The characterization and provenancing of ore, slag and iron from the Iron Age settlement at Snorup

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Abstract

A large iron production site from the Iron Age has been identified at Snorup, Jutland, Denmark. Typical slag-pit furnaces have been excavated which are related to similar iron furnaces in middle Europe. The Danish bog iron ore is rich in phosphorus, and so is the extracted bloomery iron, up to 0.6% phosphorus having been recorded in solid solution in the iron. On the site a hoard with bars of two different types were found. From metallographic analysis and comparison of slag analyses it is argued that the hoard represents iron of two different origins. Six massive wrought iron bars are rich in phosphorus and are of local production, while about 200 slender bars appear to be of ferritic-pearlitic steel, imported from southern Norway. These Norwegian bars are small (20-160g) and have a characteristic spoon shape, which for the ancient craftsman would mark them as useful for steeling tools and weapons.

Introduction

Snorup is situated in the south western part of Jutland, Denmark (Fig 1). The site was first recorded in the 1930s (Mortensen 1932) and up to the present over 4000 slag pits have been discovered within an area that covers about 40 hectares (Fig 2). Since 1986 the site has been the subject of yearly excavations conducted by the Danish National Museum and Varde Museum.

At Snorup there are slag-pit furnaces of about 0.5m in diameter and above these pits there would have originally been clay shafts with four tuyeres (Fig 3). The excavated part of the shafts show that they were made of clay bricks. The shafts appear to be very similar to the furnace shafts found at Scharmbeck near Hamburg (Wegewitz 1957). The Snorup furnaces were found in a settlement that can be dated to the Late Roman/Early Germanic Iron Age (Voss 1995). In addition to the normal excavation work, Tatyana Smekalova from the Physical Institute, St Petersburg University, Russia, has taken magnetometer measurements over most of the area.

Today Snorup is the largest known iron extraction site in Denmark. This is partly due to the fact that there has been intense research in this particular area. There are probably other sites as big as Snorup. Slag-pit furnaces occur primarily in the southern and western parts of Jutland, in some cases they are found in connection with settlements dating from the latter part of the Iron Age (Hvass 1979, Lund 1991, Voss 1995).

Slag-pit furnaces also occur in several other countries in northern Europe. In Poland approximately 5000 iron-producing sites have been recorded in the Holy Cross Mountains, and in the Masovien area there are approximately 5000 slag pits (Bielenin 1989). Most of the iron production using slag-pit furnaces here took place

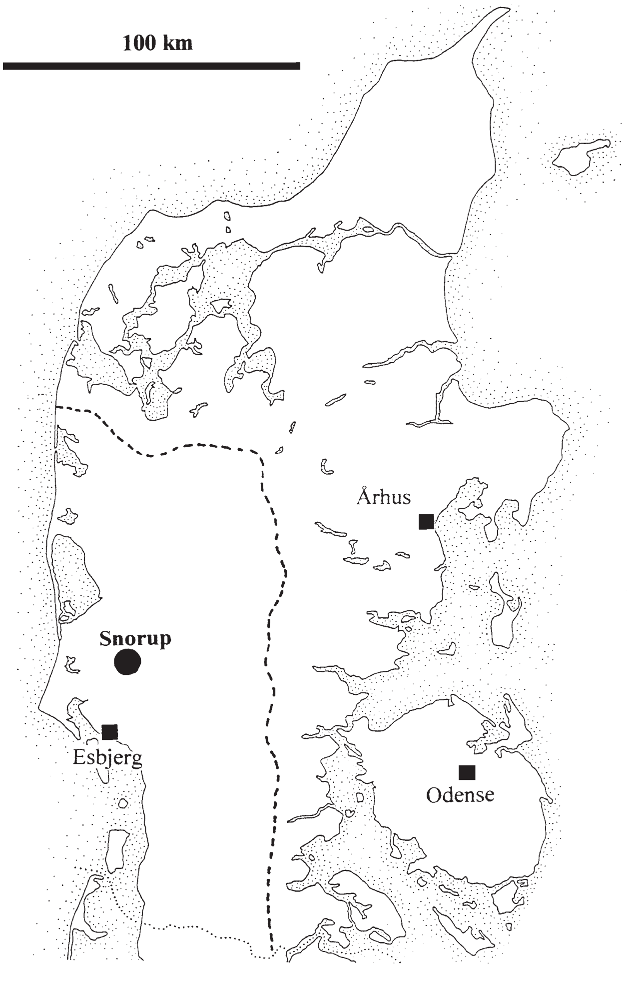

Figure 1: Map of Jutland and Funen showing the location of Snorup. The dashed line is the western limit of the last glaciation.

