and Jones 2008). The above interpretation is supported by the geographical distribution of the $\delta^{13}\text{C}$ values: the highest values derive from charred crust samples found along the ancient shorelines of the seas, whereas the inland values tend to be lower (Figure 3). Therefore, we carry out reservoir age corrections for all the charred crust samples having $\delta^{13}\text{C}$ values above -26‰ .

We defined an Arctic/Baltic limit at 67°N . The Baltic reservoir age (R_{Baltic}) was used at the southern side of this limit and the Arctic (R_{Arctic}) at the northern. The method of correction was to assume the highest isotope value in the data (-19.3‰) to represent 100% marine carbon intake and to correspond to the full reservoir age R_{Baltic} or R_{Arctic} and the adopted limit of -26‰ to 100% terrestrial and, therefore, $R = 0$. The corrections were obtained according to the $\delta^{13}\text{C}$ values as a linear interpolation between these extremes. The obtained reservoir age corrections were subtracted from the ^{14}C ages to deduce corrected ages for which the model calibrations were then performed.

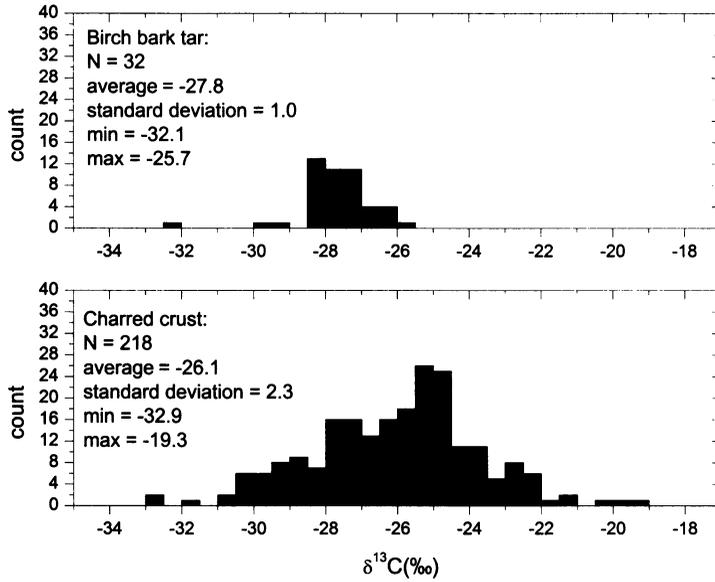


Figure 2 The $\delta^{13}\text{C}$ distributions of the birch bark tar and charred crust samples of the eastern Fennoscandian prehistoric ceramics.

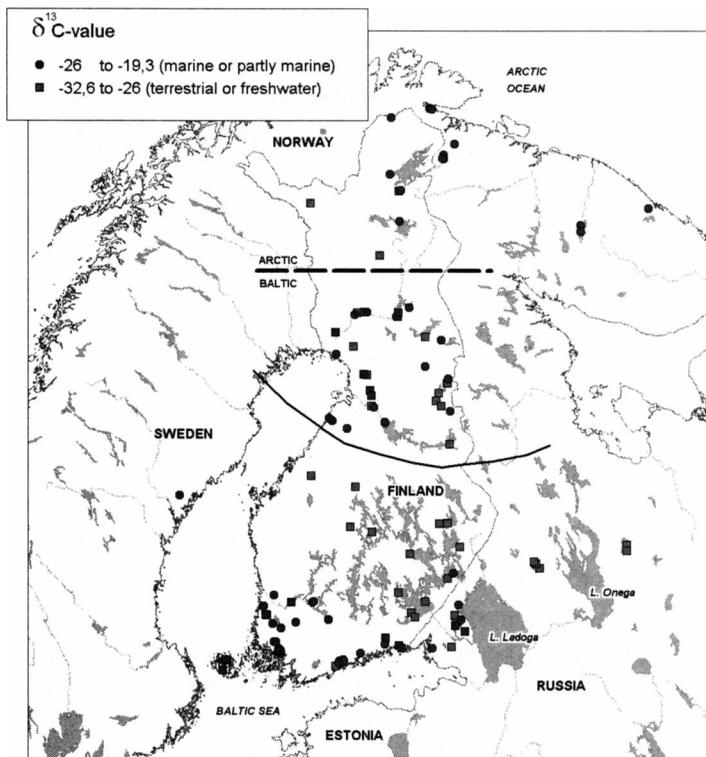


Figure 3 Charred crust $\delta^{13}\text{C}$ values in eastern Fennoscandia. The dashed line marks the border between the Baltic and Arctic reservoir correction, $\sim 67^\circ\text{N}$.

