

^{14}C DATING OF THE SETTLEMENT OF ICELAND

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ABSTRACT. The dating of the settlement of Iceland has been debated for many years. According to written sources (sagas) from the early 12th century, the first Norwegian settlers arrived in Iceland in AD 874. However, some ^{14}C dates from the earliest archaeological sites in Iceland, invariably from samples of birch and other indigenous wood species, have yielded surprisingly old ages, older by 100–150 yr than the historical date, suggesting that the settlement took place in the 7th or 8th century. In this paper, we report 16 new ^{14}C dates of pairs of barley grain and wood samples from an excavation in Reykjavík in 2001. The new results show that the wood samples tend to be older than the grain samples by up to about 100 yr. We argue that the barley grains give the true date (AD 890), whereas the wood dates are too old. The grain dates are in close agreement with the settlement year quoted in the written sources. In particular, our new data eliminate the need of any of the ad hoc theories introduced up to now to explain the suspiciously high ^{14}C ages of wood samples from the settlement of Iceland, namely, 1) the island effect, 2) the volcanic or geothermal effect, or 3) that settlement actually took place significantly before the time recorded in the sagas.

INTRODUCTION

Written Sources

The time of the settlement of Iceland has been the subject of intense debate for many years, fueled by the fact that radiocarbon dates of early human occupation often give an older age than the historical tradition, which places the first settlement in the late 9th century. The traditional settlement time is based on written sources (sagas) from the early 12th century according to which the first Norwegian settlers are said to have arrived in Iceland in AD 874 (Íslendingabók Ara fróda).

The Settlement Tephra Layer

The changes in land use following the beginning of permanent settlement show up in soil profiles as a change in soil type and pollen composition (Einarsson 1962; Hallsdóttir 1987, 1996). This stratigraphic transition is located close to a volcanic ash (tephra) layer (denoted the "Settlement" layer), which has been found in soil profiles over a large part of Iceland. Larsen (1996) reported that the tephra layer was formed in a volcanic eruption from Vatnaöldur, southeast Iceland, in the last part of the 9th century based on a relative age determination. The tephra layer was first noted in the 1940s, during an excavation in Thjórsárdalur, south Iceland, where it was found just below the oldest remains of settlement (Thórarinsson 1944). Pollen analyses have shown that changes in land use following the start of permanent settlement in some places occurred just before the volcanic eruption in Vatnaöldur, but in other places occurred just after the eruption (Hallsdóttir 1996).

Dating of the Settlement Layer

Three attempts have been made to ^{14}C date organic remains adjacent to the Settlement tephra layer in Iceland (see Figure 1a,b). Thórarinsson (1977) reported 2 ^{14}C dates with a mean calibrated value of AD 845 ± 45. Theodórsson (1993) pointed out that due to the plateau on the calibration curve between AD 770 and 880, Thórarinsson's results should not be reported as a mean value since their age range spans the plateau time interval. Haraldsson (1981) reported the calibrated age AD 860 ± 75

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based on 1 bog sample. Hallsdóttir (1987) collected 5 samples of organic remains, one from the tephra layer, two 1-cm slices above the layer, and 2 slices below the layer, and reported a mean calibrated age of AD 845. Wiggle-matching of Hallsdóttir's results gives AD 835 ± 20 (Theodórsson 1993). In addition, the Settlement tephra layer has been recognized in Irish bogs and ^{14}C dated to AD 860 ± 20 (calibrated age, Hall et al. 1993). Although all the attempts to ^{14}C date the Settlement tephra layer are mutually compatible, the age of the layer cannot be determined very accurately due to the plateau in the calibration curve. The ^{14}C dates agree, however, with the precise result AD 871 ± 2 obtained by absolute dating of the tephra layer in the GRIP ice core in Greenland (Grönvold et al. 1995). The results of both methods agree with the historical date of the settlement.

