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Radiocarbon dating of the iron production in slag-pit furnaces in Jutland

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Abstract

Seventy-three samples of charred straw and charcoal from slag-pit furnaces on eleven different iron smelting sites in Jutland have been radiocarbon dated in order to investigate the duration of the use of the slag-pit furnace in iron production. At the following four major sites we have estimated the duration of iron production:

Drengsted	*AD 410-550*
Snorup	*AD 330-570*
Starup	*AD 140-340*
Gødsvang	*AD 300-550*

Taken as a whole we have dated the use of slag-pit furnaces in Jutland to approximately AD 250-610.

Archaeological description

Iron Age iron production in Denmark is largely confined to south-western Jutland, although more than 100 iron production sites are known throughout the whole of Jutland (Voss 1993). The source of the iron ore is the abundant bog iron along the streams and lakes in Jutland. The charcoal was produced in large quantities in the surrounding forests.

When excavated, a well-preserved slag-pit generally contains a slag block weighing c. 200 kg. Each slag-pit is the result of the production of one batch of sponge iron, which was left at the bottom of the shaft of the furnace while the slag drained into the pit. The furnace itself was an almost cylindrical shaft built of half-dried clay bricks. The slag-pit under the furnace was filled with straw in order to prevent the charcoal from falling down into the pit. During the smelt, part of this straw sometimes became charred and this is the material which has been used for the radiocarbon dates in this study. We have radiocarbon dated samples from slag-pit furnaces from eleven different sites in Jutland (Fig. 1).

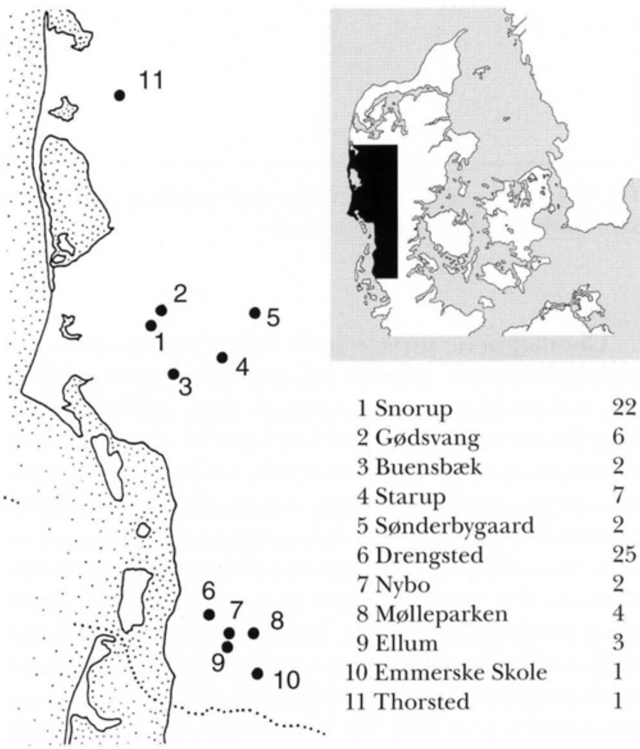

Fig. 1. Map showing the locations of the radiocarbon-dated smelting sites in Jutland. The number of radiocarbon dates from each site is indicated after the site name.

Fig. 2. The Snorup Iron Age village and smelting site. Black dots are slag-pit furnaces. Numbers in circles give the number of radiocarbon datings within a cluster.

Geomagnetic surveys have been carried out at the iron production area at Snorup (Smekalova 2003). Fig. 2 shows the positions of more than 4000 furnaces distributed over an area of c. 0.3 km^2 in clusters of different sizes, alignments and also as isolated slag-pits. One of the alignments, E11, consisting of 14 slag-pits, seems to be the result of one continuous iron production. Ten of the slag-pits are situated in pairs, probably because the furnaces were run two at a time. Such short term events cannot, however, be resolved by the radiocarbon method. Air photography and partial excavation have revealed a village within the Snorup production area (Fig. 2). The houses at the smelting sites are similar to houses in non-iron producing villages found elsewhere in Jutland. This seems to indicate that the farmers themselves carried out the iron production, possibly under the guidance of a local smith or master smelter. According to the potsherds found in the parts excavated, the houses belong to the 4th - 6th century AD. There were no signs of habitation before or after the period of iron production. It is quite possible that the site was colonized because the raw materials for iron smelting, bog iron ore and charcoal were available here. It seems that the site was abandoned when the iron smelting stopped, suggesting that the iron smelting was the basis for the economy. Contemporary farming settlements were also found in limited excavations at Horne, Gødsvang, Yderik and Krarup (see Fig. 3), so it seems that iron smelting sites are commonly connected to settlements.