The uncertainties of the corrected ages were due a) the ^{14}C ages, b) the full reservoir ages $R_{\text{Arctic}}/R_{\text{Baltic}}$, and c) the marine fraction interpolation procedure. We have assumed the analytical uncertainties in $\delta^{13}\text{C}$ values to be negligible. The first 2 contributions being fairly trivial, the uncertainties due to interpolation were obtained as follows. Since the purely terrestrial birch bark tar possesses an average value of $\delta^{13}\text{C}_{\text{birch bark tar}} = -27.8 \pm 1.0\text{‰}$, we assume the uncertainty of the $\delta^{13}\text{C}$ value corresponding to the 100% terrestrial node of the interpolation to be the same, i.e. 1‰. For the 100% marine node, we have made a survey on the $\delta^{13}\text{C}$ values of muscle of typical marine fauna in the North Atlantic and the Baltic Sea (Hobson et al. 2002; Kiljunen et al. 2006; Sinisalo et al. 2008) and used the standard deviation of all the measured $\delta^{13}\text{C}$ values as a guideline for the node uncertainty. Particularly, we obtained $\sigma_{\text{marine fauna}} = 1.6\text{‰}$ and—due to possible uncertainties in the charred crust composition—adopted the absolute 100% marine node uncertainty to be slightly larger, i.e. 2‰. We then sampled the interpolation between these 2 nodes within the adopted uncertainties along with the $\delta^{13}\text{C}$ range in question (from -19‰ to -26‰) to obtain the standard deviation for the estimated marine fraction for a given $\delta^{13}\text{C}$ value. This analysis resulted in a linear relation for a maximal $\delta^{13}\text{C}$ -dependent uncertainty due to interpolation procedure, and it was used to calculate the marine fraction uncertainty for each sample. Eventually, for the corrected ages, the 3 sources of uncertainty were combined by the law of error propagation. The original and corrected values for each sample are presented in Appendix 1.

RESULTS AND DISCUSSION

The results according to the ceramic style are given in Table 2. We discuss the results of the analyses style by style.

Säräisniemi 1 Ceramics

According to the archaeological consensus, the earliest ceramics in eastern Fennoscandia, Säräisniemi 1 and Sperrings 1, were derived from the region south of Lake Onega and the Svir River. From this region, Säräisniemi 1 ware would have spread to the north and Sperrings 1 ware to the west (Carpelan 1999; Gusentsova 2003; Piezonka 2008). While both styles are generally regarded as bearers of the Combed ware tradition, they differ typologically and geographically. The first appearance of ceramics in the northern research area represents Säräisniemi 1 ware. It stands alone without any obvious antecedents or successors. There are altogether 22 ^{14}C dates available for the style, all but one of charred crust (Figure 4). Two dates were combined to one in the analysis, with a single-phase model employed.

The uncorrected results for the beginning and the end of the era are 5365 ± 145 and 4560 ± 85 cal BC, respectively. The model considers eventually 1 date (Tua-3028) as an outlier with 58% posterior probability. From all the dates analyzed within this paper, this is the largest posterior outlier probability obtained. Based on this, we consider the correspondence between the ^{14}C data and the cultural phases fairly satisfactory. The initial uncorrected model suggests an early date for the beginning of ceramic production in northern Fennoscandia, 5365 ± 145 cal BC, with earliest examples deriving from the Varangian coast in the Arctic Ocean and along the Pasvik River on the Russian-Norwegian border as well as in the Kalmozero 11 site in Russian Karelia. The earliest Finnish date is from the Pyhänniska site in Utajärvi, north Ostrobothnia, ~ 300 yr younger than the earliest dates in Norway.

