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IRON PRODUCTION IN DENMARK IN VIKING AND MEDIEVAL TIMES

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Our knowledge of iron production in Denmark during the viking and medieval periods is very limited, especially when compared with the previous period of 100 to 700 A.D., when a large iron production in slag-pit furnaces concentrated in West and South Jutland took place (Voss 1962). The reason for this difference can probably be credited to the fact that iron age and medieval furnace types have not had the same survival possibilities in an area as heavily cultivated as Denmark.

The iron age slag-pit furnace is now known from 55 sites in Jutland, all of which contain slag blocks weighing about 200 kg, each with the top about 30 cm below the surface. Because of their great size, the farmer cannot easily overlook them when struck by the plough.

The medieval furnace type is much easier to destroy and is therefore in marked contrast to the above described situation. Traces of a slag-tapping furnace with a base 20 to 30 cm below the surface will not be preserved due to the farming techniques. The slag from these furnaces were left on the ground in heaps, which consist of slag pieces weighing a few kilograms or less. This has made their removal easy. The result is a lack of finds and no conclusion can be drawn about the size of the medieval iron production. It is possible that we have slag heaps and furnaces preserved where we have had forests for centuries, but no systematic search has yet been carried out.

What is known about medieval iron production today comes from only three sites: One on Fyn, one in Jutland, and one just south of the Danish-German border in the forest north of Flensborg, excavated by Hans Hingst.

On Fyn, a slag heap was excavated in 1925 by Frydendahl, His report is in the National Museum. This slag heap was 6 m in diameter and contained plano-convex slags, tap slags, and a few potsherds which can be dated to the 13th-14th century. No furnace was found. In the same area - which is a forest close to the former Cistercian Cloister "Holme", founded in 1172, -

several more slag heaps have been reported. Holme Cloister, now Brahetrolleborg, was a daughter cloister of Harrisvad Cloister in Skåne (Scania), founded 1144 from Citeaux in France.

In Jutland, a slag heap which was partially destroyed by ploughing has been excavated at Jels Skov, west of Haderslev. Only 10 cm of the height was left and it covered an area of 6x7 m. It contained tap slags, plano-convex slags, and a few medieval potsherds. Charcoal from this find was radiocarbon-dated to 1165 A.D., calibrated according to Stuiver & Pearson 1986 (K-5625). No trace of the furnace was found.

150 years ago, this area was part of a forest, and 30 years ago the slag heap was still ½m high.

From Jutland, two more slag heaps are known: one, only 3 m in diameter, is in a forest near Silkeborg. The other one is from Kjellerup, north of Silkeborg in the middle of Jutland. The latter was recorded by Niels Nielsen in 1920, estimated to contain 50 cubic meter of slag - which is the equivalent of 170 ton. Not very much is left now, but an excavation of the remainder is planned.

With so few bloomery sites in Denmark, we can get additional information by looking a few hundred meters south of the Danish border to Germany, where Hans Hingst (1969; 1981) has found 52 slag heaps. They are 2-11 m in diameter and up to 1 m high. Slag heap No.62a is 5x3 m, 0,8 m high, and contains 5 m^3 of slag. The furnace is situated 2 m from the heap. It has an internal diameter of 45 cm and the bottom is about 20 cm below the surface. At the eastern side of the furnace there was, at the bottom, a 15 cm wide opening, which led out to a 1 m wide shallow pit, into which the slag must have been tapped. At the bottom, the furnace wall is about 20-25 cm thick.

Based on the excavation results, Hans Hingst in 1969 has sketched a reconstruction of it.

All the slag heaps mentioned contain tap slag and they have all been dated within the 12-14th century. This means that we have a gap in our knowledge of more than 400 years regarding the iron production from the 8th to the 11th century. From historic sources we know that the Danish production of iron ceased about 1600 A.D. This means that we are still missing

information on furnaces from the 15th and 16th centuries.
There are only few historic sources. In 1198 archbishop Absalon of Lund donated the parish Tvååker in Halland to the cloister in Sorø, "Tvååker, where they are producing salt and where they are extracting iron from the soil". In a dispute about the extent of the donation c.1215 A.D., the final document states that the land "runs from the mill, where iron is fabricated, along the road to the southern iron works, and from there to the parish of Tyllered." (DRB xxxx). The parish of Tvååker was evidently producing iron from local bog iron ore and finished it - or part of it - at the water mill. Presently there are plans to initiate archaeological excavations on the site.