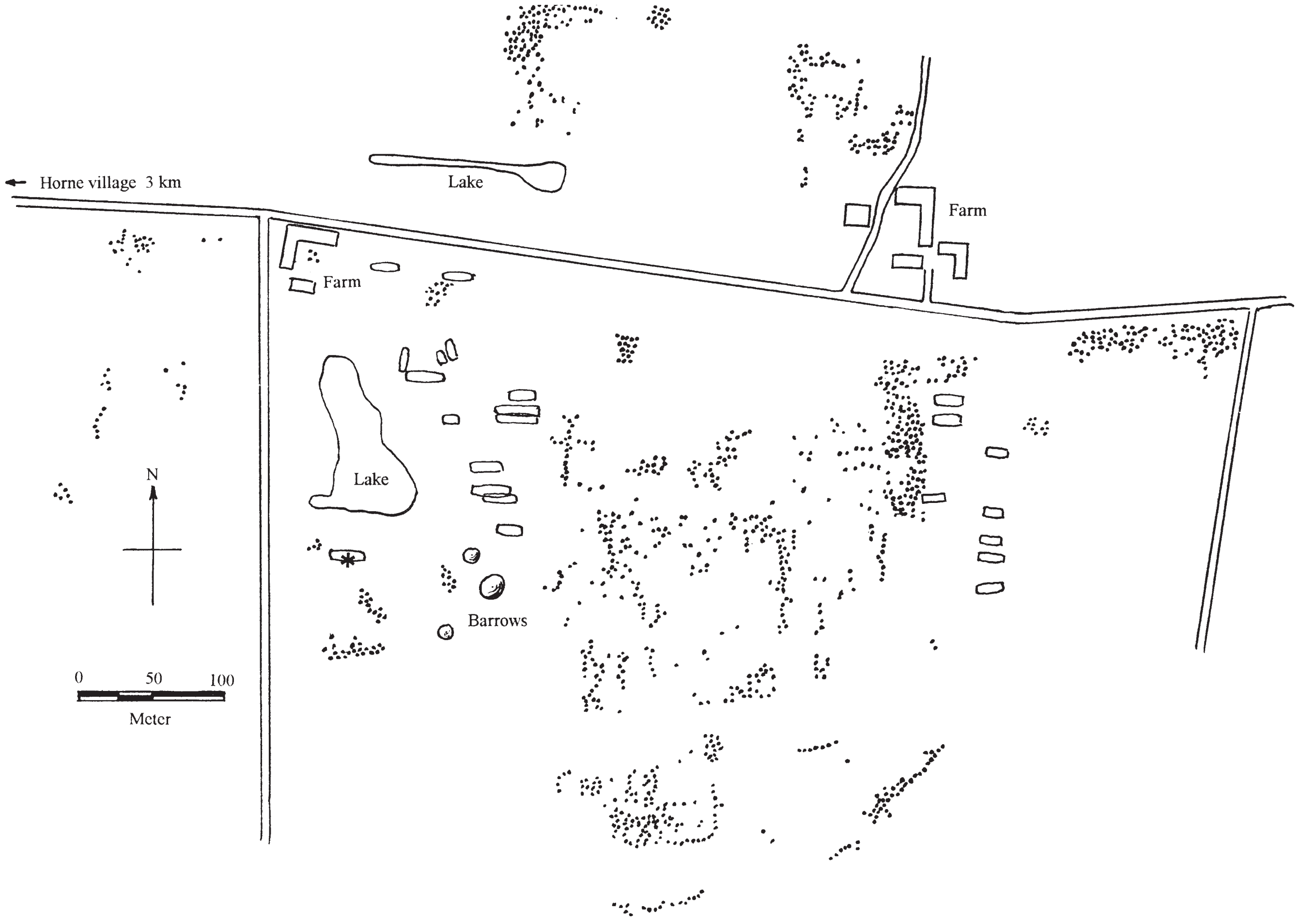

Figure 2: The Snorup site is located 3km east of the church village Horne. The large number of slag-pit furnaces are shown as dots. Excavated Iron Age houses and two modern farms are also marked. The iron hoard was found inside the house in the western part of the excavation marked with a star (redrawn from a plan by Lars Nørbach).

between the 1st-3rd centuries AD (Bielenin 1992). In the German area the slag-pit furnaces are found in the northern and eastern part of the country. The sites are small- to middle-sized, the largest known site being Göhlen in Kr Ludvigslust which has about 2000 slag-pits. Most of the sites can be dated to the Late Roman and Early Germanic Iron Age just like the Danish sites (Jöns 1997).

Slag-pit furnaces have also been excavated in the Netherlands. They date from the 3rd and 4th centuries AD, are small in number and probably only supplied local needs (van Nie 1997). In the Czech and the Slovakian areas the earliest known slag-pit furnaces date back to the 2nd century BC. Only a few of the known sites have any significant numbers of slag-pit furnaces and so far none has been found with more than 400 pits (Pleiner 1989, Kuna and Zavrel 1989, Hasek and Merinsky 1989). In Norway and Sweden there are some slag-pit furnaces of the same type as those in Snorup, but other furnace types dominate the archaeological record (Magnusson 1991, Hjärthner-Holdar 1993).

The iron bars

In Snorup a hoard of iron bars was located and excavated in a trial trench in 1986 (for location see Figure 2). Excavations in the summer of 1998 focused on the area around this trial trench. The archaeological excavation (L H-M) showed that the hoard was located inside a 30m long house, near the southern wall (Fig 4). The house was similar to the other houses of the Snorup area, which are of the same age as the iron production of Snorup, *ie* 330-560 AD (Rasmussen *et al* in press). The hoard contained about 200 slender bars. Just over 100 of them were 260-300mm long weighing between 120-160g, and there were about 100 rather smaller bars 160-200mm long weighing 25-30g (Fig 5). Finally, at the bottom of the pit six massive bars were discovered, weighing a total of 3.2kg. The massive bars are of different sizes and cannot be related to any specific bar type (Fig 6 and Table 1).

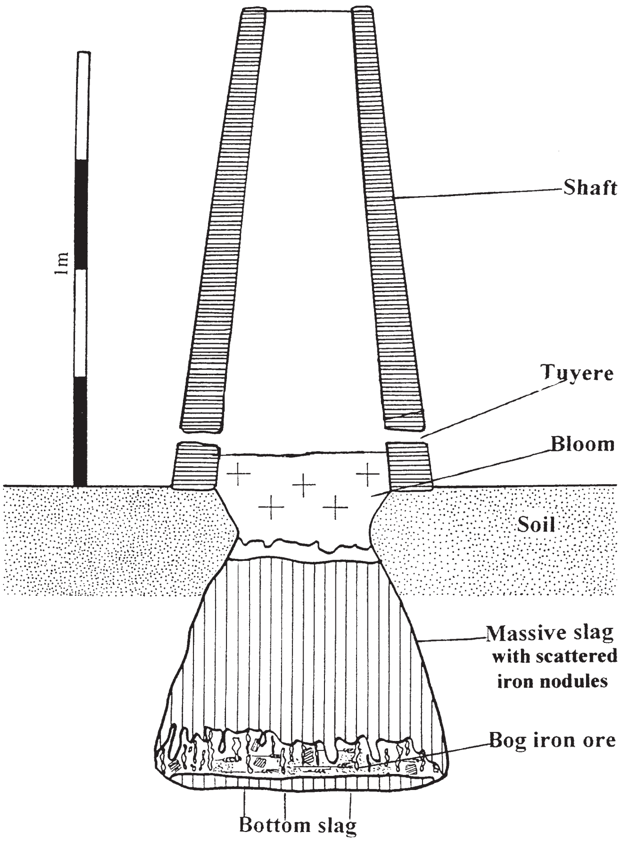

Figure 3: Reconstruction of a slag-pit furnace from Snorup

Morphologically the two types of bars are very different, but they were found together inside the house.

The slender bars are all of the same morphology: the top end of the bar has been hammered into a thin circular shape with a hole in the middle (Fig 5). This was probably used to tie the bars together during transport and storage. The bars are so corroded that it is impossible to tell if the hole was made with a punch or by bending the iron. Below the hole the bar is slender and has a rhomboid cross-section. The iron at the lower end of the bar is hammered into a thin rounded blade with a spoon-like shape at right-angles to the top. It appears that the blacksmith forged the rods with rhomboid cross sections and then cut these into suitable sizes and prepared the ends.

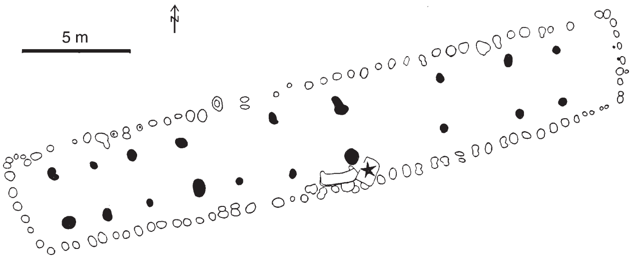

Figure 4: Plan of the excavated house; the star marks the iron hoard. Postholes of the roof structure are shaded and those of the walls open.