The surprisingly early dates for the Norwegian Säräisniemi 1 ceramics have not really been questioned in Norwegian research, though the possibility of the reservoir effect has been noted (Skandfer 2003, 2005, 2009). These dates were accompanied with high $\delta^{13}\text{C}$ values, thus indicating a need for

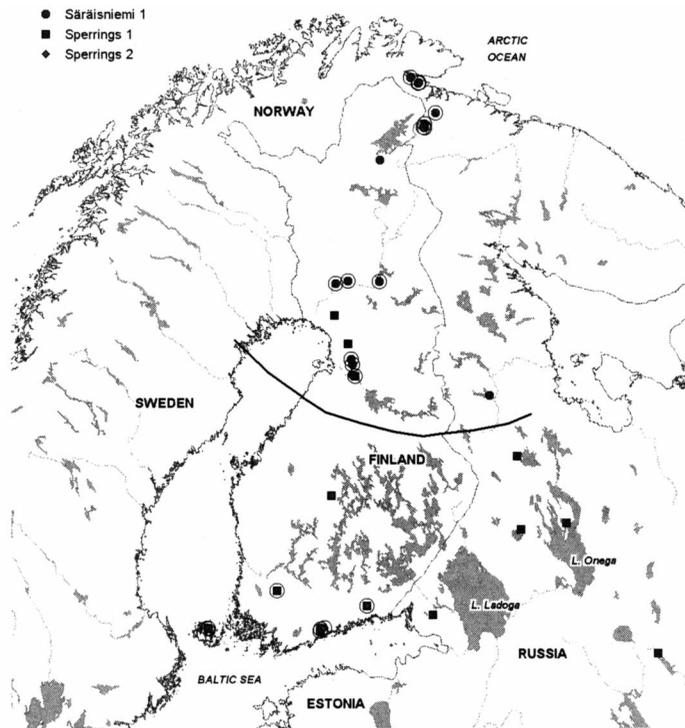


Figure 4 The distribution of Säräisniemi 1, Sperrings 1, and Sperrings 2 samples in the data. A circled symbol denotes that reservoir correction has been performed with the sample in question.

reservoir age correction. In Säräisniemi 1 ceramics, $\delta^{13}\text{C}$ values vary between -20.3‰ and -30.3‰ . All the values in the Norwegian coastal area are over -26‰ , a value considered as a “marine limit.” This holds also for the values along the Kemijoki River in the southern Lapland. Clearly terrestrial/freshwater values are in the inner Lapland, as expected. Altogether, out of 21 usable dates on the Säräisniemi 1 data set, a significant number of dates (13, i.e. 62%) has a $\delta^{13}\text{C}$ value above -26‰ , thus indicating a need for correction.

The reservoir correction makes the boundaries of the Säräisniemi 1 ceramics younger, the beginning and the end of the era being 5190 ± 100 and 4455 ± 110 cal BC, respectively. The outlier probability for Tua-3028 is decreased to 15%. Therefore, the reservoir age correction makes the data set more consistent, producing smaller outlier probability for Tua-3028 and uncertainty for the beginning of the phase. High $\delta^{13}\text{C}$ values, smaller outlier probability, and reduced uncertainty all support the hypothesis that Norwegian coastal crust dates should be considered as affected by old carbon, probably because of the marine food ingredients in the charred crust (e.g. seal, sea fish, blubber). Due to the lack of more detailed analyses on the compounds in the crust, the reservoir correction must be held as a tentative one, for the time being.

