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THE SETTLEMENT DATE OF ICELAND REVISITED: EVALUATION OF ^{14}C DATES FROM SITES OF EARLY SETTLERS IN ICELAND BY BAYESIAN STATISTICS

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ABSTRACT. The settlement time of Iceland has been debated for years as radiocarbon dates of bulk wood samples have been interpreted to set a timing 150–200 yr earlier than indicated by tephrochronology (later than AD 871 ± 2) and the Sagas (AD 874). This early date is also in conflict with the dating results on extensive series of short-lived material such as grain and domestic animal and human bone remains of early settlers. The old-wood effect for the charcoal and bulk wood samples has been suggested to explain this controversy. This study uses a Bayesian model, implemented in the OxCal program, to show that the charcoal data combined with short-lived material (grain/bone) suggest ages anywhere in the interval AD 854–922 (95.4% probability), indicating that the available ^{14}C data cannot be taken as compelling evidence that there was a settlement any earlier than AD 922. The Bayesian model shows that the observed exponential distribution of the excess age of the bulk wood samples is exactly as expected if there was an old-wood effect evident in the samples.

KEYWORDS: inbuilt age, Iceland settlement, Bayesian modeling.

INTRODUCTION

The settlers of Iceland were farmers originating from northwestern Norway and the northern British Isles. According to the Sagas, written down in the 12th century, the settlers sailed across the sea with families and domestic animals around AD 874. The date of the settlement of Iceland has widespread implications for the Norse colonization of the North Atlantic.

Changes in land use following the beginning of permanent settlement is recorded in soil profiles across Iceland as a change in soil type and pollen composition (Hallsdóttir 1987, 1996; Erlendsson and Edwards 2010). The most pronounced change is in the abundance of birch (*Betula* sp.) and grass pollen, where the *Betula* pollen declines simultaneously with increasing grass pollen. Close to this stratigraphic transition, a volcanic ash layer occurs, denoted the settlement layer due to its position in the soil. This ash layer is very distinct and easily recognized and has been found in soil profiles over a large part of Iceland. Based on a relative age determination, the tephra layer likely formed in an eruption in the last part of the 9th century (Larsen 1996).

Several attempts have been made to date the settlement tephra layer by ^{14}C dating organic remains adjacent to the tephra, as reviewed by Sveinbjörnsdóttir et al. (2004). All the ^{14}C dates are mutually consistent, but they cannot give a precise date of the settlement tephra due to the plateau in the calibration curve (Reimer et al. 2013) during this time interval. The calibrated probability distribution is very large, from about AD 700 to 1000. However, ^{14}C wiggle-match dating of five samples across a soil profile gave a more precise date of AD 835 ± 20 (Theodórsson 1993). The tephra layer has also been recognized in Irish bogs and ^{14}C wiggle-match dated to AD 860 ± 20 (Hall et al. 1993).

An absolute dating of the tephra layer was obtained from the GRIP and GISP deep ice cores at Summit, Greenland. By counting annual layers down to the ash, the precise date of AD 871 ± 2 was obtained from the GRIP core (Grönvold et al. 1995) and AD 877 ± 4 from the GISP core

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(Zielinski et al. 1997). These dates agree both with the earlier ^{14}C dates of the tephra layer and the historical date of AD 874. As the chronological association between the tephra layer and the earliest human occupation is not always clear, the settlement time is however still debated (e.g. Theodórsson 1998, 2011, 2012) and needs to be resolved.

Since the 1970s, many attempts have been made to establish the chronology of the colonization of Iceland. In the beginning, the dates were largely performed on large bulk wood samples using the conventional ^{14}C method (Grímsson and Einarsson 1970; Nordahl 1988; Hermanns-Audardóttir 1989). Some datings were also performed on large human and animal bone collagen samples. No information is available on the $\delta^{13}C$ of these samples; therefore, correction for the marine protein potentially consumed by the individuals cannot be performed. Those samples might thus indicate earlier ages than the event they were supposed to date. Since 1990, accelerator mass spectrometry (AMS) dates on short-lived Icelandic material (grain/bone) have been performed and $\delta^{13}C$ have been used for reservoir correction estimates (Sveinbjörnsdóttir et al. 2004, 2010; Ascough et al. 2007, 2010, 2011, 2012).

^{14}C dates of charcoal and wood samples have been interpreted as evidence of an earlier settlement date than indicated by the tephrachronology and the Sagas (Hermanns-Audardóttir 1989; Theodórsson 1993, 1997, 1998, 2009, 2010, 2011, 2012). However, AMS ^{14}C dates of truly short-lived material of barley grains (*Hordeum sativum*) as well as domestic animal and human bone remains of early settlers (Sveinbjörnsdóttir et al. 2010) are not in conflict with the traditional date discussed above. The old-wood effect for the bulk wood samples has been suggested to explain this discrepancy between the two approaches to ^{14}C dating of the event (Sveinbjörnsdóttir et al. 2004). Most of the dated charcoal and wood samples are taken from cooking pits and floor deposits inside buildings made of turf walls. In the walls, the settlement tephra layer has been recognized. Therefore, the wall turfs have been cut after the deposition of the tephra layer (AD 871 ± 2; AD 877 ± 4); thus, the high ^{14}C age of the charcoal and wood samples seem unlikely to reflect the true age of the human occupation at the site. It has, however, been argued that the turf could have been continuously renewed so that it cannot be taken to represent the first occupation of the site (e.g. Theodórsson 1998, 2012). In this paper, we therefore refrain from using the tephra data but solely base our arguments on ^{14}C data.