From the 15th and 16th centuries a few taxation lists, wills, and other testimonies concerning iron exist. The taxation lists show, e.g., that the peasants in 28 parishes in central Jutland in 1586 paid 410 "kloder" to the representative of the crown, the lensmand, in Silkeborg (Nyrop 1878). The word klode may be found in a few other testimonies, such as letters, from which it is clear that the term must concern some kind of iron. Today, however, the word is obsolete and so little understood that even the authoritative 27-volume Dictionary of Danish Etymology is unable to give a reasonable explanation of the word. For the interpretation of iron in a Danish context it is, however, important to understand the meaning of the word.

The taxation lists put the value of one klode (in English perhaps clot) to 12 skilling, or equal to 1/8 of a barrel of corn (barley or wheat), or equal to 1/8 of a pig. The weight, dimensions or quality of the iron are, unfortunately, nowhere indicated. In two certificates from the royal anchor smithy at Bremerholmen, Copenhagen, there are, however, some very important clues. The iron master acknowledges here the receipt in 1596 of 103 clots from Simmelkjer (near Karup, Jutland), and later, in 1599, the receipt of 187 clots from the same source. In the last receipt the clots are described as being <u>an aggregate of four pieces</u> (Buchwald 1992).

It is fortunate that a few, rare samples that fit this description have been found. In Vejle Museum there are two specimens, found near Karup about 1920, but except for short descriptions by Mortensen (1940) and Nielsen (1941), they have received little attention and had been stored away. In October 1991 a new find was made on the churchyard in the city of Skjern. Common to the three finds are the finger shape and a specific gravity of 4.5-

5.5 g/cm^3, which is far too low for iron (sp.gr. 7.8 g/cm^3). The best preserved clot (Fig.1) has all four fingers intact, while the others already in ancient time lost two, respectively one of the four fingers. Similar hand-shaped iron products have been reported from Sweden and Norway under the name blestrjern (Nihlén 1939; Hauge 1946). In a correspondence with Reykjavik in 1991, it was learned that the National Museum of Iceland also possesses a few clots (Fig.2). All the Scandinavian clots are stray finds without good archaeological dating. If, however, the present interpretation is correct, we can conclude i) that production of iron from bog iron ore took place in Denmark as late as 1600 A.D., ii) that stray finds of the hand-shaped clots may be dated to (late) medieval and renaissance time, and iii) what was termed blestrjern elsewhere in Scandinavia was called klode (clot) in Denmark.

The three Danish clots have been subjected to metallographic and analytical studies. They are very heterogeneous, being composites of about equal volumes of iron and slag, which explain their low specific gravity. By moving a hand magnet along the surface it is easily demonstrated that iron-rich and slag-rich areas alternate. On some of the fingers are axe marks which indicate that the cakes were standing upright when they were partially cleft by violent strokes.

The iron part of the Danish clot is phosphorus-rich. Microprobe analysis shows a range from zero to one weight% P, sometimes even showing spots of P-rich melts. The high phosphorus content, a bulk average of the iron 0.2-0.4 wt.%, is in our experience common to iron objects of Danish origin. The examination of a large number of medieval iron objects from Denmark, such as knives, axes, ploughshares and nails, shows that phosphorus is omnipresent, occurring in streaky zones, that originate from forging of the heterogeneous clot. Also the slag inclusions are phosphorus-rich. The slags usually consist of fayalite and wüstite, disseminated in a glass matrix. Phosphorus is concentrated in the glass matrix, that locally reach concentrations as high as 12 wt.%P, but P is also present substitutionally in fayalite (0.5-2 wt.%P) so this phase can properly be termed a phosphofayalite. Finally, in several cases the slags contain apatite, $Ca_3(PO_4)_2$.

