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THE FRESHWATER RESERVOIR AND RADIOCARBON DATES ON COOKING RESIDUES: OLD APPARENT AGES OR A SINGLE OUTLIER? COMMENTS ON FISCHER AND HEINEMEIER (2003)

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ABSTRACT. Fischer and Heinemeier (2003) present a hypothesis that the freshwater reservoir effect produces old apparent ages for radiocarbon dates run on charred cooking residues in regions where fossil carbon is present in groundwater. The hypothesis is based in part on their analysis of dates on charred cooking residues from 3 inland archaeological sites in Denmark in relation to contextual dates from those sites on other materials. A critical assessment of the dates from these sites suggests that rather than a pattern of old apparent dates, there is a single outlying date—not sufficient evidence on which to build a case for the freshwater reservoir effect.

INTRODUCTION

Fischer and Heinemeier (2003) suggest that accelerator mass spectrometry (AMS) assays on charred cooking residues (hereafter, residues) from northern Europe may result in old apparent ages as the result of the freshwater reservoir effect (e.g. Geyh et al. 1998; Cook et al. 2002; Borić and Miracle 2004). Old apparent ages will occur if aquatic resources, especially fish or shellfish, were the primary contributors to the residue formation. Fossil carbon dissolved in groundwater in areas with calcareous bedrock and/or the decay of old organic material in a lake are potential sources for ancient carbon reservoirs (Fischer and Heinemeier 2003:454). Their argument has potential global significance, given that freshwater fish and other aquatic resources were widely used where available (e.g. Rau 1884; Clark 1948; Yesner 1979; Cleland 1982; Moseley and Feldman 1988; Plew 1996; Erlandson 2001), and residue has been used for AMS dating in many areas of the world (e.g. Mason 1966; Lovis 1990a,b; Carr and Haas 1996; Kuzmin and Keally 2001; Nakamura et al. 2001; Fischer 2002; Hart and Brumbach 2003, 2005; Clark 2004; Means 2005). Here, we test this freshwater reservoir effect hypothesis through a critical assessment of Fischer and Heinemeier's interpretations of AMS dates on charred cooking residue from 3 northern European sites. We conclude that while the freshwater reservoir effect is of potential concern, the data presented by Fischer and Heinemeier do not support their hypothesis that the effect results in a pattern of old apparent ages for radiocarbon dates on charred cooking residues from the 3 Danish sites.

COOKING RESIDUES, AMS DATES, AND THE FRESHWATER RESERVOIR EFFECT

Fischer and Heinemeier (2003:455–6) were able to demonstrate the reservoir effect on flesh samples from 5 modern fish and 5 modern shellfish from Lake Tissø in the Åmose Valley. Lake Tissø is fed by groundwater that dissolves carbonates in the surrounding moraine hills. The assays returned an average ^{14}C age of 300 BP, as opposed to an expected post-atmospheric atomic bomb test age of –700 BP, extrapolated by Fischer and Heinemeier (2003:455) to 109.4 pMC using the data set in Goodsite et al. (2001). The average age of the flesh samples is 1000 yr. The ^{14}C ages of archaeological fish bone relative to terrestrial animal bone and a charred rootlet from the Åkonge site suggest reservoir ages of 115–480 ^{14}C yr (Fischer and Heinemeier 2003:456). These results led Fischer and Heinemeier (2003:457) to the conclusion, "if the food residues in the pots from Åkonge are exclusively derived from the cooking of freshwater fish or mollusks, these residues would theoretically have apparent ages in the order of 100–500 ^{14}C yr."

Fischer and Heinemeier (2003:457–9) then present a series of dates comparing AMS assays on residues to assays on terrestrial materials from the same contexts and other materials from the same sherds (e.g. from exterior deposits of soot) from 3 sites in the Åmose Valley: Åkonge, Spangkonge, and Mossby. They find differences between the ages of contextual samples and those of residues from sherd interiors at the 3 sites to range between 30 and 300 ^{14}C yr, with average differences at Åkonge of 143 ± 31 ^{14}C yr and at Spangkonge of 72 ± 52 ^{14}C yr. They find a difference of between 10 and 190 ^{14}C yr when comparing interior residues to coatings on the exterior of the same sherds, and a difference of 290 ^{14}C yr between a charred rootlet from within the sherd's fabric and interior residue from the same sherd.

The results of Fischer and Heinemeier's analysis of modern and prehistoric freshwater fish and modern freshwater shellfish clearly establish the existence of a freshwater ancient carbon reservoir in the Åmose Valley. Their hypothesis that this reservoir will result in apparent ages up to several centuries too old on residues is seemingly supported by their analysis of dates on residues and contextual dates on other materials. Our reanalysis of their data, however, suggests that there is only 1 anomalous date on residue, not a pattern of old apparent ages.