There has been limited research on the maximum lifespan of Icelandic birch and its resistance to decay after death. It is known, however, that at the boundary between the boreal and arctic zones in the North Atlantic the maximum age of mountain birch (*Betula pubescens* var. *pumila*) is more than 100 yr (Govaerts and Frodin 1998). Furthermore, in a dendroclimatic analysis of 35 birch samples in south Greenland the oldest datable stem was 143 yr old (Kuivinen and Lawson 1982). In Iceland, the oldest living birch tree recorded is 180 yr old and is found in the forest of Hallormsstaðaskógur in east Iceland (Eggertsson 2006). Decay of dead wood has been assumed to be fast, although the cold climate and absence of ants in Iceland may slow down the decay process. It has also been argued that dead trees in the upright position may survive decay for several decades (Ó Eggertsson, personal communication, 2015), though this is still debated (Theodórsson 2010). Based on the age of the oldest tree recorded in Iceland and assuming that trees can survive decay for 10–20 yr, it is clear that Icelandic birch may have inbuilt age exceeding 200 yr. Consequently, the assumption of short-lived indigenous trees to prove an early settlement is misleading. However, to avail of the extensive volume of existing bulk wood dates and at the same time to quantify in detail the interpretation of the large set of all available ^{14}C data, we use a Bayesian "charcoal outlier" model, implemented in the OxCal program (Bronk Ramsey 1995, 2009), combining data from both charcoal and short-lived material.

This approach of benefitting from charcoal samples with inbuilt age by suitable modeling has recently been discussed in detail by Dee and Bronk Ramsey (2014). Our model assumes that the charcoal may be older than the deposition and takes into account the range of dates in determining how old the charcoal is on average. The excess age of the charcoal samples is assumed to follow an exponential distribution with the greatest probability that the charcoal is just before deposition and exponentially decreasing probability towards higher ages. This gives us information on the likely age of the wood used, and on the possible range of dates for the start of the settlement of Iceland.

THE DATA

In the presented Bayesian model, we use the four ^{14}C data sets from the settlement period, listed below, that are available from the literature. An overview of these data sets has been given in Sveinbjörnsdóttir et al. (2004, 2010), Vilhjálmsson (1991), and Hermanns-Audardóttir (1989). We have excluded two charcoal samples that are too young to be associated with the settlement phase, both giving calibrated ^{14}C ages later than AD 1400 (U-4030 and U-2532). The dates used are listed in the plot of the model output in Figure 1a–c.

Data Sets

1. In the 1970s, archaeological excavations were undertaken in Reykjavík at sites from the settlement period and samples were submitted for dating (Nordahl 1988). The 35 conventional ^{14}C dates obtained were compiled by Vilhjálmsson (1991). Most of the samples are from birch (*Betula* sp.), but also one from European larch (U-2082) and one sample represents a collection of short-lived grains (U-2674). The dated samples are either charcoal from cooking pits and fires or wood samples from floor and hearth deposits. The ^{14}C dates have been interpreted to show that Reykjavík was settled around AD 700 (Theodórsson 2012). The samples are listed in the topmost six sum groups in Figure 1 ("Reykjavik charcoal/grain").
2. Eleven conventional ^{14}C dates on charcoal from the first human site in the Vestman Islands (labeled Vestmannaeyar in Figure 1b) off the south coast of Iceland were obtained by Hermanns-Audardóttir (1989). Based on these dates, Hermanns-Audardóttir (1989) places the beginning of the settlement period to AD 650.
3. In 2001, another opportunity came to ^{14}C date one of the earliest human occupations in Reykjavík when excavation was undertaken in the center of the city of Reykjavík. The excavation revealed a complete Viking Age longhouse. Eight pairs of barley seeds and wood samples (Icelandic birch) from the same, oldest stratigraphic context of the site were ^{14}C dated by AMS (Sveinbjörnsdóttir et al. 2004), labeled "Reykjavik AMS charcoal: Betula" and "Reykjavik AMS grain: Barley" in Figure 1b. Based on the grain results, Sveinbjörnsdóttir et al. (2004) suggested that the settlement would not necessarily have to be placed any earlier than AD 890, whereas taken at face value, i.e. assuming no old wood age excess, the birch samples alone would place the settlement at least 100 yr earlier.
4. Sveinbjörnsdóttir et al. (2010) report 19 AMS ^{14}C dates of early Icelanders, i.e. individuals from pagan graves from different places in Iceland: 15 from human skeletons and 4 from domestic animals (Figure 1c). The Norse settlers in Iceland were pagans, as the country had not converted to Christianity until around AD 1000. In Sveinbjörnsdóttir et al. (2010), the reservoir age corrections were checked by comparing ^{14}C dates of a horse (terrestrial), a dog (highly marine), and a human (mixed diet) from the same burial. These relatively short-lived samples yield reservoir-corrected dates compatible with the grain dates in data set 3.

