MEDDELELSER OM GRØNLAND

Ancient Iron and Slags in Greenland

Vagn Fabritius Buchwald

MAN & SOCIETY

26 · 2001

Ancient Iron and Slags in Greenland

VAGN FABRITIUS BUCHWALD

MEDDELELSER OM GRØNLAND • MAN & SOCIETY 26 • 2001

Vagn Fabritius Buchwald: Ancient Iron and Slags in Greenland.
Meddelelser om Grønland, Man & Society 26. Copenhagen, Danish Polar Center, 2001.

Publishing editor Kirsten Caning
Printed by Special-Trykkeriet i Viborg a-s

Scientific Editor:
Hans Christian Gulløv, The National Museum of Denmark, Frederiksholms Kanal 12, DK-1220 Copenhagen K, Denmark. Phone (+ 45) 3313 4411, fax (+ 45) 3347 3320, email: hans.christian.gullov@natmus.dk

About the monographic series *Meddelelser om Grønland*
Meddelelser om Grønland, which is Danish for *Monographs on Greenland,* has published scientific results from all fields of research in Greenland since 1879. Since 1979 each publication is assigned to one of the three subseries:
- *Man & Society*
- *Geoscience*
- *Bioscience*

This publication is no. 26 in the series *Man & Society. Man & Society* publishes papers that contribute significantly to studies in Greenland concerning human beings, in research fields such as anthropology, archaeology, arts, economics, education, ethnology, history, law, linguistics, medicine, psychology, religion, social science. Papers dealing with borderline subjects as for instance exploitation of natural resources and environmental research may be referred to one of the series Bioscience, Geoscience, or Man & Society according to what is considered appropriate from an editorial point of view.

For more information and a list of publications, please visit the web site of the Danish Polar Center *http://www.dpc.dk*

Cover: Two corroded nails and a bent fitting from the 13th century. Of Norwegian origin. From Abel's farm, the Eastern Settlement.

All correspondence concerning this book or the series *Meddelelser om Grønland* (including orders) should be sent to:

Danish Polar Center
Strandgade 100 H
DK-1401 Copenhagen
Denmark
tel +45 3288 0100
fax +45 3288 0101
email dpc@dpc.dk

Accepted May 2001
ISSN 0106-1062
ISBN 87-90369-49-1

Contents

Abstract

Buchwald, V. F. 2001. Ancient Iron and slags in Greenland. Meddelelser om Grønland, Man & Society 26. Copenhagen, Danish Polar Center. 92 pp.

The bloomery iron production method, which was in general use in medieval time, is presented in some detail. It is discussed how slags are formed, and how production slags and purification slags may be distinguished. The slag-analytical method is introduced and is applied on a large number of iron objects from ancient Norse and Inuit sites. Particular emphasis is placed on scanning electron microscopy and microanalysis of the minute slag inclusions in the artefacts. It is shown that a major part of the iron objects on Norse sites was probably made from Norwegian iron ores, and arrived as finished products from Norway. The presence of a few purification slags in the Eastern and Western Settlements prove, however, that raw blooms were sometimes shipped from Norway and afterwards finished by smithing in Greenland. The present study does not support the theory that primary iron production took place in the Norse settlements. A number of iron tools on Inuit sites are shown to be of Walloon origin, having arrived on whaling and expedition ships since the late 16th century. It is argued that many of the harpoon heads and knives were forged by the ships' blacksmiths according to the desires of the Inuit. Walloon iron was also present in Haabetz Colonie in 1721 A.D. Some puddled iron nails were identified in Washington Land. They are probably relics from some 19th century American expedition. Finally, the northernmost and largest iron meteorite tool ever found, a lancehead, was identified in Washington Land. Also, a meteoritic arrowhead was identified in the Western Settlement. The arrowhead was made from Cape York meteoritic iron and must have been traded to the Norsemen before 1350 A.D.

Key words: Iron tools, iron slags, slag inclusions in iron, bloomery iron, Walloon iron, puddled iron, Norwegian *blastrjarn*, slag analytical method, hardness of iron alloys, meteoritic iron.

Dr. scient. Vagn Fabritius Buchwald, Ingeborgvej 4. DK-2920 Charlottenlund, Denmark

Introduction

The archaeological interest in ancient Inuit and Norse sites in Greenland has for many years concentrated on establishing the migration routes of the Inuit and solving the enigma of the disappearance of the Norse settlements in the 15th century. House ruins and tent rings, farm complexes and churches have been thoroughly excavated and documented and related to written sources and oral tradition. Many objects of stone, wood, bone and antler have been retrieved and discussed and have served to illustrate the material culture. Objects of iron have, however, turned out to be few and small, and have attracted little attention. Their rarity has generally prevented a meaningful analysis and discussion of their quality and origin. An exception are perhaps the scattered fragments of meteoritic and telluric iron which at an early date were identified and documented (*e.g.* Lorenzen 1882; Holtved 1954; Buchwald and Mosdal 1985).

Since improved analytical techniques have facilitated the precise description and identification of ancient iron objects (Buchwald and Wivel 1998; Buchwald 1999) it has now become relevant to examine a suite of iron objects from Greenland in order to establish their quality and type. This may ultimately provide us with a clue to their origin or provenance. It will be necessary for the discussion to include the most humble and least understood of all archaeological material, the iron slags.

The material for the present examination was made available by the kind cooperation of Claus Andreasen, Nuuk, Jette Arneborg and Martin Appelt, The Greenland Research Centre at the Danish National Museum, and Jørgen Meldgaard, The Danish National Museum, Copenhagen. The material comes mainly from excavations in the late twentieth century. In addition, however, a number of specimens from the expeditions of Therkel Mathiassen and Erik Holtved have been included. On the map of Greenland (Fig. 1) are marked most of the localities mentioned in the text. In general, the samples have been selected among fragmented objects, raw material and scrap iron, while better preserved or more attractive items were reserved for exhibition purposes and future studies. Almost all samples were examined in their natural state before any treatment for conservation purposes had been applied.

Analytical methods

From each specimen two or more samples were cut, embedded in plastic, and polished by routine methods, using wet abrasive papers to No. 1000 and finishing with 3μm diamond powder on a rotating disc. Etching was not applied until after the analytical work was finished. Etching was performed with 2%

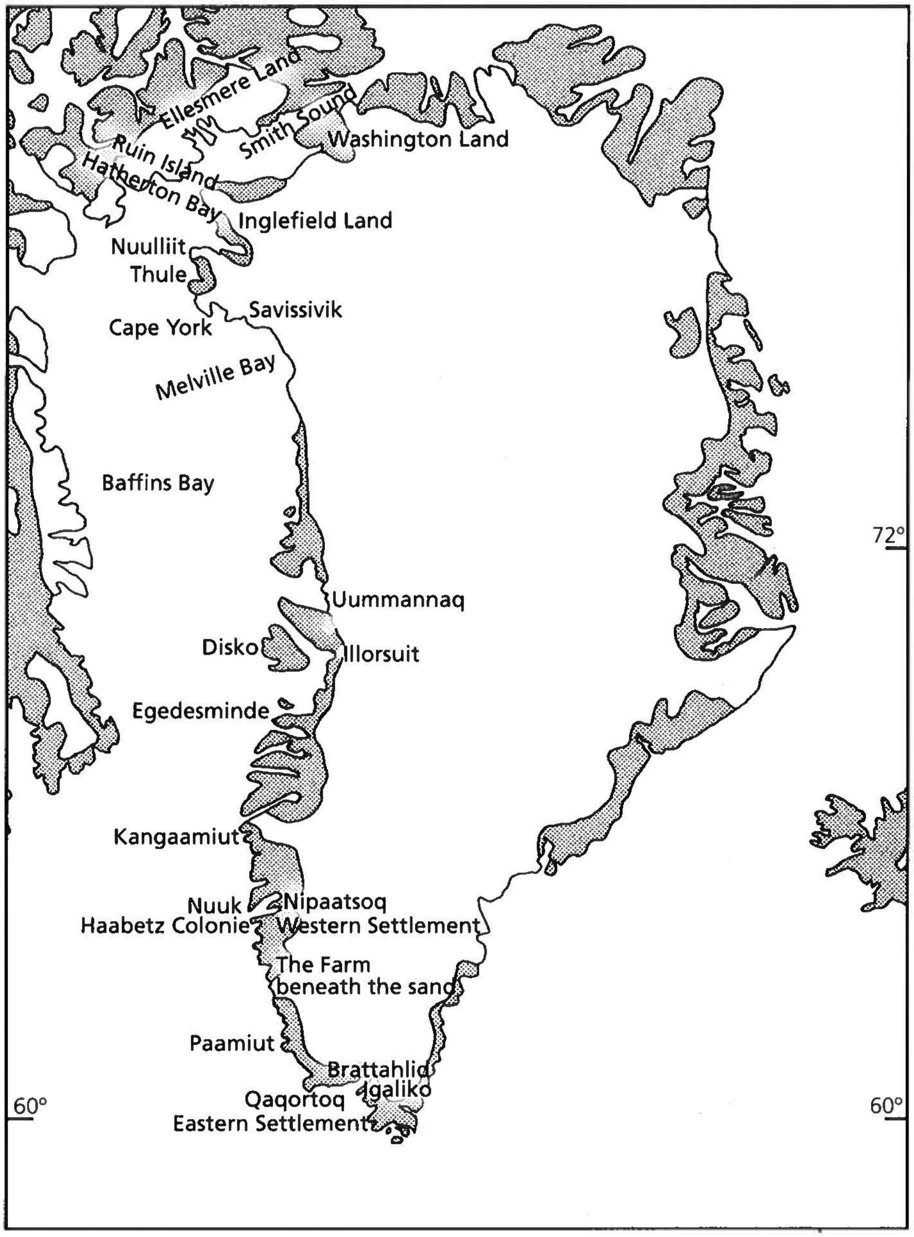

Fig. 1. Map of Greenland showing the localities mentioned in the text.

Nital, *i.e.* a 2 vol% solution of nitric acid in ethanol. Ferrite rich in phosphorus is only slightly attacked by this etchant, while normal ferrite and pearlite structures are well developed. For a contrast-rich etching of phosphorus ferrite a solution of 24 g sodiumthiosulfate, 3 g citric acid and 2 g cadmiumchloride in 100 ml distilled water was prepared.

Microhardness testing was performed on a Leitz Durimet at 200 g or, sometimes, 100 g load, and 5 impressions were made according to the international standard ASTM (1990).

	Process components	Equip-ment	Atmo-sphere	Product A	Waste B	Relative quantity of slags
1. Roasting	iron ore, wood	roast	oxidizing	roasted iron ore	ashes, unpro-cessed ore	no slags
2. Production, reduction	roasted iron ore, wood/charcoal	furnace	reducing	slag-rich bloom	production slag	1000
3. Purification	slag-rich bloom, charcoal, sand etc.	hearth P	oxidizing	slag-poor iron (bar)	purification slag	20-50
4. Manu-facture	slag-poor iron (bar), charcoal, sand etc.	hearth M	oxidizing	horseshoe, knife, nail etc.	manu-facturing slag	1-2

Table 1. *The four steps in bloomery iron production*

Compositional analyses were performed on a Philips scanning electron microscope (SEM 505) with attached energy dispersive spectroscopy equipment (EDAX 9900) at 20 kV. About 400 analyses were taken, partly as spots in individual slag phases (wüstite, fayalite, hercynite, leucite, magnetite, iron- and calcium phosphates etc.), partly as averages. Care was taken to exclude corroded parts of the slags. Averages were usually taken over areas of 300x200 μm, but in several forged items the slags were small and averages had to be taken over only 30x20 μm. It is the average analyses that are entered in the Tables of the present work.

A total of 13 elements were usually determined – namely, Na, Mg, Al, Si, P, S, K, Ca, Ba, Ti, V, Mn, and Fe – and counting times were 50 live seconds. The EDAX program converted the analytical data into weight% FeO, SiO_2, Al_2O_3, and so forth. The analytical method can not distinguish between Fe^{+2} and Fe^{+3} so all iron is reported as FeO. The standard error on elements present in concentrations above 2 weight% oxide is below 5%, but 10-25% on elements present in lower concentrations. The data for Na_2O have not been used in the interpretations. When barium was present, the titanium value became uncertain because of the coincidence of the signals for $BaL\alpha$ and $TiK\alpha$.

The bloomery iron production method

In the Viking age and early medieval period the only method for production of iron was the bloomery method. Although often called the direct method, it did in fact involve four different steps, each requiring its own equipment and each resulting in definite products and waste materials (Table 1). In the first step the iron ore (bog iron ore, lake iron ore, red earth, see *e.g.* Buchwald 1998) was roasted in order to dry it, to free it from sulphur and hydrated minerals, and to make it easier to crush for the following step. The roasting was accomplished on a loosely built grid of wooden logs, the roast. The temperature hardly increased above 500°C and the process typically lasted a few hours. Slags were not formed in this step. The roasting places have in some cases been identified by archaeologists due to the presence of ashes and pulverized, roasted ore. In some cases the roasting step may have been omitted. However, it would certainly be a clever praxis to apply roasting to sulphur-rich, humid and massive bog iron ores.

In the second step the roasted ore, pulverized or at least fragmented to nut-size, was loaded into a hot furnace, fired with wood and/or charcoal. The reduction process resulted in free iron, disseminated in a slag matrix, formed by the reaction between ore minerals, iron oxide and ashes from the charcoal. The maximum temperature in the furnace did not need to exceed 1250°C for the necessary reactions to occur, but locally near the blast hole, the tuyere, the temperature easily increased to 1350°C. Furnaces were of a wide variety. In particular there were many solutions to the problem of separating fluid slag from solid iron. In the end the blacksmith had produced a bloom (*Danish, luppe*), essentially consisting of iron, and a waste product, essentially consisting of slag. The waste product accumulated on the production site, and since it was rather stable, it has survived to our days and is, when in quantity, the most important indicator of an ancient iron production activity. The specific gravity of the slag is 3.0-3.5 g/cm^3. It may be estimated that for every 100 kg of production slags left on a site, about 15 kg of iron bloom has been removed for further treatment. In medieval Scandinavia the bloom was usually squeezed and shaped into a 5-15 kg heavy cake, the bloom or *blastrjarn*. This was often partially cleft on an anvil stone while still glowing hot, either into two parts (Norway) or four (Denmark, Iceland) (Fig. 2). In Norway the cleft bloom was called *fellujarn*, in Denmark – at least in late medieval times – a *klode*. A finger separated from the *klode* was called a *klimp* (Buchwald 1999).

In the third step the slag-rich iron bloom, or rather its individual fingers which were smaller and easier to handle, were heated in an open hearth charcoal fire. The hearth was a simple clay-lined cavity, either in the open on the ground or built up inside a hut. Through a hole in a fire resistant stone (baked clay or soapstone) the double bellows provided an energetic blast that burned part of the bloom's iron to iron oxide under a violent heat evolution. Simultaneous heating and forging consolidated the bloom and resulted in a semi-product, an iron which was rather poor in slag and had acquired a shape decided by the blacksmith. During the entire operation the blacksmith added quartz sand, SiO_2, or other material rich in SiO_2. It might be beach sand in which case some calcium oxide might enter the slag, or it might be roasted iron ore, *e.g.* the SiO_2-rich variety from Jutland, called iron stone (Danish,

Fig. 2. Typical bloom (Danish, klode) from Karup, Jutland, Denmark. Weight 8.25 kg. The four parts, when separated, are called klimps. Scale in cm.

jernal). Recent archaeological excavations at Hørup, Sjælland, suggest that also crushed flint might sometimes have been in use as a flux (Sørensen 2000). The SiO_2 additions reacted with FeO of the glowing bloom, 1 mol of SiO_2 and 3 mol of FeO forming a low-melting eutectic with 77-78% FeO and a melting point of about 1180° C. The heat of reaction helped to keep the bloom glowing hot and to free it from excess slag. The eutectic and surplus of sand reacted with the liberated, exuding slags of the bloom and formed the purification slag. This slowly filled the cavity of the hearth, creating a hearth-bottom slag, a plano-convex lump (Danish, *kalotslagge*). The purification slag is usually heterogeneous and layered, and it contains fragments of unreacted quartz, feldspar, hearth walls and charcoal. Locally near the strongly oxidizing blast, iron would oxidize to Fe^{+3} and exsolve magnetite skeleton crystals. The magnetic parts are easily revealed by applying a pocket magnet to the rough surface. Also, the plano-convex slag may have a depression in the upper surface, created by the blast of air, causing the slag to flow to the sides of the slag cake.

Now and then the hearth was cleaned, and the solidified slag cake was thrown into a corner. Unmolested purification slag cakes usually weigh between 0.1 and 1.0 kg. They are round and have diameters of 8-15 cm with specific gravities of 2.5-3.0 g/cm^3, Figs. 3-4. The quantity of purification slags is difficult to estimate, but certainly constitutes only a small fraction of the production slag on any given site.

Since it was common practice to freight blooms to places more or less distant from the production site in order to further treat them, *purification slags*

Fig. 3. Purification slag of the plano-convex type (Danish, kalotslagge) seen from the side. Weight 753 g, 15 x 13 cm in cross section and 5 cm high. About 400 AD. Snorup, section 800, Jutland, Denmark. Courtesy Olfert Voss.

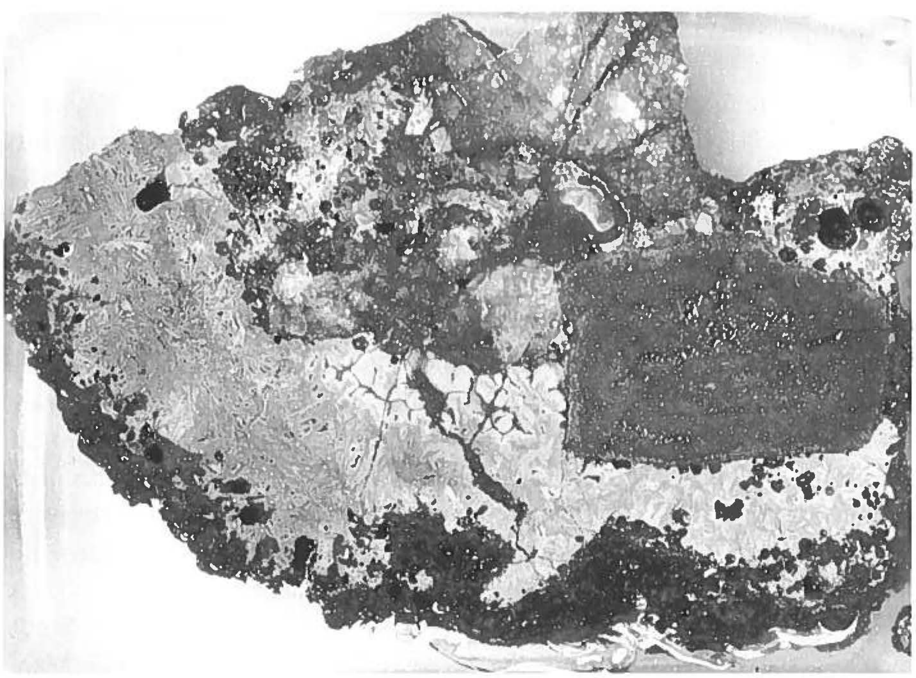

Fig. 4. Part section through a 728 g purification slag, displaying the typical heterogeneities. Greenish, whitish and reddish rock and clay fragments are included, the one to the right rather square and measuring 3½ x 2½ cm. Krogdal Vang, Sjælland, Denmark. About 1500 AD.

may be found on sites where iron production never took place. Slags reported from *e.g.* forges and hearths on larger farms, on manors, in the cities and in monasteries are usually purification slags. In Denmark purification slags are present on archaeological sites from 200 BC to 1600 AD. Then they disappear, because the bloomery process became obsolete.

In the fourth step the iron, purified for most of its slag, served as a start for the manufacturing blacksmith. From a bar (Norwegian, *teintjarn*) he forged nails or horseshoes in an open charcoal fire. Or a specialist blacksmith cemented iron to steel and made inlays of steel in tools, knives and axes (McDonnell 1984). Or another specialist blacksmith would manufacture tools, locks, keys or other intricate products. Since the *teintjarn* iron was rather pure, only few slags exuded during the process. The slag accumulated in a day's work in the forge consisted therefore at the most of a few hundred grams of porous to glassy cinder with low specific gravity, 1.0-2.5 g/cm^3.

In medieval time the hearth was charcoal fired, so the cinder would be composed of charcoal ashes, diluted by eroded hearth walls, by iron oxide from burned iron and by silicon oxide from added flux. The glassy, pumice-like cinders are rarely reported from archaeological sites, partly because they are inconspicuous, partly because they constitute a very minor fraction of all iron slags. Sometimes they are difficult to tell apart from fused fragments of the clay-built furnaces or from broken blow-pipes.

The slag-analytical method

After this general presentation of slag types and iron products the slag-analytical method will be introduced (Buchwald and Wivel 1998; Buchwald 1999), and we will discuss such analytical parameters that are relevant for the recognition of types and origins.

In Table 2 are three sets of analyses of medieval production slags, Step 2B (Table 1), from various places in Norway, Iceland and Denmark. The slags are composed of iron oxide (wüstite, FeO), fayalite ($(Fe,X)_2SiO_4$, where X may be manganese, magnesium and calcium), hercynite ($FeAl_2O_4$), leucite ($KAlSi_2O_6$) and glass. These phases occur in widely different ratios and since they are small, about 0.05 mm in diameter, they require microscopic examination for identification (Figs. 5-6). Magnetite, though reported, only rarely occurs in production slags. The slag analyses of the table are the average analyses of several different slag fragments, or of several different slag inclusions in solid iron. Care has been taken not to involve corroded material.

Common to the production slags is a rather high content of FeO + MnO, mostly above 54 weight%, and the presence of some titaniumoxide. Manganese is common, and locally some bariumoxide may be associated with it. In Denmark phosphorusoxide is common in the production slag, sometimes appearing with more than 10 weight%. The sum of all analyzed components

	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	SO_3	Σ	G	F	C
Norwegian slags															
Beitostølen, Valdres	30.0	56.0	0.8	–	0.1	1.6	8.8	1.6	0.6	0.3	0.2	100.0	22.1	3.41	18.8
Dokkfløyvann, Oppland	28.4	47.1	7.3	0.5	0.2	2.3	10.1	1.9	0.3	0.7	0.2	99.0	26.5	2.81	12.3
Hovden, Telemark	26.5	57.0	1.4	–	0.3	1.4	8.9	2.0	0.5	0.2	0.3	98.5	21.8	2.98	18.9
Storebekken, Trøndelag	28.9	57.9	1.7	–	0.1	1.3	6.7	0.9	0.6	0.4	1.0	99.5	15.9	4.31	22.2
Icelandic slags															
Belgsá, Fnjoskar-dalur	31.6	48.9	2.8	–	0.3	3.9	9.3	1.3	0.6	0.6	0.3	99.6	29.0	3.40	8.1
Lundur, Fnjoskar-dalur	24.0	62.4	1.3	–	0.2	2.4	6.0	0.9	0.8	0.5	0.4	98.9	15.8	4.00	10.0
Danish slags															
Hinge, Silkeborg	19.6	53.9	6.6	0.9	8.7	4.3	1.7	2.3	0.7	0.2	0.4	99.3	14.7	11.5	4.6
Ferritslev, Fyn	28.8	51.9	7.1	0.7	3.4	4.1	2.6	0.7	0.5	0.1	0.1	100.0	12.5	11.1	7.0

Table 2. *Medieval production slags. Step 2B in Table 1. SEM-EDAX analyses in weight%.*

approaches 100%, the missing part usually being small quantities of Na_2O and V_2O_5.

The glass parameter, G, is the quotient $100x(CaO+Al_2O_3+K_2O+MgO)/(FeO+MnO+BaO+P_2O_5)$. In the cases quoted here, G ranges from 12 to 29, but in, *e.g.*, slags from a blast furnace, G attains values of 500 and above, thus helping to distinguish them from other slags (Buchwald 1999). The parameter $F = SiO_2/Al_2O_3$ (in weight %) turns out to be a particularly useful characteristic. Already from the few examples given in Table 2, it may be seen that the Norwegian and Icelandic material display F-values between 2 and 5, while the Danish material has values above 8.

Other parameters, such as $C = SiO_2/CaO$, $M = SiO_2/MgO$ or $K = CaO/K_2O$ may sometimes be of help, but they are not sharply discriminative.

The analyses of medieval purification slags, Step 3 B (Table 1), are presented in the first two lines of Table 3. The Danish example is a typical plano-convex *kalotslagge*, while the Norwegian example is a fragment of one. The

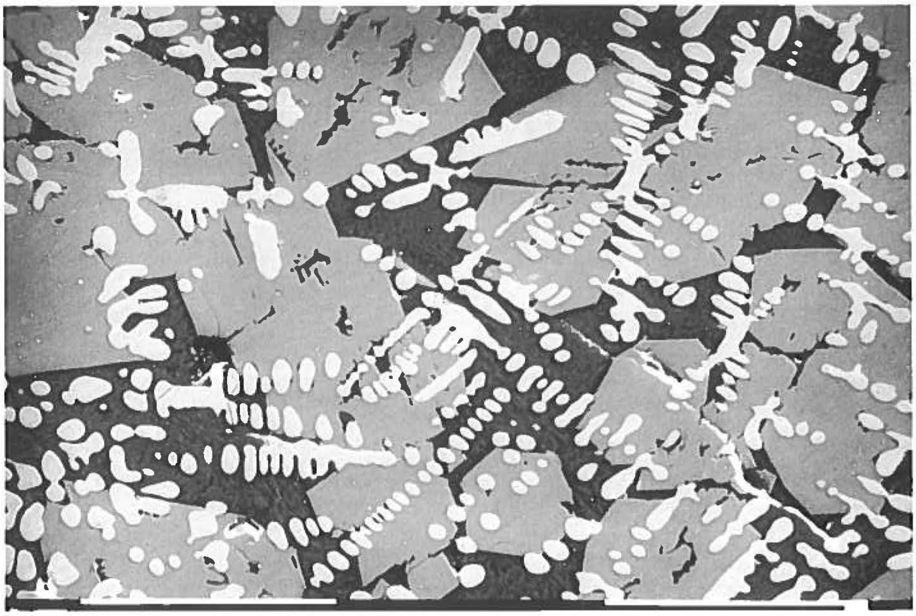

Fig 5. Polished section through a production slag, a tap slag from Tranemo, Väster Götland, Sweden 1200 AD. White wüstite dendrites, grey fayalite laths and black glass matrix. Scale bar 0.1 mm.