STATISTICAL ANALYSES

Throughout the following analyses, we use Ward and Wilson's (1978) technique to determine if ^{14}C dates differ significantly using the sample significance test module in CALIB 5.0 (Stuiver et al. 2005). This module reports results at the 95% level of confidence. We report the degrees of freedom (n – 1) and t scores for each result. We use Ward and Wilson's (1978) technique for calculation of pooled means for ^{14}C dates that are not significantly different. The CALIB 5.0 module for creating pooled means was used for these calculations. We also provide 2-σ probability distribution plots for dates generated in OxCal 3.10 (Bronk Ramsey 1995, 2001); cal 2-σ ranges generated with CALIB 5.0 (Stuiver and Reimer 1993; Stuiver et al. 2005) are provided for each date in Tables 1–4. The IntCal04 (Reimer et al. 2004) data set was used with both calibration programs.

ASSESSING FISCHER AND HEINEMEIER'S ANALYSIS

The ^{14}C dates from layer 3b at Åkonge are presented in Table 1 (Fischer 2002:358; Fischer and Heinemeier 2003:457). Date AAR-2678 is on residue from a "blubber lamp." Assuming this functional attribution is correct, it is likely that blubber from marine mammals was burned in the vessel. This date can be eliminated from further consideration in that it would not reflect the freshwater reservoir effect, but rather the marine reservoir effect. Included in our analysis are all of the remaining dates published for layer 3b of Åkonge in Fischer (2002) and Fischer and Heinemeier (2003) (Table 1, Figure 1). These include dates on residue as well as on soot from the exterior of pottery sherds, charred wood, and bone not considered by Fischer and Heinemeier (2003:457) in their assessment of residue versus context dates. Fischer and Heinemeier (2003:459) did include some of these dates in their subsequent comparisons of dates on interior residues with those on external sooting and/or organic material from within pottery fabric. Fischer (2002:354) suggests "residues from the outer sides (probably mainly soot from firewood) appear to be in better agreement with the reliable dates of the context."

Date AAR-5108 on residue is clearly an outlier among the Åkonge dates (Table 1, Figure 1). Including this date with the others in a test of sample significance of the ^{14}C ages indicates that the ages are significantly different (df = 16, t = 52.4). AAR-5108 is significantly different from every other date from Åkonge when compared on an individual basis, with the exception of AAR-2678. If

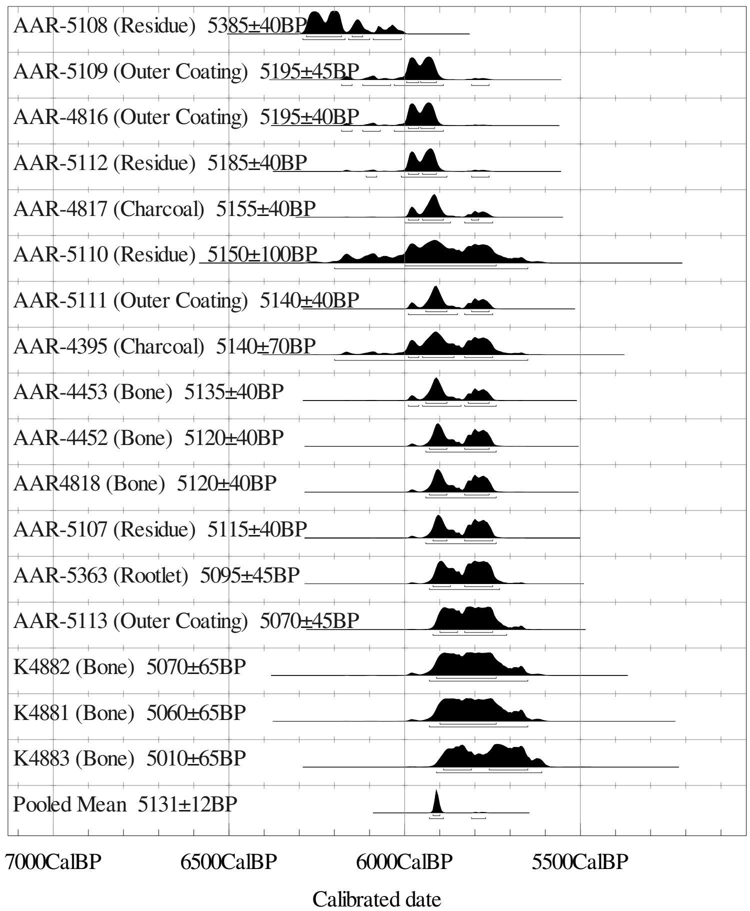

Figure 1 2-σ probability distributions for calibrated dates from Åkonge (pooled mean excludes AAR-5108).