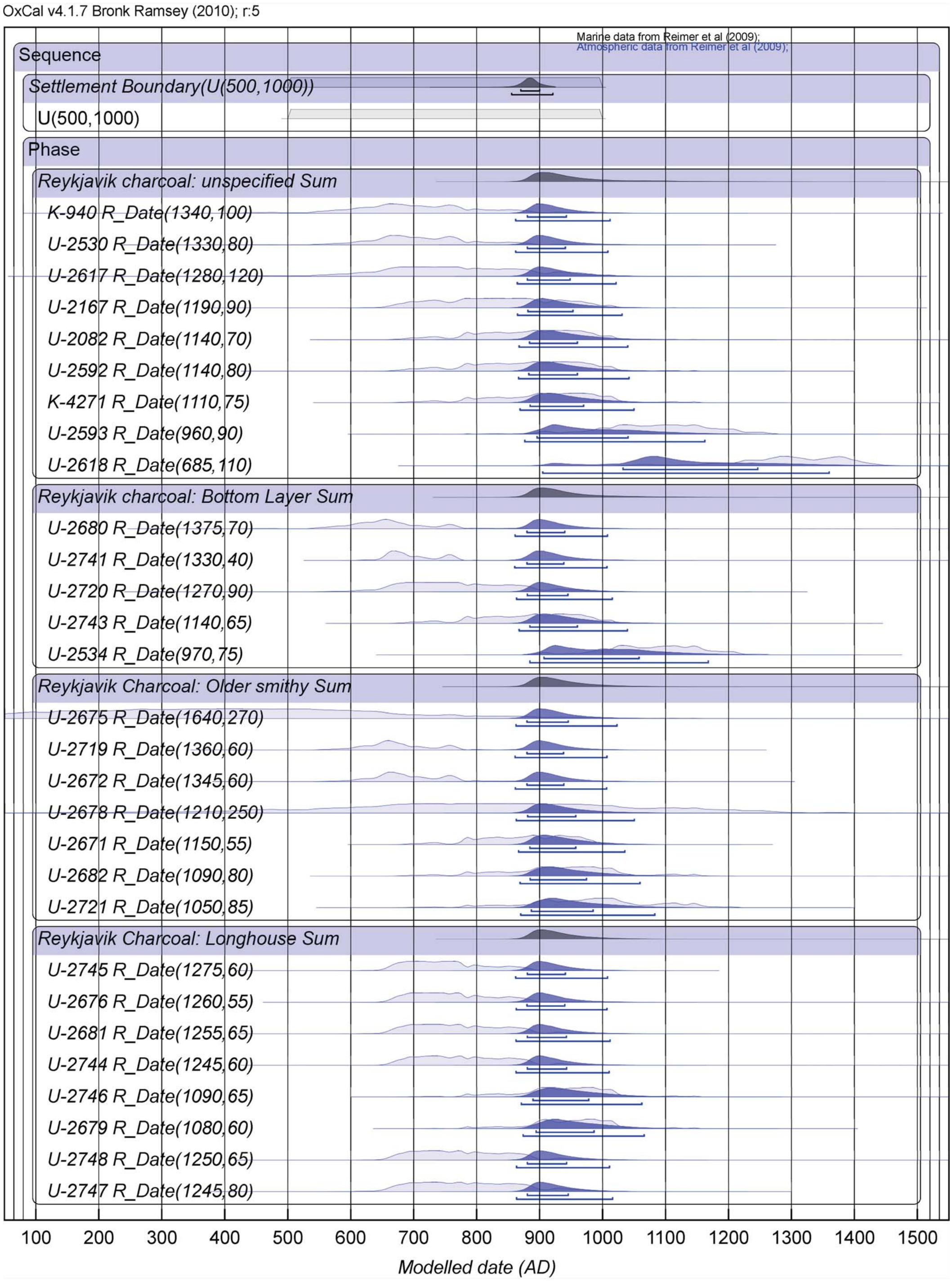

Figure 1a–c Overview of the model output in terms of the probability distributions of the calibrated ages of all the ^{14}C samples prior to (light shades) and after modeling (dark shades). The samples are grouped and the sum distributions given for each site. The samples are ordered according to decreasing age. The modeled (posterior) age distributions of all samples clearly concentrate in the interval AD 800–1000 as do the prior (unmodeled) distributions of all the short-lived samples.