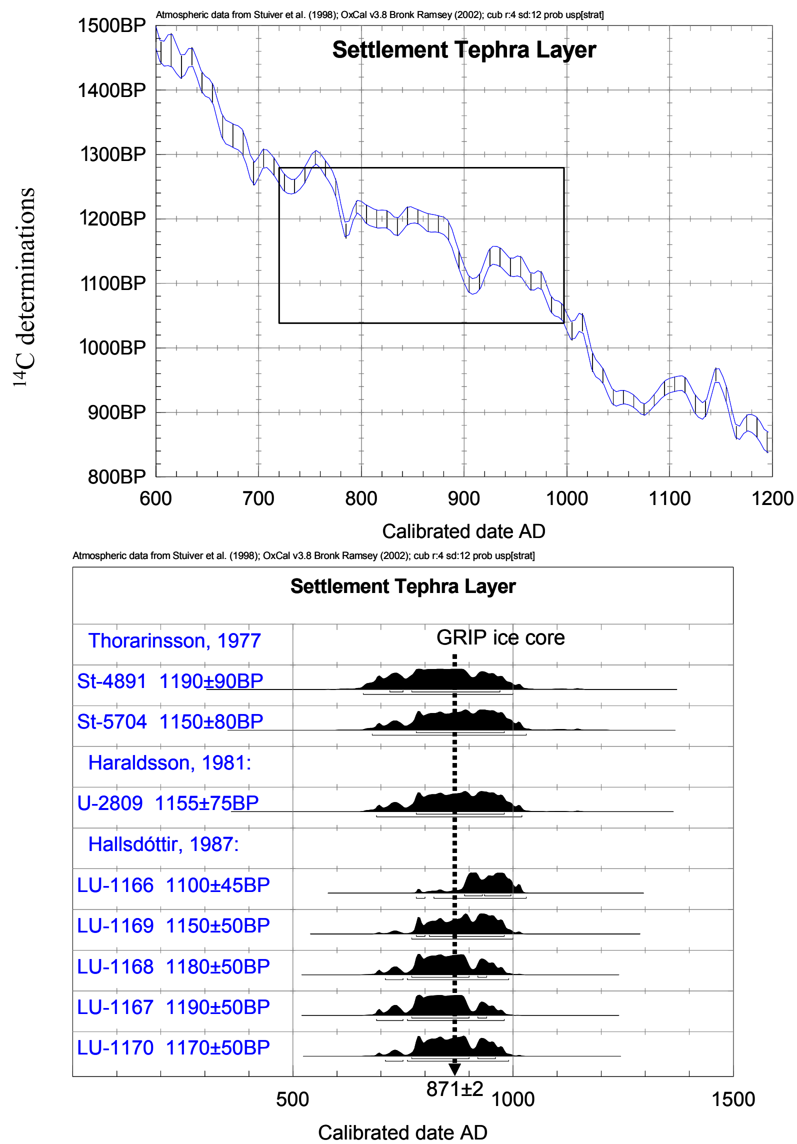

Figure 1 a) The calibration curve with the region of interest for the settlement time period indicated. The age plateau makes it difficult to achieve accurate ^{14}C-based age determination of samples from the settlement period. b) Attempts to date the Settlement ash layer are mutually compatible, as shown by the probability distributions as calculated by the OxCal v3.8 calibration program (Bronk Ramsey 2001).

Previous ^{14}C Dates of Archaeological Sites from the Settlement Period

Although we now know precisely the age of the Settlement tephra layer, the age of the settlement is still debatable, since the chronological association between the tephra layer and the earliest strata of human occupation is not always clear and the ^{14}C dates of archaeological remains often indicate earlier settlement (Nordahl 1988; Hermanns-Audardóttir 1989). Vilhjálmsson (1991) has compiled ^{14}C dates from archaeological sites in Iceland and criticized ^{14}C dating laboratories, archaeologists, and geologists for misinterpreting ^{14}C dates. In the following, we examine the previous results from Reykjavík and Vestmannaeyjar for comparison with our new ^{14}C dates from Reykjavík reported below.

Reykjavík Site

In the 1970s, archaeological excavations were undertaken in Reykjavík at sites from the settlement period. About 30 ^{14}C dates were obtained (Nordahl 1988). Of the 35 results shown in Figure 2, 13 dates have their 68.2% (1 σ) probability interval older than the Settlement tephra layer, the difference being as much as 100 yr for the 6 oldest samples. Based on these, one would have to accept a *terminus ante quem* (TAQ) for the first settlement of about AD 780 (indicated by the dotted line), assuming negligible lifespan and deposition time before the wood was charred. The same TAQ would result using the 2-σ interval (based on the 2 oldest samples). All of the samples in Figure 2 are from birch, *Betula pubescens*, *B. tortuosa*, and/or *B. nana*, apart from 1 European larch-sample, *Larix decidua* (U-2082), and 1 grain sample (U-2674). In the case of wood samples, the measured ^{14}C age depends on the biological age of the dated tree rings and the time interval between death and subsequent use of the wood. The highest biological age for Icelandic birch is about 100 yr. The maximum age of the European larch is about 200 yr. These trees grow in Central Europe and the wood has probably been shipped to Iceland as building material (Grímsson and Einarsson 1970). In light of this, wood samples can be expected to give greater ^{14}C ages than that of the archaeological event. Grain, on the other hand, is probably from the latest harvest and, therefore, most likely to give a reliable date of the human activity. The 2-σ calibrated age range of the grain sample (U-2674) is AD 860–1160 (Figure 2 *continued*, last sample).