Sperrings 1 and 2 Ceramics

Another line of stylistic development is seen in Sperrings ceramics, which is a southern variant of the Early Combed Ware, its distribution area overlapping with Säräisniemi 1 ceramics in Russian Karelia, Finnish North Karelia, and North Ostrobothnia (Torvinen 2000; German 2009). There is an older and younger variant within the Sperrings style, called here subsequently Sperrings 1 and Sper-

rings 2. In our northern research area, Sperrings 1 seems to stand alone, without antecessors or successors in the dating scheme. This is only a partial truth, since Sperrings 2 distribution covers the same area in southern Lapland as Sperrings 1 does (Pesonen 1999b), but so far Sperrings 2 ^{14}C dates are lacking from the area. In the southern research area, the situation is better. There are altogether 28 Sperrings 1 dates (6 from the northern area) and 6 Sperrings 2 dates (Figure 4). The northern dates were treated separately in order to find out whether there was a delay in the arrival of the style to the north (single-phase model). In the southern area, a model was created assuming also a succession from Sperrings 1 to Sperrings 2 ceramics (2-phase model).

The $\delta^{13}\text{C}$ values in Sperrings wares showed some higher, possibly marine-based values and reservoir correction was performed for the dates accordingly. Since all the Sperrings-style dated samples have been found below 67°N latitude, the reservoir correction was made with R_{Baltic} . The correction did not significantly affect the boundary ages.

The northern area yields only 6 Sperrings 1 dates and the results indicate that the style indeed arrived there quite late (4860 ± 160 cal BC), while its beginning lies in the more southern areas ~ 300 yr earlier (5155 ± 65 cal BC). The results indicate a gradual spreading of Sperrings 1 ceramics to the more northern areas of eastern Fennoscandia, where its distribution area finally overlapped with the distribution area of Säräisniemi 1 ceramics and a hybrid form is found in the contact area (Torvinen 2000: Figure 2).

When assuming the successive Sperrings phases 1 and 2 without an overlapping possibility (2-phase model), the boundary between the older and younger variant is located at 4400 ± 30 cal BC. Sperrings 2 lasts only about 200 yr according to the model and ends at 4175 ± 95 cal BC. In the northern area, where the 2-phase model cannot be constructed, the end of Sperrings 1 is modeled at 4505 ± 160 cal BC, i.e. the same within the experimental uncertainties. The analyses with the individual single-phase model (allowing for overlap) and the successive, 2-phase modeling provide nearly similar results.

Traditionally, the phases Sperrings 1 and 2 are dated in Finnish archaeology at about 5100–4500 and 4500–4000 cal BC, respectively (e.g. Carpelan 1999, 2002; Table 2). According to the model results, the Sperrings 1 and Sperrings 2 phases could have slightly altered periods of 5150–4400 and 4400–4200 cal BC, respectively. There are far too few datings of Sperrings 2 ceramics to make definite statements on the duration of the style, however.

CONCLUSIONS

The results of our journey into Bayesian modeling of the ^{14}C dates can be summarized under 2 headings: 1) the advantages of the modeling and 2) the implications for the Subneolithic chronology in eastern Fennoscandia.

The principal advantage of the Bayesian approach lies in introducing archaeological knowledge into a mathematical procedure in a statistically approved manner. The boundaries in the form of absolute timings should be quite useful for archaeology, e.g. in studying transformations or innovation spread between different areas. Obviously, the more dates, the more accurate the results will be. Assuming strictly successive non-overlapping phases (2-phase models) tends to bring down the modeling uncertainties compared to individual, overlapping phases (single-phase models). In reality, the ceramic traditions may have had some temporal overlap and, therefore, the individually estimated phase boundaries may be more realistic. Nevertheless, we want to point out that models assuming both individual and successive phases provided reasonably similar results in our work.

According to the reservoir-corrected model, the Säräisniemi 1 ceramics tradition began in the northern regions of eastern Fennoscandia several hundred years later compared to the original data and the uncorrected model (Figure 5). We suggest that some of the early dates are probably affected by the reservoir effect, which is indicated by high $\delta^{13}\text{C}$ values compared to the typical terrestrial/fresh-water material and the more consistent reservoir-age corrected data set.