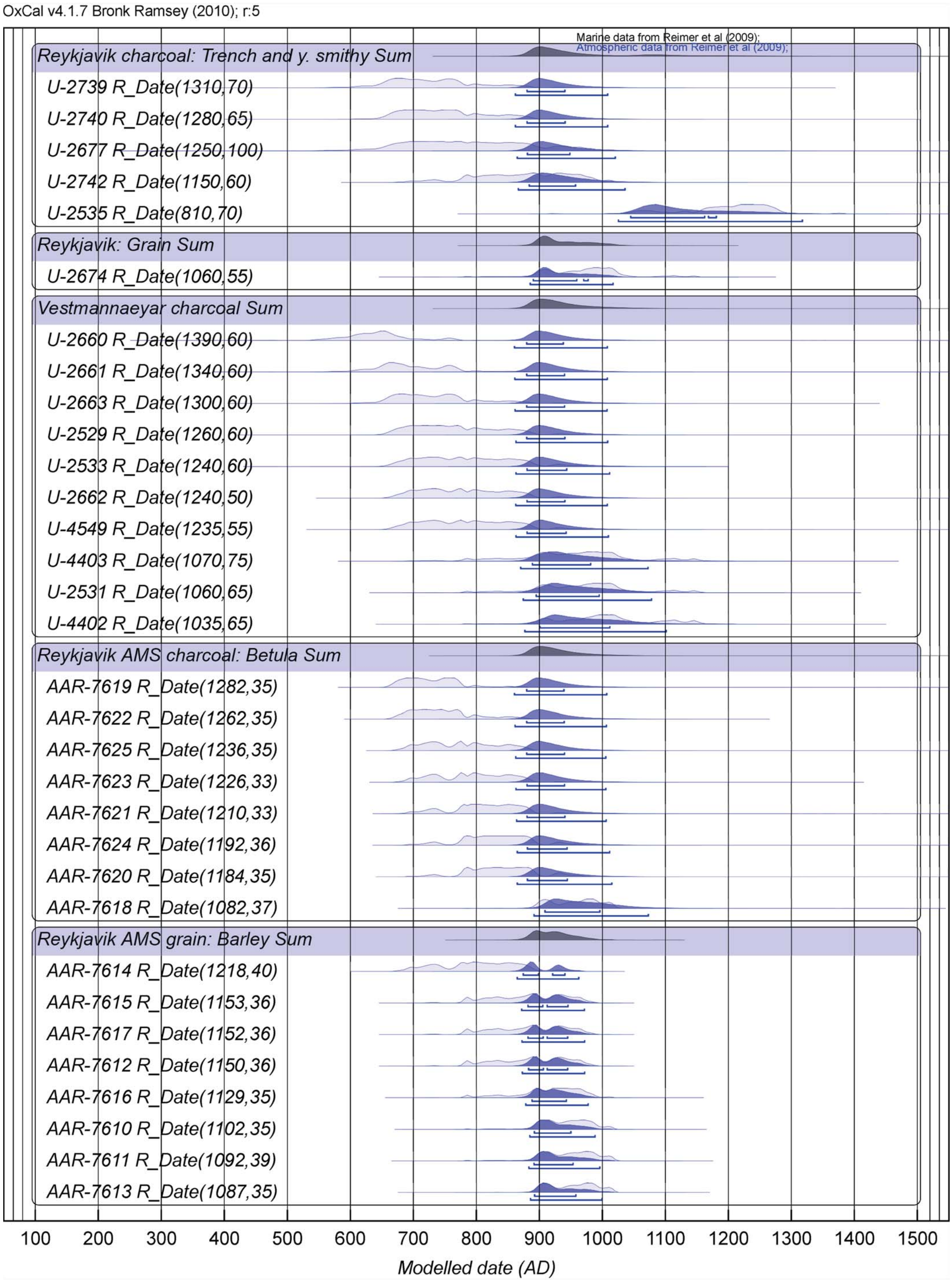

Figure 1a–c *(Continued)*

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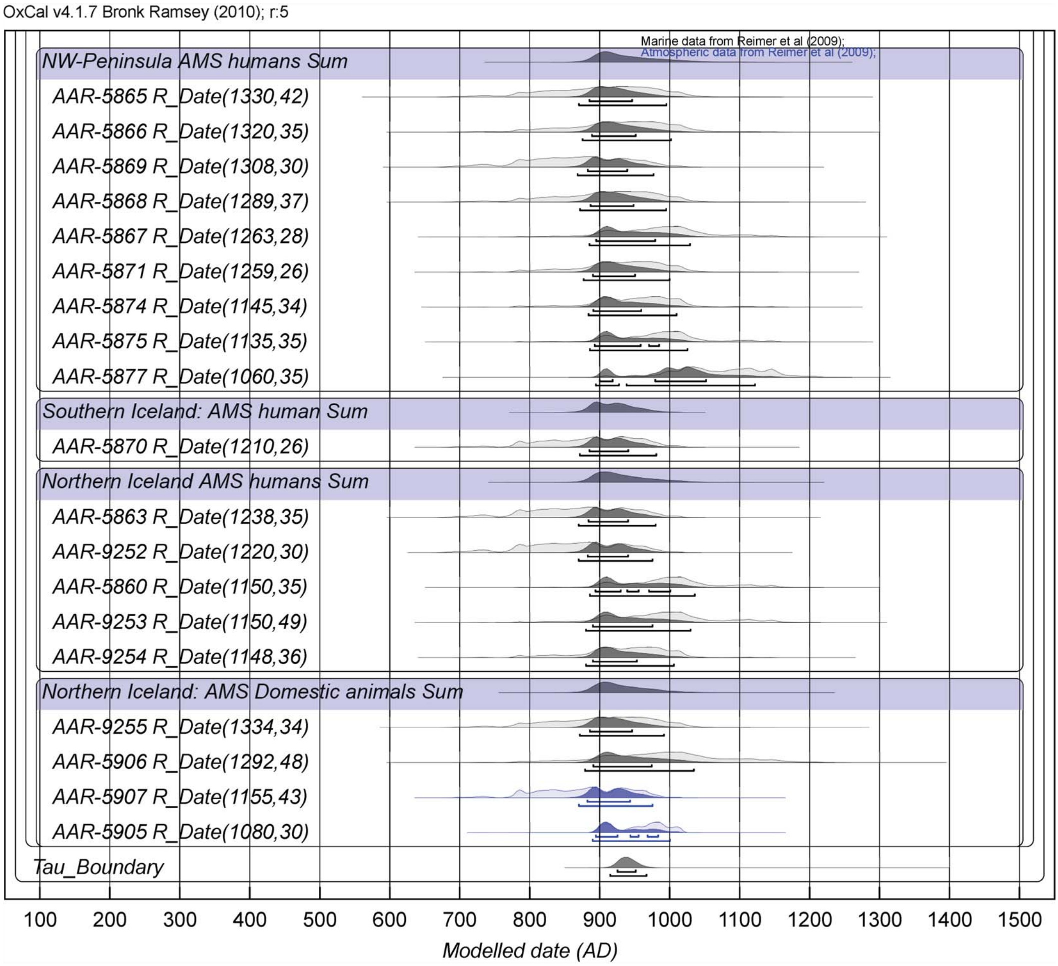