Vestmannaeyjar Site

Figure 3 shows the ^{14}C results of samples from an excavation in Herjolfsdalur in Vestmannaeyjar (the Westman Islands) off the southwest coast of Iceland (Hermanns-Audardóttir 1989). Six out of 10 results give older calibrated ^{14}C ages (1 σ) than the Settlement tephra layer by 100 yr or more for three of them. With the assumptions discussed for the Reykjavík site the TAQ for the settlement of Vestmannaeyjar would be AD 690 or, omitting the oldest sample, AD 780 (shown by the dotted line on Figure 3). All measurements were done on wood samples, mostly Icelandic birch (*Betula*) and 1 larch (*Larix*) sample (U-4403). Two samples were not species-determined (U-2529 and U-2533). On the basis of these measurements, Hermanns-Audardóttir (1989) concluded that the settlement of Iceland had taken place in the 8th century, or even as early as the 7th century.

Abnormal ^{14}C Condition in Iceland?

Most of the igneous rocks in Iceland are basaltic (about 90%), the rest is of rhyolitic and intermediate composition. About 90% of Iceland above sea level consists of volcanic rocks, only about 10% being consolidated sediments, which are mainly interbedded tuffaceous layers of short transport, and tillite. Icelandic bedrock contains no calcareous rocks and, therefore, hardwater effect is absent. Volcanic and geothermal activity is widespread. According to Saemundsson (1979), 24 volcanic