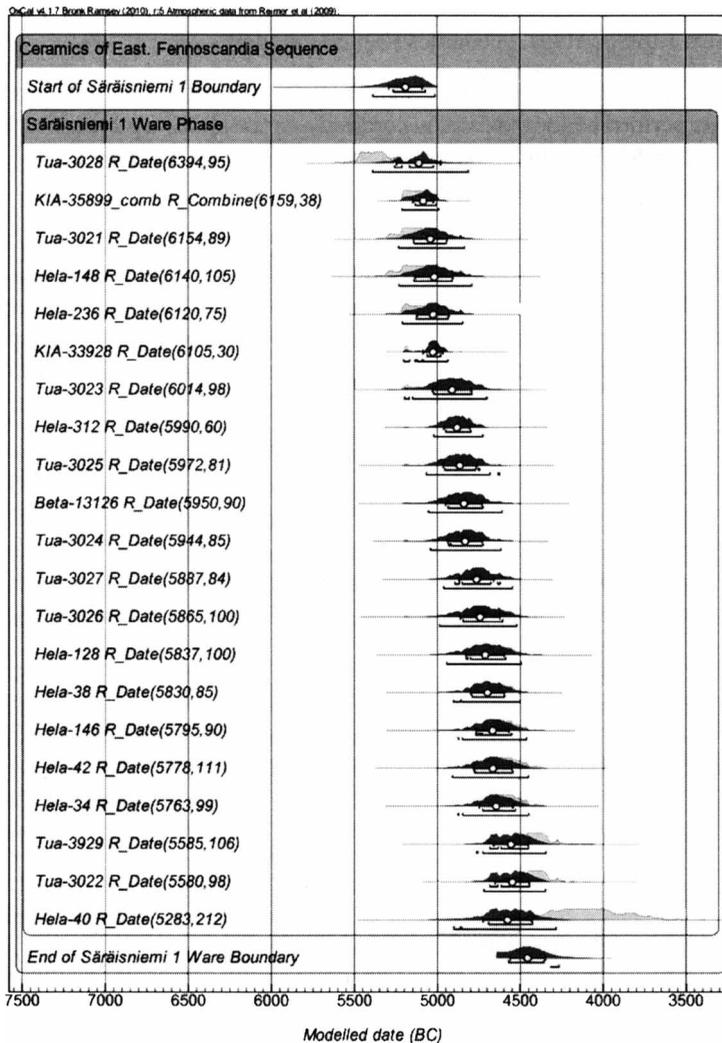


Figure 5 OxCal model for the reservoir-corrected Säräisniemi 1 ceramics serves as an example of the resulting plot. The mean value, its standard deviations, and 95.4% range of the probability distribution are shown under the individual probability distributions. The OxCal code for this model is given in Appendix 2.

The manufacture of Sperrings 1 ceramics began in the southern area 300 yr earlier compared to the north, i.e. by ~5150 cal BC. The number of Sperrings 1 dates in the northern area is limited thus far, but we suggest that the spread of this tradition in the north was delayed. One reason for this might be the presence of Säräisniemi 1 ceramics tradition bearers in the area. Eventually, the distributions of these ceramic styles overlapped in the Oulu-Kainuu region. The earliest Subneolithic ceramic

phases of Säräisniemi 1 and Sperrings 1 seem to end nearly at the same period, around 4500–4350 cal BC, throughout eastern Fennoscandia. The Sperrings 2 style then continues the legacy of Sperrings 1 in the region.

Definitely, the reservoir effect is one of the most serious challenges for future investigations in the Baltic Sea region. Once its magnitude during prehistory can be estimated better, it will be possible to start building schemes of innovation spread in eastern Fennoscandia with better accuracy than before. Charred crust stable isotope ratios of carbon and nitrogen and possibly lipid analyses should yield detailed dietary reconstructions on which more accurate ^{14}C datings could also rely. Another challenge lies in the uneven distribution of AMS dates. More dates are needed, especially from central Russia and the upper reaches of Volga in order to understand the background of the ceramic innovation spread and from Russian Karelia and eastern Baltic, to complement our results. Also, we look forward to the luminescence dating of pottery, which should yield reservoir-age-free results to be compared with the ^{14}C dates.

This paper discusses the Early Subneolithic pottery traditions of eastern Fennoscandia. Middle and Late Subneolithic eastern Fennoscandia experienced major changes in ceramic traditions. Whereas some of the periods are still suffering from lack of data to develop a combined archaeological and natural scientific understanding on them, the future looks fascinating. The forthcoming studies of food residues could bring in massive data sets—with Bayesian modeling tying parts together, while also taking archaeological and environmental understanding into consideration.