Figure 1a–c *(Continued)*

THE BAYESIAN MODEL

The Bayesian model makes use of the fact that in general charcoal dates will always be older than their context as they relate to the growth of wood in living trees. There will always be some passage of time between this growth, through the death or cutting of the tree to its use in a building or as firewood. The subsequent conversion to charcoal may also be some time later than this, though in this particular instance it is the use of the wood in which we are primarily interested. A “non-informative” neutral assumption is built into the charcoal outlier model of Bronk Ramsey (2009). This model assumes that charcoal most often has a date close the date of the context, but with an exponentially decreasing chance of being substantially older. The time constant associated with the exponential is left undetermined in the model and can take any value from 1 to 1000 yr. To maximize the chronological precision of the settlement and in order to gain some information on the real time difference between the charcoal and short-lived material, we have in the general model included data from both charcoal samples and short-lived material from some of the earliest recognized settlement sites. This provides the charcoal outlier model with the likely average age (the time-constant of the exponential) for the general model. The outlier model allows the charcoal to have an excess age (old-wood effect) anywhere in the range between zero and 10 times the modeled average excess age. In our general model for the settlement, we simply assume that all of the dated samples from these early sites come from a single phase of activity starting with the settlement. The settlement is allowed to take place anywhere between AD 500 and 1000. The end boundary of the phase is a so-called Tau boundary, where it is assumed that the distribution of samples declines exponentially towards the end of the phase.

The Bayesian general model input is listed in Appendix A (Supplementary Online Material). In the model, the ^{14}C ages for humans and dogs from the pagan graves are corrected for marine reservoir effect corresponding up to 60% marine dietary protein component using the $\delta^{13}C$ model of Arneborg et al. (1999) and assuming the regional offset ΔR to be 52 ± 71 yr (Belfast online Marine Reservoir Correction Database: http://calib.qub.ac.uk/marine/), corresponding to a reservoir age of approximately 450 yr.

RESULTS

Figure 1a–c gives an overview of the individual probability distributions of the calibrated ages of all the ^{14}C samples prior to (light shades) and after modeling (dark shades). The samples are listed in groups corresponding to the individual sites and ordered according to decreasing age. For each group, the sum distribution is shown with the heading indicating the site and sample material. The seven groups listed first and marked with laboratory numbers U- and K- are samples from data sets 1 and 2 above, dated by conventional decay counting. The remaining six sample groups are from data sets 3 and 4 and measured by AMS as indicated in the headings (AAR- laboratory numbers). No stratigraphic information is used in the model, apart from assuming that all samples belong to the settlement phase. Terrestrial samples are shown in blue while mixed marine samples (humans and dogs) are shown in black.

The modeled (posterior) age distributions of all samples clearly concentrate in the interval AD 800–1000 as do the prior (unmodeled) distributions of all the short-lived samples. By contrast, the charcoal prior distributions, corresponding to no assumption of old-wood offset, generally fall in a wide age range, starting around AD 650.

In the statistical model that we have set up, the settlement is allowed to start anywhere between AD 500 and 1000. As illustrated by the details of the settlement start boundary in Figure 2, the model narrows the settlement to take place anywhere within AD 853–924 (95.4% probability). This indicates that, although the settlement could be as early as AD 853, the ^{14}C data as it stands does not constitute evidence that there was a settlement any earlier than AD 924.

Figure 3 illustrates the model output in terms of the excess age distribution of the charcoal samples. The shape of the distribution closely resembles the prior assumption of charcoal most often having a date close to the date of the context, but with an exponentially decreasing chance of being substantially older. The model provides a median excess age for the charcoal of 84 yr with 95.4% being less than 270 yr. These excess ages may seem surprisingly high, although not incompatible with observed biological ages and estimates of preservation of dead wood in Icelandic contexts and the fact that some of the wood used might originate from driftwood. However, most of the bulk dates indicate inbuilt ages less than 100 yr, and inspection of the model (Figure 3) as well as the individual probability distributions in Figure 1 reveal very few excess ages that are above 200 yr.