Bars of similar types have been found in central Europe and in Norway. The bars from central Europe vary in length from 60mm for the smallest ones to 450mm for the largest (Pleiner 1961). Previous work has dated these bars to the 8th-10th centuries AD (*ibid*, 448). The central European bars show a certain resemblance to the bars from Snorup, but they are more triangular in shape and have a rectangular cross section (Voss 1996, 26). The top part is thicker and the holes are rectangular rather than round.

The Norwegian bars, known as R438 (after Rygh 1885, figure 438), are apparently almost identical to the bars from Snorup (Fig 7). In 1918 Jan Petersen was the first to note that this type of object could be an iron bar and not — as previously presumed — a loom weight (Petersen 1918). Since then more bars of this type have been found in the southern Norwegian area, and to date about 8500 have been recorded (Resi 1995); they are mostly found in undated hoards. Jan Petersen thought these bars belonged to the Viking Age and to the early Middle Ages, viewing them as part of a typological development in bar types (Petersen 1918). More recently Irmelin Martens has concluded that this type of bar first appears about 600 AD and that most hoards should be referred to the Viking Age (Martens 1979, Martens 1988).

Table 1: Dimensions (in mm) of the massive bars from Snorup

Bar No	Length	Width	Depth	Weight (g)
2	45	33	29	247.8
3	42	34	27	227.2
4 (300B)	125	50	22	1240.0
5	137	28	26	455.4
6	142	30	28	728.0

Bar 1 was not available for measuring

At Nordre Bjerke in Gran, Oppland, Norway, a hoard containing at least 568 iron bars with a total weight of just over 77kg has been found. Three C-14 dates on charcoal taken from between the bars while the hoard was still *in situ* have produced surprisingly early dates indicating a Pre-Roman Iron Age origin (Resi 1995, 131). This is the earliest dating of bars of this type so far. Also, in the area of Modvo at the head of the Sognefjord in Norway a slender bar was found in an Iron Age farm, archaeologically dated between the beginning of the 4th-6th centuries AD (Kristoffersen 1993, 178-81, fig 22). These two finds are so far the only slender bars that have been dated in the Norwegian area. The Norwegian iron bar material is in great need of an up-to-date study of their typology and geographical distribution and Hege Svane from the University of Oslo is working on a dissertation concerning these questions (Svane 1991).

In Denmark iron bars of the slender Norwegian type have been found outside Snorup. The site of Dankirke near Ribe in the south western part of Jutland is an Iron Age village with a rich collection of imported objects (Jensen and Watt 1993, 197). On this site one bar of slender type has been found in a post hole of an Iron Age house dating to the transition to the later Germanic period, *c*520-530 AD (Hansen 1991, 21, fig 7).

Lundeborg, an Iron Age trading centre on the south eastern part of Funen, was the source of another slender bar, which was found in a layer dated to the period between 220-250 AD. A piece that might be the spoon-shaped end of a slender bar was also found at the same site. According to Olfert Voss, the preserved part of the shaft has a rectangular cross section which is a feature of the central European slender bars. The bar was found in a layer that can be dated to the Late Roman/Early Germanic period, *ie* between 200-600 AD (Voss 1996, 26).

Metallography and analysis

In order to characterize the Snorup iron production site in a quantitative way, it was decided to analyse a number of representative samples by metallographic methods. Specimens of bog iron ore, of slags from the furnace pits, of bloomery iron and bar iron were embedded in resin, and ground and polished by standard metallographic methods. The metal was examined both as polished and after etching, and Vickers hardness was measured at 200gf

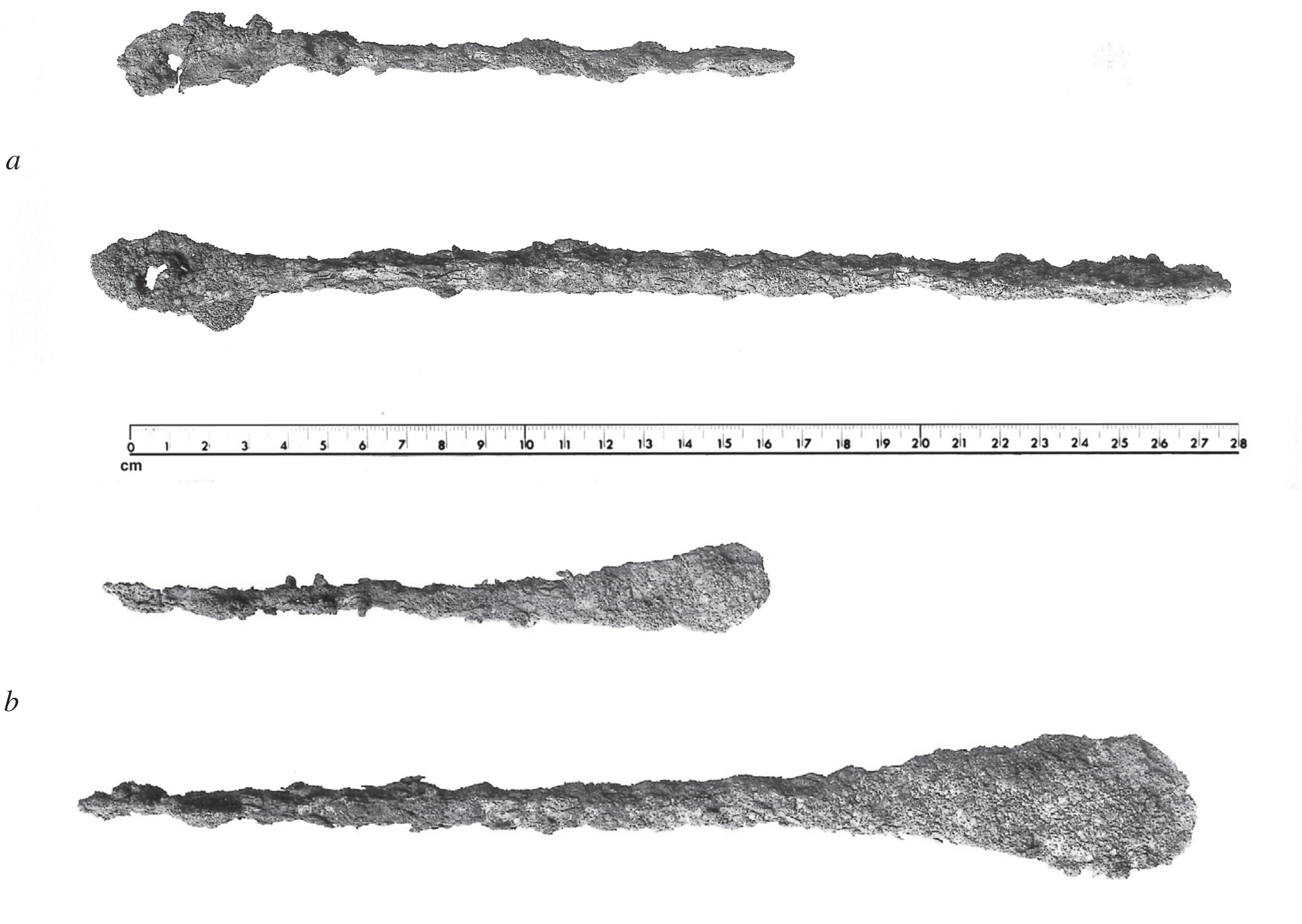

Figure 5: A long and a short slender bar from the hoard at Snorup, from (a) the side and (b) the front (photo: Larsen)