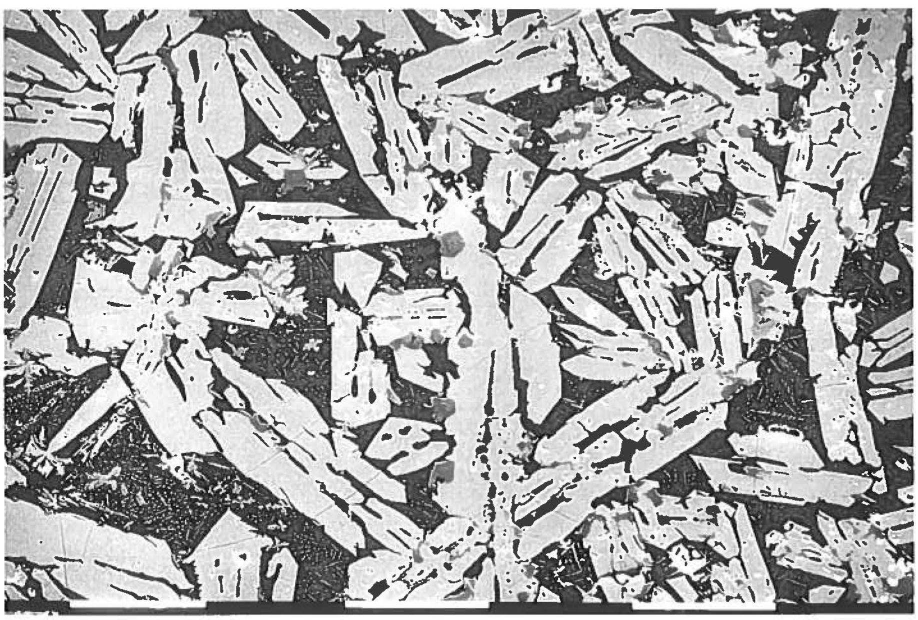

Fig. 6. Polished section through a production slag, a tap slag from Belgsá, Fnjóskardalur, Iceland. About 1000 AD. No wüstite, but fayalite laths (grey) and microcrystalline matrix. Hercynite is present as scattered angular 0.01 mm crystals (dark grey). Scale bar 0.1 mm.

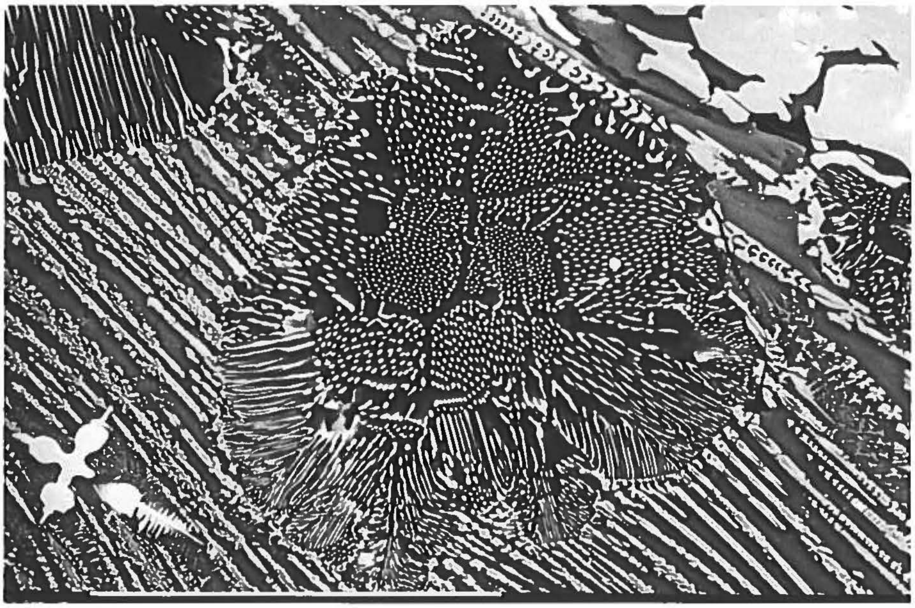

Fig. 7. Polished section through a 535 g purification slag (kalotslagge) from Ugglehult, Halland, Sweden. 1200 AD. The center is a eutectic intergrowth of wüstite (white) and leucite (black). It is surrounded by fayalite laths in glass. Scale bar 0.1 mm.

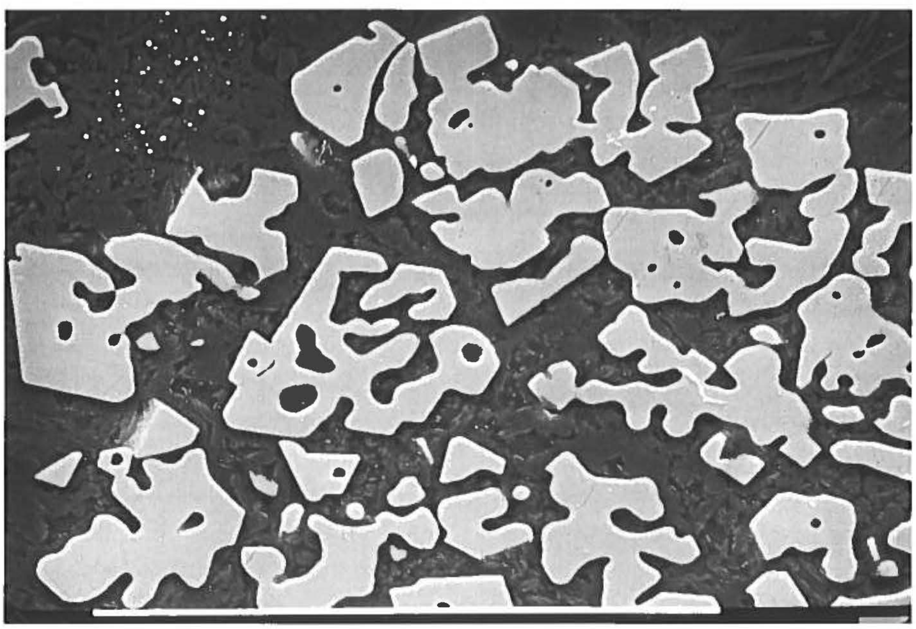

Fig. 8. Polished section through a 785 g purification slag (kalotslagge) from Kringelborg, Lolland, Denmark. Medieval. Near the tuyére the upper part of the slag is slightly oxidized and has exsolved numerous, magnetic skeleton crystals in a microcrystalline matrix. The skeleton crystals contain aluminium oxide and have compositions between magnetite and hercynite. Scale bar 0.1 mm.

	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	SO_3	Σ	G	F	C
Purification slags															
Hovden, Norway	18.5	67.7	0.3	–	0.2	1.2	9.1	1.2	0.4	0.2	0.3	99.1	17.4	2.03	15.4
Budolfi, Roskilde, Denmark	28.7	56.7	0.1	–	0.4	7.0	3.4	2.2	0.3	0.1	0.1	99.0	22.5	8.44	4.1
Slag inclusions in iron objects															
Hardingbukta, No. bloom	27.4	58.8	0.7	–	0.1	1.8	6.8	1.7	0.8	0.3	0.2	98.6	18.6	4.03	15.2
Dokkfløyvann, No. bar	20.4	63.6	1.2	–	1.1	3.0	7.0	1.1	1.1	0.3	0.2	99.0	18.5	2.91	6.8
Valler, Telemark, No. nail	24.1	55.3	6.1	–	1.2	2.5	7.9	0.9	0.7	0.3	0.4	99.4	19.2	3.05	9.6
Hinge, Jutland, Dk. bloom	19.3	56.3	6.5	0.6	8.2	4.3	1.8	1.6	0.9	0.1	0.4	100.0	12.0	10.7	4.5
Ravning Enge, Dk. horseshoe	27.9	55.4	1.5	–	4.2	3.9	3.4	1.2	0.9	0.1	0.5	99.0	15.4	8.21	7.2

Tabel 3. *Purification slags (step 3B) and slag inclusions in iron objects (steps 2A, 3A and 4A). SEM-EDAX analyses in weight%. No. = Norway, Dk. = Denmark.*

sum of FeO and MnO is still high, but it is important to note that manganese taken alone is low, below about 0.3%, and so is phosphorus, compared to production slags from the same region. Manganese is low because most was absorbed by the production slags, while phosphorus is low because essential parts have remained in solution in the solid iron product. It is also characteristic that the purification slag is relatively poor in titanium, and that barium is always absent. A mineral rarely met with in production slags, leucite, is rather common in purification slags (Fig. 7). It often forms beautiful eutectic intergrowths with wüstite. The upper part of the plano-convex slag may contain complex iron oxides (with Al, Ti, V, Mn) in the shape of cubic, mostly magnetic skeleton crystals (Fig. 8). The parameters G and F are similar to those of the production slags, and F is again different from region to region.

The lower part of Table 3 shows analytical data for slag *inclusions inside the different iron products*, Steps 2 A – 4 A (Table 1). It is easily seen that the composition of the inclusions is quite different from that of the purification slags, but rather similar to the production slags of Table 2. The slag inclusions are thus the remains from the site of production (Figs. 9-10). They are crucial for our understanding of production methods and location. The purification step evidently mainly serves to free the iron from excess production slag, without introducing new slags or altering the existing inclusions. The F-ratio for

Fig. 9. Polished section through a bloom from Hardingbukta, Møsstrond, Norway. Viking age? The iron (white) is penetrated by wüstite-glass slags. Scale bar 1 mm.

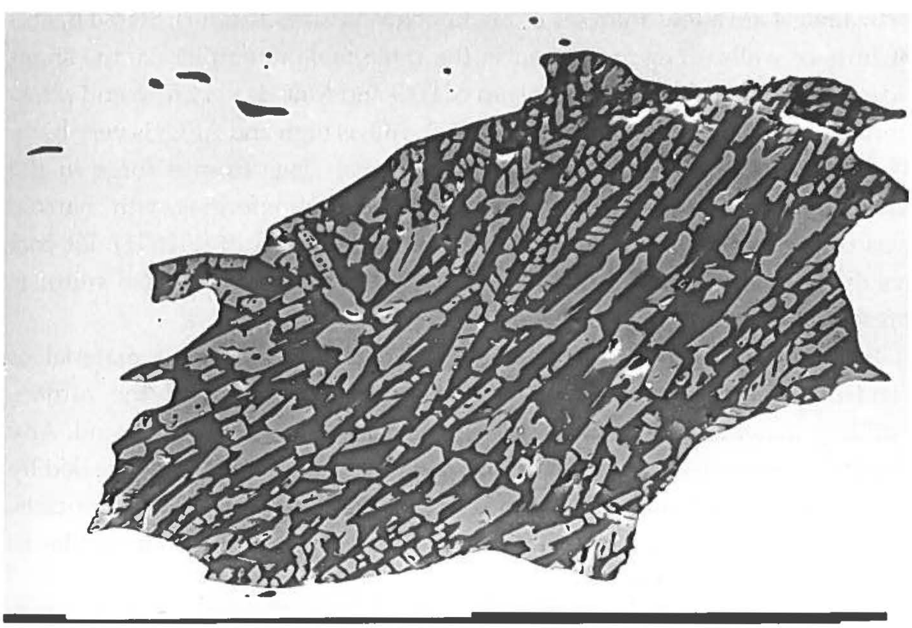

Fig. 10. Polished section through a Norwegian axe found at Højby, Sjælland, Denmark. Typical slag inclusion in steel. Broken fayalite laths (grey) in glass matrix. Scale bar 0.1 mm.

	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	SO_3	Σ	G	F	C
Manufacturing slags															
Nykøbing F. DK, charcoal	69.5	5.2	0.2	–	0.2	1.5	15.6	3.7	1.7	0.9	0.2	98.7	402	4.46	46.3
Nykøbing F. DK, pitcoal	57.4	4.3	0.1	–	0.5	1.9	29.1	2.7	0.7	1.3	1.8	99.8	702	1.97	30.2
Furnace walls															
Dokkfløyvann, Norway	61.0	7.5	0.1	–	0	4,5	18.0	3.3	2.1	0.9	0	97.4	367	3.39	13.6
Tystrup, Sjælland, DK	72.0	6.7	0.1	–	0.1	1.3	13.7	3.3	1.2	0.7	0.4	99.5	283	5.26	55.4
Beitostølen, No. blowpipe	67.9	7.8	0.4	–	0	4.4	12.0	3.1	2.1	1.6	0.2	99.5	263	5.66	15.4

Table 4. *Manufacturing slags (step 4B) and furnace walls. SEM-EDAX analyses in weight%.*

Norway is still between 2 and 5, and for Denmark above 8, and the Danish slags are rather rich in P_2O_5. Even some barium may still be preserved. The parameter G, 12-19 in the quoted cases, indicates that the iron samples are of a soft, ferritic nature. We shall later see that the G-value for slag inclusions in pearlitic or martensitic steel increases to 100 or more.

In Table 4 are a few analyses of manufacturing slags (cinder), Step 4 B, and of furnace walls. They are placed in the same table to emphasize the significant analytical similarities. The sum of FeO and MnO is very low, and phosphorus is low. The G-values are above 200, TiO_2 is high and Al_2O_3 is very high. The two manufacturing slags are experimental slags from a forge in the Medieval Center in Nykøbing Falster, Denmark, where forging with charcoal was compared to forging with pit coal (Danish, *nøddekul*) (Fig. 11). Pit coal results in an exceedingly Al_2O_3 – and TiO_2 – rich slag, while also sulfur is present on an unusually high level.

The analytical figures for the furnace walls are typical for material of Danish, Norwegian and Swedish origin. They suggest that the furnace building material was a mixture of feldspar-rich clay and quartz sand. Any organic construction material as *e.g.* straw or twigs would not be revealed by the analytical method, but can often be identified on the fossil imprints. Analyses of blow pipes, of which one is presented in Table 4, are similar to that of the furnace walls.

Furnace wall samples visibly blackened or fused by reaction with the slags inside the furnace will show slightly higher iron and manganese values, *e.g.* 12% FeO and 0.4% MnO. On the other hand, if parts of the furnace wall are

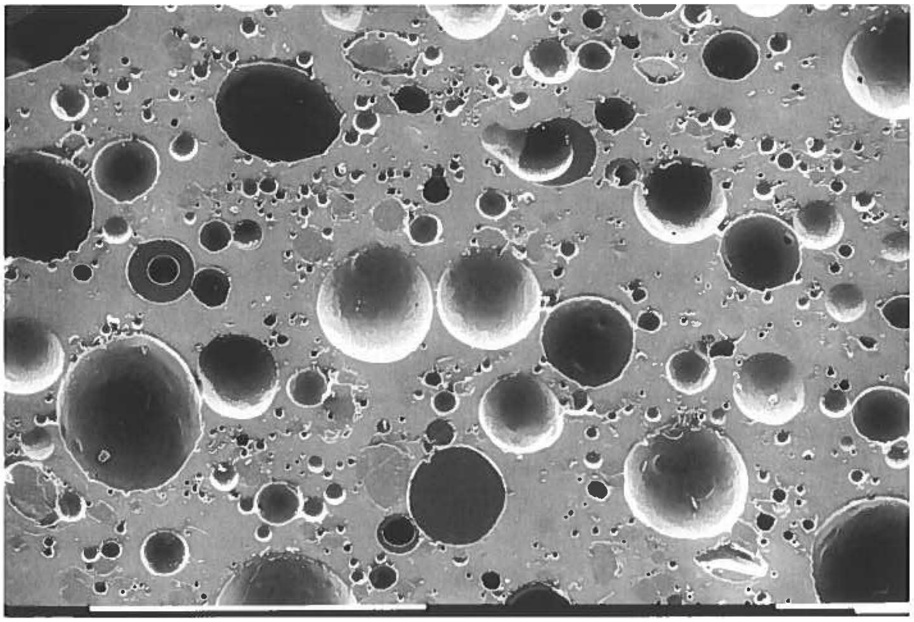

Fig. 11. Polished section through cinder produced in the hearth during the fourth step, manufacturing. The cinder is glassy, rich in SiO_2, highly porous (note the empty bubbles) and has a low specific gravity. Nykøbing Falster, Denmark, experimental. Scale bar 1 mm.

smelted down, ultimately to become a part of the production slag, it may be observed that the ratio F of the production slag is not likely to be changed very much by small additions of furnace wall.

Brief survey of Greenland excavations that have yielded slags and objects of iron

In the vast literature on excavations in Greenland there are not very many reports on iron and slags. All authors agree that iron has been a rare commodity. Tools and weapons which in Scandinavia were produced from iron and steel, were in Greenland usually made from bone, wood and antler.

Holm (1894) found two slag fragments, about 4 and 2 cm in diameter, in Qassiarsuk (Brattahlid) in the Igaliko Fjord. Bruun (1918) reported a small collection of slag fragments, probably from Timmiut. Nørlund (1929) found "many large and small lumps of slag ... among the rubbish ... outside the smithy" in Gardar (Igaliko). Nørlund and Stenberger (1934) found three slag fragments, 4-5 cm in diameter, during their excavations at Brattahlid, and Roussell (1936) found a heap of 32 small slag fragments inside the smithy at Sandnes (Kilaarsarfik). Nielsen (1930, 1934, 1936) examined all slag fragments known up to his time and concluded that they were evidence of iron extraction by the Norsemen, in both the Eastern and the Western Settlement. This opinion has for generations been cemented and the results quoted at various occasions in both scientific and popular papers, *e.g.* Gad (1965, 1967, 1986), Nørlund (1967), Krogh (1967, 1982), Erngaard (1973) and Vebæk (1963, 1992). The present publication will, however, throw a critical light on the supposition that the Norsemen ever produced iron from local bog ore occurrences.

Several excavations in the Eastern and Western settlements have yielded implements, tools and nails of iron. The total number of objects is, however, small and the variation is not impressive compared with what is known from contemporary sites in Norway and Denmark. Nørlund (1929:144) recorded no more than a table knife, a gimlet, a hook and a few coffin nails from the episcopal seat at Gardar. The better of the very few iron objects found at Brattahlid were figured by Nørlund and Stenberger (1934), a spear head, eight or nine fragmentary knives, a hasp for a casket, an awl, a pincet, and an ice-spur. More humble objects such as nails, rivets and two incomplete iron-rods were just mentioned. The authors had the impression that the Norsemen at Brattahlid "have had no great knowledge of the art of the smith", and "the spear head is a wretched piece of work". Roussell (1936) recorded similar results from Sandnes, describing two sickle-shaped iron knives, two chisels, two awls, nine fragments of iron knives and an arrow head. He was amazed "at the perceptible shortage of iron at the settlements".

Mathiassen (1936) found very little iron on Inuit settlements in the Julianehåb district. He reported two iron nails, a knife blade, a lump of iron and some iron pieces, and assumed that the site had been occupied till about 1650 AD. In addition three small whetstones of a hard red siliceous schist were referred to bartering with the Norse settlements. Roussell (1941) recorded a few nails, seven knife fragments, a pair of scissors, a hunting spear, two iron sickles and a smith's tongs from the scattered farms in the Western Settlements in Austmannadal.

Vebæk (1993) excavated a very early Norse farm near Narsaq and was able to date it to the *landnáma* period, just after 1000 AD. He found almost no iron, but there were many ornamented objects of bone, tusk and wood. There was one short iron nail – while there was a great number of wooden nails. There were two rather complete iron knives. There was one arrowhead of iron – but nearly a dozen arrowheads of caribou antler. Vebæk speculated that the settlers soon after the *landnáma* started to make arrowheads, tools and weapons from the bones of various animals and from antler, and that they had to do so because the iron supply was totally insufficient.

Further reports by Andreasen (1982), Vebæk (1992), Appelt *et al.* (1998) and others will be discussed in the following in association with the detailed treatment and analysis of the excavated objects. Finally, as a curiosity, it may be mentioned that in one of the earliest reports on the exploration of Greenland, Frobisher mentioned a box of iron nails which he came across when landing in southern Greenland in 1578. The box was discovered in an abandoned Norse settlement, but which one we will probably never find out, and the box has long since been lost (Fitzhugh and Olin 1993).

Detailed studies of slags and iron objects from Greenland

All objects examined in the present publication are mentioned in Table 5. They are arranged according to find locality, compare Fig. 1. The table records the museum numbers, dimensions and weights. The iron quality is very briefly described by stating the phosphorus content, the hardness and the structure. Usually five hardness indentations were made in each iron object and all are quoted, instead of just giving the average, since it helps to illustrate the heterogeneity of the iron (ASTM 1990).

Eastern Settlement, Abel's Farm, nr.167, file no. D 24/1991

During the excavation of the Norse farm nr. 167 in 1949 various objects of iron were found (Vebæk 1992). There were tools, such as knives, sickles, and keys, and there were raw material and scrap iron.

Three items are relatively large. No. 150, Table 5, is the major part of an iron

Nr.	Type	Dimensions, mm	Weight, g	%P in iron	Hardness	Note
The Eastern Settlement						
150	sickle	130 x 15 x 2.5	102	0.1-0.2	116-122-124-126-132	P-ferrite
154	bent nail	38 x 5 x 5	5	0.3-0.6	162-177-214-225-240	P-ferrite
164	nail	35 x 5 x 5	4	<0.1	97-102-109-109-119	Ferrite
170	knife	50 x 13 x 3	30	0-0.6	730-505-215-268-593	Martensite
171	knife	120 x 17 x 3	50	<0.1	143-147-151-151-154	Ferrite
172	fragment	65 x 22 x 12	70	0.3-0.6	110-149-160-166-174	P-ferrite
175	scrap	67 x 9 x 5	15	<0.1	103-111-115-116-121	Ferrite
177 b	nail	28 x 5 x 5	4	0.1	116-117-125-130-139	P-ferrite
228	plate	60 x 60 x 14	173	0-0.1	108-108-127-132-136	Ferrite
230	bar	121 x 14 x 12	126	<0.1	87-101-144-197-237	Ferrite-pearlite
245	fitting	112 x 20 x 3	50	<0.1	126-149-158-170-211	Ferrite-pearlite
275	bent nail	85 x 7 x 6	23	0.1	125-139-158-166-183	P-ferrite
The Western Settlement, Nipaatsoq, KNK 991 x						
7	scrap iron	10 x 1.5 x 1	0.3	0-0.6	227-237-264	P-ferrite
30	knife	74 x 15 x 14	40	0.1-0.27	annealed[a]	P-ferrite
34	rivet & plate	22 x 14 x 13	6	<0.1	too corroded	Ferrite
54	scrap iron	11 x 1.5 x 1	0.3	<0.1	110-121-148	Ferrite, cw
59	bar	80 x 9 x 8	22	0.07	annealed[a]	Ferrite
144	ring	28 x 2	4	<0.1	107-107-113-118-123	Ferrite, cw
159	nail	40 x 6 x 6	7	0-0.2	163-164-204-213-269	Ferrite-pearlite
162	arrowhead	45 x 29 x 2	6	0.1	283-285-296-301-313	Meteorite
181	rivet & plate	12 x 4 x 4	4	0	155-161-162-168-178	Ferrite-pearlite

182	plate for rivet	25 x 2	4	0.1	129-131-144-147-170	Ferrite, cw
183	knife fragment	26 x 10 x 3	3	0-0.15	139-169-283-364-388	Martensite
335	rivet & plate	36 x 22 x 16	10	0.15	too corroded	Ferrite-pearlite
377	nail	19 x 5 x 5	5	0.1	94-103-109-129-166	Ferrite-pearlite
417	knife	73 x 14 x 5	8	0	too corroded	Ferrite
618	knife	80 x 18 x 4	15	0.17	too corroded, cw	Ferrite-pearlite
1483	harness rings	app. 10 x 10	5	–	too corroded	No sections
The Western Settlement, The Farm beneath the Sand						
701	knife blade	41 x 8 x 2	3.4	0.1-0.2	113-137-169-176-179	Ferrite, wq
796	nail	27 x 5 x 4	3.7	0.4-1.0	192-222-238-257-283	P-ferrite, cw
992	knife blade?	42 x 4 x 1	2.7	0.1-0.3	147-148-152-153-162	P-ferrite
1025	knife blade	20 x 10 x 3	2.3	<0.1	157-175-186-223-282	Ferrite, wq
2302	nail	30 x 4 x 4	4.5	0.1-0.3	129-145-154-162-169	P-ferrite, cw
2511	knife blade	20 x 8 x 0.5	1.3	0	423-450-457-540-540	Martensite
880	slag	30 x 30 x 10	15	–	–	Purification slag
Sandnes	slag	52 x 30 x 15	15	–	–	Purification slag
Haabetz Colonie, 1721-1728 AD						
h 6130A	nail	86 x 7 x 7	43	0.14-0.60	134-179-185-186-220	P-ferrite Nbd
h 6130B	nail	117 x 6 x 6	24	0.17-0.63	166-168-192-202-203	P-ferrite
Hatherton Bay						
18 A	nail	25 x 4 x 3	2.5	0-0.55	122-141-161-163-177	P-ferrite
18 B	nail	55 x 3 x 3	4.0	0-0.36	124-156-172-177-179	P-ferrite
16	nail	22 x 6 x 6	10.2	0-0.5	156-163-169-202-210	P-ferrite
12	nail	26 x 7 x 5	7.5	0-0.6	213-215-220-220-232	P-ferrite

Objects from ancient Inuit settlements

Nr.	Type	Locality	Age	Dimensions, mm	Weight, g	%P in iron	Hardness	Note
L3.12673	knife	Nuulliit	1200-1400	25 x 22 x 3	3.0	<0.1	147-183-187-199	Ferr-pearlite
L3.12572	knife	Nuulliit	after 1500	81 x 17 x 3	11.0	0.1-0.3	195-209-224-272-274	P-ferrite, cw
Lc 297	arrow	Uummannaq	after 1650	39 x 21 x 2	3.5	0.13-0.34	205-224-247-287-327	P-ferrite, cw
L12.292	knife	Kangaamiut	1650-1750	153 x 19 x 6	38.5		222-224-270-276	P-ferrite, cw
It 93	nail	Egedesminde	1650-1750	43 x 6 x 5	7	0-0.24		
L6.3479	nail	Illorsuit	1700-1800	48 x 9 x 5	3.5	0-0.25	123-133-153	P-ferrite
L 8356	knife	Uummannaq	1650-1750	120 x 24 x 7	19	0.2-0.5	151-182-330-348-413	Ferrite-mart.
L 2856	ulo	Uummannaq	1650-1750	54 x 51 x 1.5	13	0-0.9	222-235-274-333-360	P-ferrite, cw
L6.3308	knife	Illorsuit	1700-1800	125 x 18 x 4	34	0-0.14	185-194-194-195-206	P-ferrite, cw
L6.3316	knife	Illorsuit	1700-1800	140 x 26 x 10	29	0-0.3	190-205-441-488-627	Ferrite-mart.
L12.439	adze	Kangaamiut	1600-1700	113 x 47 x 41	329	0-0.11	148-159-198-205-205	Ferr.-pearlite
Crowned F	ulo	Nuuk	ab. 1850	115 x 100 x 3	80	<0.1	197-215-227-232-322	Pearlite-ferr.