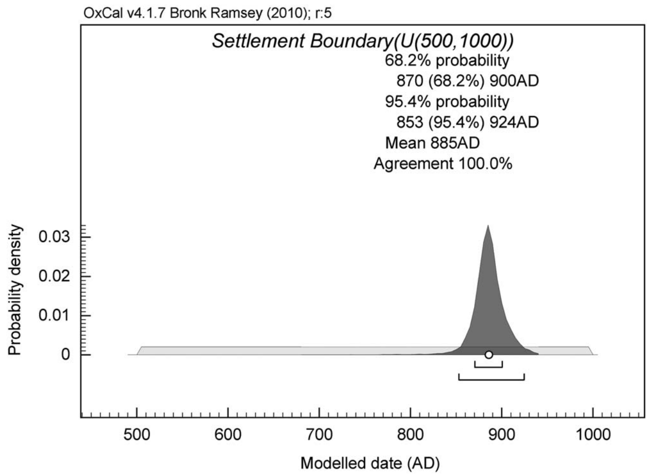

Figure 2 Probability distribution for the settlement date suggested by the model when the full data set is used and combined with the charcoal outlier model (see text). The modeled start boundary lies between AD 853 and 924 at 95.4% probability.

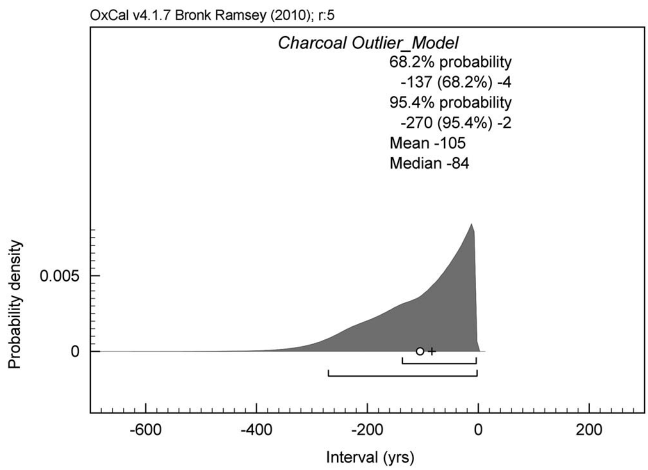

Figure 3 Model distribution for the excess age of charcoal fragments. It peaks at low age and tails off exponentially towards higher ages with a median excess age of 84 yr.

The plausibility of the results on the excess charcoal ages can be illustrated using the same charcoal outlier model but with data restricted to all short-lived material (Figure 1: "Reykjavik: grain" and "Reykjavik AMS grain: Barley") and AMS-dated charcoal samples (Figure 1b: "Reykjavik AMS charcoal: Betula") taken from the same context as the AMS grain samples. For this data subset, the model provides a median excess age for the charcoal of 93 yr with 95.4% of the charcoal samples having inbuilt age less than 235 yr, in excellent agreement with model output for the entire data set (Figure 3). The corresponding settlement boundary is AD 877–955 (95.4% probability). Similarly, if we restrict the data set used in the general model

Table 1 Bayesian model posterior output for the settlement boundary and the charcoal excess age distribution (see text).

Data set	Modeled settlement boundary (95.4% probability)	Mean excess age (yr)	Median excess age (yr)	95.4% upper limit of excess age (yr)
Full data set	AD 853–924	105	84	270
All short-lived samples + AMS-dated charcoal	AD 877–955	104	93	235
Reykjavík paired samples grain and charcoal	AD 779–942	71	53	201

to the truly paired samples of "Reykjavik AMS charcoal: Betula" and "Reykjavik AMS grain: Hordeum satvium" from the same context, the results are a median age excess of 53 yr with 95.4% being younger than 201 yr. The corresponding settlement boundary is AD 779–942 (95.4% probability), the much wider range reflecting the limited data set. A summary of the comparison between data sets is given in Table 1.

DISCUSSION

Allen and Huebert (2014) define short-lived materials as those with a lifespan of 10 yr or less and for long-lived material, those with lifespan greater than 75 yr. The latter is not well suited for ^{14}C dating, given their potential for inbuilt age. Already in the initial phase of ^{14}C dating, it was recognized that long-lived trees were not well suited for accurate ^{14}C datings since much of their stem can be early growth rings, considerably older than the outermost tree ring that reflects the true age (Arnold and Libby 1949).

The proponents of an early settlement, however, have based their arguments on bulk wood and charcoal samples, assuming that the lifespan and decay time of indigenous wood in Iceland are short. However, studies have shown that the maximum lifespan of birch in the northern regions is more than ~150 yr (Kuivinen and Lawson 1982; Govaerts and Frodin 1998; Jónsson 2004) and, according to Eggertson (2006), the oldest living tree recorded in Iceland is 180 yr old. The resistance to decay after death is debated, but there are some indications that it can be as high as several decades, resulting in excess ages of the birch (i.e. the sum of lifespan and decay time) that could be at least 200 yr.