AAR-5108 is removed, the remaining 16 dates are not significantly different (df = 15, t = 15.21); they have a pooled mean age of 5131 ± 12 BP (Table 1)[1]. Assessment of the paired dates from different contexts on single sherds presented by Fischer and Heinemeier (2003:459) yields the same result. Only AAR-5108 is significantly different from the other paired dates listed in Fischer and Heinemeier's table, as would be expected from the above.

Fischer and Heinemeier (2003) argue that the freshwater reservoir effect resulted in old apparent ages at Åkonge. Our assessment of their data, however, indicates that they obtained 1 date on a residue that is an outlier (AAR-5108). Whether this outlier results from the freshwater or marine reser-

[1]It is possible that the residue used for sample AAR-2678 resulted from the burning of oil extracted from freshwater fish. If we were to include this date in our analysis, there remains no significant difference between the dates (t = 18.51, df = 17), and the pooled mean age is only 3 yr older (5134 ± 12 BP, cal 2 σ = 5903–5641 BP). Regardless of whether the residue from the blubber lamp derived from marine mammals, catadromous, anadromous, or diadromous fish, or even whether a freshwater reservoir is present, the resulting date is statistically identical to the other dated materials. We do not include this date in our analyses because of the uncertainty surrounding its origin.

Table 1 Dates from Åkonge published in Fischer (2002) and Fischer and Heinemeier (2003).

Material	^{14}C age BP	Cal 2-σ range BP	Lab nr	Source
Interior food residue	5385 ± 40	6285–6011	AAR-5108	Fischer and Heinemeier (2003:457)
"Food" residue from a "blubber lamp"	5260 ± 70	6263–5907	AAR-2678	Fischer and Heinemeier (2003:457)[a]
Coating, outer surface	5195 ± 40	6174–5893	AAR-4816	Fischer and Heinemeier (2003:459)
Coating, outer surface	5195 ± 45	6175–5769	AAR-5109	Fischer and Heinemeier (2003:459)
Interior food residue	5185 ± 40	6102–5767	AAR-5112	Fischer and Heinemeier (2003:457)
Charcoal	5155 ± 40	5993–5754	AAR-4817	Fischer and Heinemeier (2003:459)
Interior food residue	5150 ± 100	6180–5660	AAR-5110	Fischer and Heinemeier (2003:457)
Carbonized wood and plant remains within a potsherd	5140 ± 70	6174–5664	AAR-4395	Fischer (2002:358)
Coating, outer surface	5140 ± 40	5989–5750	AAR-5111	Fischer and Heinemeier (2003:459)
Domestic ox bone	5135 ± 50	5834–5960	AAR-4453	Fischer (2002:346)
Domestic ox bone	5120 ± 40	5980–5747	AAR-4818	Fischer and Heinemeier (2003:457)
Domestic ox bone	5120 ± 40	5980–5747	AAR-4452	Fischer (2002:346)
Interior food residue	5115 ± 40	5933–5746	AAR-5107	Fischer and Heinemeier (2003:457)
Charred rootlet within sherd	5095 ± 45	5926–5735	AAR-5363	Fischer and Heinemeier (2003:457)
Coating, outer surface	5070 ± 45	5917–5671	AAR-5113	Fischer and Heinemeier (2003:459)
Red deer bone	5070 ± 65	5928–5657	K-4882	Fischer and Heinemeier (2003:457)
Red deer bone	5060 ± 65	5923–5655	K-4881	Fischer and Heinemeier (2003:457)
Red deer bone	5010 ± 65	5903–5612	K-4883	Fischer and Heinemeier (2003:457)
Pooled mean[b]	5131 ± 12	5924–5778	—	—

[a]This date is excluded from our analysis.
[b]The pooled mean excludes dates AAR-5108 and AAR-2678 (see text for explanation).