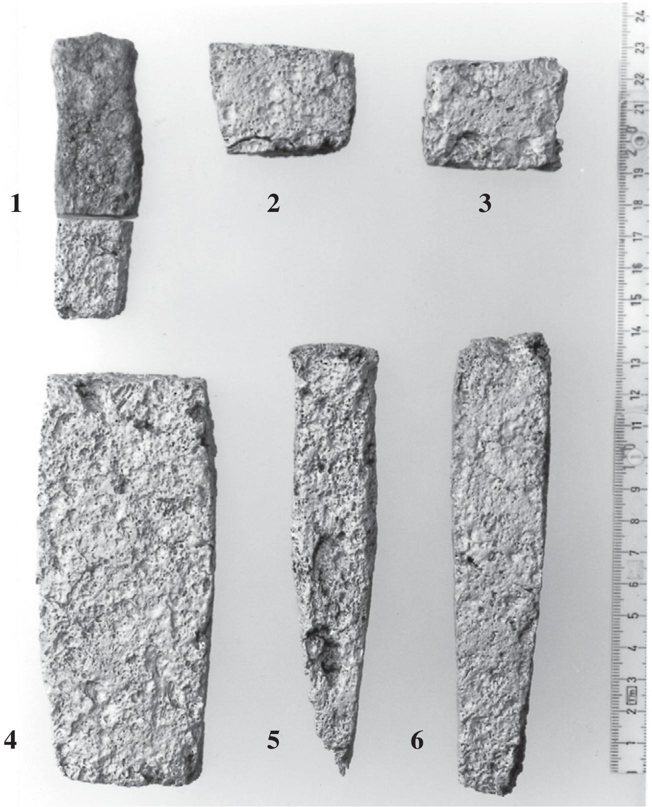

Figure 6: The six massive bars found at the bottom of the hoard at Snorup. The bottom left one (4) was examined. The cut in the top left one (1) is from a preliminary examination (photo: Larsen)

load. Slag and slag inclusions were described with reference to their wüstite, fayalite and glass contents, and individual phases were analysed on a Philips scanning electron microscope (5500) with energy dispersive X-ray analysis equipment (EDAX 9900). For the characterization and comparison of slags, the average analysis over typical, uncorroded slag parts was calculated, usually collecting data from three or four areas each of minimum 0.4mm size. The microprobe was operated at 20kV, the take-off angle was 38.7° and counting time was 50 seconds live.

The Danish bog iron ore

The Danish bog iron ore is a solid agglomerate of iron oxides and amorphous silica in which quartz and some other mineral particles (*eg* $FeTiO_3$ and $ZrSiO_4$) are embedded. X-ray analyses reveal goethite (α-FeOOH) as the only crystalline iron oxide, the bulk being amorphous matter and some organic remains. It is important to note that the SiO_2 component of the ore is present both as a gelmatrix which can not be separated from the iron oxides, and as quartz particles which may be separated mechanically. Apparently iron, manganese, barium and phosphorus have co-precipitated as oxyhydroxides wherever the environment was favourable (Buchwald 1998b).

Bog iron ore is common in Denmark, particularly west of the last ice stagnation front (Fig 1) (Christensen 1966). It is sufficiently stable to have been used as an accessory construction material for many medieval churches, built 1140-1200 AD. The apse of St Jakobs church in Varde is, for example, partially built of blocks of bog iron ore (Buchwald 1998b).

The bog iron ore of Snorup is typical for the ore deposits of Western Jutland. For the present study we isolated samples of bog iron ore from six of the slag-pit furnaces that had been examined archaeologically. Since a part of the iron ore often passed through the shaft without participating in the process, it may today be identified between charcoal and ash in the bottom pit. In this way we acquired the actual ore which was used in the past.

In Table 2 the analytical data is presented and the average of the six ore samples is shown in the bottom line.

Production slags

The slag-pit furnace was operated continuously for three or four days, resulting in a large, compact slag lump, on

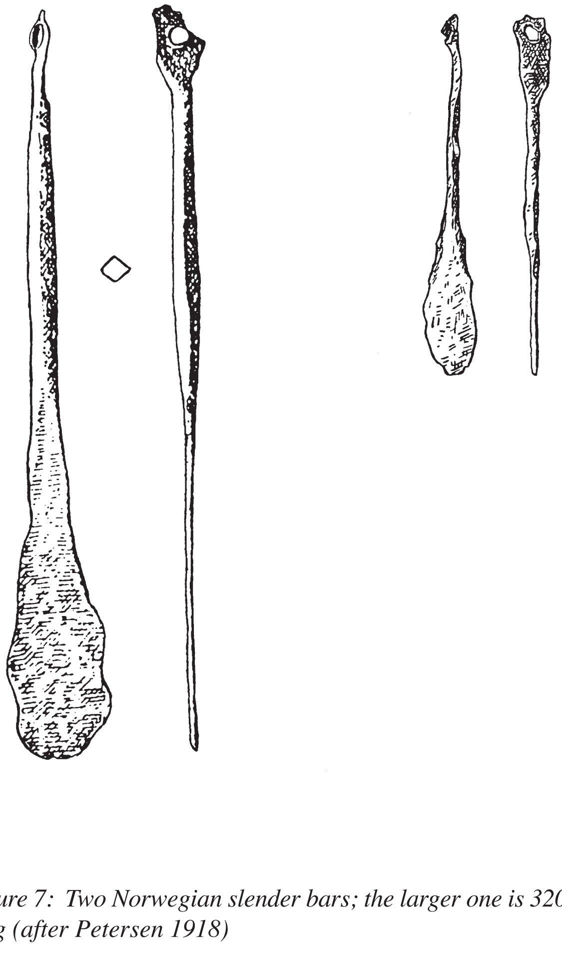

Figure 7: Two Norwegian slender bars; the larger one is 320mm long (after Petersen 1918)