Why Danish bog iron ore is relatively rich in phosphorus is not quite clear. Perhaps the intensive agrarian activity which goes back about 4000 years slowly has added phosphorus to the soil, from where it in due time has been leached and redeposited with iron hydroxides to ultimately form the bog iron ore. The corresponding ore deposits of Sweden, Finland and Norway, by comparison, occur far from agrarian activity and are usually devoid of phosphorus.

The clot, kloden, is quite clearly a semiproduct. Therefore few of them have survived to our time. The handshape was formed by axe strokes while the iron-slag mass was still red-hot. The shape fullfilled several requirements: i) the smelter obtained a first view and control of the iron quality, ii) the clot could later easily be split into handy segments of 2-3 kg, and iii) the handshaped clot could easily be gripped and tied up for transportation.

When a finger of the clot with a mass of 2-3 kg was worked into iron , two things happened: i) the iron was squeezed into elongated, fibrous structures with alternating P-rich and P-poor areas and with a few slag inclusions, and ii) the bulk of the slag was removed. The slag, in the order of 0.5-1 kg per finger, accumulated in the forge as plano-convex slag cakes, while the fibrous iron could be further worked into ploughshares, scythes, nails etc.

We assume that the production of the clots took place in bowl-shaped furnaces (Fig. 7), and we experiment presently with the operation of that furnace type under the assumption that a charge of bog iron ore and wood/charcoal could produce a clot of about 10 kg in 4-5 hours (Buchwald 1991). So far results have not been too good. We believe, however, that by establishing the right combination of wind, charge and temperature it will be possible - assisted by stirring from above - to collect the reduced iron prills into a cake of 50 volume% iron and 50 volume% slag. This cake may then be lifted out from the bowl furnace and immediately cleft to produce a clot. Several papers (e.g.Solders 1946) describe a similar process as performed in Sweden in the 18th and 19th centuries. We assume that a comparable process was in use in Denmark in late medieval time, but furnace remains have so far not been documented.

The chemical balances and the yield of the process can be exemplified by calculations. Albeit approximate, we find that 36 kg of roasted bog iron ore will produce a cake of 2 l, consisting of 6.7 kg iron and 3.5 kg slag. In addition, another 7 l of slag will sit around the cake/ clot and protect it from the wind. This slag will solidify in the bowl furnace and will have to be lifted out before the next run can be started. The balance in a chemical reaction scheme is, of course, not realistic when it comes to carbon consumption, since only the small fraction used for reduction is considered.

The entire operation may have taken place during a short campaign each year in the autumn (September-October). Each parish operated one or a few furnaces near the bog iron ore deposits that usually were distant from the village. A few farmers with their families ran the furnace for a week or two, producing enough iron for local consumption and for some sale and bartering, as well as for taxation purposes.

The farmers took the clots on horseback to their village, where the clots were converted to iron and plano-convex slags. The farmer would make his own horseshoes, ploughshares, nails etc., but would take some of the clots to the specialized smithy to provide iron for more complicated items and for steeling. Many clots went to the cities (Viborg, Skjern, Holstebro etc.), the cloisters or the medieval manors and castles, where they were made into finished objects, among other things also into weapons. Therefore, a high concentration of plano-convex slags is bound to occur in these places where the semiproduct was converted to useful items. At water mills the clots were transformed into bars and band iron, the last item particularly needed for barrels and wagon wheels.

It appears that several Danish water mills have produced bar and band iron, but the only evidence today is a significant concentration of plano-convex slags around some mill sites (Bundesbæk Mølle and Damsø Mølle, both in Ringkøbing Amt), and a few rusted fragments of band iron. Preliminary attempts of dating the activity at the iron mills indicate 14th to 16th century, but we know that the Tvååker mill, mentioned above, was operating about 1200 A.D. We feel that we have so far only located a small fraction of the potential iron mill sites, and we expect that many Danish mills, before they became regular corn mills, had a significant era as iron mills. The ancient place name Klode Mølle in central Jutland may support this idea (Buchwald 1992).