This connection between settlements and iron production sites is supported by three cases in southern Jutland: at Drengsted, Nybo and Mølleparken. The latter sites have only been partially excavated. At Drengsted 243

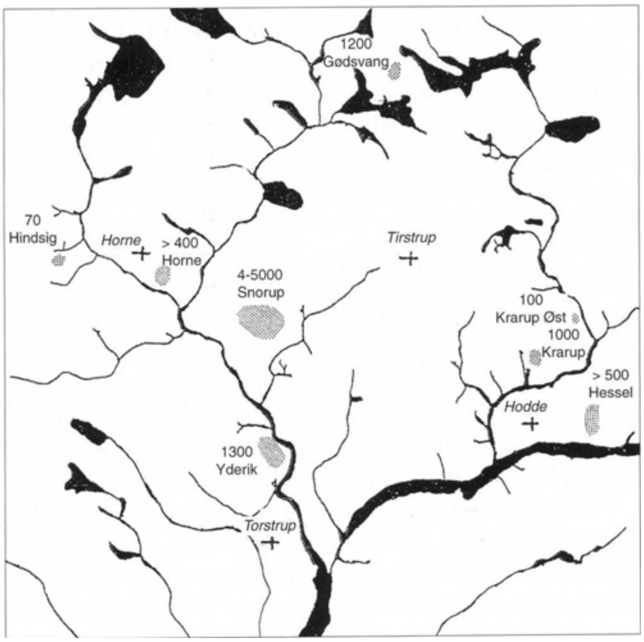

Fig. 3. Within the 10x10 km area around Snorup magnetic surveys have been carried out at seven new smelting sites of different sizes: Hindsig with 70 slag-pits; 300 or more in Horne; Gødsvang with 1200 or more; Yderik with probably 1300; Krarup 1000; Krarup East with 100 slag-pits and Hessel with more than 500. There are four medieval churches in this area: Horne, Tistrup, Hodde, and Torstrup. All are surrounded by cemeteries with stone dikes containing from a few up to several hundred slag blocks and parts of blocks.

slag-pits have been located within the 50.000 m^2 area excavated. Excavations at the settlements at Drengsted revealed pottery and artefacts, which are dated to the 4^{th} and 5^{th} century AD. At Starup, a modern village 16 km southeast of Snorup, some 400 slag-pits, which are only a part of a larger, but destroyed iron smelting site, have been excavated on the eastern and western side of the modern village.

Dating method

The samples for radiocarbon dating were pre-treated according to the standard procedure with hydrochloric acid and sodium hydroxide in order to remove possible contamination with carbonate and humid acid (Mook & Waterbolk 1985). After pre-treatment the organic material was burned in an atmosphere of pure oxygen and thus converted to carbon dioxide, which was further purified in order to eliminate ^{222}Rn, SO_x, and NO_x. Three litres of carbon dioxide at standard conditions was admitted to a proportional counter equipped with a guard counter, where the natural radioactivity was measured for at least 20 hours. $\delta^{13}C$ was measured on 50 samples, i.e. those dated after 1971. These samples were corrected to the terrestrial value ($\delta^{13}C$ = -25 o/oo PDB). The 27 samples dated prior to 1971 were assigned larger standard deviations in order to compensate for the lack of isotopic fractionation correction. The radiocarbon dates were calibrated to calendar years according to the bidecadel atmospheric calibration curve of Stuiver & Pearson (1993) using the calibration program Calib ver. 3.0.3C from University of Washington (Stuiver & Reimer 1993)[1].

It should be noted that whenever possible charred straw was preferred to oak charcoal in order to minimize the effects of any possible external age (i.e. the difference between the age of the sample and the archaeological event to be dated). In some cases further samples from the same site were dated in order to estimate the period of use of the individual sites.

Results

The laboratory numbers, radiocarbon dates, most likely calibrated dates, and calibrated age intervals at $\delta \pm 1$ standard deviation are given in the appendix. Fig. 5 shows an example of the calibration of a radiocarbon date. Calibrating the unimodal normal distributed radiocarbon dates (the y-axis in Fig. 5) frequently results in multimodal (i.e. having several peaks) non-parametric age distributions in calendar years (the x-axis in Fig. 4). This complex multimodal distribution is the final result of the radiocarbon dating.