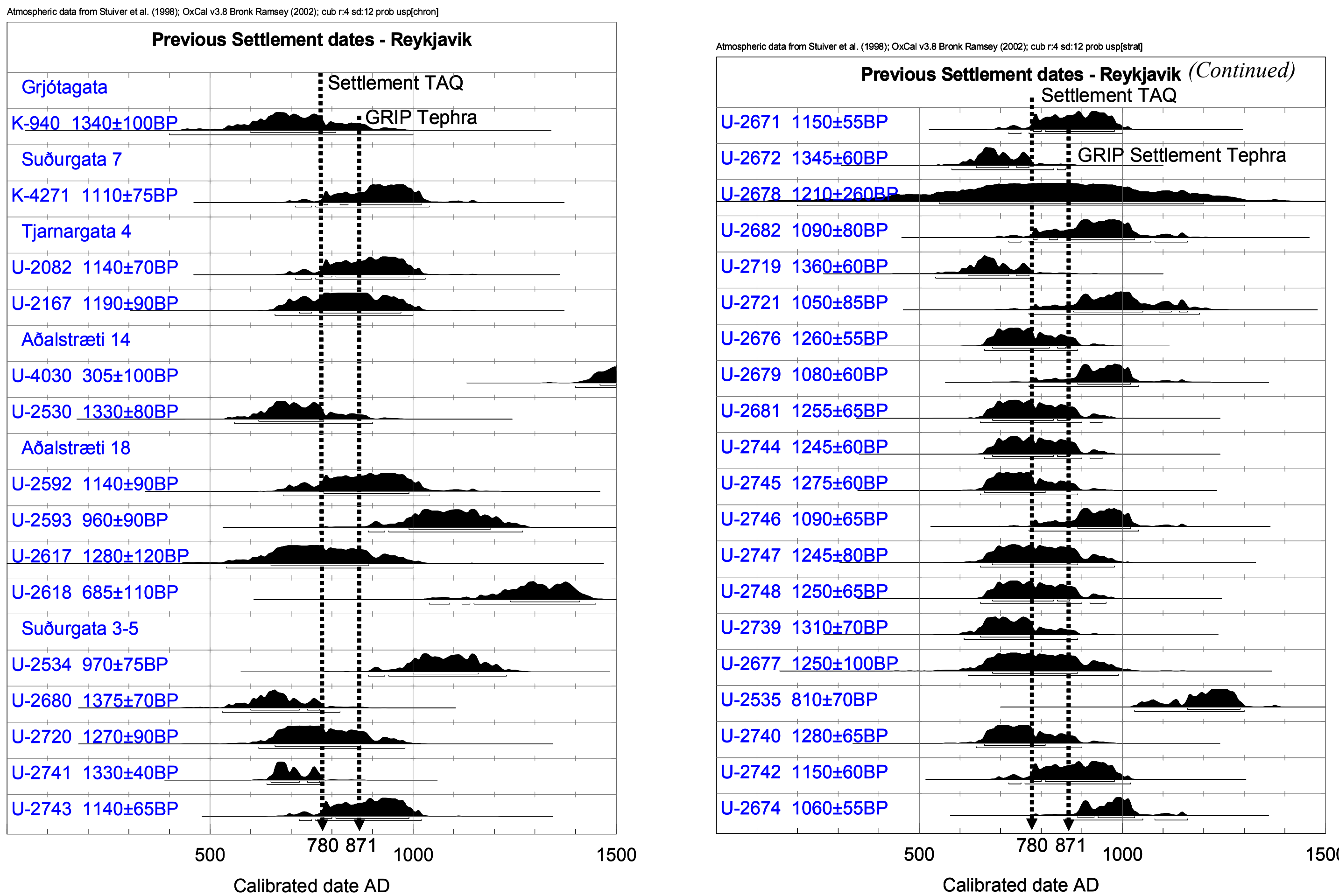

Figure 2 Probability distribution (OxCal v3.8) of calibrated ages of samples from the center of Reykjavík previously ^{14}C dated (Nordahl 1988; Grímsson and Einarsson 1970). The dotted lines indicate *terminus ante quem* (TAQ) for the settlement, derived from the 1-σ intervals (see text), and the Settlement tephra date AD 871 (Grönvold et al. 1995).

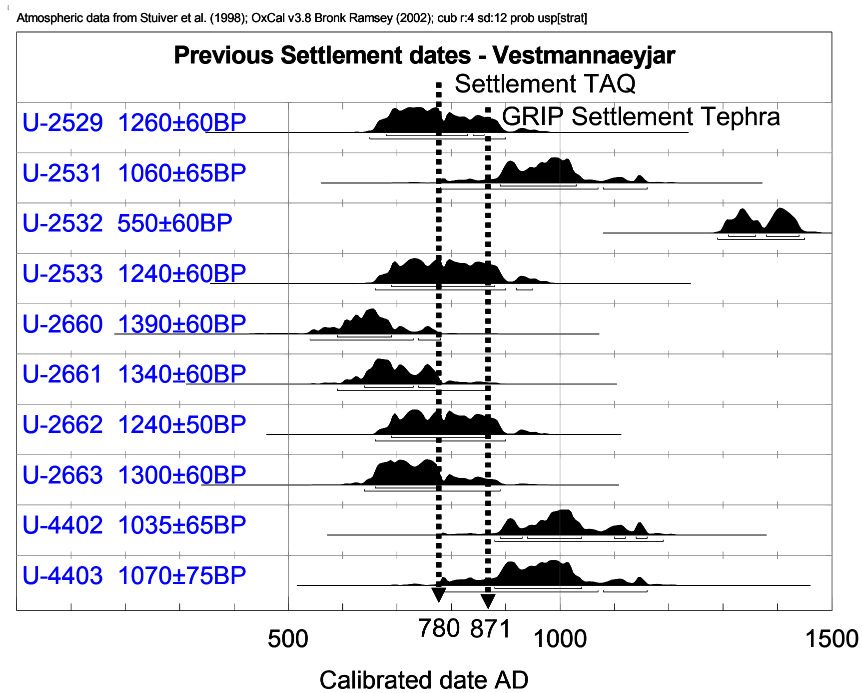

Figure 3 Probability distribution (OxCal v3.8) of calibrated ages of samples from Vestmannaeyjar previously ^{14}C dated (Hermanns-Audardóttir 1989). The dotted lines indicate *terminus ante quem* (TAQ) for the settlement, derived from the 1-σ intervals (see text), and the Settlement tephra date AD 871 (Grönvold et al. 1995).

systems have been active in postglacial time, producing about 400–500 km^3 of lava, and geothermal areas are frequently associated with these volcanic complexes. Despite the volcanic activity, ^{14}C dates of mollusks and plant remains have produced consistent results, with wood samples from the settlement period as an exception. In only 1 case, anomalously high ^{14}C ages (older by 8000 yr) have been reported that can be explained by volcanic activity (Sveinbjörnsdóttir et al. 1992), namely aquatic moss samples that have grown in geothermal water. Apart from this, volcanic activity has not been known to have caused any major errors in ^{14}C results of geological samples. Shore et al. (1995) explicitly studied modern moss samples in the vicinity of the Katla volcano, Iceland (3 samples) and compared them to modern moss (2 samples) in Scotland and found no difference in the $^{14}C/^{12}C$ ratio. After extensive data collection, Olsson (1983) proposed a general ^{14}C depletion in atmospheric CO_2 in Iceland, which she explained by the so-called "island effect," which would make ^{14}C ages in Iceland appear slightly too high due to isotopic exchange between the atmosphere and the sea surface.