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APPENDICES

Appendix 1 The ^{14}C dates used in the study. Explanations: Sär 1 = Säräisniemi 1; Spr 1 = Sperrings 1; Spr 2 = Sperrings 2; (#) = combined dates; (*) = date was not included in the study due to uncertainties of sample content; (F) = Finland; (N) = Norway; (R) = Russia; S = southern area; N = northern area; CC = charred crust; BBT = birch bark tar.

Lab code	Site	Area	Age (BP)	$\delta^{13}\text{C}$ (‰)	Reservoir-corrected age (BP)	Material	Ceramics	References
Ua-17856	Saltvik Östra Jansmyra I (F)	S	6186 ± 120	-26.8		CC	Spr 1	Stenbäck 2003; Hallgren 2008
KIA-33927	Veksa 3 (R)	S	6185 ± 30	-30.3		CC	Spr 1	Piezonka 2008
Ua-17859	Saltvik Vargstenslätten II (F)	S	6165 ± 75	-26.4		CC	Spr 1	Stenbäck 2003; Hallgren 2008
Ua-17854	Saltvik Östra Jansmyra I (F)	S	6100 ± 75	-25.7	6088 ± 84	CC	Spr 1	Stenbäck 2003; Hallgren 2008
KIA-36724	Sulgu 2 (R)	S	6085 ± 30			CC	Spr 1	Piezonka 2008
Ua-17855	Saltvik Östra Jansmyra I (F)	S	6065 ± 80	-24.8	6015 ± 91	CC	Spr 1	Stenbäck 2003; Hallgren 2008
Hela-395	Kouvola Ankkapurha (F)	S	6060 ± 60	-26.5		CC	Spr 1	Schulz 2004
KIA-33925	Sulgu 2 (R)	S	6015 ± 30			BBT	Spr 1	Piezonka 2008
Ua-17857	Saltvik Vargstenslätten II (F)	S	5990 ± 90	-25.8	5982 ± 97	CC	Spr 1	Stenbäck 2003; Hallgren 2008
Ua-17858	Saltvik Vargstenslätten II (F)	S	5990 ± 75	-25.5	5970 ± 84	CC	Spr 1	Stenbäck 2003; Hallgren 2008
Hela-442	Saarijärvi Rusavierto (F)	S	5985 ± 80	-27.9		CC	Spr 1	Leskinen 2002
Hela-149	Utajärvi Roinila (F)	N	5975 ± 105	-25.6	5959 ± 112	CC	Spr 1	Jungner and Sonninen 2004
Hela-80	Simo Tainiaro (F)	N	5940 ± 100	-27.6		CC	Spr 1	Jungner and Sonninen 2004
Ua-32194	Vantaa Palmu (F)	S	5925 ± 45	-24.8	5875 ± 63	CC	Spr 1	Leskinen and Pesonen 2008
Hela-79	Simo Tainiaro (F)	N	5920 ± 100	-28.6		CC	Spr 1	Jungner and Sonninen 2004
Hela-887	Vantaa Viinikkala 2 (F)	S	5865 ± 55	-26.0	5865 ± 66	CC	Spr 1	Leskinen and Pesonen 2008
Hela-554	Muolaa Telkkälä (R)	S	5830 ± 80	-27.5		CC	Spr 1	Takala and Sirviö 2003
Hela-886	Vantaa Viinikkala 2 (F)	S	5805 ± 50	-25.9	5801 ± 62	CC	Spr 1	Leskinen and Pesonen 2008
Hela-394	Kouvola Ankkapurha (F)	S	5800 ± 70	-26.1		CC	Spr 1	Schulz 2004
KIA-33924	Panozero 1 (R)	S	5795 ± 35			BBT	Spr 1	Piezonka 2008
Hel-2376	Loimaa Kojonperä (F)	S	5790 ± 140	-25.0	5749 ± 146	CC	Spr 1	Luoto and Terho 1988
Hela-96	Yli-Ii Pahkakoski 1 (F)	N	5770 ± 80	-28.4		CC	Spr 1	Jungner and Sonninen 2004
Hela-99	Yli-Ii Pahkakoski 1 (F)	N	5745 ± 130	-26.2		CC	Spr 1	Jungner and Sonninen 2004
Hela-445	Kouvola Ankkapurha (F)	S	5650 ± 80	-25.2	5617 ± 90	CC	Spr 1	Schulz 2004
Hela-98	Yli-Ii Pahkakoski 1 (F)	N	5615 ± 95	-27.9		CC	Spr 1	Jungner and Sonninen 2004
Hela-443	Kouvola Ankkapurha (F)	S	5595 ± 90	-27.1		CC	Spr 1	Schulz 2004
Hela-546	Saarijärvi Summassaari Uimaranta (F)	S	5590 ± 75	-27.4		BBT	Spr 1	Unpublished
KIA-35901	Vozmaricha 26 (R)	S	5505 ± 50			CC	Spr 1	Piezonka 2008
Hela-446	Kouvola Ankkapurha (F)	S	5590 ± 70	-23.9	5503 ± 88	CC	Spr 2	Schulz 2004
Hela-392	Kouvola Ankkapurha (F)	S	5510 ± 60	-26.6		CC	Spr 2	Schulz 2004