In addition, 20 **meteorite fragments** (see Table 13), and two objects produced from **meteoritic iron** (see Table 14) were examined.

Legend
a) annealed in conservation; cw) coldworked; Nbd) Neumann bands; wq) water quenched; mart.) martensite; p) phosphorus.

Table 5. *List of samples examined in this study. With dimensions, weights, phosphorus in iron (weight%) and hardnesses (HV 200 g).*

sickle (Fig. 12). The blade is 130 mm long, 14-15 mm wide and the cross section is 1-2.5 mm thick, thickest along the back (Vebæk 1992, Fig. 116[2]). The polished and etched specimens show that the sickle consists of well forged ferritic iron with a number of slag inclusions. The extensive forging required to create the slim blade has kneaded and broken the slag inclusions (Fig. 13). These are three-phased and contain about 25vol% wüstite and 75vol% of a fine-grained matrix of fayalite and glass. The ferrite is recrystallised to rather soft 100-150 μm equiaxed grains with some phosphorus in solid solution, averaging 0.15%P.

No. 228 is a massive, squarely cut iron slab of variable thickness, 14 mm at one corner tapering to 5 mm at the opposite end (Vebæk 1992, Fig. 119[4]). Its purpose is not obvious, perhaps it is some raw material (Figs. 14-15). The metallography shows a forged, rather heterogeneous structure, where fine-grained ferrite dominates, but ferrite-pearlite patches are also present. The average composition is 0.1% C and less than 0.1% P.

No. 172 is an irregular wedge-shaped fragment of 70 g (Vebæk 1992, Fig. 119[3]). The end cut shows a coarse structure of phosphorus-rich ferrite that locally displays intriguing ghost structures. The phosphorus was measured to between 0.3 and 0.6% in solid solution in the ferrite. The ferrite grain size ranges from 25 to 500 μm, the coarsest grains having the highest phosphorus content and the highest hardness, 165-175 HV. The ghost structure is characteristic for iron-phosphorus alloys that have been forged (Fig. 16). When the present alloy with an average phosphorus content of 0.45% was worked at

Fig. 12. An iron sickle, no. 150, from Abel's Farm, the Eastern Settlement. 13th century. Weight 102 g, length 13 cm.

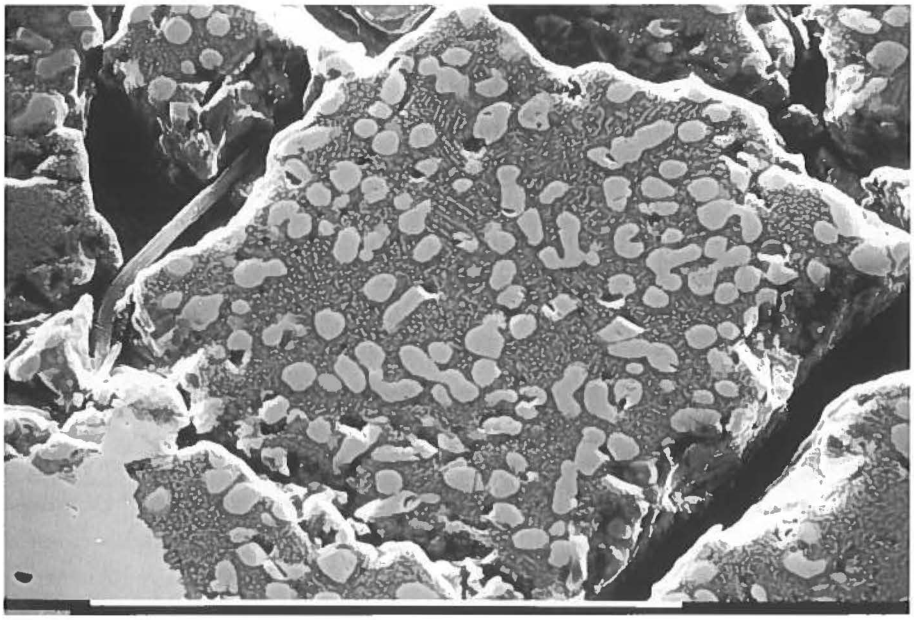

Fig. 13. Polished section through the sickle, Fig.12. Broken slag inclusion consisting of wüstite dendrites (white) in a fine matrix of fayalite and glass. Scale bar 0.1 mm.

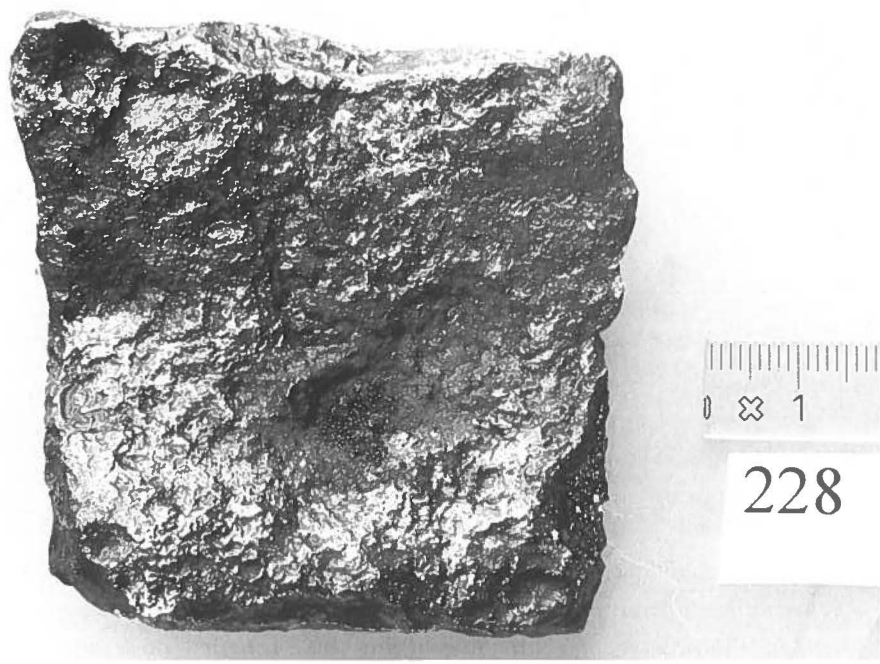

Fig. 14. A massive, squarely cut iron slab of 173 g, no. 228, from Abel's Farm, the Eastern Settlement.

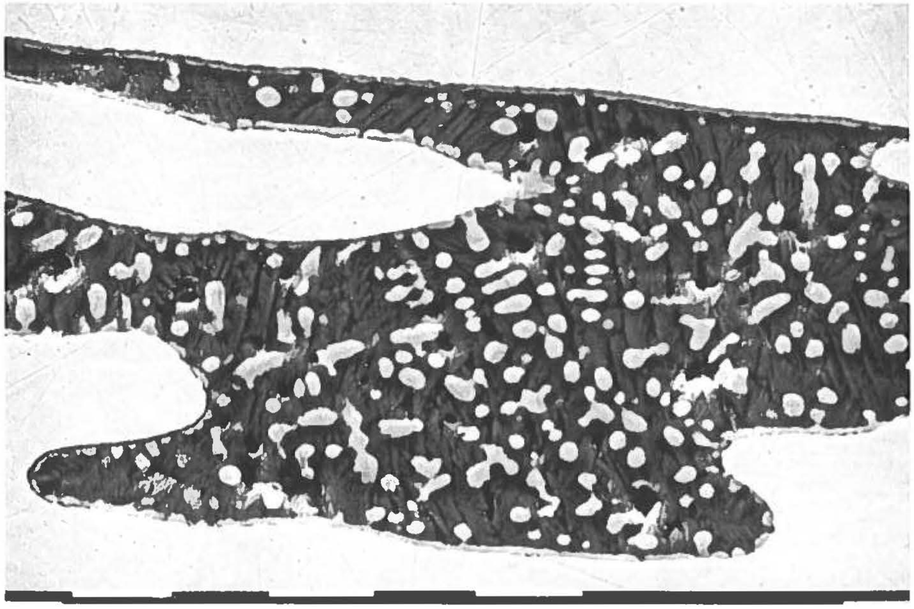

Fig. 15. Polished section through the iron slab, no. 228, Fig. 14. Slag inclusion with wüstite dendrites (white) in a fine grained matrix of fayalite and glass. This slag is surrounded by ferritic iron.Scale bar 0.01 mm.

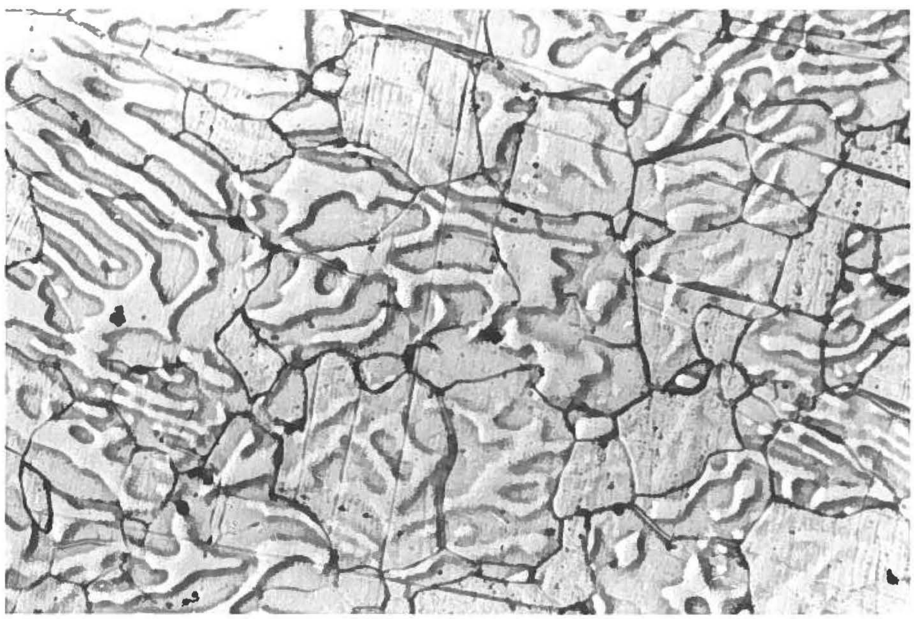

Fig. 16. Ghost structure in ancient, phosphorus-rich iron. It is an unequilibrated structure, caused by air cooling from the $\alpha+\gamma$ field at about 1000°C in the iron-phosphorus diagram in Fig. 17. The average content of phosphorus in the picture is 0.35%, and there is no carbon. Snorup iron bar 201. Side length 0.4 mm. Courtesy Lene Høst-Madsen.

forging temperatures, *e.g.* at 1050°C, it became two-phased: It split up in about 50% ferrite with 0.6% P and 50% austenite with 0.3% P in solid solution (Fig. 17). The material recrystallized repeatedly under the forging conditions, but finally upon cooling the phases became unstable and partly transformed to others. The phosphorus-rich ferrite quickly attained some grain growth, while the phosphorus-poor austenite slightly later transformed to ferrite. This new ferrite was, however different from the high temperature form because of its lower phosphorus content, and it is significantly softer. The phosphorus-rich ferrite is recognizable on its large grain size, by being difficult to etch with Nital, by developing microscopic etch-pits (Fig. 18), and by having hardnesses in excess of about 165 HV. The two ferrite types became intergrown upon cooling, the details being determined by starting temperature, phosphorus content and cooling rate. Upon etching the P-rich parts become less attacked than the P-poor parts, and two sets of grain boundaries may be distinguished, especially when alternately focusing and defocusing the microscope. The microstructure is quite characteristic for ancient iron objects, but often overlooked. Small additions, 0.1-0.2%, of carbon may initiate ternary structures with cementite, or even pearlite precipitating. This is, however, not the case here where carbon is below 0.1%.

The slag inclusions of the three samples are presented in Table 6 together with analyses of slag inclusions in a nail from Valler, Norway, and a horse-

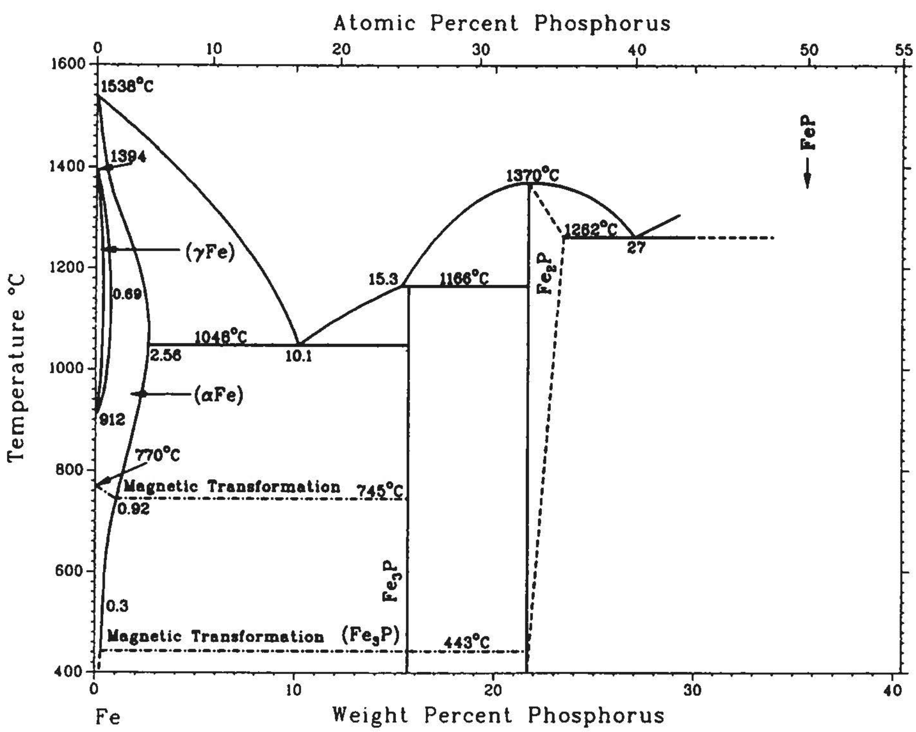

Fig. 17. The iron-phosphorus equilibrium diagram (American Society of Metals).

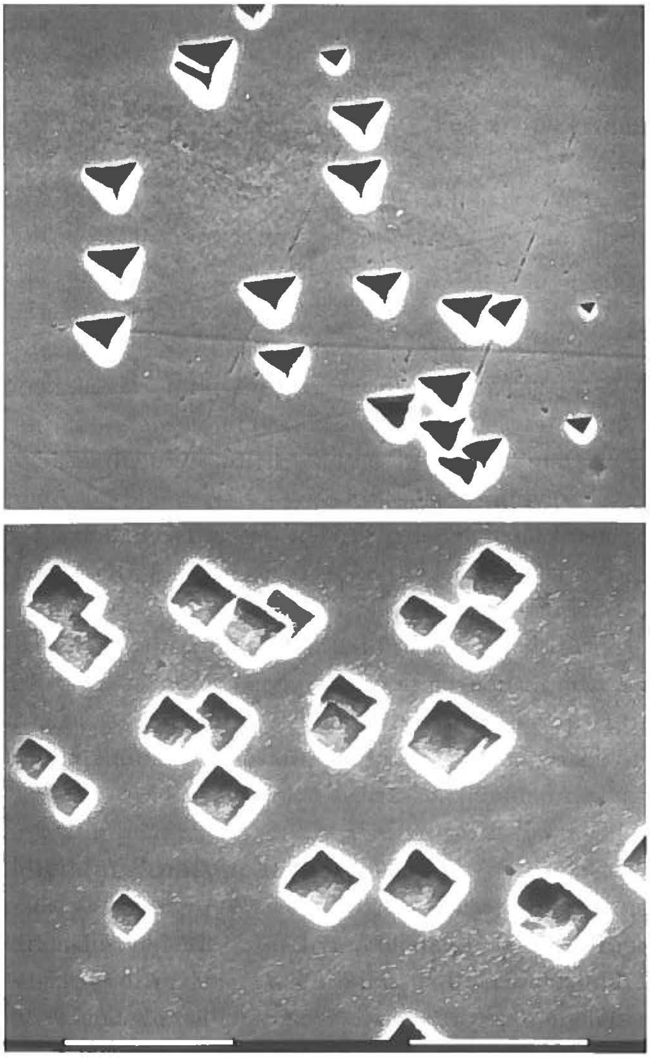

Fig. 18. Polished and etched sections through experimental iron-0.8% phosphorus alloy displaying geometric etch figures in two differently oriented ferrite grains. Within the same grain the etch pits are uniformly oriented. Scale bar 0.01 mm.

	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	SO_3	Σ	G	F	%P in iron
Sickle 150	22.5	56.8	4.8	–	1.5	3.2	5.8	1.8	0.9	0.4	0.5	98.2	18.4	3.88	0.1-0.2
Plate 228	32.4	39.9	1.4	–	4.2	5.4	9.8	2.4	1.9	0.5	0.5	98.4	43.2	3.31	0-0.1
Wedge 172	26.7	36.1	11.5	–	4.4	4.5	9.5	3.8	1.6	0.5	0.4	99.0	37.4	2.81	0.3-0.6
Valler nail[a]	39.4	31.8	0.4	–	2.4	6.7	11.3	2.9	2.6	1.1	0.3	98.9	67.9	3.49	0.1-0.2
Sjørring[b]	19.0	51.7	12.4	1.3	9.3	2.3	1.5	0.8	0.9	0.1	0.9	99.3	7.34	12.7	0.3-0.6

a) a 5.7 g nail excavated at Valler, Eidanger, Telemark, Norway, mrk. C 28429 h2, HV 200 g: 172-176-186-223-274

b) a 4 g horseshoe nail excavated at Sjørring Volde, Jutland, Denmark; mrk.2, HV 200 g: 139-155-160-178-196.

Table 6. *Eastern Settlement, compared with Norwegian and Danish objects. Analysis of slag inclusions, SEM-EDAX in weight%.*

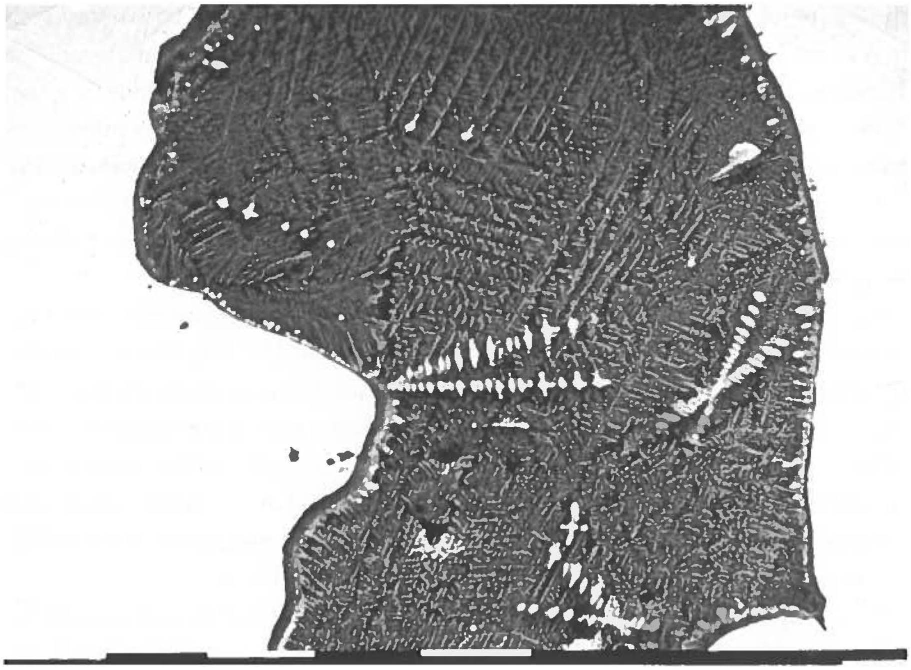

Fig. 19. Polished section through the wedge shaped fragment, no. 172, from the Eastern Settlement. Slag inclusion with fine wüstite dendrites (white) in an ultrafine matrix of fayalite and glass. Scale bar 0.01 mm.

shoe nail from Sjørring Volde, Denmark. The foreign material, which is also medieval, is included in an attempt to identify the origin of the Greenland irons. The slag inclusions are regarded as a mirror of the ores used on the production site. Although they are diluted by ashes from the charcoal, and to a very minor extent by additions from the furnace wall, the slags have preserved important characteristics of their production site. Within a given region, such as Southern Norway, the bog iron ores and ochres can be shown to be rather similar – and different from *e.g.* bog iron ores from Jutland.

Most important is the ratio F = SiO_2/Al_2O_3. It is 2.81-3.88 for the three Greenland irons, 3.49 for the Norwegian and 12.7 for the Danish iron. Also the ratio C = SiO_2/CaO and the titanium content are compatible with a Norwegian origin, compare Table 3. Other ratios or absolute values such as MnO and P_2O_5 in the slag, and phosphorus in the iron, are of secondary importance, since bog iron ores locally may vary quite considerably in their manganese and phosphorus content. So it is provisionally concluded that the three samples 150, 228 and 172 may be best explained as produced from Norwegian bog iron ores.

The next two items, <u>no. 170 and 171</u> (Table 5) are fragments of two knives. The cross section of <u>170</u> is very heterogeneous. The surface is fine-grained, martensitic and attains hardnesses of 730 HV. The interior consists of phosphoferrite with indistinct grain boundaries, many microscopic etch pits (Fig. 20 A), and hardnesses of 215-240. The presence of Neumann bands locally in the ferrite suggests some coldwork, possibly in connection with finishing the blade. The maximum phosphorus content was measured to 0.6%, while the P-content of the martensitic surface zones was below the detection limit of 0.1% P. The quality of the knife was excellent. However, after some further sharpening on a whetstone the hard martensitic surface layers would have entirely disappeared.

The other knife fragment, no. 171 of 3 g, displays homogeneous, very fine grained ferrite with a hardness range of only 143-154 HV. The ferrite is of the serrated, irregular type , suggesting water quenching of an austenite with only 0.1% C and <0.1% P. Apparently the blacksmith water-quenched his knife in the traditional way, unaware of the insufficient carbon content and the ensuing poor result. An ancient knife produced from proper steel and hardened and tempered correctly would easily reach hardnesses of 550-900, so the present knife fragment is certainly of inferior quality.

For comparison Table 7 shows the average composition of slag inclusions in the Greenland knives and in a Norwegian nail. The important ratios F are very similar, while the G-ratios vary somewhat. The indication is a Norwegian origin for the knives, although not exactly from Valler in Eidanger.

The following six items are nails, fittings and small fragments of uncertain

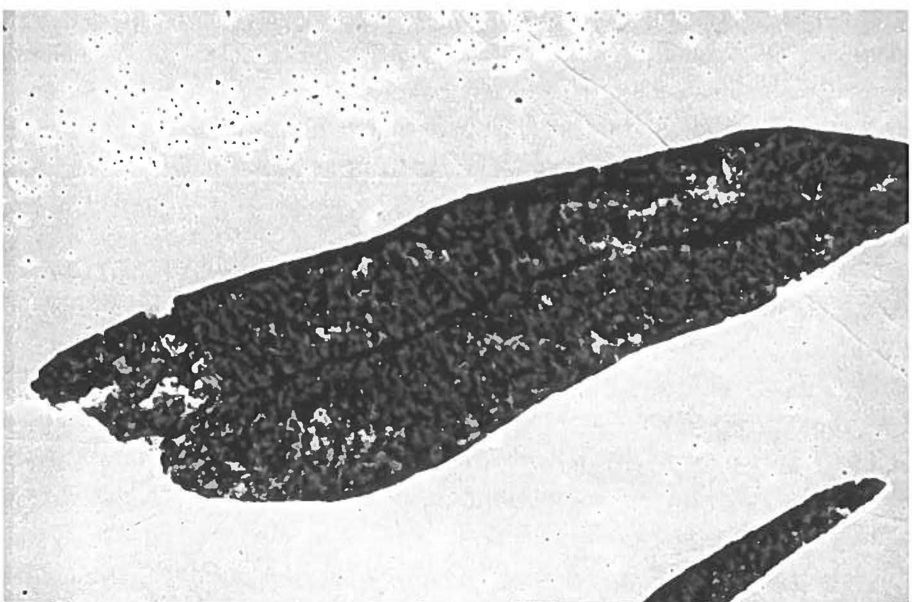

Fig. 20 A. Polished section through the knife, no. 170, Abel's Farm. The slag inclusion is very rich in phosphorus, 15% P_2O_5, and the ferrite has developed etch pits by natural corrosion. The ferrite has here 0.6% P in solid solution. Scale bar 0.01 mm.