Table 2: Bog iron ore samples from Snorup

Furnace No	SiO_2	Fe_2O_3	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	Na_2O	SO_3	Total
4075M	5.90	88.20	0.58	0.00	2.29	0.32	2.18	0.25	0.26	0.02	0.00	0.00	100
4081M	4.40	92.03	0.73	0.00	1.39	0.35	0.60	0.15	0.23	0.12	0.00	0.00	100
4119M	4.52	91.93	0.31	0.00	1.83	0.46	0.59	0.16	0.13	0.07	0.00	0.00	100
4120M	4.57	92.23	0.26	0.00	1.28	0.53	0.72	0.10	0.18	0.13	0.00	0.00	100
4125M	4.48	92.29	0.24	0.00	2.34	0.16	0.49	0.00	0.00	0.00	0.00	0.00	100
4141M	6.81	88.44	0.21	0.00	3.01	0.15	0.86	0.02	0.00	0.16	0.16	0.18	100
Average	5.11	90.85	0.39	0.00	2.02	0.33	0.91	0.11	0.13	0.08	0.03	0.04	100

top of which the slag-rich iron bloom was located (Fig 3) (Voss 1993). The massive part of the slag varied in weight between about 90-300kg. The large mass cooled relatively slowly and the structure became coarse, displaying wüstite dendrites and fayalite laths up to 0.2mm across. Some slag ran along the sides of the pit and solidified as a bottom slag. For analytical purpose six samples have been taken from various furnaces (Table 3), and the average has been calculated in the bottom line.

The bloom

In some of the archaeologically investigated slag-pit furnaces remnants of bloom-material were identified. Centimetre-sized iron nodules and millimetre-sized iron filaments occur together with slags forming irregular lumps which, due to their content of reduced iron, are rather corroded. Uncorroded parts were isolated, examined under the microscope and analysed with SEM-EDAX equipment. The iron phase contains small amounts of phosphorus in solid solution (<0.1%), but virtually no carbon, and the structure is that of coarse ferrite with ghost structures. The hardness is approximately the same as that of pure ferrite (80-100 HV).

The slags in the blooms (Table 4) are enriched in P_2O_5, MnO, CaO and SO_3 relative to the bulk slags (Table 3). A similar shift has been noted when comparing slag and blooms from other production sites in Denmark and Sweden (Buchwald, unpublished). Apparently the

Table 3: Smelting slags from Snorup

Furnace No	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	Na_2O	SO_3	SiO_2/Al_2O_3
105	24.33	67.67	0.32	0.22	2.21	0.58	3.33	0.31	0.75	0.19	0.00	0.31	7.31
115	25.76	63.88	1.41	0.19	3.75	0.95	3.11	0.46	0.45	0.00	0.00	0.00	8.28
133	24.04	68.36	1.44	0.00	1.74	1.28	2.25	0.36	0.07	0.00	0.00	0.27	10.68
4088A	25.40	65.40	0.23	0.00	2.58	1.05	3.34	0.72	0.22	0.20	0.54	0.32	7.60
4141B	25.69	66.11	0.34	0.00	2.38	1.21	2.44	0.77	0.10	0.17	0.47	0.32	10.53
4141A	21.67	70.54	0.31	0.00	2.85	0.89	2.29	0.37	0.06	0.12	0.55	0.35	9.46
Average	24.48	66.99	0.67	0.07	2.58	0.99	2.79	0.50	0.28	0.11	0.28	0.26	8.77

Table 4: Slag inclusions in blooms from Snorup

Sample	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	Na_2O	SO_3	SiO_2/Al_2O_3
MA	21.47	62.80	1.59	0.00	8.32	2.56	1.07	0.48	0.15	0.22	0.74	0.60	20.00
MB	21.03	64.65	1.47	0.00	7.02	2.10	1.13	0.32	0.43	0.14	0.89	0.63	18.61

Table 5: Slag inclusions in the massive bar 300B from Snorup

Sample	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	Na_2O	SO_3	SiO_2/Al_2O_3
300B	30.05	54.61	1.76	0.00	7.86	1.83	1.91	0.72	0.27	0.17	0.24	0.58	15.73

Table 6: Slag inclusions in slender steel bars from Snorup

Bar No	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	Na_2O	SO_3	SiO_2/Al_2O_3
45-2	26.64	57.69	2.31	0.00	2.51	1.96	6.00	1.56	0.89	0.16	0.00	0.28	4.44
50	27.18	52.49	5.41	0.00	4.37	1.91	5.01	1.10	0.99	0.34	0.99	0.21	5.43
56-1	55.11	4.70	11.61	0.00	0.00	11.91	9.41	3.09	2.91	0.91	0.00	0.35	5.86
70	59.57	5.12	1.58	0.18	0.00	7.06	17.44	3.03	3.40	1.00	1.52	0.10	3.42
92	32.86	33.27	16.37	0.82	0.43	4.16	6.84	1.99	1.21	0.84	0.89	0.32	4.80
201-1	23.52	57.09	2.08	0.00	5.71	1.66	6.43	0.91	0.72	0.33	1.07	0.48	3.65
201-2	21.88	59.04	1.96	0.00	6.22	1.44	6.25	0.65	0.68	0.28	1.22	0.38	3.50
201-3	50.11	22.67	3.88	0.00	0.80	3.53	13.49	2.46	1.34	0.67	0.75	0.30	3.71
201-4	45.97	28.56	3.72	0.00	1.31	3.28	12.23	2.18	1.28	0.54	0.61	0.31	3.76

phosphorus of the ore is reduced and dissolved preferentially in the iron phase during the reduction process in the slag-pit furnace. Slags that are closely associated with the iron phase are enriched in phosphorus, perhaps representing some sort of partial equilibrium between iron and slag at the end of the process. Since the temperature and the CO/CO_2 ratio are not known for the individual stages of the process it is not easy to be more precise, but it appears that the phenomenon could be examined by experimental archaeology and metallurgical analysis. For the present examination it is, however, sufficient to note that the slag inclusions of the bloom are not of exactly the same composition as that of the bulk slags in the furnace, especially with reference to P_2O_5 and the SiO_2/Al_2O_3 ratio.

The iron bars

We have analysed samples from the largest of the massive bars, No 300B (Fig 6,4). It is forged to compact rectangular form, but still contains numerous slag inclusions. Its average density is 7.5-7.7 Mg/m^3. The metal is ferritic, complex ferritic coarse-grained materials alternating with ghost-ferritic structures (Fig 8). The coarse-grained ferrite has a hardness of 183-232 HV, while the ghost ferrite is slightly softer 175-192 HV. EDAX analyses show about 0.6% P in the hard ferritic material, and 0.4-0.5% P in the ghost structures. The slag inclusions have the average composition shown in Table 5.