1. New calibration curves (Radiocarbon 1998) have been introduced during the eight year publishing process for this paper. The differences between the 1993 and the 1998 calibration curves only amount to 5-10 years in the present age range. Considering the uncertainties of the dates and calculations in this paper the introduction of the new calibration curves will have very little influence on the results, and it has thus been decided not to re-calibrate according to the 1998 curves.

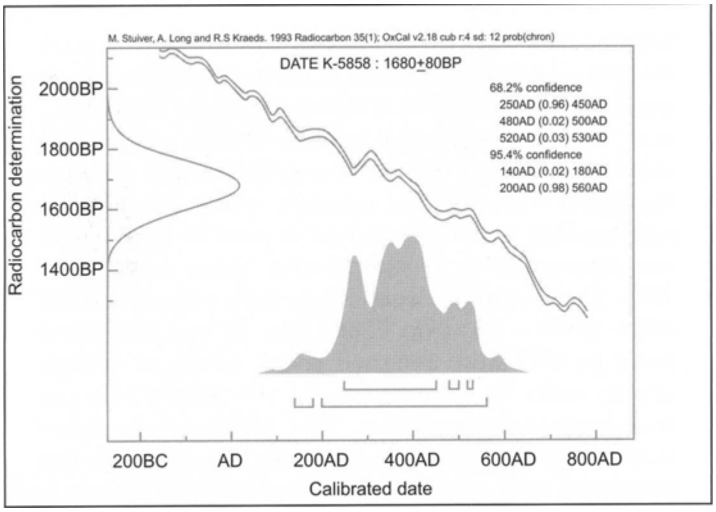

Fig. 4. Example of calibration of one of the radiocarbon dates (K-5858).

The wiggles in the calibration curve especially in the Iron Age (Fig. 5) constitute an inherent ambiguity in the radiocarbon dating technique, as the calendar year probability distributions are broader in these time intervals. A wiggle makes it almost impossible to distinguish dates between approximately AD 430 to AD 550. Fig. 6 shows the calibrated age distributions of the samples from the four major sites included in the present study.

The first analysis to be performed on the data is to establish whether or not the samples can be assumed to be contemporaneous. A hypothesis of contemporaneousness for a set of radiocarbon dates can be tested statistically by a χ^2-test. χ^2-tests show that the probability for all samples being contemporaneous is less than 5% at Snorup, Drengsted, Starup, Gødsvang, and for the data taken as a whole. The dated samples therefore most likely represent prolonged activity rather than an event limited in time to one or two generations.

The next point of interest is whether there is any geographical system for the exploitation within an iron-producing site. At Snorup, where we have 11 radiocarbon dates in an area with a concentration of c. 800 furnaces, we find no significant correlation between location and age, so it is likely that the smelting activity took place randomly within the sites throughout the time of production.

We believe that we have dated a sufficient number of samples from Snorup and Drengsted to ensure that the dated samples are representative for the level of smelting activity at these sites. Accordingly we have constructed a combined probability curve for all the dates at Snorup in order to investigate the possible changes in activity through time (Fig. 7). Adding together the calibrated probability distributions has produced this curve. Three main factors may influence this sum curve. First, the selection of samples could possibly favour samples from certain parts of the period of activity. Secondly, the wiggled nature of the calibration curve could artificially, so to speak, cause an uneven probability distribution and thirdly, the shape of the sum curve could quite simply reflect the level of production activity at the site at different times. Let us address each of these factors.

The first factor that could influence the sum curve is sampling bias. It is conceivable that younger furnaces are better-preserved or more easily accessible than older furnaces. If this were the case it would most likely add probability to the late part of the combined probability curve. The archaeological excava-

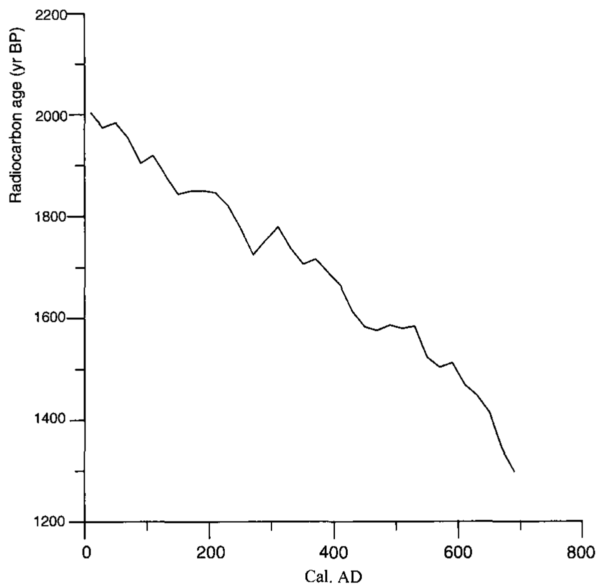

Fig. 5. The radiocarbon calibration curve shows many wiggles in the Iron Age. Calibrating a conventional radiocarbon age into calendar years where there is a wiggle in the calibration curve produces a longer interval of calendar years than would otherwise be expected from a smooth calibration curve. The calibration curve is from Stuiver and Pearson (1993).