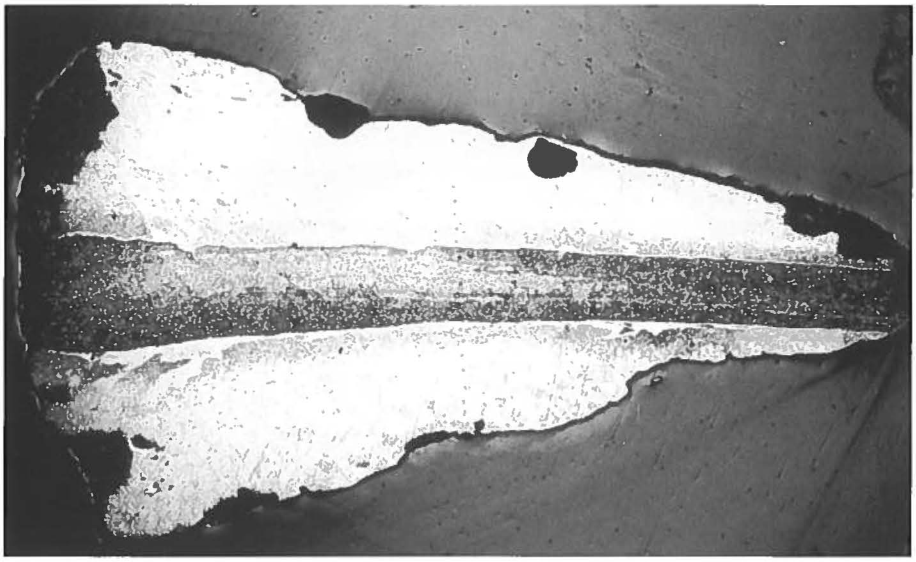

Fig. 20 B. Polished and etched section through a knife from Aggersborg, Denmark, 980 AD. The central section is martensitic with hardnesses up to 400 HV, while the ferritic zones on both sides are softer, 119-148 HV. Many Norwegian knives were produced by forging low and high carbon irons together. Side length 10 mm.

application, perhaps just scrap iron. The three nails, no. 154, 177 b and 275, (Table 5) have square sections (Fig. 21). They are ferritic and rich in phosphorus containing zones. Nr.154 has ferrite grains with up to 0.6% P. It displays indistinct grain boundaries, because etching is difficult, and has hardnesses up to 240 HV. Some grains have exsolved fine phosphide needles that resemble nitrides. Others have numerous microscopic etch pits. The phosphorus level of no. 177 b and 275 is rather low. No. 275 shows elongate ferrite grains from coldwork. The slag inclusions have been disturbed and sheared and the ferritic matrix has acquired a high hardness due to coldwork.

The scrap iron, no. 175, was too corroded for a meaningful analysis. The iron appears to have been of a ferritic nature with patches of pearlite and

	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	SO_3	Σ	G	F	%P in iron
Knife 170	30.6	32.6	0.9	–	9.9	11.0	6.8	3.1	2.5	0.5	0.4	98.3	54.0	4.50	0-0.6
Knife 171	24.7	53.2	8.7	tr.	0.8	2.7	6.5	1.6	0.9	0.4	0.2	99.7	18.6	3.80	<0.1
Valler nail[a]	28.7	43.9	0.5	–	9.0	4.2	7.0	1.7	2.2	0,7	1.0	98.9	28.5	4.10	0.1

a) a 4.9 g nail excavated at Valler, Eidanger, Telemark, Norway. Mrk. C 28429 h5. HV 200 g: 208-220-231-232-268.
tr. trace

Table 7. *Eastern Settlement, compared to Norwegian nail. SEM-EDAX analysis of slag inclusions, weight%.*

Fig. 21. A bent nail covered with corrosion products, before cleaning. No. 154 from the Eastern Settlement. 13th century. Scale in mm.

cementite, possibly with about 0.15% C and <0.1% P. The corrosion products are interesting and will be treated later. The fitting, no. 245 (Figs. 22-24) is ferritic-pearlitic, displaying Widmanstätten structures with 0.2-0.5% C. Finally, the nail, no. 164, is of a soft ferritic nature, low in phosphorus (Fig. 25).

The analytical data of the slag inclusions may be compared with those of three Norwegian samples, the last three lines of Table 8. The first three nails compare well with the nail from Hovden, Telemark, while the fitting and the nail 164 are better compared to the steel bars from Prestegaarden and Brattaker, Oppland. Comparison with Danish and Swedish material did not suc-

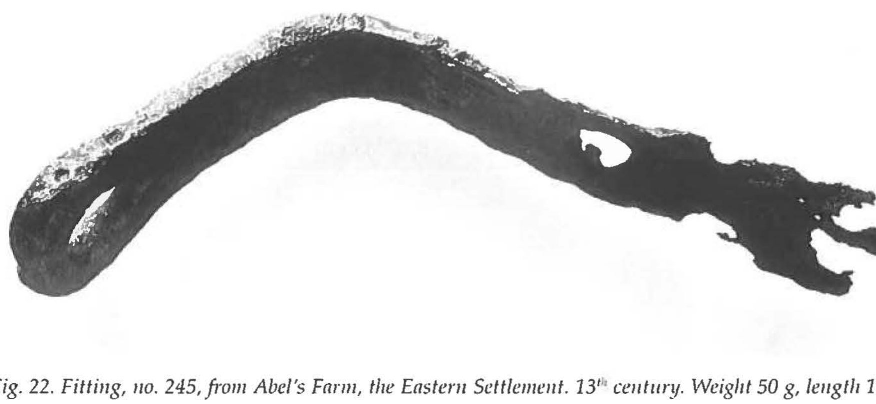

Fig. 22. Fitting, no. 245, from Abel's Farm, the Eastern Settlement. 13th century. Weight 50 g, length 112 mm.

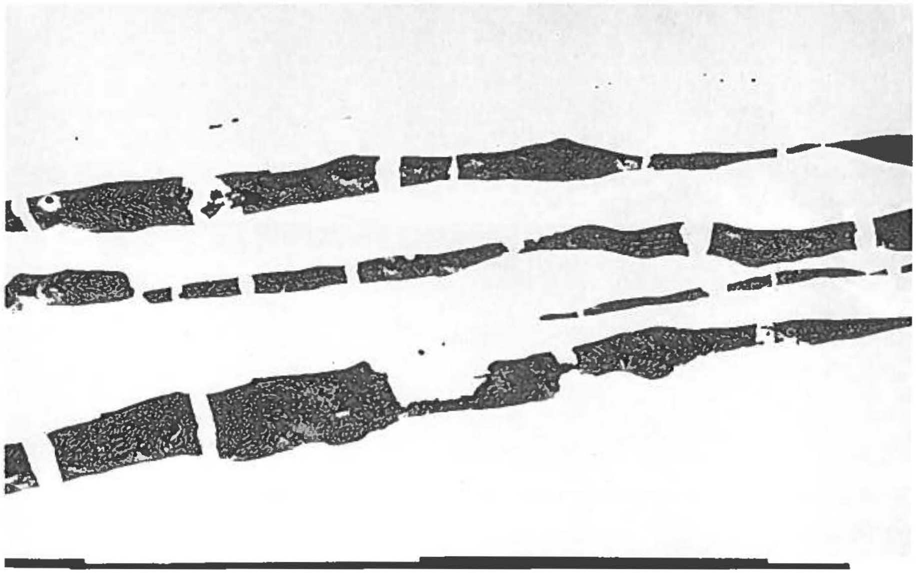

Fig. 23. Polished section through the fitting, Fig. 22. The slags have been deformed and broken during extensive and repeated hot forging. Scale bar 0.1 mm.

ceed in any pairings, so it is concluded that the samples may all be of Norwegian origin.

The last item from the Eastern Settlement, no. 230, is a 126 g slender iron bar, deeply marked by beautiful corrosion pits (Vebæk 1992, Fig. 119[1]). It is 121 mm long, with a slightly varying cross section of 12-14 mm (Figs. 26-27).

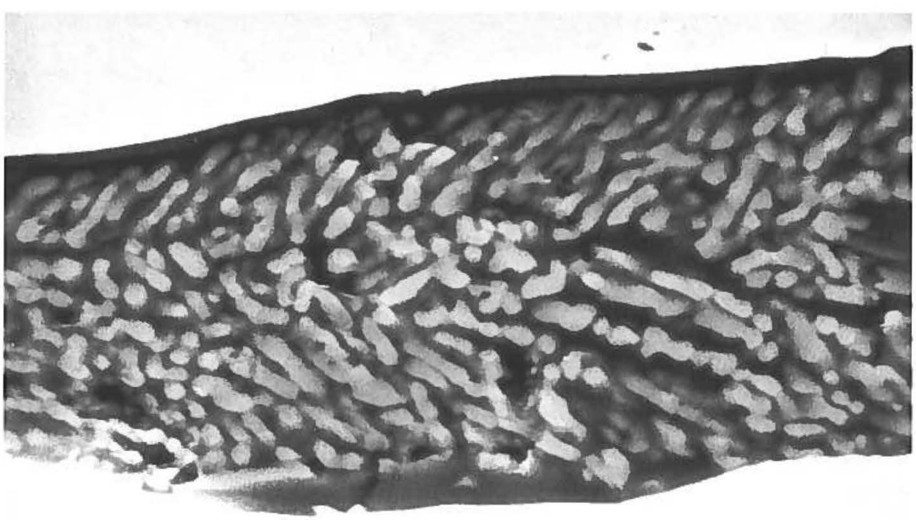

Fig. 24. Magnification of a broken slag from Fig. 23. The slag is an extremely fine mixture of fayalite crystals (white) in a glassy matrix. Scale bar 0.01 mm.

Fig. 25. Corroded nail with square section, no. 164, from the Eastern Settlement. 13th century. Length 35 mm. Weight 4 g.

	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	V_2O_3	SO_3	Σ	G	F	%P in iron
Nail 154	14.2	66.9	4.4	-	1.2	5.4	3.9	0.9	1.5	0.3	0.1	0.3	99.1	16.1	3.64	0.3-0.6
Nail 177 b	16.9	65.0	5.0	-	2.1	2.7	4.4	0.9	1.3	0.2	0.1	0.3	98.9	12.9	3.84	0.1
Nail 275	19.1	66.0	2.5	-	0.4	1.8	6.6	0.2	1.6	0.3	-	0.6	99.1	14.7	2.89	0.1
Fitting 245	30.8	29.8	21.8	0.4	0.2	3.8	7.6	2.2	1.7	0.4	-	0.1	98.8	29.5	4.05	<0.1
Nail 164	37.4	27.4	7.2	-	0.5	7.0	13.4	1.6	2.5	0.6	-	0.2	97.8	69.8	2.79	<0.1
Hov-den[a]	17.0	67.0	3.3	-	0.3	3.1	4.5	1.1	2.1	0.2	-	0.2	98.8	15.1	3.78	0.1
Preste-går-den[b]	46.0	18.0	11.0	-	0.4	3.8	14.2	3.2	2.2	0.8	-	0.4	100	79.0	3.24	<0.1
Bratt-aker[c]	50.7	13.0	19.3	-	-	2.2	10.9	1.9	0.9	0.8	-	0.3	100	48.8	4.65	<0.1

a) a 1.1 g nail excavated at Hovden, Telemark, Norway. Mrk. Hovden 5, C 34524 a.

b) a 16 g steel bar from a hoard at Prestegården, Gran, Oppland. Mrk. C 3454. HV 200 g: 110-114-135-216-245.

c) a 160 g steel bar from a hoard at Brattaker, Øyer, Oppland. Mrk.C 23191. HV 200 g: 196-207-210-238-245.

Table 8. *Eastern Settlement, compared to Norwegian objects. SEM-EDAX analysis of slag inclusions, weight%.*

Fig. 26. Iron bar of 126 g, no. 230, from Abel's Farm, the Eastern Settlement. Forged from fined iron, produced in Bergslagen, Central Sweden. The irregular surface is due to corrosion through 700 years. Length 120 mm.

The overall shape and size would probably correspond well to the ancient Norwegian term *teintjarn*. The polished and etched section displays heterogeneous structures where ferritic parts of grain size 25-100 μm alternate with Widmanstätten structures and even dense pearlitic zones. The carbon content varies from about 0.05 to 0.6%. Phosphorus is below the detection limit of 0.1%. For comparison Table 9 includes the analytical data of slag inclusions in a fined iron bar excavated at the early blast furnace site at Lapphyttan, Sweden (Magnusson 1985; Björkenstam and Fornander 1985). The data of the

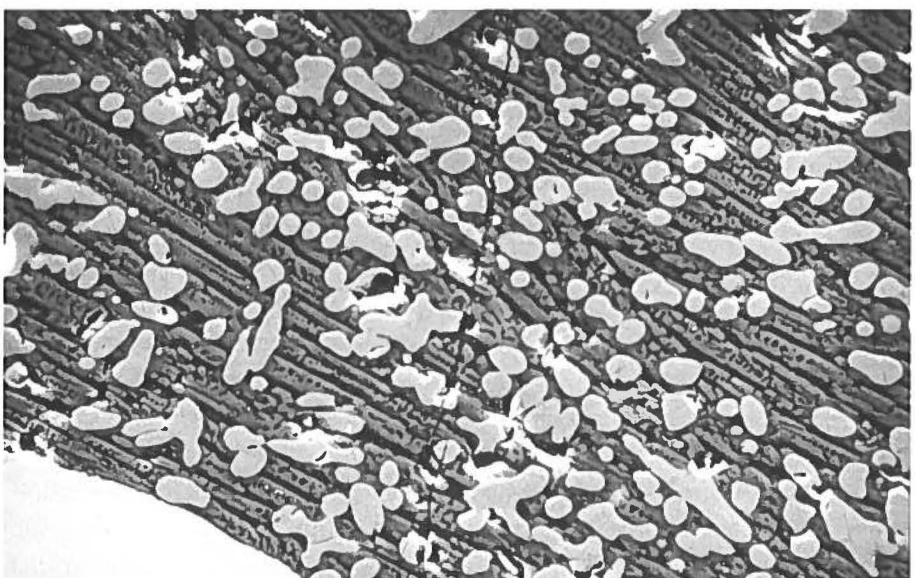

Fig. 27. Polished section through the fined bar, Fig. 26. Distinct wüstite dendrites and well developed fayalite laths in a glass matrix. The slag is very low in phosphorus, <0.5% P_2O_5. Scale bar 0.1 mm.

	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	SO_3	Σ	G	F	%P in iron
Iron bar 230	38.2	42.9	1.7	–	0.3	7.2	4.7	2.6	1.1	0.3	0.3	99.3	34.5	8.13	<0.1
Iron bar 1614[a]	38.6	45.4	1.5	–	0.1	3.5	6.0	1.7	1.1	0.2	0.8	98.9	26.0	6.43	<0.1

a) a slender, fined iron bar of 22 g from Lapphyttan, Bergslagen, Sweden. Mrk. L 1614. HV 200 g: 102-103-110-114-120.

Table 9. *Eastern Settlement. An iron bar compared to a Swedish iron bar. SEM-EDAX analysis of slag inclusions, weight%.*

Greenland bar and the Swedish bar correspond sufficiently well to suggest that the Greenland bar was produced by fining pig iron in Bergslagen, Central Sweden. The blast furnace method was introduced around 1150 AD, and Sweden dominated for several centuries the North European iron market with this iron quality, the socalled osmunds (Buchwald 1999). In the present context the fined Swedish iron may be recognized on F-ratios of 5.0- 8.5, low P_2O_5-content of the slag, and low P-content in the iron phase. It may be supposed that iron bars from Bergslagen were carried along the trade routes through Herjedalen and the mountainous border zone to Trondheim, from where it could be shipped to Greenland.

The twelve iron samples of the Eastern Settlement may thus be divided into ten that probably are bloomery iron of Norwegian origin, one that is of Swedish fined iron, and one (no. 175) that could not be examined properly because of its advanced state of corrosion. The iron samples are probably all from the 13th century according to Vebæk's (1992) datings.

Western Settlement, Nipaatsoq, V 54 77-2, file no. KNK 991

The isolated Norse house ruin, Nipaatsoq no. 54, is located inland, about 4 km by foot from the south coast of Ameralik (Ameralla, Lysefjord). A full excavation report has not yet appeared, but preliminary reports have been published by Meldgaard (1977) and Andreasen (1980, 1982). In addition, the author has drawn upon unpublished data of Jette Arneborg, The Greenland Research Centre. The house was poor in iron objects, containing mainly fragments of knives, rivets and nails. In addition there were four arrowheads, three of bone and one of iron. Fifteen of the better preserved iron objects are listed in Table 5, and of these six were good enough for slag inclusion studies. One of the six, no. 162 turned very surprisingly out to be an arrowhead made from meteoritic iron. It is so far the only meteoritic item ever identified in a Norse settlement.

The other five are presented in Table 10 where they are arranged after decreasing amount of FeO in the slag inclusions. No. 377 is a heavily corroded nail, encrusted in goethite-bound soil. Upon sectioning a sound, uncorroded nucleus became available. It is heterogeneous and characteristic of ancient bloomery iron, with alternating ferritic and ferritic-pearlitic zones (Figs. 28-32). The hardness is 94-109 in the ferritic parts, but increases to 166 in a zone of fine-grained ferrite-pearlite with about 0.3% C. Phosphorus is estimated to be about 0.1% on the average, but locally there are more P-rich zones. Many ferrite grains have here become supersaturated with respect to phosphorus and have upon cooling exsolved an abundancy of fine phosphide needles (Fig. 30). Ferrite grains with needles tend to be some ten points softer than similar grains where phosphorus is still in solid solution. Locally there are zones of ternary Fe-C-P structures of ferrite with double ghostlines, "phosphorus-eyes" and pearlite.

No. 144 is a broken ring plate from a boat rivet (Figs. 33-35). It is about 28 mm in outer diameter, and has a hole to fit a nail/rivet 8-9 mm in diameter. The metallographical section displays a slag-rich, fully ferritic structure. The ferrite is pure and equiaxial, but slightly coldworked as proven by the many grains displaying Neumann bands. The hardness is correspondingly somewhat higher, 107-123, than that of pure, annealed ferrite. The slag inclusions are three-phased, displaying wüstite dendrites in a fayalite-glass matrix.

The slag compositions of no. 377 and 144 are rather well duplicated by those of the nail from Dokkfløyvatn, Norway (Table 10). There is little doubt

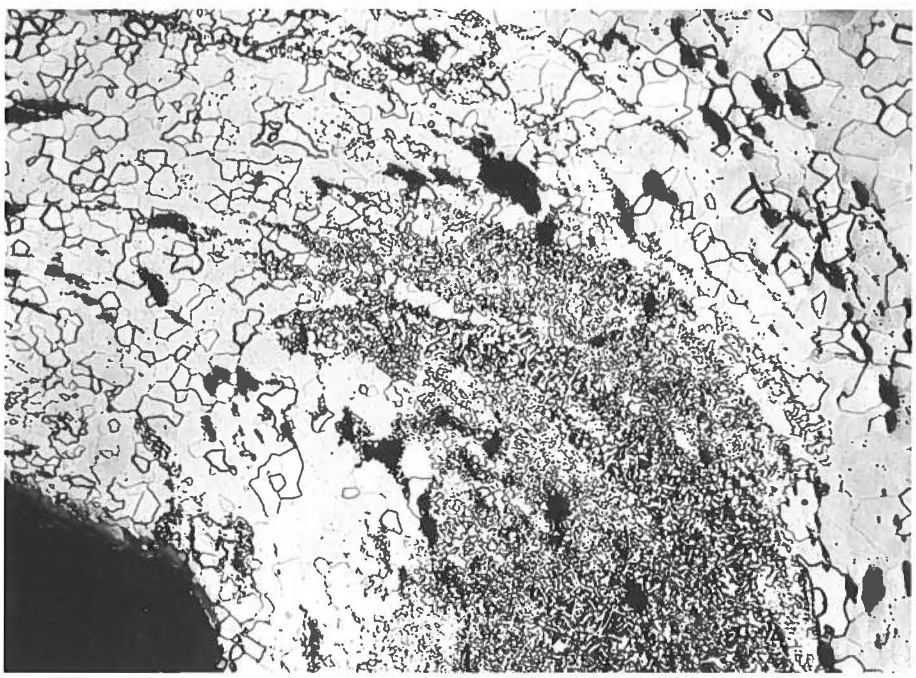

Fig. 28. Polished and etched section through the nail no. 377 from Nipaatsoq, the Western Settlement. The picture shows the region where shaft and head merge. Heterogeneous structure with ferrite grains in relief and fine grained ferrite-pearlite zones. Side length 5 mm.

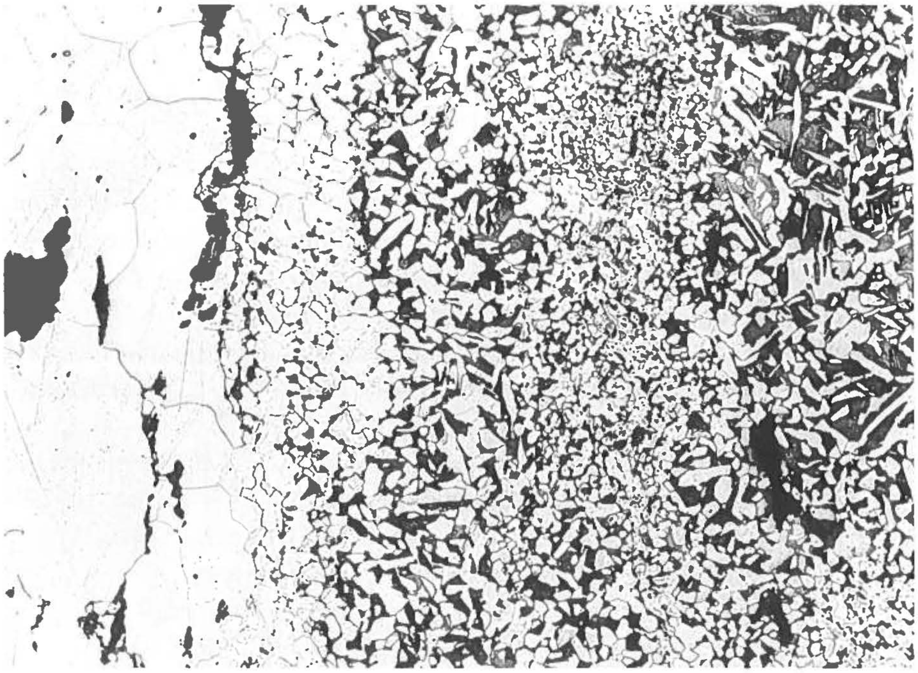

Fig. 29. Polished and etched section through the shaft of nail no. 377, Nipaatsoq. Heterogeneous structure, from left coarse ferrite, phosphoferrite with ghost structure, ferrite-pearlite, ternary Fe-P-C structure and medium grained Widmanstätten structure. Side length 1.7 mm.

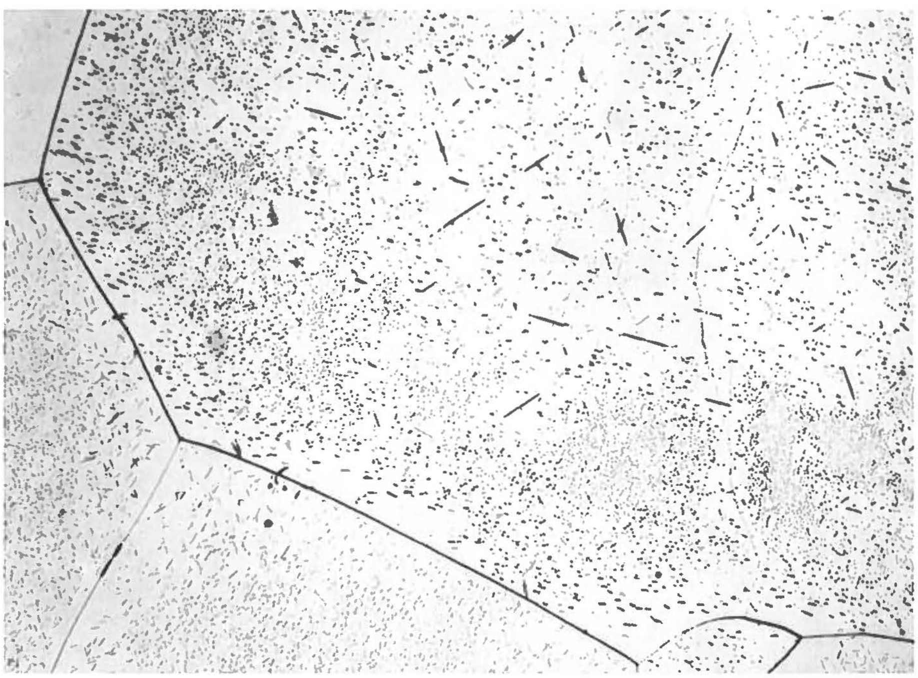

Fig. 30. Polished and etched section through the shaft of nail no. 377, Nipaatsoq. Zone with coarse, phosphorus rich ferrite grains. Surplus of phosphorus has precipitated as iron phosphide needles and as grain boundary coatings. Oil immersion. Side length 0.2 mm.