Finally a word about an entirely different approach. Since the written sources are so scarce, a new method of documentation is presently being tested. There are about 2000 stone churches in Denmark. The oldest parts of these date back to 1140-1200 A.D. The building material is usually granite or limestone or brick. However, blocks of bog iron ore has been used as a subsidiary construction material in some of the churches. The map shows the location of the 25 churches which so far have been identified. The massive variety of Danish bog iron ore has been inserted among other stones, both in the foundation, in the apsis and the choir, i.e. in the oldest parts of the buildings. Sometimes the red bog iron ore has been used decoratively to ornament a triumphal vault or to frame a door or a window opening (e.g.Gjellerup and Vejerslev churches).

The use of iron ore as a building stone suggests that bog iron ore was a well known commodity that was easily available about 1200 A.D. and - by implication - that the parishes where these churches were erected were producing iron at the time. It is quite interesting that the high concentration of iron-ore-containing churches coincide rather well with the parishes which 400 years later were iron producing, according to the taxation lists.

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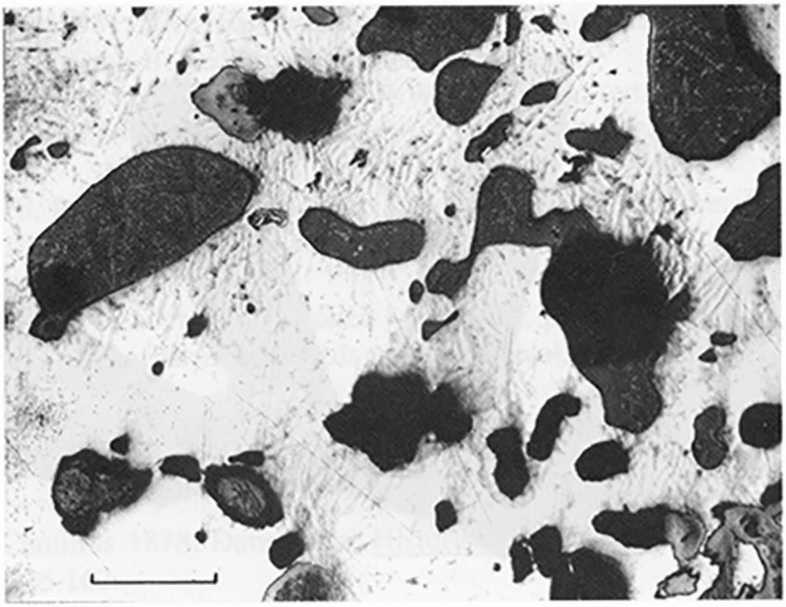
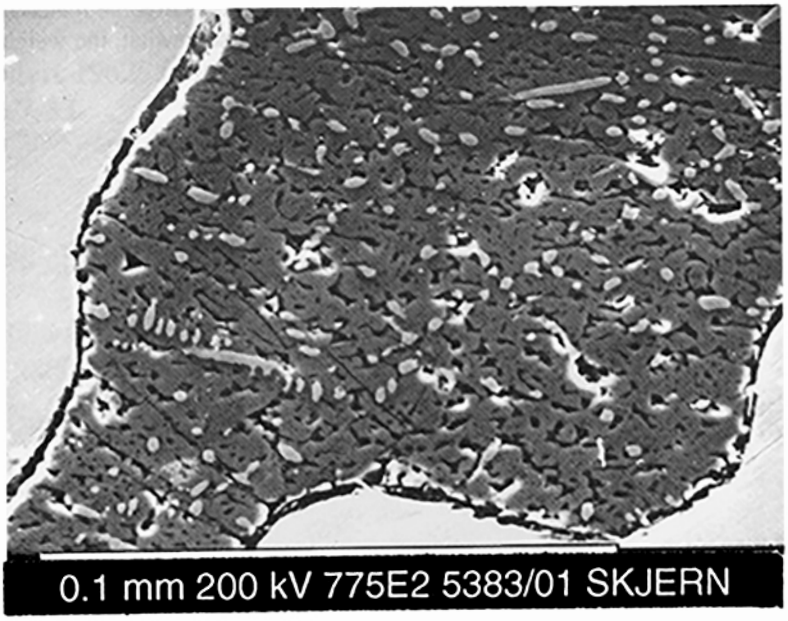
1. Four-fingered clot (Danish: klode) found in 1920 near Karup, Jutland. Now in Vejle Museum (Karup I, nr.963x1). With a volume of 1.9 l and a weight of 8.2 kg, the specific gravity is only 4.3g/cm^3. Metallographic examination shows that the material is 50 vol% iron and 50 vol% slag. Before corrosion altered the clot somewhat, the weight must have been about 10 kg and the spec. grav. about 5.2 g/cm^3.