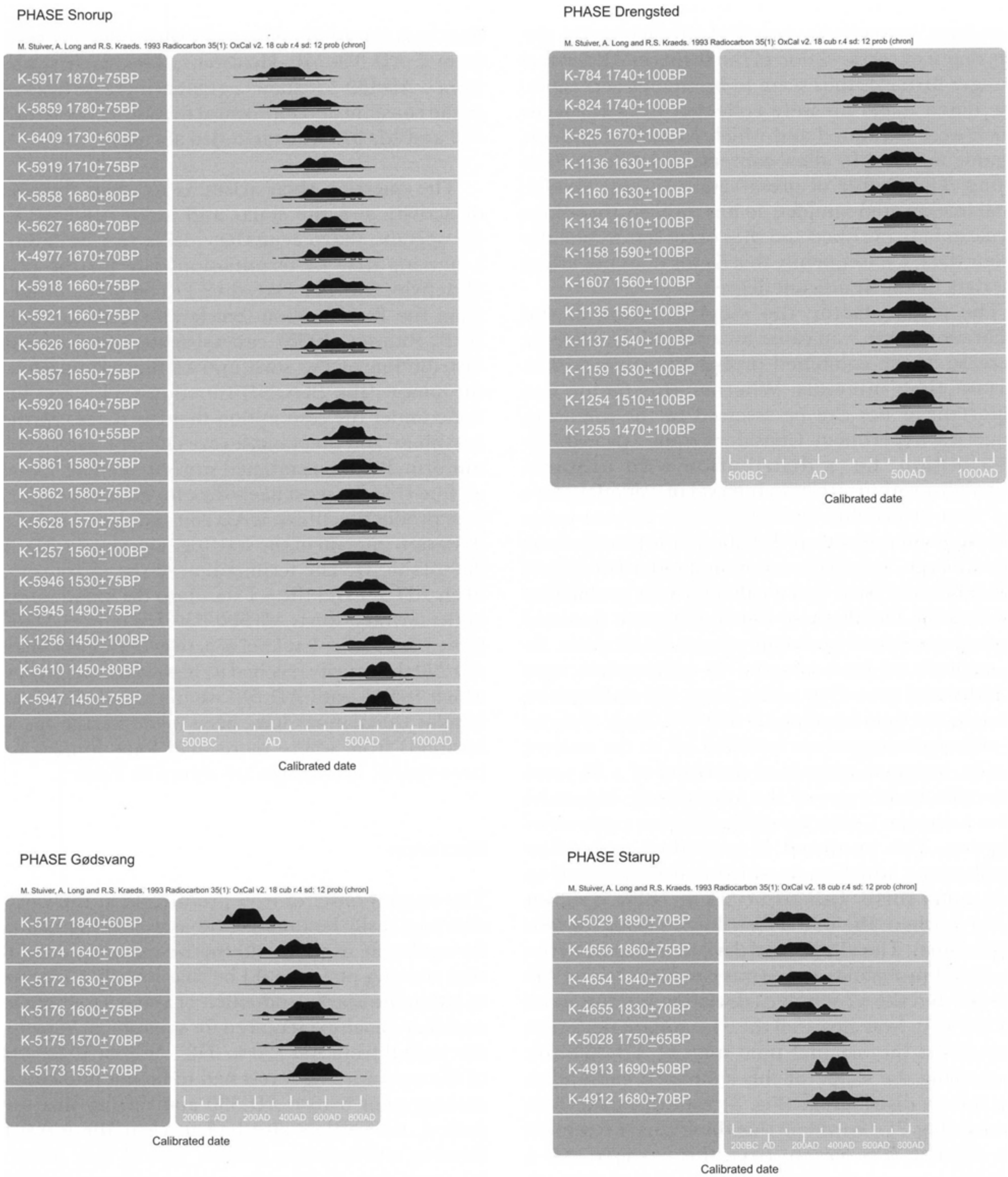

Fig. 6. The calibrated ages for all the radiocarbon dates from the four major sites in the present study.

tions have, however, not revealed any changes in the size, depth or construction of the furnaces. Older and younger furnaces thus seem to be equally accessible. The dated materials were collected from furnaces which were excavated and which contained enough organic material to allow conventional radiocarbon dating. The degree of preservation is quite similar in all investigated samples, so it is unlikely that older furnaces have perished and thus occur less frequently in our data. Consequently this factor does not affect our data to any significant degree.