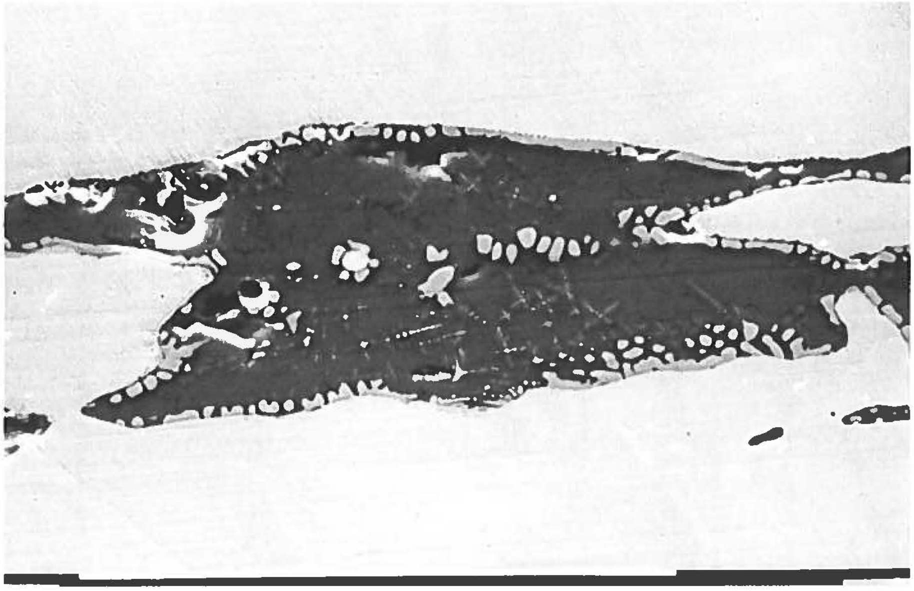

Fig. 31. Polished section through nail no. 377 from Nipaatsoq. Slag inclusion with wüstite nucleated along the walls. Glassy interior with incipient crystallization. Scale bar 0.1 mm.

that the two Greenland samples could have been made from ores such as those available at Dokkfløyvatn.

No. 183 is a small fragment of a corroded knife blade (Figs. 36-39). The width of the blade was originally about 10 mm and the thickness at the neck a

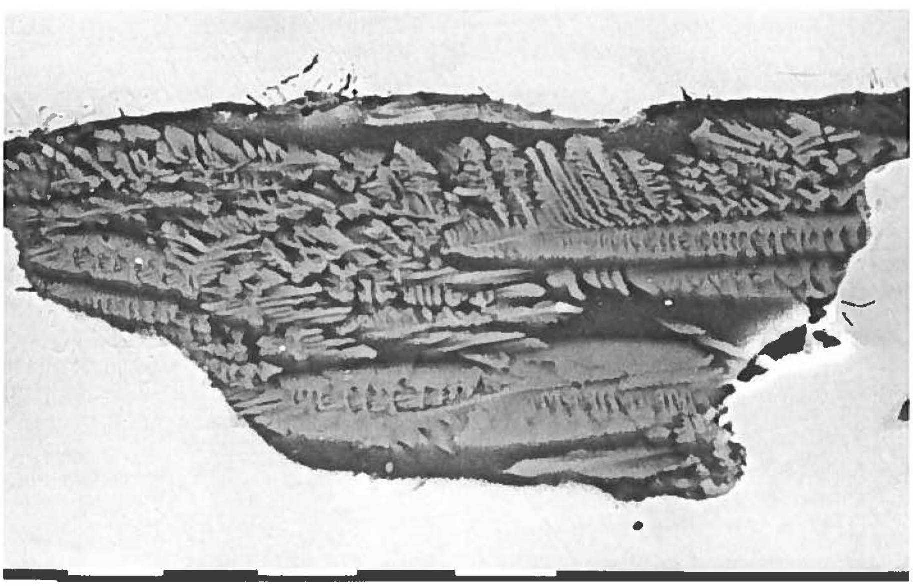

Fig. 32. Polished section through nail no. 377, Nipaatsoq. The slag inclusion displays feathery fayalite dendrites in glass. The slags in the nail are as different as are the metallic structures, compare Figs. 28-32. Scale bar 0.01 mm.

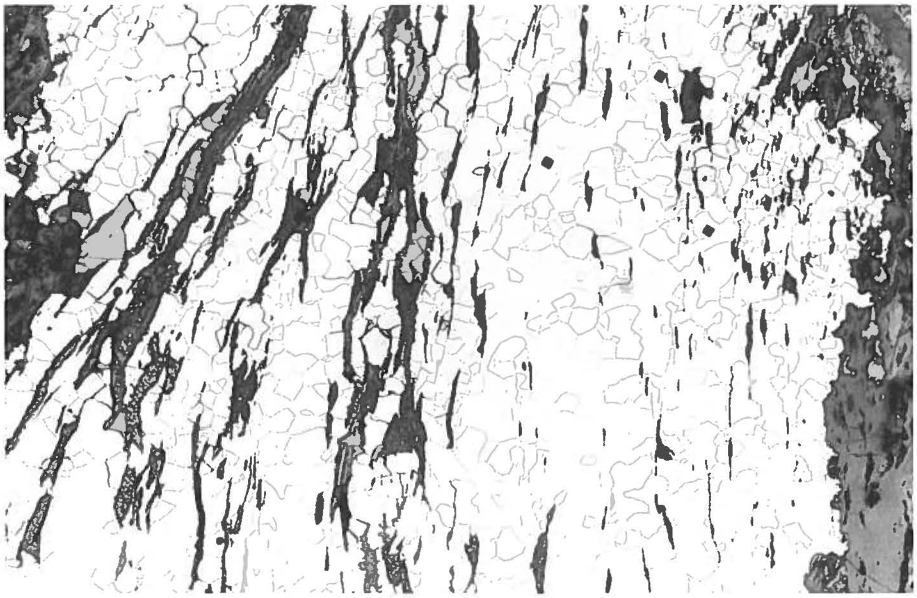

Fig. 33. Polished and etched section through a ring plate, no. 144, Nipaatsoq. Uniform equiaxial ferrite grains with numerous slags. Side length 2 mm.

maximum of 3 mm. The cross section reveals that it is composite, having a wedge-shaped iron nucleus surrounded by layers of steel. The nucleus is forge-welded and the weldings are of good quality, only revealed by strings of fine slags. A particularly large slag, situated at the center of Fig. 39, is

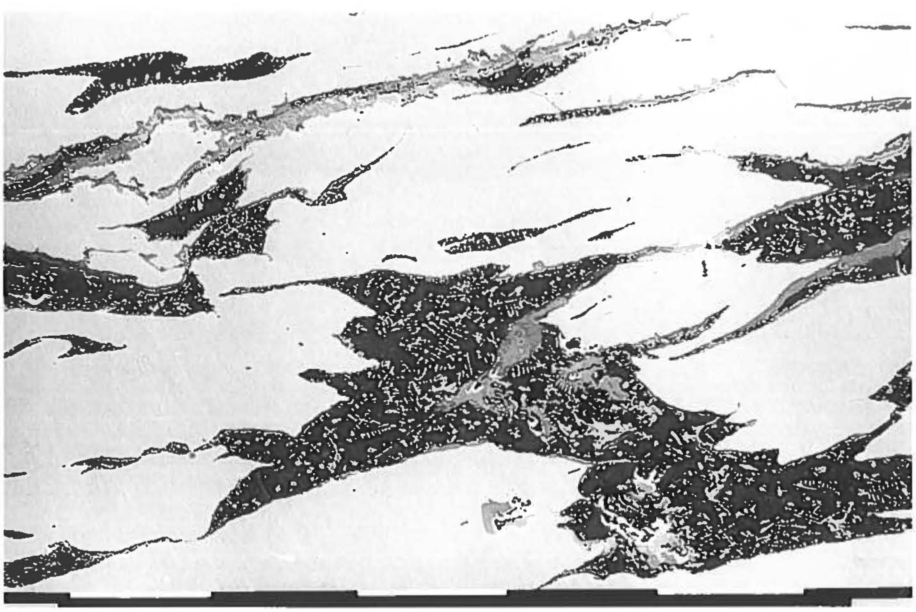

Fig. 34. Polished section through the ring plate no. 144, Nipaatsoq. Slag rich ferrite structure and numerous corrosion filled cracks (light grey). Scale bar 0.1 mm.

Fig. 35. Enlarged part of the central slag in Fig. 34. Wüstite dendrites in dense fayalite-glass matrix. Above uncorroded iron, to the right akaganeite replacing the iron. Scale bar 0.01 mm.

	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	V_2O_3	SO_3	Σ	G	F	%P in iron
Nail 377	28.3	51.7	1.4	-	1.6	4.1	8.0	1.9	0.7	0.3	0.1	0.4	98.5	26.9	3.54	0.1
Ring 144	30.2	50.2	1.8	-	0.6	4.5	7.9	2.1	1.3	0.3	-	0.3	99.2	30.0	3.82	<0.1
Knife 183	36.5	34.1	6.4	0.3	1.1	7.1	9.1	2.3	1.5	0.6	-	0.3	99.3	47.8	4.01	0-0.2
Rivet 181	52.2	13.4	2.7	-	0	8.2	15.2	3.6	2.4	0.8	0.1	0	98.6	182	3.43	0
Nail 159	43.4	10.7	0.5	-	2.0	24.4	8.6	3.3	5.5	0.3	-	0.1	98.8	316	5.05	0-0.2
Nail, Dokk[a]	28.0	53.5	1.7	-	2.3	3.8	6.5	2.3	0.8	0.1	-	0.4	99.4	23.4	4.31	-
Steel bar[b]	50.6	7.5	2.6	-	0	14.7	15.4	3.8	4.4	0.6	-	0.4	100	379	3.29	0

a) a 5 g horseshoe nail from Dokkfløyvann, Norway. Mrk. C 37471 a. HV 200 g: 106-108-113-113-133.

b) a 235 g steel bar from Nøstevoll, Gausdal, Oppland, Norway. Mrk. C 24075. HV 200 g : 134-213-242-260-270.

***Table 10.** Western Settlement, Nipaatsoq, compared to two Norwegian objects. SEM-EDAX analysis of slag inclusions, weight%.*

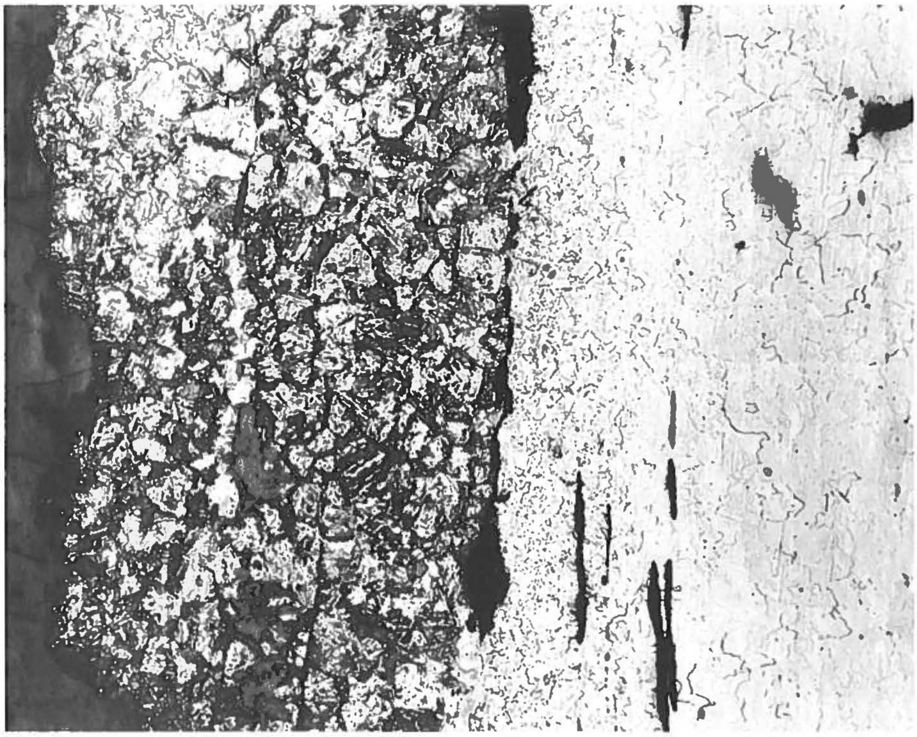

Fig. 36. Polished and etched section through the knife no. 183, Nipaatsoq. Martensitic edge to the right, parallel, vertical ghost lines due to phosphorus in the ferrite to the left. Side length 1.5 mm.

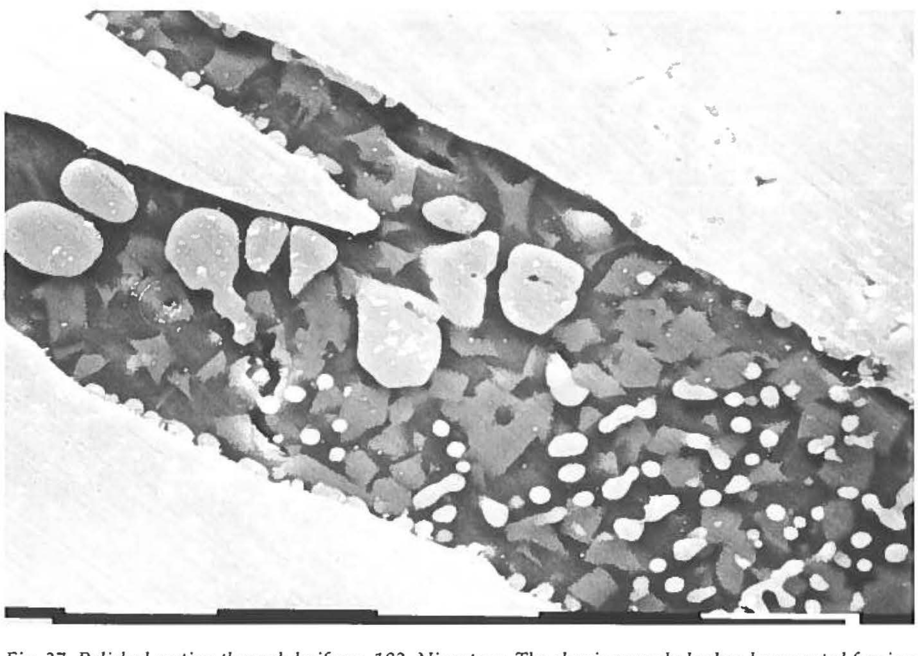

Fig. 37. Polished section through knife no. 183, Nipaatsoq. The slag is severely broken by repeated forging and coldwork. Blebs of wüstite (white to the right) and fragments of fayalite (grey) in glass matrix. Scale bar 0.01 mm.

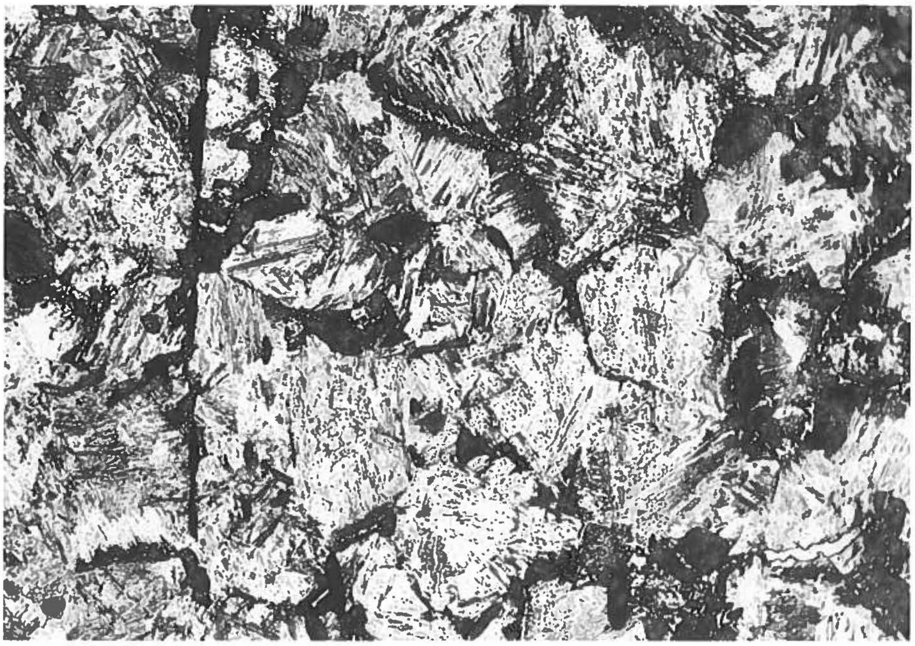

Fig. 38. Enlarged part of the martensitic surface zone in Fig. 36. The martensite is of the colony type with about 0.3%C and has a correspondingly low hardness of about 350 HV. Side length 0.4 mm.

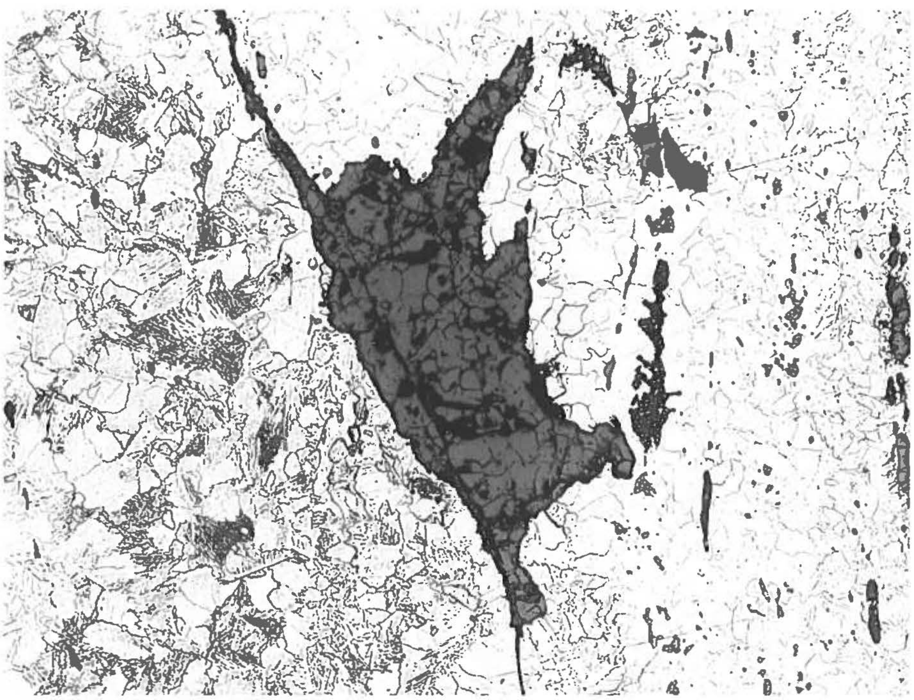

Fig. 39. Polished and etched section through the knife no. 183. In the centre a large, pure iron oxide (wüstite) mass, located at the tapering end of the ferritic insert. Side length 0.6 mm.

entirely composed of pure wüstite, FeO. It testifies that a significant part of the iron surface was lost as oxides during the welding operation. The nucleus shows serrated ferritic grains of the type that develops when quenching low-C and low-P austenite. The phosphorus content in the ferrite is revealed by parallel ghost lines originating from repeated forging. The hardness is 140-170 HV.

The steel surface is 0.5-1.0 mm thick on either side of the up to 1.5 mm thick ferritic nucleus. Below the wedge (Fig. 39) the two surface layers coalesce to one solid steel. At low magnification and defocusing a number of parallel, diffuse, 1-5 μm wide bands reveal that the steel part itself is a composite. The blacksmith has probably made the knife by repeatedly bending a steel strip back on itself and forge welded it until the required thickness of the blade was obtained. Then in one of the final steps a ferritic wedge was squeezed into the split-opened back of the steel blade. The inserting of ferrite probably occurred in order to save precious steel material. Water quenching has transformed the outer parts of the knife to martensite, more precisely to colony-martensite of the type with 0.25-0.4% C. The hardness is only 285-390 HV, because the relatively small amount of carbon is insufficient to create optimal hardnesses of 700-900. Corrosion has removed part of the exterior surfaces, but the picture is nevertheless quite clear.

The slag inclusions (Table 10) have different appearances in the ferritic and martensitic parts. In the ferrite they are composed of wüstite, fayalite and glass (Fig. 37). The fayalite laths have become sheared and fragmented during the repeated forging operations. In the martensite the slags are glassy with low FeO-content. The analytical data is the average of four different slag inclusions. The data is consistent with a Norwegian origin, not unlike the two previous examples.

No. 181 is a rivet with an anchoring plate, the two parts today solidly bonded by rust products (Figs. 40-41). The rivet is about 4x4 mm square and probably too frail to be a boat rivet. A longitudinal section through the rivet shows a fine ferritic-pearlitic structure with 0.25-0.30% C. Over large areas the structure forms an open meshed Widmanstätten pattern with hardnesses of 155-178 HV. The slag inclusions are almost all of a glassy nature, Table 10, showing the average of three rather uniform slags. The small specimen is unusually homogeneous, both with respect to the metallic phases and the slags. In Table 10 last line, is also shown the slag data for a Norwegian steel bar. Although the Norwegian bar is still more steely, as revealed by its hardness and high G-value, the two samples have much in common and could perhaps come from the same region.

No. 159 is a corroded and slightly bent nail with a 6x6 mm square section (Fig. 42). It displays a heterogeneous structure where ferritic-pearlitic zones with up to 0.4% C alternate with ternary Fe-C-P zones with about 0.2% C and 0.2% P. The phosphorus rich zones have decomposed to a microscopic mixture of very fine phosphide- and cementite-particles in ferrite (Fig. 43).

Fig. 40. A 5x5 mm thick rivet with an anchoring square plate, solidly grown together by corrosion products. Nipaatsoq, no. 181.

The hardness is 200-270 HV in the ferrite-pearlite and 160-200 HV in the ternary areas. The slag inclusions (Table 10) are apparently normal glasses, but they are unusual in their high CaO- and MgO-content and hence in their characteristic ratios. It has so far been impossible to match the steel nail no. 159 with anything in the author's database. The high Ca-Mg-content

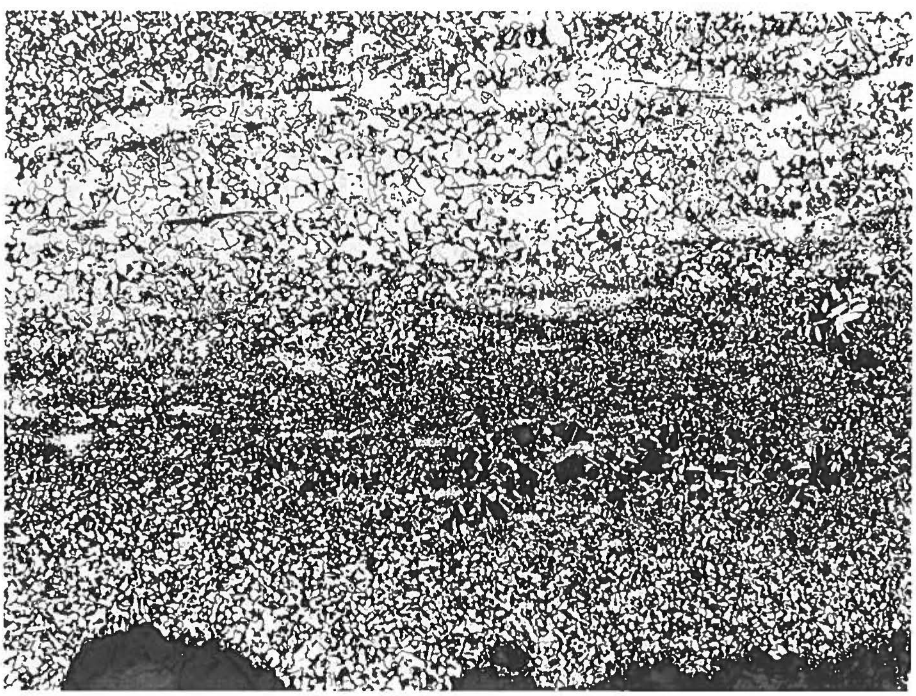

Fig. 41. Longitudinal, polished and etched section through the rivet, Fig. 40. Ferritic and ferritic-pearlitic zones alternate. Below a part of the corroded surface. Side length 3 mm.

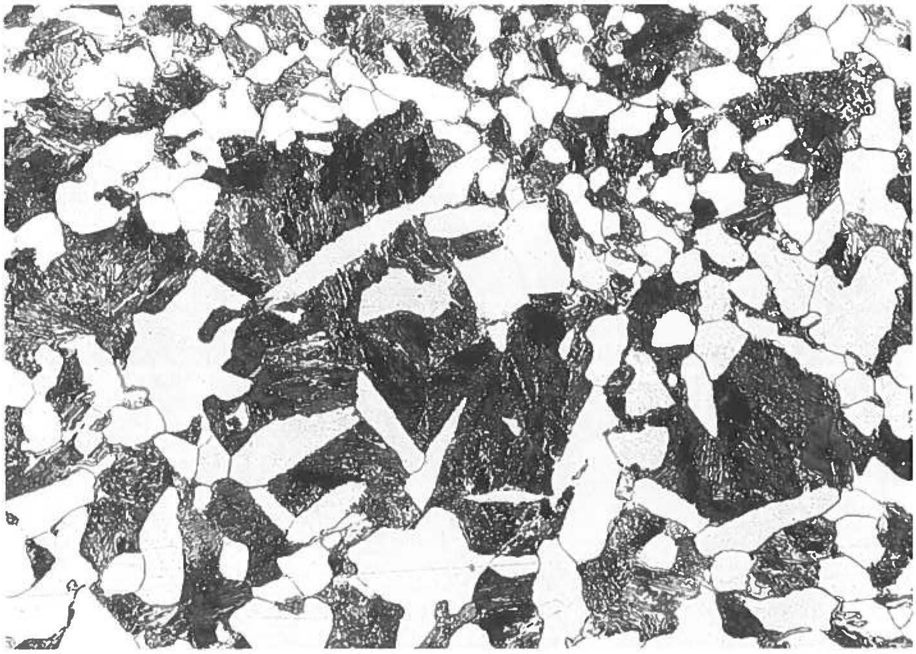

Fig. 42. Polished and etched section through the nail no. 159, Nipaatsoq. Ferritic-pearlitic structure with about 0.4% carbon. Side length 0.4 mm.