The metal and the slag in bar 300B are closely related to that of the blooms (Table 4). Since the bloom material was collected inside one of the actual furnaces, we assume that the massive bar 300B was a product of Snorup in ancient time.

The long slender bars now weighing 120-160g are severely corroded, but it was possible to select sound sections from six of them (Table 6). The short slender bars which originally may have weighed 30-35g were unfortunately so transformed by corrosion that quantitative analysis could not be performed. What little was left was studied by metallography and revealed no differences from the long bars.

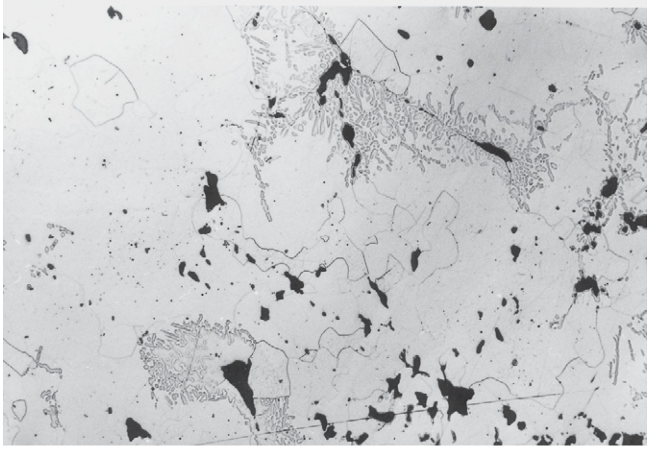

Figure 8: Etched sample of the massive bar 300B showing areas with ghost structures and slag inclusions (x56)

Table 7: Slag inclusions in bars from Oppland, Norway

Bar No	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	Na_2O	SO_3	SiO_2/Al_2O_3
C23191	52.91	19.54	8.38	0.00	0.00	1.96	11.14	2.44	1.55	0.70	0.00	0.17	4.75
C24075	50.57	7.53	2.59	0.00	0.00	1.91	15.38	3.84	4.38	0.64	0.00	0.35	3.29
C27975	57.67	10.26	5.90	0.33	0.00	11.91	11.73	2.81	2.07	0.55	0.00	0.00	4.92
C39270-94	47.26	19.06	6.30	0.45	0.00	7.06	13.54	3.44	2.40	0.68	1.08	0.10	4.49
C3454	45.99	18.11	10.98	0.00	0.39	4.16	14.15	3.17	2.20	0.80	0.00	0.44	3.25
C3549	41.22	26.47	6.52	0.00	0.03	1.66	14.49	3.08	2.57	0.73	0.00	0.00	2.85

The long slender bars are pearlitic or ferritic-pearlitic with small grain size. Locally the structure displays Widmanstätten patterns (0.3-0.4% C) (Fig 9) or phosphorus ghost structures. The hardness is highly variable, 103-315 HV, the softest being in 100% ferrite, the hardest in 100% pearlite. The slender bars are all of steel quality, albeit heterogeneous with respect to the carbon content.

The heterogeneity may be exemplified by the four slag analyses taken in different places on the same object, bar 201 (Table 6). Although the individual values for SiO_2, Al_2O_3, CaO etc vary widely, the ratios SiO_2/Al_2O_3, SiO_2/CaO, CaO/TiO_2 etc remain fairly constant. As shown elsewhere (Buchwald and Wivel 1998, Buchwald 1998a) this is a general phenomenon associated with the iron reduction process. When FeO is reduced to Fe, it disappears from the slag, which becomes correspondingly enriched in all the other components. Since they are not soluble in the iron matrix they must remain in the slag, *ie* their individual ratios do not change, as exemplified by the four analyses quoted.

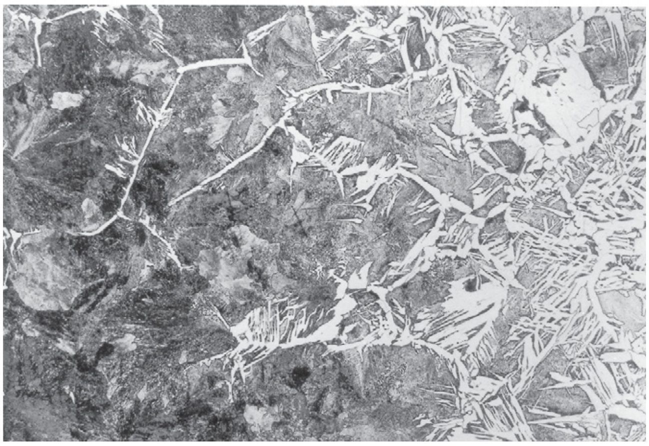

Figure 9: Etched area of long slender bar Sn 92 showing a pearlitic structure to the left changing to a ferritic-pearlitic structure with Widmanstätten patterns to the right (x85)

There is a strong correlation between the composition of the slag and that of the surrounding metallic matrix. The most reduced slag, *ie* with little FeO, is situated in the most reduced metal, *ie* the high carbon pearlitic steel. Slag with high FeO content is, on the contrary, located in the least reduced metal, *ie* in ferritic iron. It may also be stated this way: glassy slag inclusions are usually small and located in pearlitic steel, while wüstite-rich inclusions are rather voluminous and located in ferritic iron. The slender bars would be well suited for steeling, *ie* inlaying by forge-welding as edges in knives and similar cutting and wear-resistant tools.

Common to the slender bars is the rather low SiO_2/Al_2O_3 ratio. Figure 10 shows the SiO_2/Al_2O_3 ratios for bulk slags and slag inclusions in iron and steel of the specimens mentioned in the text.

Discussion

The ancient iron production site in Snorup may be characterized and defined by the chemical composition of the bog iron ore (Table 2), of the production slags (Table 3) and of the slag inclusions in the blooms (Table 4). The slag material has high SiO_2/Al_2O_3 ratios, above 6 (Fig 10), limited amounts of manganese, calcium, magnesium and titanium, but significant amounts of phosphorus and sulphur.

The massive bar 300B from the hoard contains a number of slag inclusions, the average of which (Table 5) corresponds well with the Snorup finds, and particularly well with the bloom material (Table 4). We therefore suggest that the massive bars were produced in Snorup in the period when the furnaces were in production (330-560 AD) (Voss 1993, Rasmussen *et al* in press).