The second factor, the wiggled nature of the calibration curve, can cause an artificial decrease or increase in the combined probability curve within certain time intervals. Whether this factor was important or not can be assessed by the following numerical experiment. Consider a square probability distribution, i.e. a distribution with uniform probability within a certain interval of calendar years and zero probability elsewhere. Each 20-year-point from this square-formed distribution is transformed into a ^{14}C-age, assigned a common standard deviation and calibrated back into a calendar year probability distribution. Finally these distributions are summed to give a combined probability curve for all dates. As an example we have sampled 13 radiocarbon ages of bidecadel tree ring series from the calibration curve in the time interval AD 330-570. Each of these 13 radiocarbon ages was rounded off to the nearest decade, assigned a standard deviation of ± 65 years and calibrated by use of the atmospheric bidecadel curve using the University of Washington calibration program. This produced 13 individual probability distributions, which were added and normalized to yield a sum curve. This artificial sum curve is shown in Fig. 8, where the initial distribution is also shown (stipled line). The ±1 standard deviation interval of the combined probability curve was calculated to be AD 330-550 and the ±2 standard deviation interval to be AD 230-620. Note how well the ±1 standard deviation interval fits the original time span of AD 330-570. Comparing the shape of this simulated calibration of a square distribution (Fig. 8) with our data from Snorup (Fig. 7) it is evident that these curves resemble one another. It is obvious from this example that a uniform (square) distribution can be altered through the radiocarbon calibration procedure into a shape very similar to the one found for Snorup in the present study. From the comparison of Figs. 7 and 8, shown in Fig. 9, it can be deduced that the level of activity at Snorup is consistent with a uniform production activity from c. AD 330-570. However, a slow starting phase from c. AD 150-330 shows a gradual increase from zero to the constant and uniform activity level between AD 330 and AD 570 when it ended abruptly.

The question then arises as to when the phase of activity at a site starts and when it terminates. No specific sharp boundary dates can be given as a starting date or termination date for the phase of activity, but the OxCal v2.17 computer program from the Radiocarbon Accelerator Unit in Oxford (C.B. Ramsey, 1995) can estimate the probability distribution of the start and of the termination of the phase (the BOUND-function). This has been done under the assumption that the dates represent one phase and that samples are chronologically fairly uniform. For the combined sum curve of all 73 dates we find that the most likely date for the starting of the iron production phase is AD 250 and the ± 1 standard deviation interval of the starting boundary is AD 220-290 (Table 1). The termination of the phase is most likely AD 610 and the ± 1 standard deviation interval of the termination is AD 590-630. Initially, at AD 250, there was a rather low level of activity. At approximately AD 290 the activity reached its high and constant level, which lasted until AD 610 where it ended abruptly. Similar calculations have been made for the specific locations from where more than four samples have been dated. The results are shown in Table 1.

Discussion

The uneven onset of iron production at the various sites can easily be understood as a growing demand for malleable iron. An alternative explanation of the slow starting phase could be that it took a long time to attain the yearly production of about 5 tons of charcoal that was alone required for smelting in Snorup in the period from AD 330 to 570. At least 10 hectares of the surrounding forest had to be put into coppice management before AD 330 and during that same period, the settlers also had to clear the forest for farming and building houses. Typical time intervals for coppicing, 10-30 years, cannot however be distinguished by the radiocarbon method due to wiggles in the radiocarbon calibration curve. According to the archaeological finds the Snorup site was not settled prior to AD 200.

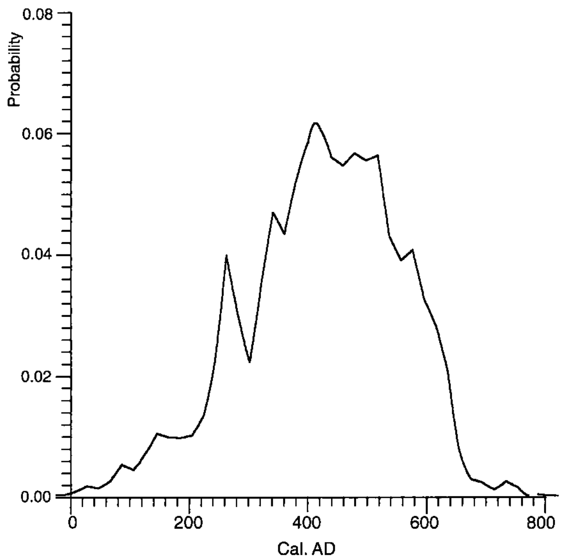

Fig. 7. The combined probability distribution of all the radiocarbon dates at Snorup. The curve has been constructed by stacking the calibrated age distributions from Snorup shown in Fig. 6.