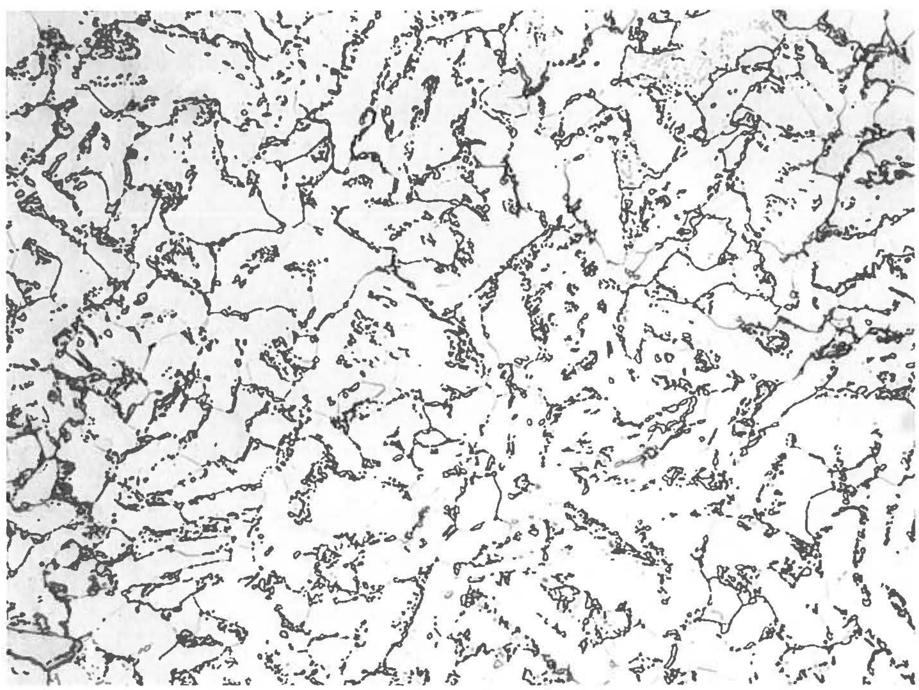

Fig. 43. Polished and etched section through the nail no. 159. Certain zones display a ternary structure of ferrite and micron sized cementite and phosphide particles. Side length 0.3 mm.

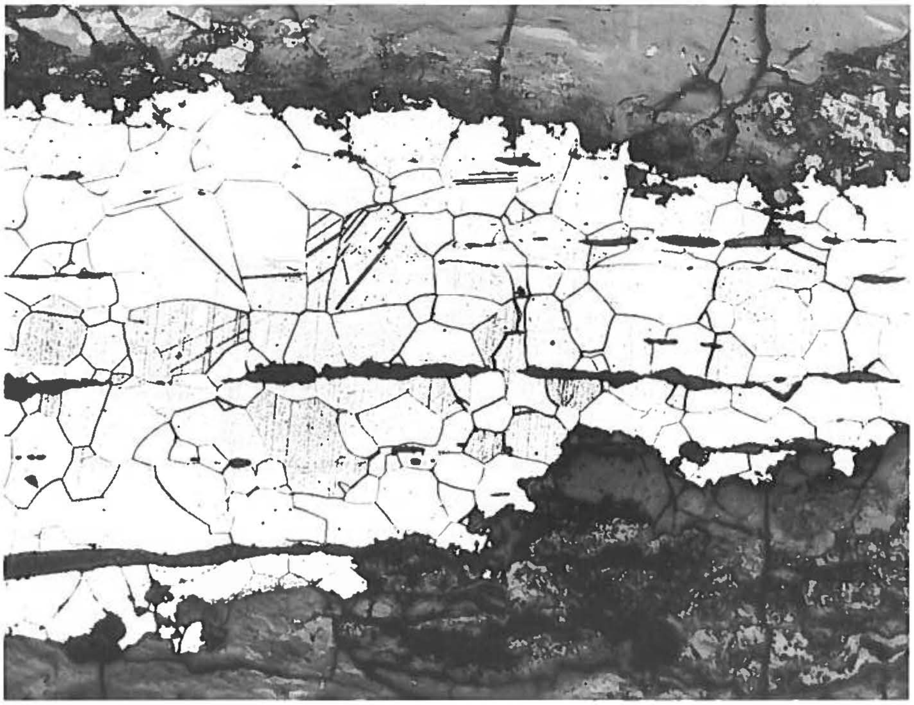

Fig. 44. Polished and etched section through the severely corroded rivet plate no. 182, Nipaatsoq. Horizontal, almost pure wüstite slags penetrate fully ferritic material with Neumann bands. Side length 2 mm.

suggests, however, a production site rich in dolomite and its weathering products.

In addition to these five Nipaatsoq samples ten other minute or severely corroded specimens were cursorily examined (Table 5). No.7 is a small piece of scrap iron with extremely phosphorus-rich ferrite, up to 0.6% P in solid solution. The hardness is correspondingly high, well above 200 HV. Some of the hardness is, however, due to coldwork. No. 30 is a corroded fragment of a knife blade which unfortunately has been annealed at 800°C during the con-

Fig. 45. A knife fragment from Nipaatsoq, no. 618. Although apparently in a good state of preservation, very little metal remained in the sections and also the slags were severely corroded. Lenght 8 cm.

servation treatment. Phosphorus lies between 0.1 and 0.27% in solid solution, and the structure is ferritic with ghost lines from forging. No. 34 is a rivet with its plate. It appears to be ferritic, but is too corroded for further work. No. 54 is a small piece of scrap iron. The ferrite is slightly coldworked and displays Neumann bands. No. 59 is a 22 g irregular bar, which has been annealed at 800°C for conservation purposes. It is now composed of equiaxial ferrite grains. No. 182 is a plate for a rivet. It is composed of pure, equiaxial ferrite grains, 75-200 µm across, which locally display Neumann bands (Fig. 44). The hardness is due to a combination of about 0.1% P and some coldwork. The slags are very rich in wüstite.

No. 335 is a 10 g rivet and plate, displaying alternating Widmanstätten structures with about 0.35% C, and equiaxial ferrite grains with some cementite and phosphides. In these zones P was measured to 0.15%, while the carbon was estimated to be 0.1%. There were glassy slags present in the Widmanstätten zones, but wüstite-rich slags in the ternary zones. No. 417 is the rusty remnants of a knife of which little can be learned. No. 618 is a severely corroded knife fragment (Fig. 45). It is, however, not water quenched but consists of heavily worked ferrite-pearlite with 0.10-0.17% P in solid solution. Locally there is some incipient recrystallization. The glassy slags are few, most of them having been crushed by coldwork. No. 1483, finally, consists of four rings from a harness. They are severely corroded and forms today an irregular lump, which it was decided to leave for future research.

The slag inclusions in these ten samples could not be subjected to analysis because they occurred too sparsely or were too corroded. Of a total of 16 samples from Nipaatsoq, four could be referred to Norway, one was a meteorite, see below, one (No. 159) was of unusual composition, while the origin of the other ten for various reasons could not be determined. It appears that the iron objects all belong to the last phase of the Nipaatsoq farm's life, *i.e.* they are probably from 1250-1350 AD (Jette Arneborg, pers.comm.).

Western Settlement, "The Farm beneath the Sand", file no. KNK 1950

Since 1991 an inland Norse farm, situated about 6 km ESE of Nipaatsoq has been excavated systematically. The farm had been occupied continuously from about 1000 to 1350 AD, when it had to be abandoned because of heavy sandstorms. Since then the farm has been entirely buried under the sand-dunes and up to 150 cm thick layers would have to be removed before archaeological work could begin. Preliminary results have been presented by Arneborg and Gulløv (1998) and Berglund (2000). From the excavations a few metallic remnants and slag fragments were available (Table 5). The metallic fragments were examined before they were given over to conservation treatment. In Table 11 five iron samples have been arranged according to

	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	V_2O_3	SO_3	Σ	G	F	%P in iron
Nail 796	21.0	57.7	1.6	–	7.6	2.9	4.9	1.1	0.8	0.3	–	0.9	98.8	14.5	4.29	0.4-1.0
Nail 2302	26.2	57.5	2.3	–	1.2	3.8	5.7	2.1	0.5	0.4	–	0.2	99.9	19.7	4.60	0.1-0.3
Knife 2511	42.1	23.4	3.0	–	0.4	9.6	12.3	3.8	2.9	0.8	–	0.3	98.6	107	3.42	0
Knife 701	48.2	5.9	5.4	–	0	7.1	22.3	6.6	1.8	0.6	0.2	0.1	98.2	335	2.16	0.2
Knife 1025	54.6	6.0	4.4	–	0	12.8	14.4	2.4	3.9	0.8	–	0.1	99.4	325	3.79	0
Nail[a]	28.7	43.9	0.5	–	9.0	4.2	7.0	1.7	2.2	0.7	–	1.0	98.9	28.5	4.10	0.3-0.5
Steel bar[b]	47.3	19.1	6.3	0.5	0	5.7	13.5	3.4	2.4	0.7	–	0.1	99.0	97.1	3.50	0

a) a 4.9 g nail excavated at Valler, Telemark, Norway. Mrk.C 28429 h5. HV 200 g: 208-220-231-232-268.

b) a 66 g steel bar excavated at Nordre Bjerke, Oppland, Norway. Mrk. C 39270-94. HV 200 g: 181-187-190-209-247.

Table 11. *Western Settlement, the Farm beneath the Sand compared to Norwegian objects. SEM-EDAX analysis of slag inclusions, weight%.*

decreasing FeO-content in the slag inclusions. A sixth sample, no.992, had inclusions that were too corroded to become incorporated.

No.796 is a 3.7 g nail with square section. It displays corrosion products that are stained with faint azure-blue colours. They are probably due to the presence of small quantities of vivianite, $Fe_3(PO_4)_2,8\ H_2O$, from centuries of exposure to weathering. The phosphorus may have been derived from the nail itself since it is rich in this element, containing up to 1 weight%. Similar staining by vivianite has previously been reported from iron objects found in Comer's midden, Thule (Buchwald and Mosdal 1985). The polished and etched section displays ferritic structures with bulky slags. The ferrite grains are 100-400 μm across and show ghostlines and numerous etch pits. The hardness is unusually high for a ferritic structure. This is due to a combination of a high phosphorus content and significant coldwork during the manufacture of the nail. The bulky slags have become severely sheared and crushed. The analytical data show that the slags are unusually rich in phosphorus and sulfur. A very similar case is found in the nail from Valler, Norway (Table 11), where the characteristic ratios and the P and S contents are sufficiently alike to support the hypothesis that no.796 could be of Norwegian origin.

No. 2302 is a 4.5 g nail with a large, flat head which is obliquely placed relative to the square nail shaft. The section displays a ferritic structure with faint forging lines and double grain boundaries due to some phosphorus in solid solution, about 0.1-0.3%. A large portion of the slag inclusions have been split and displaced during forging (Figs. 46-47), and later coldwork is also

Fig. 46. Polished section through the nail no. 2302 from the Farm beneath the Sand. The slag has been split and displaced during forging. Scale bar 0.1 mm.

apparent. The slag analyses put the nail in the Norwegian category, the rather high F-value placing it, however, at an extreme position.

No. 2511 is a very small, flat fragment of doubtful purpose. However, since the structure is that of a water-hardened item, it is probably safe to conclude that 2511 is the surviving part of a knife blade. The structure is martensitic,

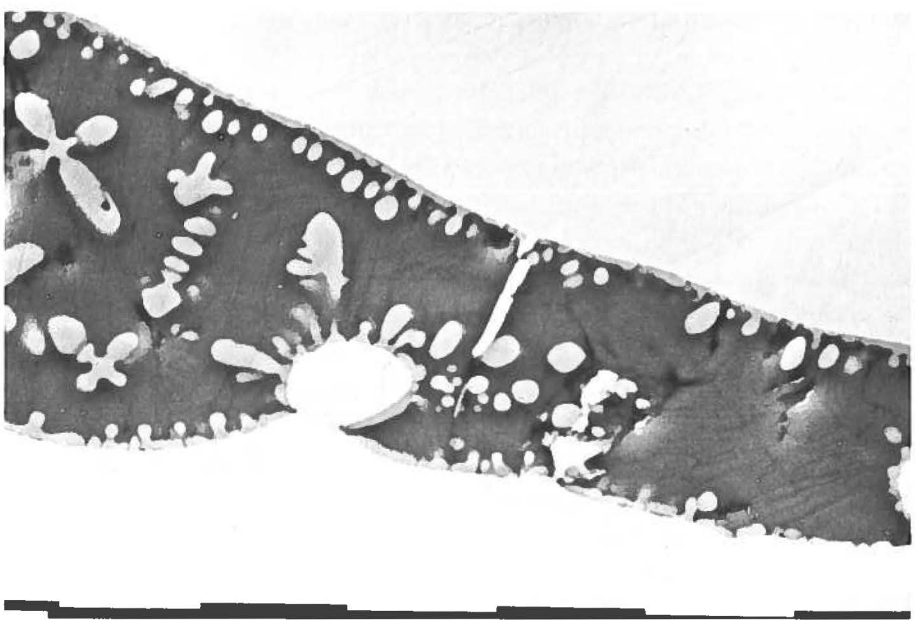

Fig. 47. Enlarged view of the displaced slags in Fig. 47. Wüstite has nucleated and grown upon the metal walls but is also present inside the slag. The matrix consists of fayalite laths in a little glass. Scale bar 0.01 mm.

with 0.4-0.6% C, and the hardness is between 540 at the present surface and 423 in the center. The slags are all glassy as they usually are in carbon steel, and they are crushed and scattered from both forging and coldwork.

No.701 is a fragment of a knife blade up to 2 mm thick. The structure is variable due to alternating phosphorus-rich (~0.2% P) and carbon-rich (~0.3% C) zones. Some zones consist apparently of fine grained ternary ferrite-cementite-phosphide mixtures. The ferrite is serrated and unequilibrated of the type that results from water-quenching a low carbon austenite. The hardness is no more than 179, possibly due to some tempering. The knife is certainly of inferior quality. All slag inclusions are glassy and very many have been crushed and displaced. The slag analysis is unusual in showing about 1% cerium oxide, an element not met with in other ancient objects. If correct, it may help in pinpointing the area of production.

No. 1025 is a small fragment of a knife blade. Its structure is variable due to phosphorus (~0.1%) and carbon (~0.3%) in varying proportions and mixtures. Water-quenched ferrite and ternary structures of ferrite, cementite and phosphides are common, and the hardness reaches 232 HV, not quite satisfactory for a knife. The slag inclusions are homogeneous glasses of rather uniform composition.

The three knife fragments, 2511, 701 and 1025, have similar slag inclusions, and the characteristic ratios are similar. The steel bar from Nordre Bjerke, Norway (Table 11 last line), may serve as a comparison for all three. The agreement is good and we are probably justified in pointing to Norway as the site of origin. It is worth noting that the G-value for all four is about 100 or higher, in accordance with all objects being of a steely nature. The two first items in Table 11 have, on the other hand, low G-values, in accordance with their soft iron nature.

No.992 (Table 5) is a severely corroded flat piece of iron with loosely adhering greenish corrosion products that may have come from some closely attached bronze- or copper item. No trace of copper-containing metal was, however, noted in the section. The iron displays phosphorus-rich ferrite (~0.3%), 25-75 μm across, with some etch pits and some coldwork. The hardness is correspondingly up to 162 HV. The slags were too few and too corroded for a meaningful analysis to be performed. In a later section the corrosion mineral hibbingite will be discussed.

Summarizing, it may be concluded that the few iron artefacts from the Farm beneath the Sand are bloomery iron of Norwegian origin and from the period 1200-1350 AD.

Bulk slags from the Western Settlement

Two slags from ancient activities in the Western Settlement were available for examination (Table 12). One was found in 1953 by Jens Rosing on the beach in front of the Sandnes smithy, house 7 in Roussell (1936, Fig. 4), the other, No. 880, was excavated from the Farm beneath the Sand, see p. 48.

Slag 880 weighs 15 g and has a specific gravity of 2.8 g/cm^3. It is one of a group of small, black slag fragments with a greenish tint. It is irregular and heterogeneous. The section shows alternating dense and porous parts, where wüstite generally is the major component. In addition a little fayalite and leucite ($KAlSi_2O_6$) are present in the matrix glass phase. The leucite is rather pure, but does accomodate some iron, calcium and sodium atoms in solid solution. The slag composition is typical for slags that build up in an open forge when working a *luppe* or bloom in order to free it for excess slag, compare Table 3. It is of particular interest to note the very weak manganese signal and the relatively weak phosphorus signal. The analytical values correspond pretty well with Norwegian purification slags.

The Sandnes slag is black (Figs. 48-51). It is rounded from the many centuries it has been exposed to wind, water and ice. It weighs 65 g and has a specific gravity of 2.8 g/cm^3. The section is heterogeneous and suggests some layering, *i.e.* consecutive slag portions having accumulated on top of each other. Like no. 880 it is a typical slag from purifying a bloom. It is not a slag from a production site. The major component is wüstite which forms massive dendrites. Between the dendrites, which typically make up 60% by volume, there is a fine grained matrix of equal portions of fayalite and glass. The manganese content is very low, and the ratios are those of typical iron items from the Western Settlement.

For comparison, medieval slags from Norway and Iceland are included in Table 12. One is a plano-convex slag cake (*kalotslagge*) from Bergen, one is a tap slag from a production site at Beitostølen, Valdres, Oppland, and the third is a Viking age tap slag from an Icelandic production site. The important thing to note is the major differences in the manganese contents. In Scandinavian bloomery practice, the production slags are rich in manganese (>0.8% MnO),

	SiO_2	FeO	MnO	BaO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	SO_3	Σ	G	F
Slag 880	12.2	78.7	0.1	–	0.4	1.4	3.9	1.2	0.5	0.1	0.4	98.9	8.80	3.13
Sandnes	17.8	65.1	0.1	–	1.1	7.2	4.2	2.0	0.9	0.2	0.3	98.9	21.5	4.24
Bergen[a]	29.7	48.4	0.3	–	0.7	5.2	7.5	3.0	2.3	0.3	0.2	97.6	36.5	3.96
Beitostøl[b]	28.4	49.8	3.7	0.5	0.3	3.0	11.3	1.6	1.0	0.2	0.2	100	31.0	2.51
Belgsá[c]	31.6	48.9	2.8	–	0.3	3.9	9.3	1.3	0.6	0.6	0.3	99.6	29.0	3.40

a) purification slag (kalotslagge) from Bergen, Norway. Early medieval. Mrk. 245 x 1497.

b) tap slag from a Viking age production site at Beitostølen, Valdres, Oppland, Norway. Mrk.B 40.

c) tap slag from a Viking age production site at Belgsá, Fnjoskardalur, Iceland.

Table 12. *Two purification slags from the Western Settlement compared to various slags from Norway and Iceland. SEM-EDAX analysis, weight%.*

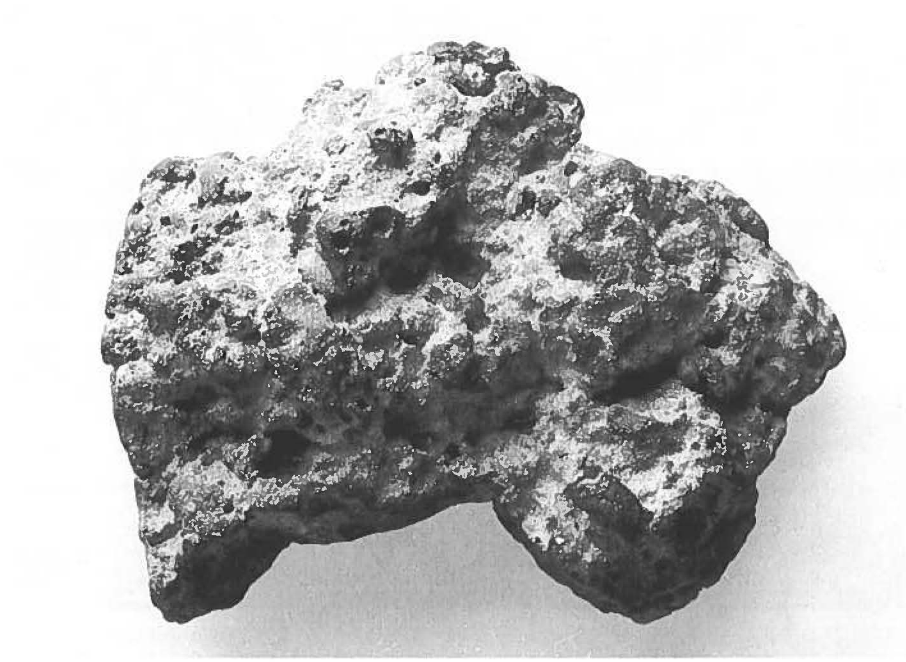

Fig. 48. A rounded slag fragment of 65 g, 52 mm long. Purification slag from Sandnes, the Western Settlement.

Fig. 49. Polished section through the Sandnes purification slag. Layering is evident. Dense wüstite structure below, more open above. Scale bar 0.1 mm.

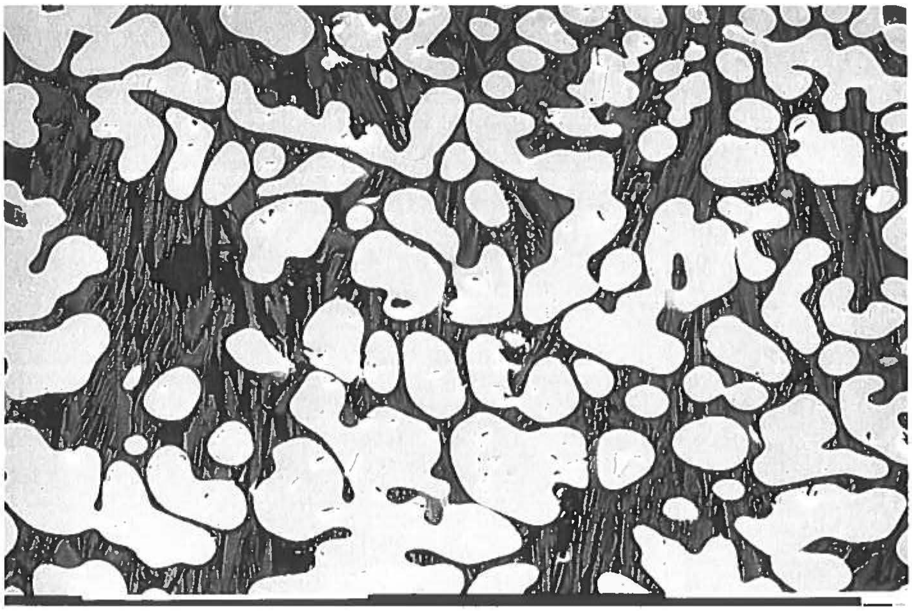

Fig. 50. Enlarged view of the more open structure in the Sandnes slag, Fig. 49. Wüstite dendrites (white) dominate, while the matrix displays fayalite laths in a glass matrix. Scale bar 0.1 mm.

while the purification slags are poor (<0.5% MnO). The Bergen plano-convex slag is typical for Norwegian purification slags and support the conclusion that the two Greenland slags are from imported and processed Norwegian blooms and not from primary production. This conclusion is supported by

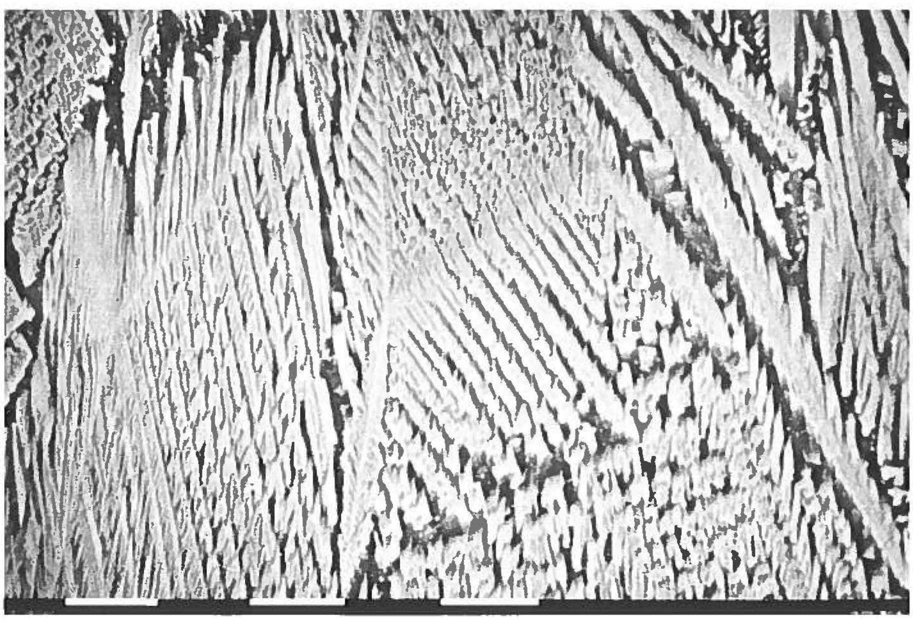

Fig. 51. Another enlarged view of the Sandnes purification slag. The matrix displays fine grained, feathery skeleton crystals of fayalite in glass. Scale bar 0.01 mm.

the small size of the Greenland slags and their location near smithies. Also the very limited quantity points to a purification origin, while slags on an iron production site usually make up considerable heaps.