RESULTS AND DISCUSSION

In the present work, we have measured ^{14}C dates on samples from an excavation (site AST-01) in the center of the city of Reykjavík. The operation was part of a larger excavation program carried out in the early 1970s (Nordahl 1988). The excavations in 2001 revealed a complete Viking Age longhouse and also cultural layers from later times. The longhouse was erected shortly after the deposition of the Settlement tephra. A sampling program carried out throughout the excavation was designed to address some of the questions regarding the Icelandic ^{14}C dating problems. Eight pairs of barley seeds and wood samples (Icelandic birch) from the same, oldest stratigraphic context of the site were ^{14}C dated by accelerator mass spectrometry (AMS).

After standard chemical pretreatment of the samples with 1M HCl and 1M NaOH, the carbon was combusted to CO_2, which was partly converted to graphite for AMS ^{14}C dating with the EN tandem accelerator at the University of Aarhus and partly used for δ^{13}C measurements by conventional mass spectrometry at the Science Institute, University of Iceland. The accuracy of the δ^{13}C measurements is better than 0.1‰. The AMS results are given in Table 1 with the 1-σ precision indicated. That the accuracy is of the order of the precision is demonstrated by our results in the Fourth International Radiocarbon Intercomparison (FIRI, Scott 2003a), where our weighted average deviation from consensus values on 18 measurements was only 0.8 ± 12 ^{14}C yr (Scott 2003b, participant laboratory #88).

Table 1 ^{14}C dates and δ^{13}C values for grain (*Hordeum Sativum*) and charcoal (*Betula*) samples paired according to context from an excavation in the center of Reykjavík (site AST-01). Calendar age single interval corresponding to 68.2% probability (1 σ), calculated by the OxCal v3.8 calibration program (Bronk Ramsey 2001).

Lab nr AAR-	Object ID nr	Sample type	Conventional ^{14}C age (yr BP)	Calendar age (cal AD)	δ^{13}C (‰ VPDB)	Context location
7610	AST01-AMS-1	grain	1102 ± 35	895–985	–21.44	Context 646: Fill of
7618	AST01-AMS-18	charcoal	1082 ± 37	890–1020	–25.71	temp. hearth
7611	AST01-AMS-2	grain	1092 ± 39	895–1000	–25.63	Context 792: Upper
7618	AST01-AMS-19	charcoal	1282 ± 35	685–775	–24.83	fill of longfire
7612	AST01-AMS-3	grain	1150 ± 36	780–980	–23.94	Context 795: Lower
7620	AST01-AMS-20	charcoal	1184 ± 35	780–890	–25.29	upper fill of longfire
7613	AST01-AMS-4	grain	1087 ± 35	895–1000	–25	Context 802: Upper
7621	AST01-AMS-21	charcoal	1210 ± 33	770–890	–26.35	lower fill of longfire
7614	AST01-AMS-5	grain	1218 ± 40	720–890	–25.9	Context 831: Bottom
7622	AST01-AMS-22	charcoal	1262 ± 35	685–780	–26.35	fill of longfire
7615	AST01-AMS-6	grain	1153 ± 36	780–970	–25.21	Context 858: Floor
7623	AST01-AMS-23	charcoal	1226 ± 33	720–880	–27.98	deposit N of longfire
7616	AST01-AMS-7	grain	1129 ± 35	890–980	–24.32	Context 864: Upper floor
7624	AST01-AMS-24	charcoal	1192 ± 36	780–890	–25.88	deposit, W of longfire
7617	AST01-AMS-8	grain	1152 ± 36	780–980	–23.42	Context 873: Lower floor
7625	AST01-AMS-25	charcoal	1236 ± 35	690–870	–27.31	deposit W of longfire

The ^{14}C dates of the 8 grain/wood sample pairs are given in Table 1 and the calibrated probability distribution shown in Figure 4. The results show that the wood samples (Icelandic birch) tend to be older than grain samples. With the same assumptions for these wood samples as for the previous sample series discussed above, one would reach the same conclusion, namely, that the settlement in Reykjavík has occurred no later than around AD 780 (dotted line in Figure 4). However, the grain samples date the settlement in Reykjavík to no later than around AD 890.