The slender bars of the hoard are very different, in size and shape, as well as in structure and slag composition. The metal is ferritic-pearlitic and all bars have sufficient carbon to allow for a pronounced hardening effect by water

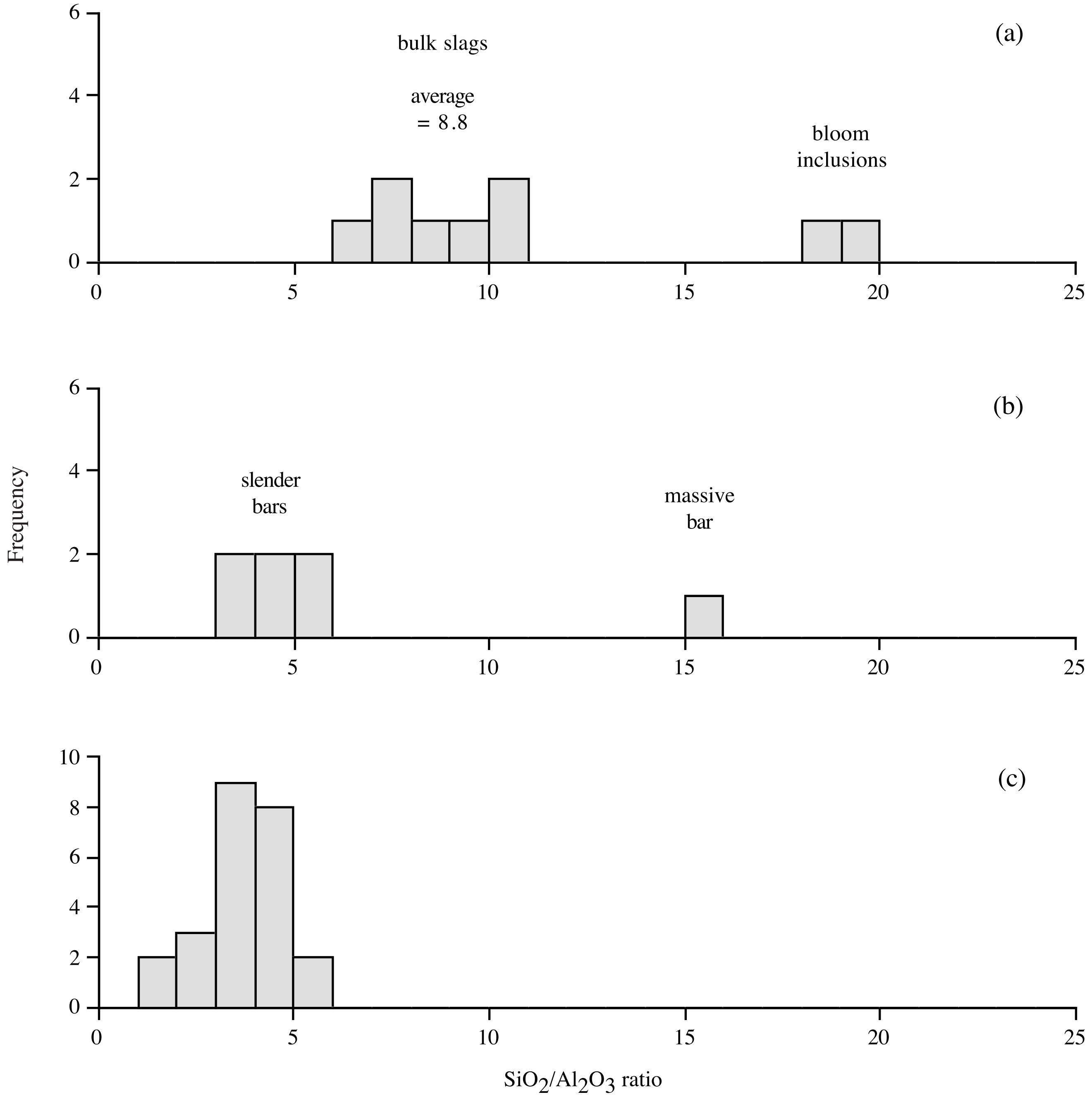

Figure 10: Histograms comparing the SiO_2/Al_2O_3 ratios (data mostly from Tables 3-7): (a) bulk slags and slag inclusions in blooms (MA, MB), (b) Slag inclusions in the slender bars and massive bar (300B) from Snorup, (c) Slag inclusions in iron and steel from southern Norway.

quenching. It appears that these bars were not produced in Snorup, so we must look for iron production sites elsewhere. As discussed above, similar bars have been produced elsewhere in Europe. The nearest area to Snorup in this respect is southern Norway, and since the Norwegian bars display a general morphology similar to the Snorup bars, we have concentrated our interest on the Norwegian material.

We have examined typical iron bars from Oppland, each weighing from 15g to 2kg (Table 7). Of these six bars, two (C3454 and C3549) are almost identical in size and shape to the slender bars from Snorup. The average slag analyses of the Norwegian material have typically rather low SiO_2/Al_2O_3 ratios, high manganese, calcium, magnesium and titanium contents, and limited phosphorus and sulphur content. They are also of a ferritic-pearlitic to pearlitic nature; a blacksmith would not have hesitated to use this material whenever he needed steel. A histogram of the six Oppland bars, supplemented by 18 other iron objects from southern Norway (Fig 10c), shows that the Norwegian material and the Snorup bars are closely related. We therefore suggest that the slender bars of the Snorup hoard were imported from Southern Norway between 330-560 AD with the intention of using them for steeling tools and knives.

Conclusions

In ancient iron objects there is a strong correlation between the appearance of slag inclusions and the adjacent metal matrix. Glassy slags with low iron oxide content are situated in pearlitic, steely material, while wüstite-rich slags are found in ferritic iron. Transitional cases also occur, *eg* wüstite-fayalite slags appearing in ferritic-pearlitic metal.

The SiO_2/Al_2O_3 ratio of slag inclusions is helpful when discussing the provenance of ancient iron objects. The level of impurities such as calcium, magnesium, titanium, vanadium, sulphur, and their ratios may be of further assistance.

The Danish iron province of Snorup is characterized by rather high SiO_2/Al_2O_3, SiO_2/CaO, SiO_2/MnO and SiO_2/MgO ratios, while phosphorus and sulphur occur in significant amounts. Phosphorus is present in solid solution in the ferrite, leading to hardnesses of up to 300 HV, significantly above the 80-100 HV of pure ferrite.

The massive bar that we examined is of ferritic structure and is argued to be of Snorup origin, but about two hundred slender bars are, according to our analyses, argued to be imported and of Norwegian origin. They contain 0.4-0.7% C and should, in fact, be termed steel bars although they have previously been called iron bars (Petersen 1918, Svane 1991). Their particular shape and small size becomes meaningful as an expression and guarantee that the material was of a steely nature. We also believe that there would be little reason to fabricate and to trade wrought iron as items of so small a shape.

It might seem strange to import iron to an iron extraction site, but these bars are not iron but steel. As the two other finds of slender bars in Denmark were located on the Dankirke and Lundeborg sites, which both show strong indications of trade, this supports the idea that the slender bars were trade objects.