voir effect, lab error, or another factor cannot be readily determined. The remaining 3 dates on residue have ages that fall within the range of those for assays on other materials including bone, charcoal, and exterior sooting on pottery sherds (Table 1). This finding is further substantiated by comparing the pooled mean dates on the 3 remaining residue samples (5150 ± 27 BP) with the pooled mean for the dates on all other materials (5127 ± 13 BP); the ages are separated by only 23 ^{14}C yr (Table 2). Of note are the mean pooled ages of the radiometric dates obtained from the ^{14}C laboratory in Copenhagen (K) on bone (5060 ± 65 BP), which were used by Fischer and Heinemeier as valid context dates in comparison with the dates on residues. These dates are 78 ^{14}C yr younger than the pooled mean age of the non-residue AMS dates (5138 ± 14 BP) obtained from the AMS laboratory at the University of Aarhus, Denmark (AAR) (Table 2). It is possible that this is the result of differing dating methods and laboratories. It is seemingly not a result of the material dated, because the pooled mean age of the K dates on bone are 64 ^{14}C yr younger than the pooled mean age of the AAR dates on bone (5124 ± 25 BP). Only 20 ^{14}C yr separate the mean pooled age of the AAR dates on bone from the pooled mean age of AAR dates on non-bone contextual materials (5144 ± 17 BP), and 26 ^{14}C yr from the mean pooled age of the dates on charred cooking residues. Regardless, the cal 2-σ ranges for these various pooled means exhibit little variation (Table 2). Dates from Spangkonge and Mossby are presented in Tables 3 and 4 and Figures 2 and 3, respectively. For these sites, there also is no significant difference between the ^{14}C ages of dates on residues and those on other materials.

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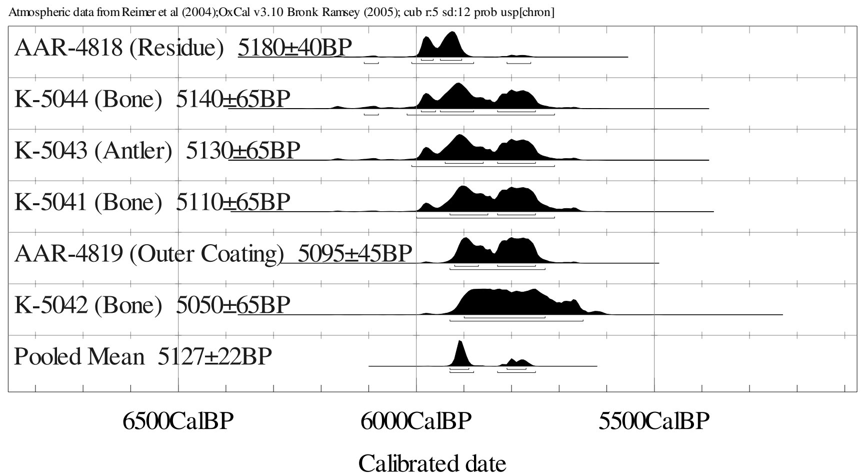

Figure 2 Probability distributions of calibrated dates from Spangkonge

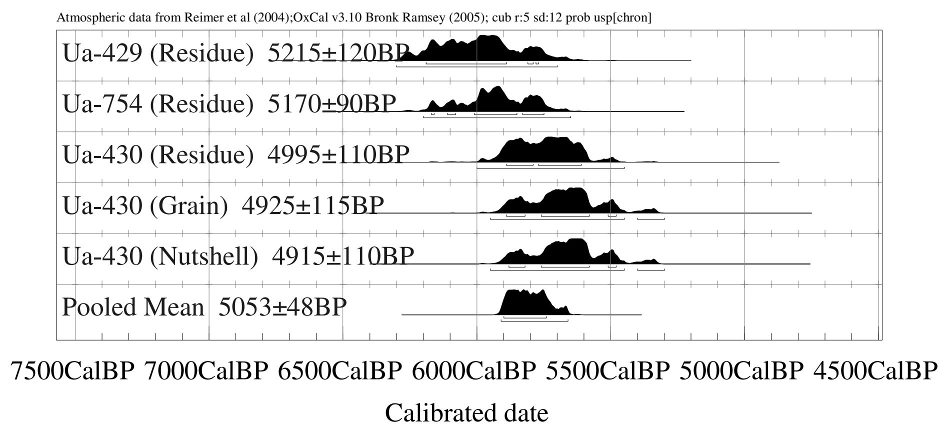

Figure 3 Probability distributions of calibrated dates from Mossby

Table 2 Pooled means for combinations of dates from Åkonge.