The tap slag from Iceland is almost indistinguishable from the Norwegian tap slag. Little is unfortunately known of the composition of irons and slags from Iceland. Perhaps the relatively high titanium and calcium oxide contents are significant? In addition, barium seems to be absent from Icelandic material.

Meteoritic iron on Inuit and Norse sites

In previous studies (Buchwald and Mosdal 1985; Buchwald 1992 b) a significant number of meteoritic fragments and tools with inserts of meteoritic and telluric iron has been discussed. It was shown how meteoritic iron differed from native, telluric iron, and it was documented that the majority of objects with meteoritic inserts was in Northern Greenland north of about 70° N. The native iron tools were located around Disko Bay, where iron basalt occurs in significant outcrops. It is known that meteoritic iron is also present on many Inuit sites on the Canadian side of Baffins Bay (McCartney 1991; Pringle 1997), even as far south as Silumiut at the northwestern coast of Hudson Bay.

In the present study three new discoveries will be discussed. In Inglefield Land, Northwest Greenland, well preserved and partly undisturbed structures from the late Dorset and early Thule culture were examined and partly excavated in July and August 1996 (Appelt *et al.*1998). Six dwellings were tested and about 375 structures surveyed. Particularly interesting was the small peninsula Qeqertaaraq in Hatherton Bay, 78° 24′ N, 72° 40′ W, where six ruins after winter houses and several tent rings were uncovered. Besides numerous organic remains (cranial parts of walrus, ivory, wood, fish bones etc.) and tools of slate and agate, a number of meteoritic fragments were detected (Table 13). In House 1 were four fragments, in House 4 two and in House 6 two. The other meteoritic fragments were stray finds from detector surveys or were associated with tent rings. From the archaeological context the fragments could be dated to late Dorset or early Thule culture, *i.e.* 1200-1300 AD.

The meteorites range from very small fragments of less than 1 g to rather large slabs of 90 g and even one of 1100 g. For the examination characteristic small parts were removed with a jeweller's saw and embedded in plastic. They were all very similar, displaying medium Widmanstätten structures of the Cape York iron meteorite shower (Buchwald 1975, 1992b). The three typical phases are kamacite with about 7% nickel, taenite with 30-50% nickel and the phosphide rhabdite, $(Fe,Ni)_3P$, with about 45% iron, 40% nickel and 15% phosphorus (Fig. 52). The average composition of the fragments is about 8% Ni, 0.1% P, 0.5% Co, the remainder being iron. No troilite, FeS, was observed.

Nr.	Weight, g	Location	Structure
1	<1	tent 261	deformed
2	18	stray find	only slightly deformed
3	0.8	sray find	
5	6	house 161	violently deformed
6	6	house 1	violently deformed
7	12	house 1	
8	10	house 1	violently deformed
10	5	house 1	violently deformed
14	<1	stray find	
17	<1	stray find	
22	22	stray find	violently deformed
23	<1	stray find	
24	1100	house 6	
30	6	house 4	
31	90	house 4	
32	13	house 6	
33	2	stray find	decayed by corrosion
34	6	stray find	
35	<1	stray find	
37	2	stray find	

Table 13. *Meteoritic iron on the Inuit site in Hatherton Bay. All are fragments from the Cape York iron meteorite shower.*

The meteoritic fragments have no doubt been collected in the Cape York shower area, that reaches from near Dundas Mountain in the northwest to Meteorite Island in the southeast, a distance of about 125 km. Modern research has shown that the large, ton-sized meteorite blocks fell in the south-eastern zone, while the smaller kilogram-sized fragments mainly fell in the Thule Base area, possibly also along the coast line on the North side of Wolstenholme Fjord (Buchwald 1992b). It may be assumed that the Inuit fragments of Table 13 for the most part have been collected in the northwestern zone and thus by the Inuit have been transported at least 200 km northwards.

Small meteorite fragments *in situ* are rarely reported by modern science, presumably because the Inuit for centuries with their unerring and keen observance long since have collected all that was available. The shower probably occurred more than 2000 years ago. The small fragments were useful because they on coldworking could be shaped to lanceheads, knives and ulos. As anvils the Inuit would use large stones or even the large meteorite blocks in Melville Bay, and as hammers they used basaltic blocks from the vicinity of Cape York which were hard and tough. These hammer stones are to be found in the thousands around the large meteorites Woman, Savik and Ahnighito (Buchwald 1992b). It has been assumed that the Inuit worked the large blocks

Fig. 52. Polished and etched section through a meteoritic fragment from North Greenland, L3-12480 (Buchwald & Mosdal 1985). Heavily distorted kamacite in which ductile taenite (grey, v-shaped below) and brittle schreibersite (horizontal irregular band) are distributed. Schreibersite is a phosphide similar to rhabdite, but containing half as much nickel. Side length 0.4 mm.

in order to pry small flakes from them (Ross 1819; Peary 1898). When this idea was proposed the small meteorite fragments were unknown. It is, in fact, more likely that the Inuit rather brought the small fragments as well as the hammerstones to Woman, in particular, and here established their "workshops" with the large blocks mainly serving as proper anvils.

The metallographical examination of the Hatherton Bay fragments reveal that they have a highly distorted structure. None of the fragments have, however, been shaped by the Inuit. They are of irregular, rough shapes. The distorted structures and high hardnesses, 200-300 HV, are due to violent shock deformation when the meteorite broke up in the atmosphere and split into thousands of fragments. Their presence on the Qeqertaaraq site may be interpreted as a stock of raw iron material for future work and trade.

Washington Land meteoritic iron lancehead

In the summer of 1999 museum curators Hans Lange and Claus Andreasen, Nuuk, made a survey for Inuit sites in the little known Washington Land 200 km northeast of Inglefield Land (pers.comm.). In Fossil Bugt on the position 80° 45′ N, 65°24′ W, near the beach, a small site with the ruins of four winter

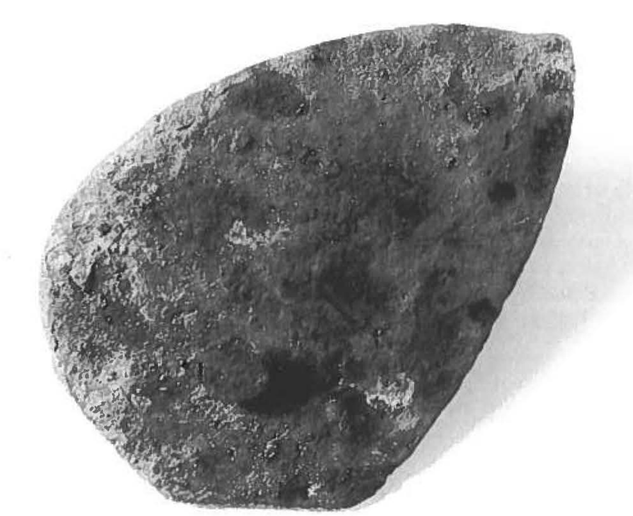

Fig. 53. The lancehead of 16 g from Washington Land. Worked by hammering a meteoritic fragment from the Cape York shower. The straight edge below is where a minute section was removed for metallographical examination. Longest dimension 50 mm. Photo Ole Bang Berthelsen.

houses was excavated. On the south side of the entrance to House 1 a lancehead, KNK 2093x3, was detected (Fig. 53 and Table 14). Its rather large size and weight (16 g) suggested a wrought iron of Norse origin. In a hole a 9 mm long iron rivet, 3.5 mm in diameter, was still sitting. The rivet was flattened in both ends by hammering, but it was not further examined. With a jeweller's saw a minute part of the lancehead was removed and embedded in plastic. It was a real surprise to learn that this lancehead was produced from Cape York meteorite iron. It is with 16 g significantly larger than any of the tools and weapons of meteoritic iron previously reported from Greenland (Buchwald 1992 a). The Inuit have succeeded in fabricating a unique and strong lancehead by cold hammering and grinding. The structural elements kamacite and taenite have become distorted and sheared and the hardness of the kamacite is high, 235-270 HV. Small inclusions of rhabdite have been broken and sheared into long lines of very hard fragments inside the malleable kamacite.

	Dimensions, mm	Weight, g	%Ni	%P	HV 200 g
Washington Land, lancehead	50 x 35 x 2	16	8	0.1-0.2	237-244-246-255-280
Nipaatsoq 162, arrowhead	45 x 29 x 2	6	8	0.1-0.2	283-285-296-301-313
Cape York, Agpalilik	about 1600	20,000,000	8	0.1-0.2	247-247-249-254-277

Table 14. *A lancehead and an arrowhead made from the Cape York iron meteorite. The average composition of the Cape York iron meteorite is presented in the last like.*

	Nickel %	Cobalt %	Phosphorus %	Carbon %	Hardness HV 200 g	Phosphides	Taenite	Slags	Maximum size, g
Meteoritic iron	>5	>0.4	0.1-0.3	<0.1	175-350	+	+	-	16
Telluric iron	1-4	0.1-0.4	<0.08	<0.2	125-250	-	-	-	1
Wrought iron	<0.2	<0.05	0-0.6	0-0.8	80-900	+	-	+	>1000

Table 15. *Characteristics of the three types of iron that were used in Greenland.*

The final shape of the lancehead was probably attained by grinding and polishing with abrasives such as wet quartz sand, or perhaps a whetting stone. The exterior layers have, however, later been removed by corrosion. The lancehead resembles very much the iron end blade excavated on the Cape Garry site on southeastern Somerset Island, Canada (McCartney 1991, Fig. 3 B).

The SEM-EDAX data confirm the meteorite as a member of the Cape York shower. It is thus the northernmost tool of meteoritic iron ever found. It is located about 500 km north of the meteorite strewnfield. It is also the largest single object of worked Cape York iron. Table 11 in Buchwald (1992 a) must therefore be updated (Table 15). The Washington Land lancehead may provisionally, from the archaelogical context, be dated to the Thule culture, 1200-1400 AD (Andreasen, pers.comm.).

Nipaatsoq meteoritic iron arrowhead, No. 162

Within the lot of samples from Nipaatsoq, the Western Settlement, received by the author from Jørgen Meldgaard in 1980 was also an arrowhead, see Table 5, no. 162. To my surprise it turned out to be of meteoritic iron. Its meteoritic nature has been reported in preliminary notes (*e.g.* Andreasen 1982). It was found in room VII of the house ruin. It measures 45 x 29 mm, has a maximum thickness of 2mm and weighs 6 g (Figs. 54-57 and Table 14). It suffers some gentle corrosion, but is stable and has not been annealed for conservation. A miniature cut was performed with a jeweller's saw. The structure is similar to that of Washington Land, and the Vickers hardness ranges from 283 to 313 (200 g load). The coldworked, slender taenite lamellae are somewhat harder than the average kamacite hardness, 366-401 HV (100 g load). The hardnesses are thus significantly higher than that of wrought iron from the Norse settlements. These high hardnesses are due to i) the meteorite alloy being rich in nickel (more than 7% Ni), ii) deformation from the meteorite break up in the atmosphere, and iii) additional coldwork by man when the small fragments were hammered into shape. The meteoritic structure and analysis is that of typical Cape York material, so the arrowhead must ulti-

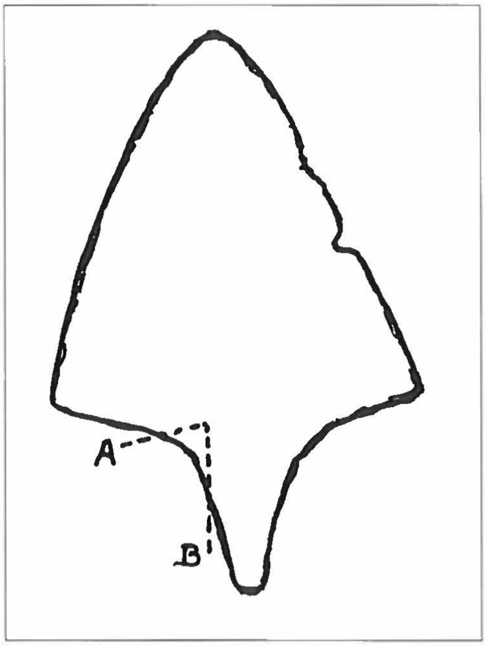

Fig. 54. Sketch of the Nipaatsoq arrowhead of meteoritic iron from Cape York, no. 162. A minute section for metallography was removed at A-B. The incision to the right is caused by corrosion. Length 45 mm. Weight 6 g.

mately be derived from the Cape York shower area, some 1400 km further north, and must have arrived at Nipaatsoq before 1350 AD.

Haabetz Colonie

In excavating Haabetz Colonie (Gulløv and Kapel 1979) very many iron artefacts were retrieved. There were hammers, knives, horseshoes, cannon balls

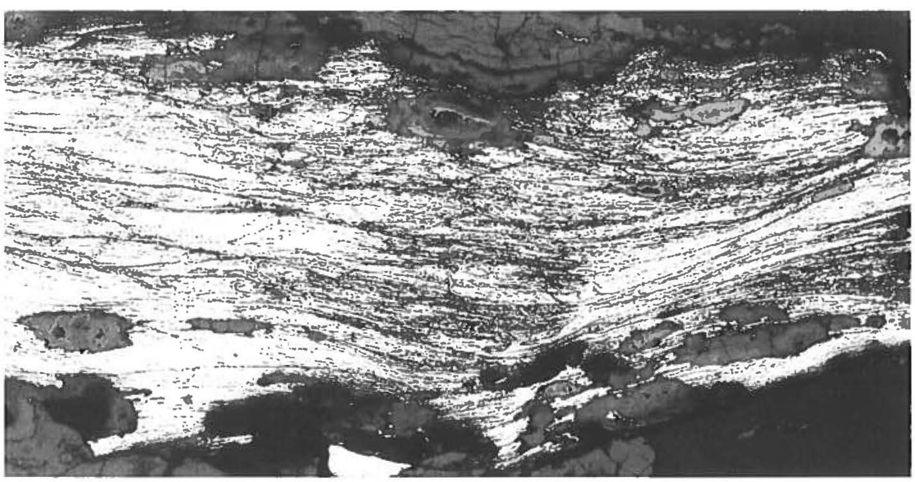

Fig. 55. Polished and etched section through the Nipaatsoq meteoritic arrowhead, no. 162. Heavily distorted structure and some corrosion products above and below. Side length 3 mm.

Fig. 56. Polished and etched section through the Nipaatsoq meteoritic arrowhead, no. 162. Mainly distorted kamacite with about 7% nickel. Side length 0.8 mm.

Fig. 57. Enlarged part of Fig. 56. Distorted, sickle shaped taenite band above and a fine line of broken, brittle schreibersite crystals. Matrix is coldworked kamacite. Side length 0.4 mm.

Fig. 58. The nail h6130 A, 43 g, from Haabetz Colonie, 1721-28 AD. The nail has been situated in a wooden (window?) frame and corrosion has selectively attacked the surface-near part. Similar corrosion attacks are also very common on screws and nails in window frames of modern Denmark.

and even a part of a small anchor. The locality only existed a few years, 1721-1728, since Hans Egede soon decided to move to a new site, Godthaab, the present Nuuk, about 20 km further East. The artifacts are thus well-dated and represent an interesting cross-section of daily objects from an early 18th century colony site. A selection of the nails found in the dwelling house in Haabetz Colonie are shown in Gulløv and Kapel (1979: 135-137). For the present study two of the nails were available, h 6130 A and h 6130 B (Table 5 and Fig. 58). The two nails have square sections with small heads and are respectively 86 and 117 mm (4½") long. The shorter nail has lost its tip, but may have been identical to h 5166 in Gulløv and Kapel (1979:136), thus originally also being 117 mm (4½") long.

Metallographic sections through the two nails are very similar. The structure is ferritic with clear indications of a significant phosphorus content. The ferrite grains are up to 500 μm (!) in diameter. They attain hardnesses in excess of 200 HV because of up to 0.6% P in solid solution. In other places there is less phosphorus and the structure is duplex, ghost-like, with hardnesses of 160-180. No carbon was detected. The slag inclusions (Table 16) are very rich in phosphorus.

While irons from the medieval Norse sites were bloomery irons with slag inclusions with rather low F-values, 2-5, significantly higher values are now met with. F-values of 6-20 are typical of slag inclusions in iron manufacture having been produced by indirect processes, that is blast furnace smelting plus fining of the resulting pig iron (Buchwald 1999). Comparisons with Norwegian and Swedish fined irons from the 16th and 17th centuries were little promising, so the attention was directed to other iron producing parts of Europe in order to disclose the origin of the Greenland iron.

The Walloon district (Liège, Namur, Charleroi) was from about 1500 AD an important iron producing region and was well known for its production of among other things guns and all sorts of finished nails (Yernaux 1939; Nilles 1997). In the author's search for authentic material for analytical purposes,

	SiO_2	FeO	MnO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	V_2O_3	Cr_2O_3	SO_3	Σ	G	F	%P in iron
6130 A	25.0	57.0	1.3	8.4	2.1	1.6	1.3	1.0	0.2	0.7	0.2	0.2	99.0	8.9	15.6	0.3-0.60
6130 B	14.2	58.2	0.6	19.0	1.9	1.6	1.0	1.0	0.2	0.4	0.2	0.3	98.6	7.1	8.9	0.3-0.63
Anholt 1[a]	13.9	61.1	1.2	18.9	2.0	1.2	0.4	0.8	0.1	0.1	-	0.3	100	5.4	11.6	0.2-0.7
Liége 1[b]	20.9	64.1	1.5	7.1	0.6	1.3	0.1	0.2	0.2	0.3	0.2	2.6	99.1	3.1	16.1	0.1-0.3
Liége 2[c]	16.5	61.4	1.4	9.1	6.5	1.0	0.1	0.7	0.2	0.2	-	2.0	99.1	11.5	16.5	0.1-0.3
Nørregade[d]	21.1	61.1	0.5	9.3	2.4	1.8	0.2	1.5	0.1	0.3	-	0.2	98.5	8.4	11.7	0.12-0.20

a) Fitting from gun produced in the Netherlands about 1520 AD. Courtesy Danish Defence Museum.

b) 65 mm (2½") nail, 7.7 g, with small head from the Iron Museum, Liége, ab.1650 AD. Courtesy Dr. Paul Nilles, Centre de Recherches Métallurgiques, Liége.

c) 130 mm (5") nail, 41.8 g, with small head from Abbey Val Saint Lambert, ab.1650 AD. Courtesy Dr. Paul Nilles.

d) Fragment of horseshoe, Nørregade, Copenhagen, ab.1650 AD. Danish National Museum D 1104.

Table 16. *Haabetz Colonie. Two nails and European material for comparison. SEM-EDAX analysis of the slag inclusions, weight%.*

he was happy to acquire two original nails from the Iron Museum in Liège (courtesy Dr. Paul Nilles 1997), dated to about 1650 AD (Figs. 59-60). For further reference material a gun fitting from a wreck salvaged in 1963 at Anholt was acquired from the Danish Defence Museum (Tøjhusmuseet). The ship had been built about 1520 AD in the Netherlands, and wrought iron guns, probably from the Walloon district, had been installed (Eriksen and Thegel 1966; R. Mortensen 1994, pers.comm.).

In Table 16 slag analytical data on three authentic Walloon iron samples are presented. In addition, an analysis of slag inclusions in a horseshoe, excavated in Nørregade, Copenhagen, is included. The horseshoe was, no doubt, forged from Walloon iron, either already in the Walloon district or by a blacksmith in Copenhagen who worked imported Walloon iron stock.

The structure of the gun fitting Anholt 1 is ferritic with up to 500 μm phosphorus-rich grains and a hardness range of 140-207, due to phosphorus variations. The slag inclusions are rich in phosphorus- and vanadium oxide, but poor in most other elements which is a characteristic of the Walloon forgings, compare the Liège nails in the same table. The microstructures of the Liège nails and the Copenhagen horseshoe are similar to that of the Anholt gun fitting.

Returning now to the two nails from Haabetz Colonie, it is obvious that microstructures and slag analyses correspond so well to that of the authentic Walloon material, that we will conclude that they came from the Netherlands. According to Gulløv and Kapel (1979) the nails were shipped from Bergen

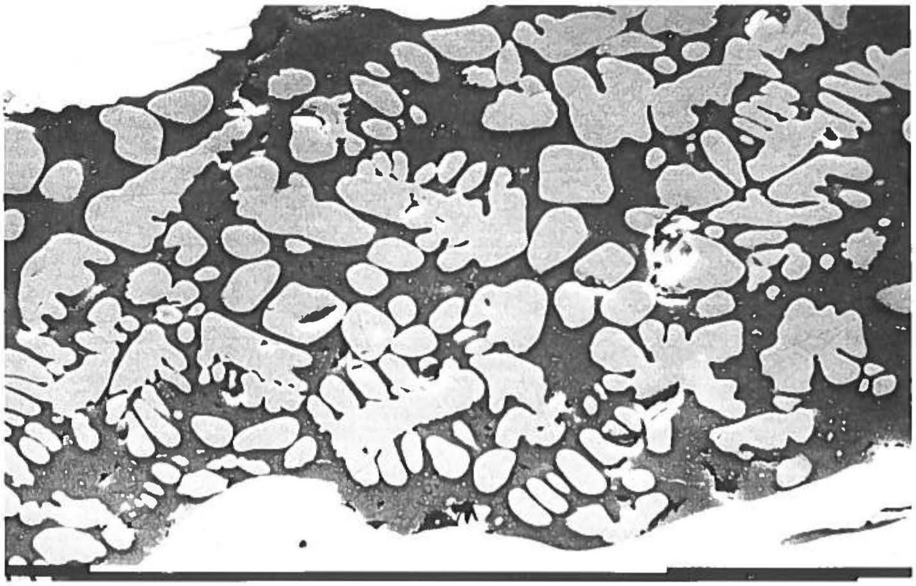

Fig. 59. Polished section through a 7.7 g nail from Liège, 17th century. Slag inclusion with predominant wüstite dendrites in a glass matrix rich in P_2O_5. Walloon iron. Scale bar 0.1 mm.

together with other provisions for the new colony, and since Bergen was a major North European trading center, it is hardly surprising that some of the goods were derived from distant places. Unfortunately the slag analytical method is not able to decide whether the actual forging of the nails took place

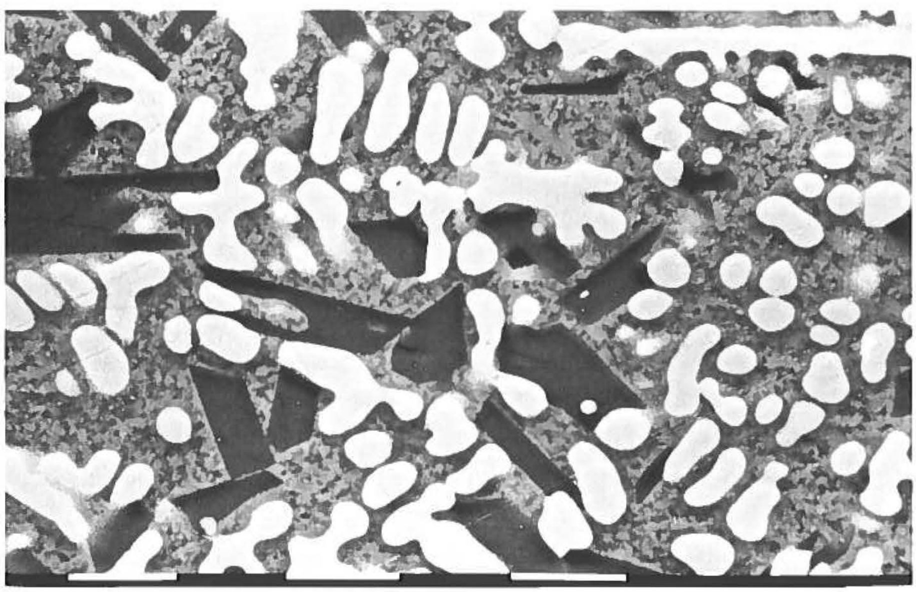

Fig. 60. Polished section through a 42 g nail from Val Saint Lambert, Liège, 17th century. Slag inclusion with wüstite dendrites (white), calcium phosphates (black idiomorphic crystals) and a fine grained matrix. Walloon iron. Scale bar 0.01mm.

in the Walloon district or in Bergen. Nail forging was for centuries a Walloon specialty (Godard 1931) and the author is inclined to think of the two nails as a purchase of finished Walloon nails rather than being forged in Bergen from imported Walloon bar iron.

Ancient iron excavated on Inuit sites

In previous papers (Buchwald and Mosdal 1985; Buchwald 1992a) a number of ancient iron samples, excavated over the last century on Inuit sites on the West Coast of Greenland, from 64° to 79° N, have been figured and analyzed. Some artifacts were made from meteoritic iron and others from telluric iron, but there were 24 objects manufactured from wrought iron. At that time it could only be speculated from where the enigmatic wrought iron could come, but the recently developed slag analytical method can now be applied. The metallographic sections have been repolished, studied under the microscope and analyzed with SEM-EDAX equipment. As it turned out, the new method could be applied to half of the samples (Tables 5 and 17), while the other half were either too small or too corroded to display useful slag inclusions.