Appendix 1 The ^{14}C dates used in the study. Explanations: Sär 1 = Säräisniemi 1; Spr 1 = Sperrings 1; Spr 2 = Sperrings 2; (#) = combined dates; (*) = date was not included in the study due to uncertainties of sample content; (F) = Finland; (N) = Norway; (R) = Russia; S = southern area; N = northern area; CC = charred crust; BBT = birch bark tar. (Continued)

Lab code	Site	Area	Age (BP)	$\delta^{13}\text{C}$ (‰)	Reservoir-corrected age (BP)	Material	Ceramics	References
Ua-32193	Vantaa Storskogen (F)	S	5415 ± 45	-25.7	5403 ± 58	CC	Spr 2	Leskinen and Pesonen 2008
Hela-444	Kouvola Ankkapurha (F)	S	5410 ± 75	-26.0	5410 ± 83	CC	Spr 2	Schulz 2004
Hela-393	Kouvola Ankkapurha (F)	S	5360 ± 70	-23.8	5269 ± 89	CC	Spr 2	Schulz 2004
Hela-642	Saarijärvi Summassaari Uimaranta (F)	S	5335 ± 45	-29.4		CC	Spr 2	unpublished
Tua-3028	Nesseby Nordli (N)	N	6570 ± 60	-22.8	6394 ± 95	CC	Sär 1	Skandfer 2005, 2009
KIA-35899#	Kalmozero 11 (R)	N	6340 ± 70			CC	Sär 1	Piezonka 2008
Tua-3021	Nesseby Nordli (N)	N	6330 ± 50	-22.8	6154 ± 89	CC	Sär 1	Skandfer 2005, 2009
Tua-3023	Sör-Varanger Noatun Inmårken (N)	N	6185 ± 65	-22.9	6014 ± 98	CC	Sär 1	Skandfer 2005, 2009
Hela-148	Utajärvi Pyhänniska (F)	N	6140 ± 105	-27.5		CC	Sär 1	Torvinen 2000
Hela-236	Oulu Vepsänkangas (F)	N	6120 ± 75	-26.3		CC	Sär 1	Torvinen 2000
KIA-35899#	Kalmozero 11 (R)	N	6080 ± 45			CC	Sär 1	Piezonka 2008
Tua-3024	Nesseby Lossoas hus (N)	N	6065 ± 55	-23.8	5944 ± 85	CC	Sär 1	Skandfer 2005, 2009
Tua-3025	Sör-Varanger Inganeset (N)	N	6065 ± 55	-24.3	5972 ± 81	CC	Sär 1	Skandfer 2005, 2009
Tua-3026	Sör-Varanger Noatun Neset Vest (N)	N	6030 ± 70	-23.0	5865 ± 100	CC	Sär 1	Skandfer 2005, 2009
Hela-128	Oulu Vepsänkangas (F)	N	5995 ± 65	-22.2	5837 ± 100	CC	Sär 1	Torvinen 2000
Hela-312	Oulu Vepsänkangas (F)	N	5990 ± 60	-27.3		BBT	Sär 1	Koivisto 1998
Tua-3027	Sör-Varanger Mennikka (N)	N	5975 ± 60	-24.4	5887 ± 84	CC	Sär 1	Skandfer 2005, 2009
Beta-13126	Sör-Varanger Noatun Neset (N)	N	5950 ± 90			CC	Sär 1	Skandfer 2005, 2009
Tua-3929	Sör-Varanger Noatun Inmårken (N)	N	5850 ± 55	-21.2	5585 ± 106	CC	Sär 1	Skandfer 2005, 2009
Hela-38	Inari Rönkön raivio (F)	N	5830 ± 85	-28.2		CC	Sär 1	Torvinen 2000
Hela-34	Kemijärvi Neitilä 4 (F)	N	5800 ± 90	-25.1	5763 ± 99	CC	Sär 1	Torvinen 2000
Hela-146	Oulu Latokangas (F)	N	5795 ± 90	-27.0		CC	Sär 1	Torvinen 2000
Tua-3022	Sör-Varanger Mennikka (N)	N	5795 ± 55	-22.1	5580 ± 98	CC	Sär 1	Skandfer 2005, 2009
Hela-42	Oulu Latokangas (F)	N	5790 ± 105	-25.7	5778 ± 111	CC	Sär 1	Torvinen 2000
Hela-40	Rovaniemi Ylitalo/Toivola (F)	N	5520 ± 185	-20.3	5283 ± 212	CC	Sär 1	Torvinen 2000
Hela-57*	Rovaniemi Jokkavaara (F)	N	5070 ± 80	-25.9	5066 ± 80	CC	Sär 1	Torvinen 2000