Material	^{14}C age BP	Cal 2-σ range BP	Lab nr
Interior food residues	5150 ± 27	5967–5764	AAR-5107, AAR-5110, AAR-5112
All context materials	5127 ± 13	5922–5769	AAR-4816, AAR-5109, AAR-4817, AAR-4395, AAR-5111, AAR-4453, AAR-4818, AAR-4452, AAR-5363, AAR-5113, K-4882, K-4881, K-4883
AAR context materials	5138 ± 14	5929–5892	AAR-4816, AAR-5109, AAR-4817, AAR-4395, AAR-5111, AAR-4453, AAR-4818, AAR-4452, AAR-5363, AAR-5113
K context material (bone)	5060 ± 65	5923–5655	K-4882, K-4881, K-4883
AAR bone	5124 ± 25	5929–5754	AAR-4453, AAR-4818, AAR-4452
AAR non-bone context material	5144 ± 17	5936–5778	AAR-4816, AAR-5109, AAR-4817, AAR-4395, AAR-5111, AAR-5363, AAR-5113

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Table 3 Dates from Spangkonge.

Material	^{14}C age BP	Cal 2-σ range BP	Lab nr	Source
Food residue inner	5180 ± 40	6167–5762	AAR-4818	Fischer and Heinemeier (2003:457)
Bone	5140 ± 65	6172–5718	K-5044	Fischer and Heinemeier (2003:457)
Antler	5130 ± 65	6094–5664	K-5043	Fischer and Heinemeier (2003:457)
Bone	5110 ± 65	5991–5664	K-5041	Fischer and Heinemeier (2003:457)
Food residue outer	5095 ± 45	5926–5735	AAR-4819	Fischer (2002:354)
Bone	5050 ± 65	5919–5652	K-5042	Fischer and Heinemeier (2003:457)
Pooled mean	5126 ± 22	5928–5758	—	—

Table 4 Dates from Mossby.

Material	^{14}C age BP	Cal 2-σ range BP	Lab nr	Source
Food residue inner	5215 ± 120	6277–5725	Ua-429	Fischer and Heinemeier (2003:457)
Food residue inner	5170 ± 90	6185–5716	Ua-754	Fischer and Heinemeier (2003:457)
Food residue inner	4995 ± 110	5987–5482	Ua-430	Fischer and Heinemeier (2003:457)
Charred cereal grain	4925 ± 115	5916–5331	Ua-755	Fischer and Heinemeier (2003:457)
Charred hazelnut shell	4915 ± 110	5909–5332	Ua-753	Fischer and Heinemeier (2003:457)
Pooled mean	5053 ± 48	5910–5663	—	—

In our view, the primary problem with Fischer and Heinemeier's analyses is their use of ^{14}C ages as fixed temporal datum points rather than as central tendency measures of probability distributions. An extension of this problem is comparing pairs of ages as if assays on the materials should result in identical ^{14}C ages if they originated at the same time. The results of 2 sets of AMS dates on split residue samples reported by Means (2005, 2006) provide an example of how ^{14}C ages on the same event will differ. Separate assays on a split sample of residue from 1 sherd returned nearly identical ^{14}C ages of 536 ± 36 BP and 540 ± 36 BP (AA52973). However, a second split residue sample from a sherd at a different site returned ^{14}C ages of 847 ± 34 BP and 802 ± 34 BP (AA53667), a difference of 45 ^{14}C yr.

One would expect a range of ^{14}C ages for any component with a large suite of ^{14}C dates, just as one would expect 1 or more outliers in such a suite (Shott 1992:210–11; Scott 2003:286). We used OxCal 3.10 (Bronk Ramsey 1995, 2001) to simulate ^{14}C ages for the calendar date 3959 BC, which is the median probability for the calibrated pooled mean of the Åkonge dates (Table 1). We used a standard deviation in the simulations of 40 yr, the modal value for the Åkonge dates. The ages for 18 simulated dates had a range of 155 ^{14}C yr, from 5047 to 5202 BP. This encompasses the range of ages from Åkonge with the exception of dates K-4883, AAR-5108, and AAR-2678, the latter 2 of which have already been identified as problematic.

CONCLUSION

In conclusion, it is clear that the dates from the Åmose Valley sites do not support Fischer and Heinemeier's freshwater reservoir effect hypothesis. Rather, at each of the 3 sites, the dates on residue are not significantly different from dates on other materials. The only exception is date AAR-5108 from Åkonge. Whether this anomalous date is the result of the freshwater reservoir effect or some other factor, its clear outlier status indicates that it should not be included in the suite of valid dates from layer 3b at the site. Outlying dates are expected to occur in a large suite of dates, and a single outlier is not sufficient evidence on which to build a case for the freshwater reservoir effect. At present, there is substantial agreement between dates on residues and those on other materials from the same contexts, consistent with the results of our assessment of AMS dates on residues in northeastern North America (Hart and Lovis 2007).

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