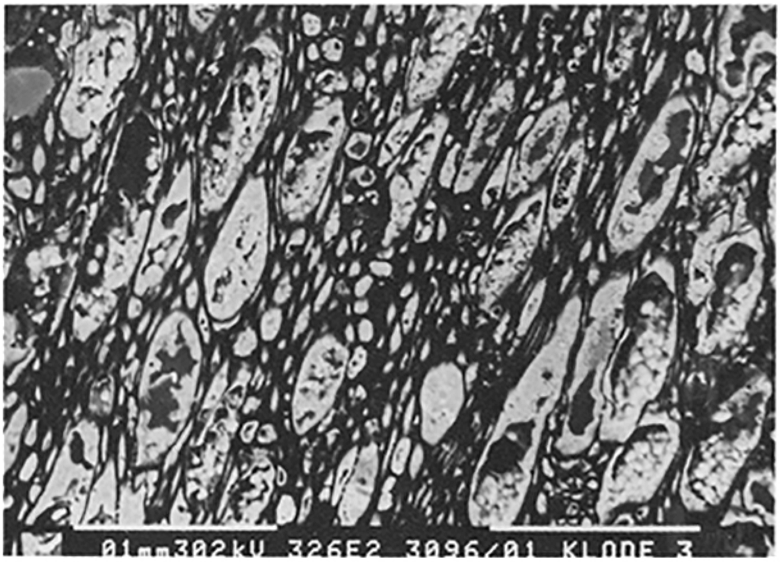
2. Three-fingered clot (klode) from Iceland, found on the farm Mynes, EiðaÞinghá, Eastern Iceland. Now in Reykjaviks Nationalmuseum (nr.1965-139). Present weight 8.6 kg (Courtesy Dr.þorkell Grímsson).



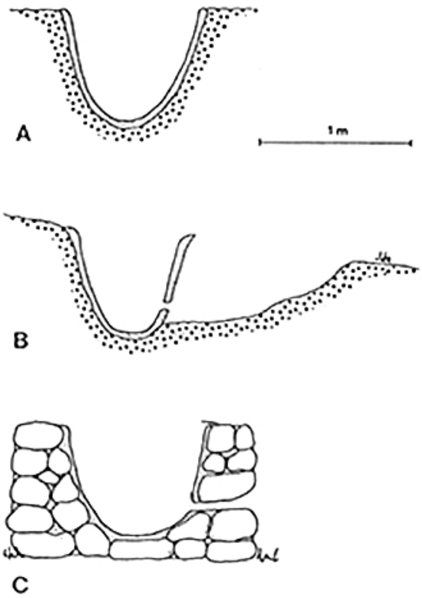
3. Polished and etched section through a Danish clot (Vejle Museum nr.22072). Phosphorus-rich iron (white), alternate with slag inclusions (grey), and voids and corrosion products (black). Scale bar 0.5 mm.