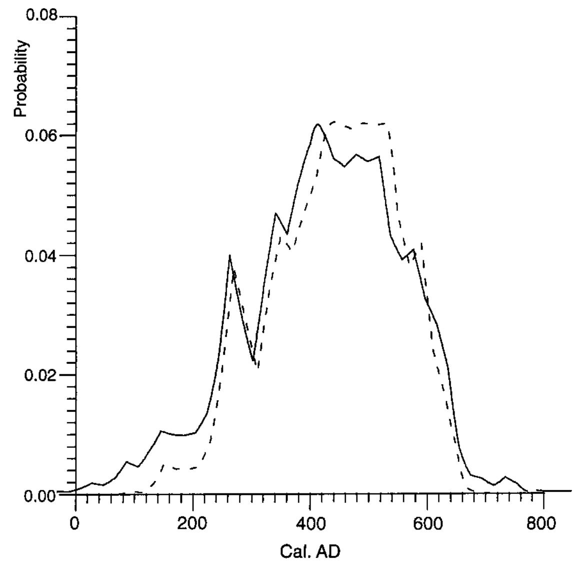

Fig. 9. The combined or stacked probability distribution from the radiocarbon dates at Snorup (solid line) shown together with the probability distribution derived as described in the text and in Fig. 8.

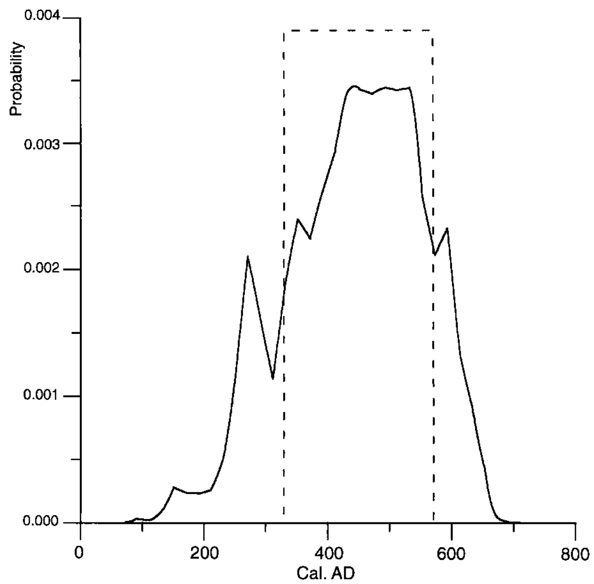

Fig. 8. Results of a numerical experiment showing the effect of the wiggled nature of the radiocarbon calibration curve. An original square calendar year distribution from AD 330 to AD 570 (dashed line) is converted into 13 equally spaced conventional radiocarbon dates using the calibration curve each of which is assigned an uncertainty of ± 65 ^{14}C-years. These 13 conventional dates are calibrated in the usual way and the resulting calendar year probability distributions are summed and normalized (solid line). Some broadening relative to the square distribution is observed due to the wiggled nature of the calibration curve.

The iron production at the excavated part of the Starup site lasted from AD 140 to AD 340. Snorup, Drengsted, and Gødsvang became major iron production sites in c. AD 350. The production activity here seems to have proceeded at a uniform pace for c. 200 years until c. AD 550, when it terminated abruptly. The reason for ending the iron production at Snorup, Drengsted, and Gødsvang, is not known. The demand for iron in this part of Europe did not diminish neither in AD 340 or in AD 550; quite the contrary - more and more iron tools came into use. It is possible that the 200 years of charcoal production had exhausted the forest to a degree where the charcoal production no longer could take place on a big scale. Archaeological evidence, with only about 10% of the settlement excavated, points to an abandonment of the settlement at Snorup some time in the 6th century AD.

This picture of more or less constant iron production activity over a period of 200 years seems somewhat special for southern Jutland, at least compared to the only other investigation where comparable results have been produced, namely at the iron production site in Joldelund, Nordfriesland (Erlenkeuser & Willkomm 1997). Extensive radiocarbon dating at Joldelund revealed both some geographical differences as well as a somewhat uneven production activity.