We argue that wood samples often give too-high ages and are not suited to date the settlement. Grain, on the other hand, is probably from the last harvest and, therefore, most suitable to give the true age of the human occupation. Similarly, Olafsson (1995) found that a birch sample from a fireplace in west Iceland from the settlement time period was 150 yr older than an associated cow bone. The fireplace is located in a cave within a lava flow (Hallmundarhraun) that sits on the Settlement tephra layer. Therefore, any human activity must be younger than the tephra layer. However, the age of the fireplace sample is older than the tephra layer and, therefore, cannot reflect the true date of the event.

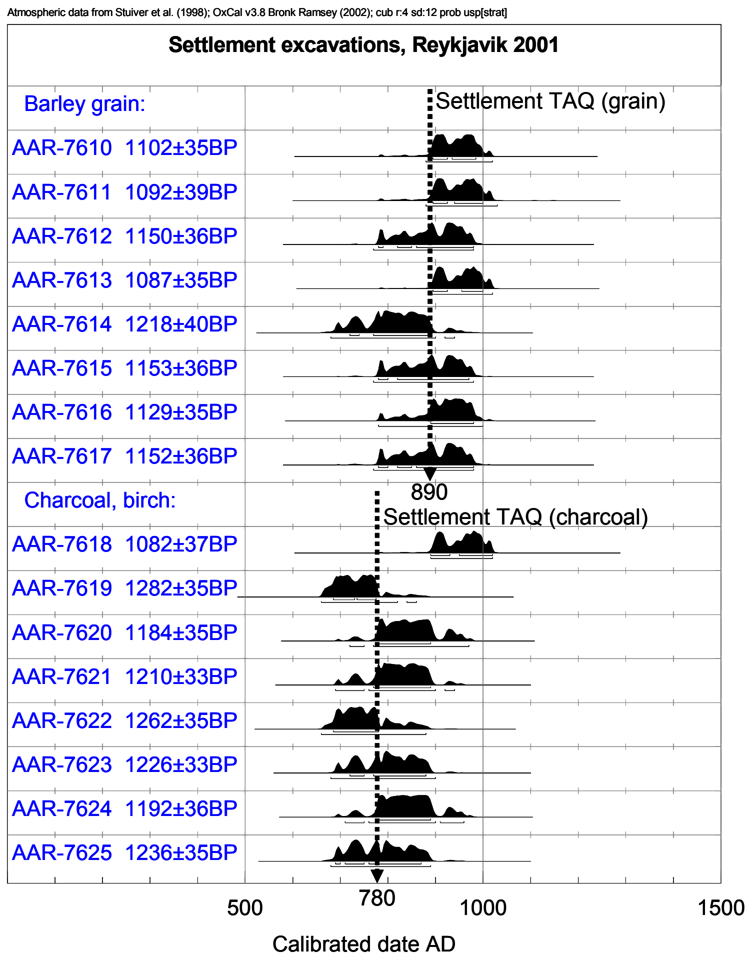

Figure 4 Probability distribution (OxCal v3.8) of calibrated ages of the series of ^{14}C dates on paired wood/grain samples from an excavation (site AST-01) in the center of the city of Reykjavík. The wood samples are shown in the same sequence as their grain counterparts. The dotted lines indicate the *terminus ante quem* (TAQ) AD 780 and AD 890, respectively, for the settlement, derived from 1-σ intervals of the wood samples and the grain samples. The grain samples have a shorter lifespan and a safer association with the settlement.

As pointed out by Ólafsson (1998), the wood collected by the first settlers in Iceland to build their fire had very likely been dead, possibly for more than a century. This makes "Settlement" wood unsuited for ^{14}C dating as it can be much older than the archaeological context. Work in progress indicates that the supply of old firewood was gradually exhausted, thus reducing the age offset of charcoal samples from the following centuries.

The interpretation of our new ^{14}C results on paired grain and wood samples eliminates the necessity of any of the ad hoc theories introduced up to now to explain the surprisingly early ^{14}C dates of the settlement of Iceland, namely, 1) island effect, 2) volcanic and/or geothermal effect, 3) early settlement. We argue that the ^{14}C dating results of wood samples in the settlement time period simply do not give the true date of human occupation.

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