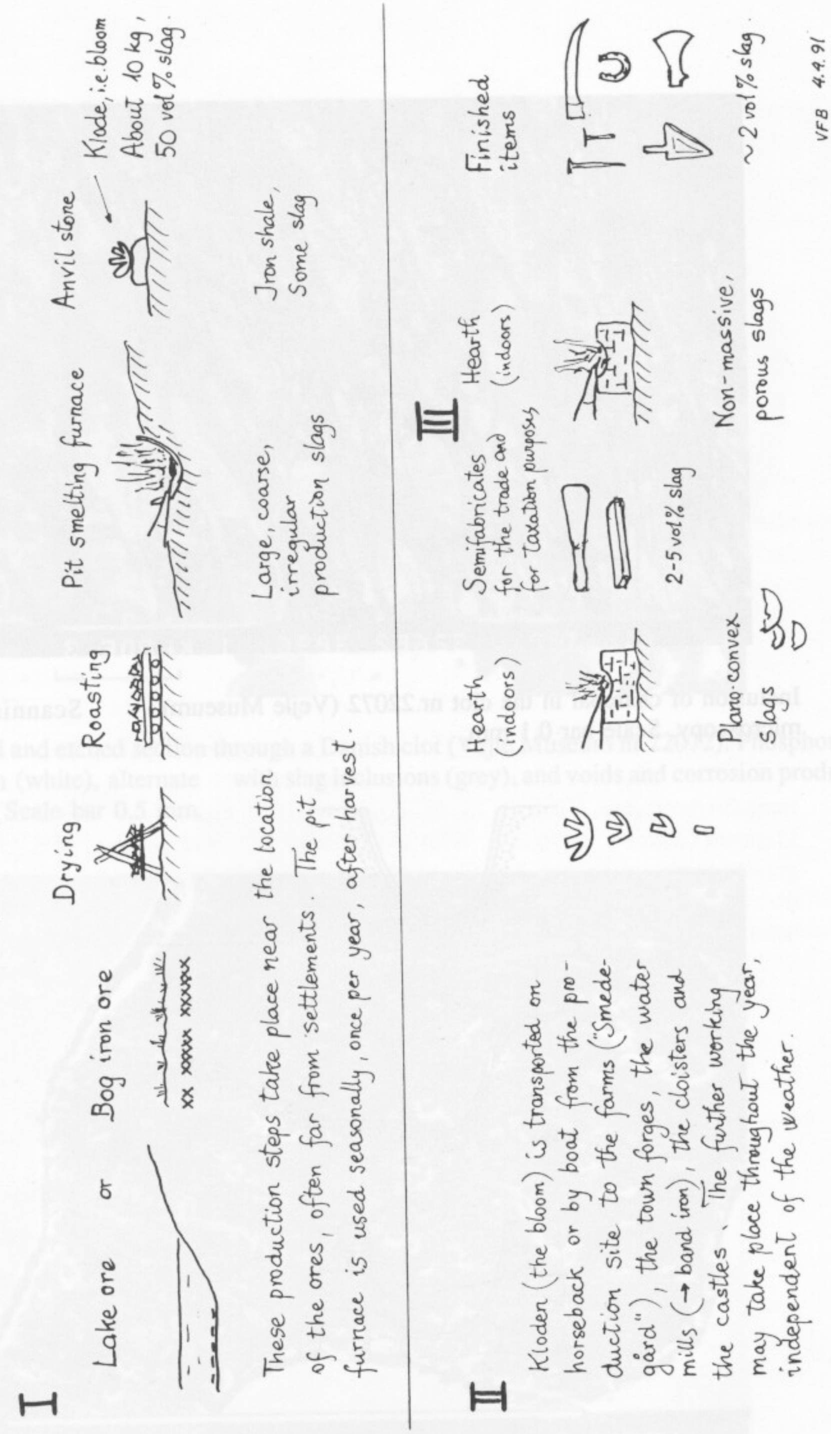
4. Polished section through a Danish clot (Skjern Museum, three-fingered, 4.8 kg). The slag consists of major phosphofayalite (grey, 1-2 wt% P) and minor wüstite (light grey dendrites) and glass matrix (black, 10-12 wt% P).



5. Inclusion of charcoal in the clot nr.22072 (Vejle Museum). Scanning electron microscopy. Scale bar 0.1 mm.



6. Sketch of three potential medieval furnace types. No one has so far been documented in a Danish context.



7. Sketch of the medieval iron production in Denmark. Stage I takes place at the bog iron ore location and leads to the semifabricate: the clot (kloden). Stage II takes place elsewhere, on the farm, at the watermill, in the city etc and leads to the finished iron product, leaving the characteristic plano-convex slags, one slag cake per finger.

8. On the map of Denmark 25 medieval churches with subsidiary use of iron ore as construction material are marked. The construction dates are 1140-1200 A.D.