Site	Start of phase (most likely date)	Start of phase at ? ± 1 std.dev.	Termination of phase (most likely date)	Termination of phase at ? ± 1 std.dev.	Number of samples dated
Snorup	AD 330	AD 270-360	AD 570	AD 530-630	22
Drengsted	AD 410	AD 340-460	AD 550	AD 500-610	13
Starup	AD 140	AD 70-230	AD 340	AD 280-430	7
Gødsvang	AD 300	AD 140-380	AD 550	AD 470-660	6
All sites	**AD 250**	**AD 220-290**	**AD 610**	**AD 590-630**	**73**

Table 1. Note that the estimates become more uncertain when based on fewer dates. Even though it only comprises seven dates, Starup seems to be an early production site, while the other sites are more or less contemporary with each other. Seen from a statistical viewpoint it is, however, not unlikely that the activity at all the sites, including Starup, has overlapped.

At Snorup, which was active for c. 240 years, a total of 4000 smelts over 240 years gives an average of c. 17 smelts per year. Each smelt produced c. 40 kg of iron yielding c. 670 kg of iron each year(Voss 1995). The production at Snorup proceeded continuously for 240 years or almost nine generations. This amounts to a total iron production at the site of c. 160 tons. A small amount was used in the village, but most of the iron must have been transported to external consumers.

Nine generations of steady primary iron production, which was used for weapons, utensils and other commodities as well as export, must have created some wealth in Iron Age Denmark. Excavations or other information sources do not, however, show any signs of such wealth. The fact that we have here proven a continuous and uninterrupted iron production for more than nine generations calls for further archaeological excavations in the area in search of the possible centre of wealth and power.

Conclusions

Seventy-three samples from iron production regions in Jutland have been radiocarbon dated. No spatial development has been found within the area with respect to time. A combined probability distribution has been constructed as the sum of individual probability distributions of all calibrated dates. The results of our investigation are that the iron production activity took place continuously from the third to the 7th century AD. The shape of the combined probability distribution of the radiocarbon dates is consistent with a fairly uniform iron production activity throughout the period AD 250-610.

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Appendix

The samples were excavated from the base of slag-pit furnaces which lack other dating artifacts. Most samples consisted of charred straw and the dates were calibrated using the 20 years averaged atmospheric curve by Stuiver and Pearson (1993). K-5857 consisted of charcoal (Quercus sp.) from a branch or trunk with more than 40 annual rings. The date of K-5857 was calibrated by use of a 40 year-averaged calibration curve.

Lab. No.	Locality	Site	Sample no.	Radiocarbon Date (BP)	Calibrated Date (AD Cal.)	Calibrated Date at±1? (AD Cal.)	?^{13}C 0/00 PDB
K-6410	Snorup	E11	1535	1450 ± 80	630	550-660	-26,4
K-6409	Snorup	E11	1534	1730 ± 60	270-330	240-410	-26,5
K-1256	Snorup	1	6	1450 ± 100	630	540-670	
K-1257	Snorup	1	7	1560 ± 100	540	410-620	
K-4977	Snorup	100	111	1670 ± 70	410	260-550	-26,7
K-5626	Snorup	100	147	1660 ± 70	410	270-450	-25,2
K-5627	Snorup	100	243	1680 ± 70	400	260-430	-27,1
K-5628	Snorup	800	329	1570 ± 75	540	420-600	-27,0
K-5857	Snorup	300	308	1650 ± 75	410	340-530	-26,6
K-5858	Snorup	500	537	1680 ± 80	400	260-440	-27,6
K-5859	Snorup	500	613	1780 ± 75	250	140-380	-26,9
K-5860	Snorup	500	618	1610 ± 55	430	410-540	-26,6
K-5861	Snorup	500	710	1580 ± 75	460-530	410-590	-27,6
K-5862	Snorup	500	758	1580 ± 75	460-530	410-590	-27,1
K-5917	Snorup	500	529	1870 ± 75	140	70-240	-24,3
K-5918	Snorup	500	574	1660 ± 75	410	270-500	-26,1
K-5919	Snorup	500	583	1710 ± 75	350-370	250-420	-27,9
K-5920	Snorup	500	694	1640 ± 75	420	340-540	-26,8
K-5921	Snorup	500	736	1660 ± 75	410	270-500	-26,0
K-5945	Snorup	500	1028	1490 ± 75	600	540-650	-27,8
K-5946	Snorup	1100	1105	1530 ± 75	550	440-620	-27,4
K-5947	Snorup	1300	1302	1450 ± 75	630	550-660	-26,5