The mean and median ages in the present study reported in Table 1 are somewhat higher than observed by Jónsson (2004) for the birch forest in Iceland (sampled in the dormant season from September 1987 to April 1988), where he reports 58.9 ± 3.9 yr (95% confidence limit) and 56.2 ± 2.8 yr for the mean age and median life expectancy, respectively. This may indicate that the age distribution of the virgin wood in Iceland prior to human influence was different from that of today. Selection of material of the first settlers was most likely different from that of the study of Jónsson (2004), as the settlers were looking for good material for building constructions, hence preferring big stems biasing towards selection of older material. It can also be assumed that dead, more easily accessible trees were common in the unexploited virgin forest, leading to a bias towards higher ages. It is also not unlikely that some of the wood that was used by the settlers originated from driftwood. Thus, the dated material may have inbuilt age associated with them to a variable degree and is therefore not well suited for establishing a reliable date for the beginning of the settlement of Iceland.

Our model, applied to both the full and the partial data sets, shows that all of the older ^{14}C dates that we see for charcoal and bulk wood are consistent with the true context age of the samples being just after the *landnám* tephra date of AD 871 ± 2. Consequently, there is no evidence in the ^{14}C dates that the settlement date should be moved back by 150–200 yr from the traditional date, as some of the charcoal dates at face value would suggest.

Given the unconstrained nature of the statistical model, it is not surprising that the data do agree well, as indicated by the resulting agreement index A_{model} = 78.6% (Bronk Ramsey 1995). Conceptually, the model simply reflects the fact that the measurements on short-lived material have ^{14}C dates that are consistent with the modeled date for the settlement, and that the distribution of charcoal dates is exactly as one would expect if there was an old-wood effect evident in the samples.

CONCLUSIONS

Our Bayesian modeling has quantified a substantial old-wood effect in the sample material and thereby negates the aforementioned assumption of a particularly negligible old-wood effect for Icelandic bulk wood samples. Our findings thus demonstrate the unsuitability of bulk wood samples *alone* to provide a reliable *terminus ante quem* for the settlement of Iceland. The use of truly short-lived material is preferential to establish an exact chronology of the settlement of Iceland. Bulk charcoal and wood samples can be useful if their potential inbuilt age is taken into account by Bayesian modeling of a combination of the two types of samples.

It is of course entirely possible that the earliest traces of the settlement have not yet been found, and that future excavations may provide ^{14}C dating of short-lived material to prove an earlier settlement date. However, the presently available ^{14}C data do not provide such a proof.

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/RDC.2016.2

REFERENCES

Allen MS, Huebert JM. 2014. Short-lived plant materials, long-lived trees, and Polynesian ^{14}C dating: considerations for ^{14}C sample selection and documentation. *Radiocarbon* 56(1):257–76.

Arneborg J, Heinemeier J, Lynnerup N, Nielsen HL, Rud N, Sveinbjörnsdóttir ÁE. 1999. Change of diet of the Greenland Vikings determined from stable carbon isotope analysis and ^{14}C dating of their bones. *Radiocarbon* 41(2):157–68.

Arnold JR, Libby WF. 1949. Age determinations by radiocarbon content: checks with samples of known age. *Science* 110(2869):678–80.

Ascough PL, Cook GT, Church MJ, Dugmore AJ, McGovern TH, Dunbar E, Einarsson Á, Fridriksson A, Gestsdóttir H. 2007. Reservoirs and radiocarbon: ^{14}C dating problems in Mývatnssveit, northern Iceland. *Radiocarbon* 49(2):947–61.

Ascough PL, Cook GT, Church MJ, Dunbar E, Einarsson Á, McGovern TH, Dugmore AJ, Perdikaris S, Hastie H, Fridriksson A, Gestsdóttir H. 2010. Temporal and spatial variations in freshwater ^{14}C reservoir effects: Lake Mývatn, northern Iceland. *Radiocarbon* 52(3):1098–12.

Ascough PL, Cook GT, Hastie H, Dunbar E, Church MJ, Einarsson Á, McGovern TH, Dugmore AJ. 2011. An Icelandic freshwater radiocarbon reservoir effect: implications for lacustrine ^{14}C chronologies. *Holocene* 21(7):1073–80.

Ascough PL, Church MJ, Cook GT, Dunbar E, Gestsdóttir H, McGovern TH, Dugmore AJ, Fridriksson A, Edwards KJ. 2012. Radiocarbon reservoir effects in human bone collagen from northern Iceland. *Journal of Archaeological Science* 39(7):2261–71.

Belfast online Marine Reservoir Correction Database. 2015. http://calib.qub.ac.uk/marine. Accessed 17 December 2015.

Bronk Ramsey C. 1995. Radiocarbon calibration and analysis of stratigraphy: the OxCal program. *Radiocarbon* 37(2):425–30.

Bronk Ramsey C. 2009. Dealing with outliers and offsets in radiocarbon dating. *Radiocarbon* 51(3):1023–45.

Dee M, Bronk Ramsey C. 2014. High-precision Bayesian modeling of samples susceptible to inbuilt age. *Radiocarbon* 56(1):83–94.

Eggertsson Ó. 2006. Fornskógar. In: Halldórsson G, editor. *Skógarbók Grænni skóga*. Akureyri: The Agricultural University of Iceland. p 23–8. In Icelandic.