APPENDIX 2: OxCal CODE

```
Sequence("Ceramics of East. Fennoscandia")
{
  Outlier_Model("General", T(5), U(0, 4), "t");
  Boundary("Start of Säräisniemi 1");
  Phase("Säräisniemi 1 Ware")
  {
```

```
R_Date("Tua-3028", 6394, 95) {Outlier(0.05)};;
R_Combine("KIA-35899_comb")
{R_Date("KIA-35899_a", 6340, 70);
 R_Date("KIA-35899_b", 6080, 45);Outlier(0.05)};;
R_Date("Tua-3021", 6154, 89) {Outlier(0.05)};;
R_Date("Hela-148", 6140, 105) {Outlier(0.05)};;
R_Date("Hela-236", 6120, 75) {Outlier(0.05)};;
R_Date("KIA-33928", 6105, 30) {Outlier(0.05)};;
R_Date("Tua-3023", 6014, 98) {Outlier(0.05)};;
R_Date("Hela-312", 5990, 60) {Outlier(0.05)};;
R_Date("Tua-3025", 5972, 81) {Outlier(0.05)};;
R_Date("Beta-13126", 5950, 90) {Outlier(0.05)};;
R_Date("Tua-3024", 5944, 85) {Outlier(0.05)};;
R_Date("Tua-3027", 5887, 84) {Outlier(0.05)};;
R_Date("Tua-3026", 5865, 100) {Outlier(0.05)};;
R_Date("Hela-128", 5837, 100) {Outlier(0.05)};;
R_Date("Hela-38", 5830, 85) {Outlier(0.05)};;
R_Date("Hela-146", 5795, 90) {Outlier(0.05)};;
R_Date("Hela-42", 5778, 111) {Outlier(0.05)};;
R_Date("Hela-34", 5763, 99) {Outlier(0.05)};;
R_Date("Tua-3929", 5585, 106) {Outlier(0.05)};;
R_Date("Tua-3022", 5580, 98) {Outlier(0.05)};;
R_Date("Hela-40", 5283, 212) {Outlier(0.05)};;
Interval("Duration of Säräisniemi 1 Ware");
};
Boundary("End of Säräisniemi 1 Ware");
};
```