Lab. No.	Locality	Sample no.	Radiocarbon Date (BP)	Calibrated Date (AD Cal.)	Calibrated Date at±1? (AD Cal.)	?^{13}C 0/00 PDB
K-784	Drengsted	EL11	1740 ± 100	260-330	210-420	-
K-824	Drengsted	3	1740 ± 100	260-330	210-420	-
K-825	Drengsted	101	1670 ± 100	410	250-540	-
K-1134	Drengsted	OV	1610 ± 100	430	350-540	-
K-1135	Drengsted	PF	1560 ± 100	540	410-620	-
K-1136	Drengsted	MF	1630 ± 100	420	270-550	-
K-1137	Drengsted	MN	1540 ± 100	540	420-640	-
K-1158	Drengsted	M?	1590 ± 100	450	390-600	-
K-1159	Drengsted	MI	1530 ± 100	550	420-640	-
K-1160	Drengsted	MO	1630 ± 100	420	270-550	-
K-1254	Drengsted	VE	1510 ± 100	560-590	430-650	-
K-1255	Drengsted	VF	1470 ± 100	610	530-660	-
K-1496	Drengsted	AAY	1630 ± 100	420	270-550	-
K-1497	Drengsted	ABJ	1650 ± 100	420	260-540	-
K-1498	Drengsted	ABR	1730 ± 100	270-330	220-420	-
K-1499	Drengsted	ABØ	1640 ± 100	420	260-550	-
K-1500	Drengsted	ACF	1570 ± 100	540	410-610	-
K-1501	Drengsted	ACG	1690 ± 100	390	240-450	-
K-1502	Drengsted	ACH	1670 ± 100	410	250-540	-
K-1503	Drengsted	ACJ	1600 ± 100	440	380-600	-
K-1504	Drengsted	ACK	1590 ± 100	450	390-600	-
K-1607	Drengsted	BAT	1560 ± 100	540	410-620	-
K-1778	Drengsted	7	1720 ± 100	340	230-430	-
K-1779	Drengsted	10	1480 ± 100	610	460-660	-
K-1780	Drengsted	ALD	1620 ± 100	430	340-550	-

Lab. No.	Locality	Sample no.	Radiocarbon Date (BP)	Calibrated Date (AD Cal.)	Calibrated Date at±1? (AD Cal.)	?[13]C 0/00 PDB
K-4654	Starup	187	1840 ± 70	220	90-320	-26,4
K-4655	Starup	245a	1830 ± 70	220	120-320	-25,8
K-4656	Starup	328a	1860 ± 75	140	80-250	-26,3
K-4912	Starup	316	1680 ± 70	400	260-430	-25,2
K-4913	Starup	139	1690 ± 50	390	260-420	-26,0
K-5028	Starup	136	1750 ± 65	260-320	230-390	-25,1
K-5029	Starup	226	1890 ± 70	130	70-230	-25,4
K-5037	Nybo	239	1700 ± 70	380	250-420	-25,3
K-5038	Nybo	407	1610 ± 70	430	400-550	-23,8
K-1253	Torsted	1	1480 ± 100	610	460-660	-
K-5172	Gødsvang	29	1630 ± 70	420	380-540	-25,4
K-5173	Gødsvang	20	1550 ± 70	540	430-610	-26,7
K-5174	Gødsvang	204	1640 ± 70	420	350-540	-27,2
K-5175	Gødsvang	101	1570 ± 70	540	420-600	-26,5
K-5176	Gødsvang	106	1600 ± 75	440	400-550	-26,9
K-5177	Gødsvang	201	1840 ± 60	220	120-250	-26,5
K-5410	Buensbæk	5	1490 ± 70	600	540-650	-26,5
K-5411	Buensbæk	83	1640 ± 70	420	350-540	-26,1
K-822	Ellum	ad C 22639	1650 ± 100	420	260-540	-
K-5406	Ellum	2026	1530 ± 65	550	440-620	-23,5
K-5407	Ellum	2058	1500 ± 70	600	530-640	-27,5
K-3846	Mølleparken	1037x540	1510 ± 70	560-590	460-640	-26,6
K-3847	Mølleparken	1037x542	1560 ± 70	540	420-600	-25,5
K-3848	Mølleparken	1037x1365	1500 ± 70	600	530-640	-26,3
K-3849	Mølleparken	1037x1373	1550 ± 70	540	430-610	-24,2