Erlendsson E, Edwards KJ. 2010. Gróðurfarsbreytingar á Íslandi við landnám. *Árbók hins íslenska fornleifafélags*. p 29–55. In Icelandic with English summary.

Govaerts R, Frodin DG. 1998. *World Checklist and Bibliography of Fagales (Betulaceae, Corylaceae, Fagaceae and Ticodendraceae)*. London: The Royal Botanical Gardens, Kew.

Grímsson Th, Einarsson Th. 1979. Fornminjar í Reykjavík og aldursgreiningar. *Árbók hins íslenska Fornleifafélag* 1969:80–97.

Grönvold K, Oskarsson N, Johnsen SJ, Clausen HB, Hammer CU, Bond G, Bard E. 1995. Ash layers from Iceland in the Greenland GRIP ice core correlated with oceanic and land sediments. *Earth and Planetary Science Letters* 135(1–4): 149–55.

Hall VA, Pilcher JR, McCormac FG. 1993. Tephra-dated lowland landscape history of the north of Ireland, A.D. 750–1150. *New Phytologist* 125(1):193–202.

Hallsdóttir M. 1987. Pollen analytical studies of human influence on vegetation in relation to the landnám tephra layer in southwest Iceland [PhD dissertation]. Lund: Lund University.

Hallsdóttir M. 1996. Frjógreining. Frjókorn sem heimild um landnámid. In: Grímsdóttir GÁ, editor. Um Landnám á Íslandi. Reykjavík: Vísindafélag Íslendinga. p 123–34.

Hermanns-Audardóttir M. 1989. *Islands tidiga bosättning*. *Studiea Archaeologica Universitatis Umensis*, 1. Umeå 184 p.

Jónsson Th. 2004. Stature of sub-arctic birch in relation to growth rate, lifespan and tree form. *Annals of Botany* 94:753–62.

Kuivinen L, Lawson MP. 1982. Dendroclimatic analysis of birch in south Greenland. *Arctic and Alpine Research* 14:243–50.

Larsen G. 1996. Gjóskulagatímatal og gjóskulög frá tíma norræns landnáms á Íslandi. In: Grímsdóttir GÁ, editor. *Um Landnám á Íslandi*. Reykjavík: Vísindafélag Íslendinga. p 81–106.

Nordahl E. 1988. *Reykjavík from the Archaeological Point of View*, Aun 12. Uppsala: Societatas Archaeologica Upsalensis. 150 p.

Olafsson G. 1998. Fylgsnið í hellinum Víðgelmi. *Árbók hins íslenska fornleifafélags*. p 125–42. In Icelandic with English summary.

Reimer PJ, Bard E, Bayliss A, Beck JW, Blackwell PG, Bronk Ramsey C, Buck CE, Cheng H, Edwards RL, Friedrich M, Grootes PM, Guilderson TP, Haflidason H, Hajdas I, Hatté C, Heaton TJ, Hoffmann DL, Hogg AG, Hughen KA, Kaiser KF, Kromer B, Manning SW, Niu M, Reimer RW, Richards DA, Scott EM, Southon JR, Staff RA, Turney CSM, van der Plicht J. 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55(4):1869–87.

Sveinbjörnsdóttir AE, Heinemeier J, Gudmundsson G. 2004. ^{14}C datings and the settlement of Iceland. *Radiocarbon* 46(1):387–94.

Sveinbjörnsdóttir ÁE, Heinemeier J, Arneborg J, Lynnerup N, Ólafsson G, Zoëga G. 2010. Dietary reconstruction and reservoir correction of ^{14}C dates on bones from pagan and early Christian graves from Iceland. *Radiocarbon* 52(2–3):682–96.

Theodórsson P. 1993. Geislakolsgreining gjóskulaga og aldur landnámslagsins. *Náttúrufrædingurinn* 63:275–83. In Icelandic with English summary.

Theodórsson P. 1997. Upphaf landnáms og geislakolsgreiningar. *Skírnir* 171:92–110. In Icelandic with English summary.

Theodórsson P. 1998. Norse settlement of Iceland – close to AD 700? *Norwegian Archaeological Review* 31:29–38.

Theodórsson P. 2009. Upphaf landnáms á Íslandi 670 AD. *Skírnir* 183:261–80. In Icelandic with English summary.

Theodórsson P. 2010. Hvað hét fyrsti landnámsmaðurinn? *Skírnir* 184:511–21. In Icelandic with English summary.

Theodórsson P. 2011. Upphaf landnáms á Íslandi. Raunvísindastofnun Háskólans. RH-16-2011. 25 p. In Icelandic.

Theodórsson P. 2012. Kolefni-14 aldursgreiningar í íslenskri fornleifafræði. Raunvísindastofnun Háskólans. RH-02-2012. 46 p. In Icelandic.

Vilhjálmsson VÖ. 1991. Radiocarbon dating and Icelandic archaeology. *Laborativ Arkeologi* 5:101–4.

Zielinski GA, Germani MS, Larsen G, Baille MGL, Whitlow S, Twickier MS, Taylor KC. 1997. Volcanic aerosol records and tephrochronology of the Summit, Greenland ice cores. *Journal of Geophysical Research* 102(C12):26,625–40.