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References

Andresen J 1994, 'Notat om jernbarrer', *Illerup Ådal. Små skrifter 1. Proveniensbestemmelse af jern fra Illerup Ådal - et pilotprojekt,* Jysk Arkæologisk Selskab, 55-79.

Bielenin K 1989, 'Frühzeitliche Eisenverhüttungscentren in Polen', in Pleiner R (ed), *Archaeometallurgy of Iron 1967-1987* (Prague).

Bielenin K 1992, *Starosytne górnictwo i hutnictwo zeleza w Górach Swietokrzyskich* [Ancient Mining and Iron smelting in the Góry Swietokrzyskie (Holy Cross Mountains)], 2nd edn (Warsaw).

Buchwald V F 1998a, 'On a method to determine the provenance and character of ancient iron objects', in Crew P and Crew S (eds), *Early Ironworking in Europe, archaeology and experiment,* Abstracts from the International Conference, Plas Tan y Bwlch, 19-25 September 1997.

Buchwald V F 1998b, 'Myremalm', *Geologisk tidskrift*, 1, 1-26.

Buchwald V F and Wivel H 1998, 'Slag analysis as a method for the characterization and provenancing of ancient iron objects', *Materials Characterization*, 40, 73-96.

Christensen W 1966, 'Myremalm', *Dansk natur - Dansk skole*, Årsskrift.

Hansen Jarl H 1991, 'Dankirke, en myte i dansk arkæologi', in C Fabech and J Ringtved (eds), Samfundsorganisation og lokal variation. Norden i Romersk Jernalder og folkevandringstid. *Jydsk Arkæologisk Selskabs Skrifter*, 27, 15-23.

Hasek V and Merinsky Z 1989, 'Geophysikalische Prospection von Eisenverhüttungsplätzen in der Umgebung von Blansko', in R Pleiner (ed), *Archaeometallurgy of Iron 1967-1987* (Prague).

Hjärthner-Holdar E 1993, *Järnets och järnmetallurgins introduktion i Sverige*, Aun 16 (Uppsala).

Hvass S 1979, 'Die Völkerwanderungzeitliche Siedlung Vorbasse, Mitteljutland', *Acta Archaeologica* (Copenhagen), 49, 61-111.

Jensen S and Watt M 1993, 'Handelscentre og centralpladser', in S Hvass and B Storgaard (eds), *Da klinger i Muld - 25 års arkæologi i Danmark* (Århus), 195-205.

Jöns H 1997, 'Frühe Eisengewinnung in Joldelund, Kr. Nordfriesland. Ein Beitrag zur Siedlungs- und Technikgeschichte Schleswig-Holsteins I', *Universitätsforschungen zur Prähistorischen Archäologie* (Bonn).

Kristoffersen S 1993, 'Gård og gjenstandsmateriale - sosial sammenheng og økonomisk struktur', *Arkeologiske Skrifter* (Bergen), 7, 151-206.

Kuna M and Zavrel J 1989, 'Die Eisenverhüttungsanlagen der Älteren Römischen Kaiserzeit in Ricany, Bez. Prag-Ost', in R Pleiner (ed), *Archaeometallurgy of Iron 1967-1987* (Prague).

Lund J 1991, 'Jernproduktion i Danmark i romersk jernalder', in C Fabech and J Ringtved (eds), Samfundsorganisation og lokal variation. Norden i Romersk Jernalder og Folkevandringstid. *Jydsk Arkæologisk Selskabs Skrifter*, 27.

Magnusson G 1991, 'Järnproduktion och järndistribution i Östersjöområdet', in C Fabech and J Ringtved (eds), Samfundsorganisation og lokal variation. Norden i Romersk Jernalder og Folkevandringstid. *Jydsk Arkæologisk Selskabs Skrifter*, 27.

Martens I 1979, 'Jerndepoterne - noen aktuelle problemstillinger', *Jern og jernvinne som kulturhistorisk faktor i jernalder og middelalder i Norge*. Arkeologisk museum i Stavanger, Varia 4 (Stavanger), 59-64.

Martens I 1988, *Jernvinna på Møsstrond i Telemark. En studie i teknikk, bosetning og økonomi*, Norske Oldfund 13 (Oslo).

Mortensen R 1932, 'Oldtidsjærn i Ribe Amt II', *Fra Ribe Amt,* 7.

Petersen J 1918, ‘Jernbarrer’, *Oldtiden* (Oslo), 7, 171-186.

Petersen J 1923, ‘Jernbarrer og Redskaber’, *Oldtiden* (Oslo), 10, 59-77.

Pleiner R 1961, ‘Slovanskê sekerovitê hrivny’, *Slovenska Arhaeologia*, 9, 405-50.

Pleiner R 1989, ‘Iron-making and -working on the territory of Czechoslovakia until middle ages (recent results)’, in R Pleiner (ed), *Archaeometallurgy of Iron 1967-1987* (Prague).

Rasmussen K L, Rahbek U and Voss O in press, ‘Radiocarbon dating of the iron production in slag-pit furnaces in Jutland’, Version 25, 17 April 1998.

Resi H G 1995, ‘The Norwegian iron bar deposits’, *Produksjon og samfunn. Beretning fra 2. nordiske jernaldersymposium på Ganavolden 7-10 maj 1992*, Varia 30 Universitetets Oldsaksamling (Oslo), 131-46.

Rygh O 1885, *Norske Oldsager* (Christiania).

Svane H 1991, ‘Rhombic Iron Axes and Axiform Currency Bars from Norway’, *Materialy Archologiczne*, 26, 31-3.

van Nie M 1997, ‘Germanic iron provision in the second half of the third century AD - Slag-pit furnaces and iron hoards’, in L Nørbach (ed), *Early Iron Production - Archaeology, Technology and Experiments*. Technical Report 3. Historical-Archaeological Experimental Centre (Lejre), 115-22.

Voss O 1993, ‘Snorup - et jernudvindingsområde i Vestjylland’, *Nationalmuseets Arbejdsmark 1993* (Copenhagen), 97-111.

Voss O 1995, ‘Snorup - an iron producing settlement in west Jutland, 1st-7th century AD’, in G Magnusson (ed), *The Importance of Ironmaking. Technical Innovation and Social Change*. Vol 1. Stockholm Jernkontorets Bergshistoriska Utskott H58.

Voss O 1996, ‘Snorup - an Iron Age settlement with iron production in the 4th to the 6th century AD’, in H Lyngstrøm (ed), *Early Iron. Netværk for tidlig jernteknologi*, 1, 19-27.

Wegewitz W 1957, ‘Ein Rennfeuerofen der älteren Römerzeit in Scharmbeck, Kreis Hamburg’, *Nachrichte aus Niedersachsens Urgeschichte*, 26.

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