L3.12673 (Table 5) is a corroded fragment of a harpoon or a knife blade, archaeologically dated to 1200-1400 AD (Holtved 1954). It was found in the Nuulliit house ruin 24 B, in which a Cape York iron meteorite fragment was also found. The location is in the Thule district about 35 km NW of Saunders Island. The structure is that of ferritic iron with only small amounts of carbon (<0.1%) and phosphorus (<0.1%) (Fig. 61). The relatively high hardness is due to coldwork that has deformed the ferrite grains and sheared the slag inclusions. These are extremely rich in manganese oxide, to an extent which is mainly known from Norwegian bog iron ore occurrences. The closest approach to objects with similar slag inclusions are two objects listed in Table 8: The fitting nr. 245 from the Eastern Settlement and the steel bar from Brattaker, Oppland, Norway. It thus appears that the Inuit sometime in the 13th or 14th century acquired a knife or a knife blade from the Norsemen.

L3.12572 is a rather large knife blade of "modern" European style. It was found in the Nuulliit house ruin 23 and assumed to be from the Thule culture (Holtved 1954), but later examination and discussions within archaelogical circles tend to regard it as a much later intrusion on the site. The structure of the knife is that of a hot-forged low carbon iron with equiaxial ferrite grains 50-100 μm across. Due to a significant phosphorus content, up to about 0.3%, the hardness reaches values of 200 HV. Slag inclusions are omnipresent and slightly corroded. The analytical values are very similar to those of the two nails from Liège (Table 16), even down to the simultaneous presence of V_2O_5, Cr_2O_3 and SO_3. The skepticism with regard to an early dating is thus strongly supported by the slag analytical method, and the knife must be referred to a Walloon origin after 1500 AD.

	SiO_2	FeO	MnO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	V_2O_3	Cr_2O_3	SO_3	Σ	G	F	%P in iron
L3. 12673	33.2	25.3	26.4	0.8	3.2	6.2	1.7	0.8	0.6	–	–	0.4	98.6	22.9	5.35	<0.1
L3. 12572	18.9	65.0	3.8	5.2	0.6	2.5	0.2	0.2[a]	0.3	0.3	0.2	2.0	99.0	4.7	7.56	0.1-0.3
Lc 297	16.2	70.4	2.3	6.3	0.6	2.5	0.1	1.3	0.3	–	–	–	100	5.7	6.48	0.1-0.3
L12. 292	16.2	58.5	7.0	11.4	2.9	1.8	1.2	0.2[a]	0.3	0.1	–	0.2	99.8	7.8	9.00	–
It 93	16.3	54.6	0.9	18.4	3.1	1.8	1.3	1.1	0.2	0.5	0.2	0.5	98.7	9.8	9.05	0-0.3
L6. 3479	17.0	68.5	0.6	6.3	2.8	2.7	0.7	1.3	0.1	–	–	–	100	9.9	6.30	0-0.3
L 8356	19.7	54.3	0.7	14.5	3.5	3.0	1.3	2.8	0.2	–	–	–	100	15.3	6.57	0.2-0.5
L 2856	20.1	43.7	11.7	16.8	2.6	2.4	0.6	1.9	0.2	–	–	–	100	10.4	8.38	0.4-0.9
L6. 3308	21.3	64.0	0.8	10.0	0.5	1.2	0.1	1.9	0.1	–	–	–	99.9	5.0	17.8	0-0.1
L6. 3316	39.7	35.2	0.6	4.8	6.9	6.8	3.3	2.3	0.4	–	–	–	100	47.4	5.84	0-0.3
L12. 439	40.4	44.2	1.0	0.7	3.4	6.5	2.1	1.4	0.1	–	–	0.2	100	29.3	6.22	0.1
Crow-ned F	45.9	30.8	3.9	1.2	5.0	5.9	1.5	1.5	2.3	1.0	–	0.2	99.2	38.6	7.78	<0.1

a) The analysis in MgO is low due to loss by corrosion.

Table 17. *Objects from Inuit sites on the west coast of Greenland, compare Table 5. SEM-EDAX analysis of the slag inclusions, weight%.*

The next nine items of Table 5, Lc 297 – L12.439, have much in common (Figs. 62-63). The archaelogical datings range from about 1600 to 1800 AD, the structures are that of ferritic iron with high phosphorus contents, up to 0.9% P in solid solution, and the hardnesses are quite high due to a combination of phosphorus and some coldwork. The knife L 8356 (Figs. 64-67), shows a combination of phosphorus ferrite and martensite, and consequently a rather high hardness achieved by water quenching. The knife L6. 3316 is correctly hardened and tempered, displaying hardnesses up to 627 HV. The knife is, however, very heterogeneous in its structure as are most other ancient iron objects; it locally contains zones of ferrite with up to 0.3% phosphorus. The blade of the ulo, L 2856, is very heterogeneous (Fig. 68). There are four or five zones, widely different in structure due to carbon and phosphorus variations. There are ferritic zones with grain sizes of 200-400 μm and up to 0.9%P. In some grains are minute particles of exsolved iron phosphides. The ferrite grains are slightly elongated and show sliplines in accordance with the high hardnesses of 280-360 HV. In other parts are ferritic-pearlitic structures of somewhat lower hardness.

The adze L12. 439 (Tables 5 and 17, and Fig. 69), is the most massive artificial object in the present study. The structure is ferritic-pearlitic, developed in the characteristic Widmanstätten pattern, suggesting air cooling after forging of an austenite with about 0.3% C. Phosphorus is present on the 0.1% level. The slag inclusions are glassy as usually is the case in ferritic-pearlitic material, and they are phosphorus poor, but relatively rich in other elements.

The metallic structures and the slag compositions of the nine objects, Lc 297

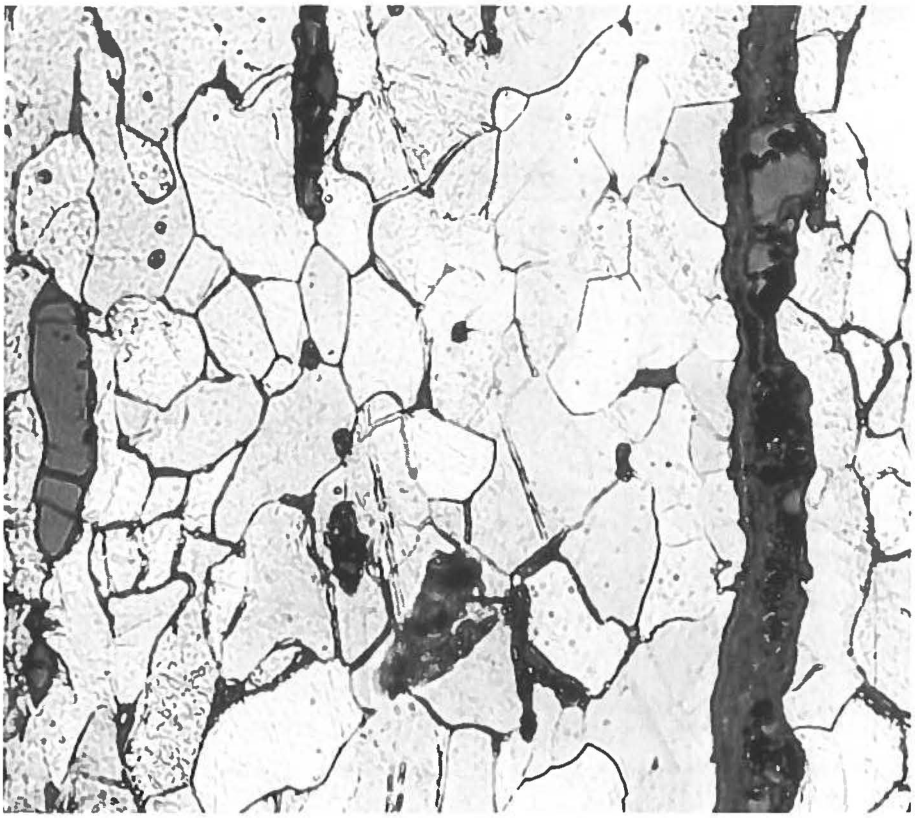

Fig. 61. Polished and etched section through the knife L3.12673, Nuulliit, House 24 B, 1200-1400 AD. Slightly elongated ferrite grains and broken iron-manganese oxide slags with up to 26% MnO. Side length 1 mm.

- L12.439 (Table 17), correspond rather well to samples from the Walloon district, presented in Table 16. The F-ratios are similar, and the absolute values of SiO_2, P_2O_5 and TiO_2 are similar. The presence of V_2O_5 and Cr_2O_3 in some cases is also noteworthy. While the high phosphorus values, in both iron and slag inclusions, were previously taken to indicate a Danish origin (Buchwald 1992a:162), it is now known that provenance can not be established on basis

Fig. 62. The arrowhead Lc 297 from the Uummannaq district, after 1650 AD. Walloon iron. Total lenght 22 cm.

Fig. 63. The knife, L12.292, from Utorqaat, Kangaamiut, 1650-1750 AD. Walloon iron. Total lenght 19 cm.

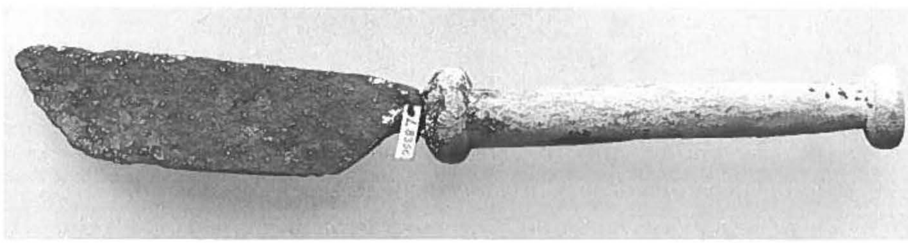

Fig 64. The knife, L 8356, from the Uummannaq district, 1650-1750 AD. Walloon iron. Total lenght 17 cm.

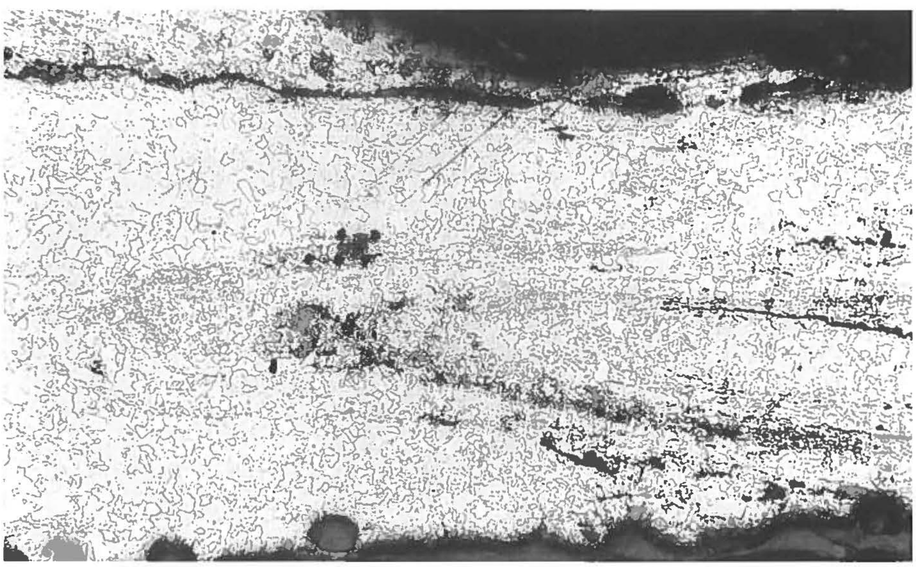

Fig. 65. Polished and etched section through the knife, Fig. 64. The knife has been forged into shape by repeated bending back on itself and forge-welding. A cluster of six hardness indentations mark a site to be analyzed. Side length 5 mm.

Fig. 66. Polished and etched section through the knife Fig. 64. Martensitic surface zone that merges into phosphorus rich ferrite. Side length 1 mm.

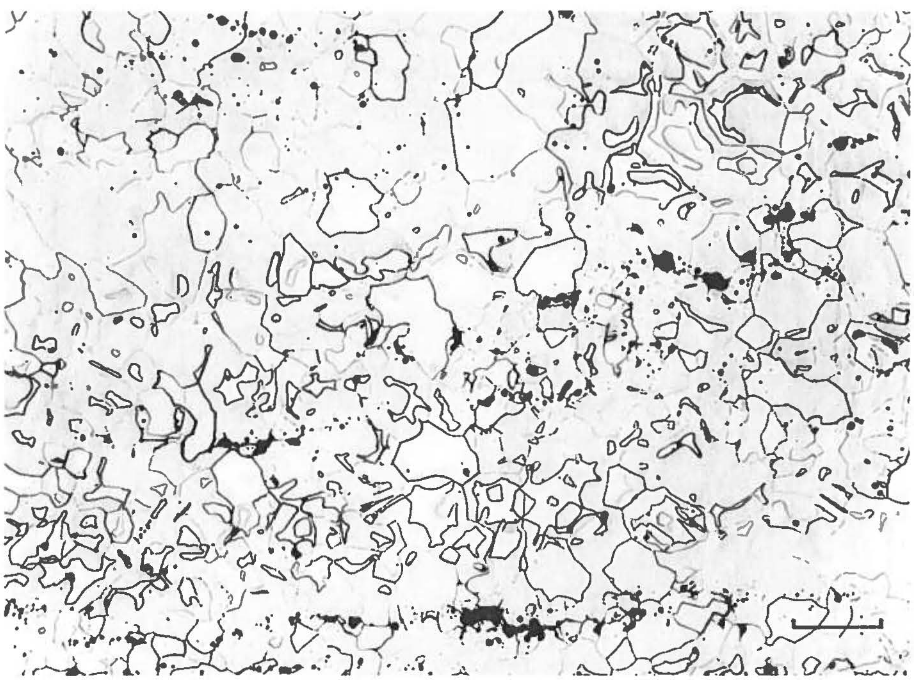

Fig. 67. Polished and etched section through the knife, Fig. 64. Enlarged part of the interior zone of phosphorus rich ferrite with ghost structure. Scale bar 0.07 mm.

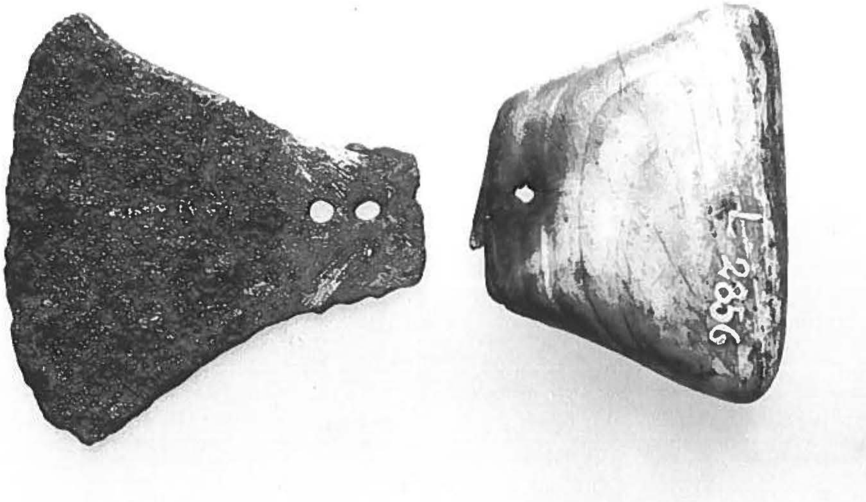

Fig. 68. An ulo, L 2856, from the Uummannaq district, about 1650 AD. Disassembled to show the large wrought iron blade of Walloon origin. Length of blade 48 mm.

of a single element like phosphorus. Instead an evaluation of a multitude of elements is required, and it leads in the present case to the conclusion that a major part of the artifacts excavated from late Inuit settlements has its origin in the Walloon district. Already Mathiassen (1931) who discussed and pictured the adze L12.439, concluded that it had been introduced by whalers in the first half of the 17th century.

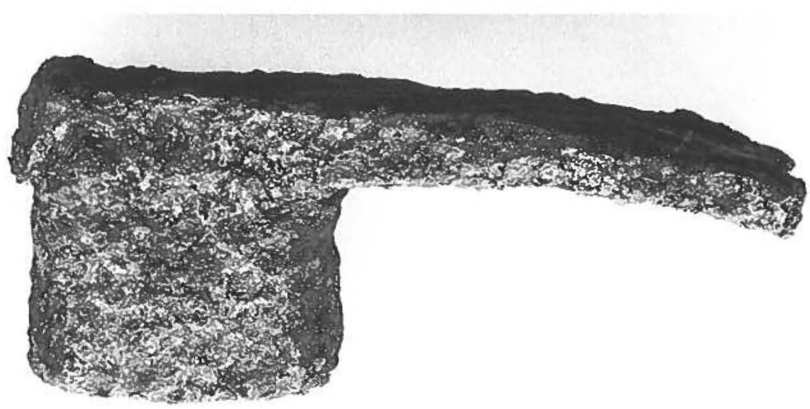

Fig. 69. An adze, L12.439, with a square hole for the shaft to the left, and the blade to the right. Walloon wrought iron. Utorqaat, Kangaamiut, about 1650 AD. Length 11 cm.

Fig. 70. Modern ulo from the 19th century, marked F with a crown above. Made of fined, wrought iron, probably from the Swedish iron works Nissafors, Småland. Total length 98 mm.

The last object in Table 17 is an ulo, a woman's knife (Fig. 70). It carries the producer's stamp a crowned F, which probably is the mark of the Anker Heegaard factory in Copenhagen. Heegaard was a manufacturer of tools and iron ware in the 19th century. The structure is pearlitic-ferritic and three zones with slightly different carbon contents may be distinguished. Phosphorus is below 0.1%. The slags are glassy, and many have been sheared by forging and some additional coldwork. The slag composition is rather unusual because of its low phosphorus and very high titanium and vanadium content. The only source of similar slag compositions that the author is aware of is the ironworks Nissafors at the Nissan River in Småland, Sweden. The slag inclusions of a wrought iron from Nissafors from about 1800 AD is listed in Table 18, last line. There may, of course, have been other ironworks in Småland operating on similar Ti-V-rich ores. Since, however, it is known that Nissafors had a significant export to Denmark in the 19th century, it is concluded that the ulo was manufactured by Anker Heegaard about 1850 AD from Swedish bar iron imported from Nissafors. The ulo probably came to Greenland with the Royal Greenland Trading Company, which shipped significant amounts of finished factory products to the colony (Gad 1976; Petersen 1999).

Hatherton Bay, Inglefield Land

In a previous section the excavations in 1996 at Qeqertaaraq in Hatherton Bay were discussed. On the site where the many iron meteorite fragments from

	SiO_2	FeO	MnO	P_2O_5	CaO	Al_2O_3	K_2O	MgO	TiO_2	V_2O_5	SO_3	Σ	G	F	%P in iron
Nail 18 A	12.9	72.8	2.1	6.3	0.5	1.3	0.1	0.6	0.2	–	1.9	98.7	3.1	9.9	0.3-0.6
Nail 18 B	17.7	63.9	4.7	7.3	1.2	1.7	0.2	0.7	0.3	0.3	1.0	99.0	5.0	10.4	0.3-0.4
Nail 16	20.4	61.9	3.9	7.1	0.9	1.8	0.2	0.3	0.4	0.2	2.0	99.1	4.4	11.3	0.3-0.5
Nail 12	21.2	61.0	0.7	8.4	2.6	1.6	0.1	0.4	1.0	0.3	1.6	98.9	6.7	13.2	0.3-0.6
Kew Garden	17.5	69.2	4.0	4.7	0.3	1.7	0.1	0.2	0.3	0.2	1.4	99.6	2.9	10.3	0.2-0.4
Albert Memorial	17.9	60.7	4.0	8.5	1.7	1.7	0.1	1.3	0.3	0.2	1.9	98.5	6.6	10.5	0.3-0.4
Nissafors	49.8	20.4	3.2	0.2	9.3	6.7	2.1	3.3	2.6	1.1	0.2	98.9	89.9	7.43	<0.1

Table 18. *Four nails from Hatherton Bay compared to English puddled iron and Swedish fined iron. SEM-EDAX analysis of slag inclusions, weight%.*

late Dorset ruins were discovered by detector surveys also ten or eleven nails were found on the surface closer to the beach (Appelt *et al.*1998, Appendix 3). Four of these were selected for metallographic examination and SEM-EDAX analyses (Tables 5 and 18). The nails are rather small, 1-2" long, and frail, and the limited corrosion attack suggests a rather short exposure to the terrestrial environment, compared to that of the artefacts from the Thule culture and the Norse settlements. The metallic structures and the slag inclusions of the four nails are not unlike each others (Figs. 71-72). The metal consists of 25-100 μm equiaxial ferrite grains with large amounts of phosphorus in solid solution, up to 0.6% P. The structures are locally blurred with ghost lines, or display numerous minute etch pits, all characteristic of a significant phosphorus level. The slag inclusions are phosphorus- and sulfur-rich, but otherwise remarkably pure (Table 18). This type of iron can be identified with puddled iron, a quality that was introduced about 1800 AD and dominated the British, French and American markets in the 19th century (Buchwald 1999). The Eiffel Tower was built in 1889 from puddled iron.

For comparison the slag inclusions of British puddled irons are shown in Table 18. From Kew Gardens is analyzed a part of a supporting iron beam from the Royal Botanic Gardens Palmhouse, built in 1848. The other item is a bolt from the Albert Memorial in London, unveiled in 1876. The metal of the two samples is ferritic with phosphor ghosts, and the hardnesses range from 109 to 173, due to variations in phosphorus content and some coldwork. The slags display wüstite dendrites (10-40 vol%) in a glassy matrix, very similar to the Hatherton Bay slags, and the chemical compositions are also very similar. The conclusion is therefore that the Hatherton Bay nails do not belong to some ancient Inuit or Norse culture, or to the whaling fleet, but are 19th century puddled iron products.

In the second half of the 19th century several expeditions, mainly American, were active in Northern Greenland. Elisha Kent Kane had his winter quarters 1853-1855 at Rensselaer Harbor, some 50 km northeast of Hatherton Bay, and

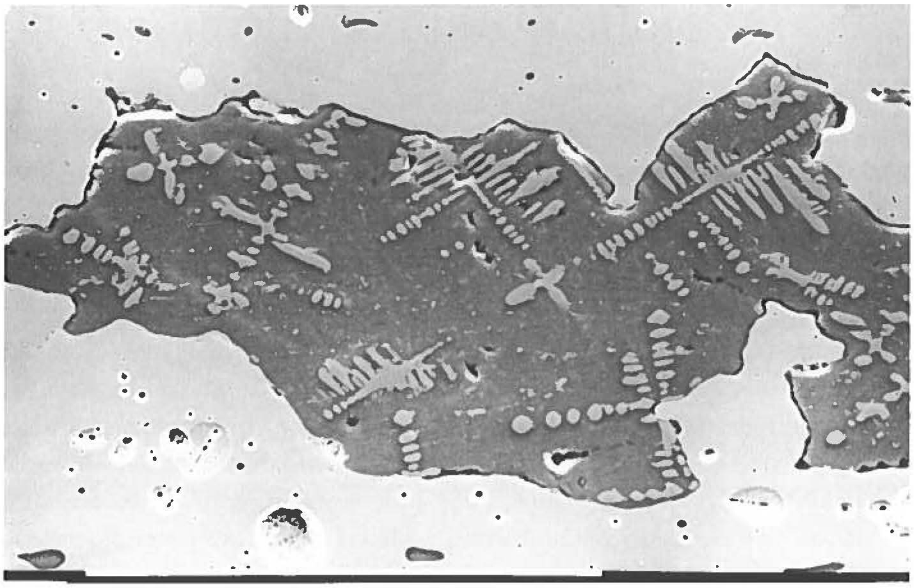

Fig. 71. Polished section through the nail, no. 18A, Hatherton Bay. One large and many very small slag inclusions. Wüstite dendrites in glass matrix. The iron is phosphorus rich (0.5%P), but carbon free. Puddled iron. Scale bar 0.1 mm.

he surveyed among other things the entire coast of Inglefield Land. He made a cache at Life-boat Cove just south of the site where the nails were found, and he noted several ancient Inuit ruins (Kane 1856, Vol.1:48, Vol.2:238). Isaac Hayes who had served as a ship's surgeon on Kane's expedition, prepared a

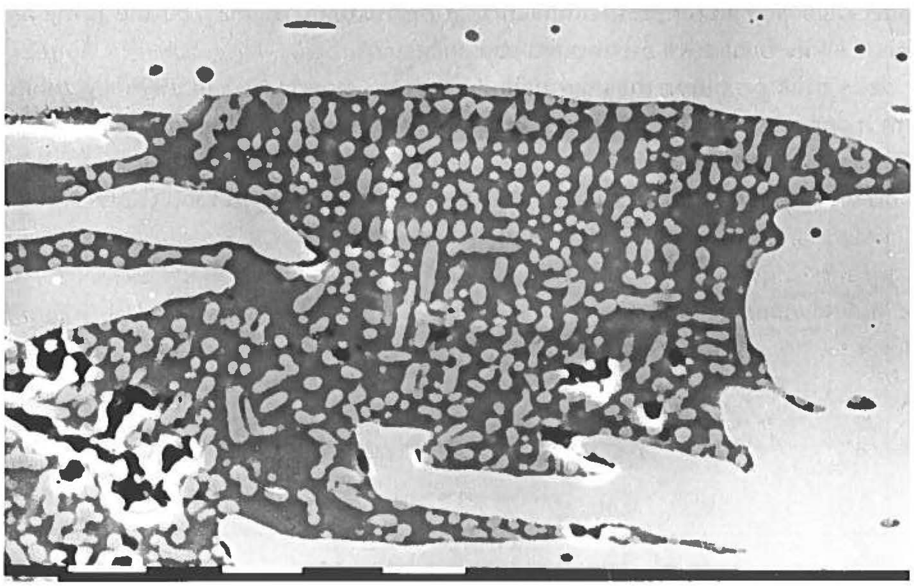

Fig. 72. Another polished section through the nail, no. 18A, Hatherton Bay. The ratio of wüstite to glass varies widely in the same small nail. Some slags are pure wüstite. Puddled iron. Scale bar 0.01 mm.

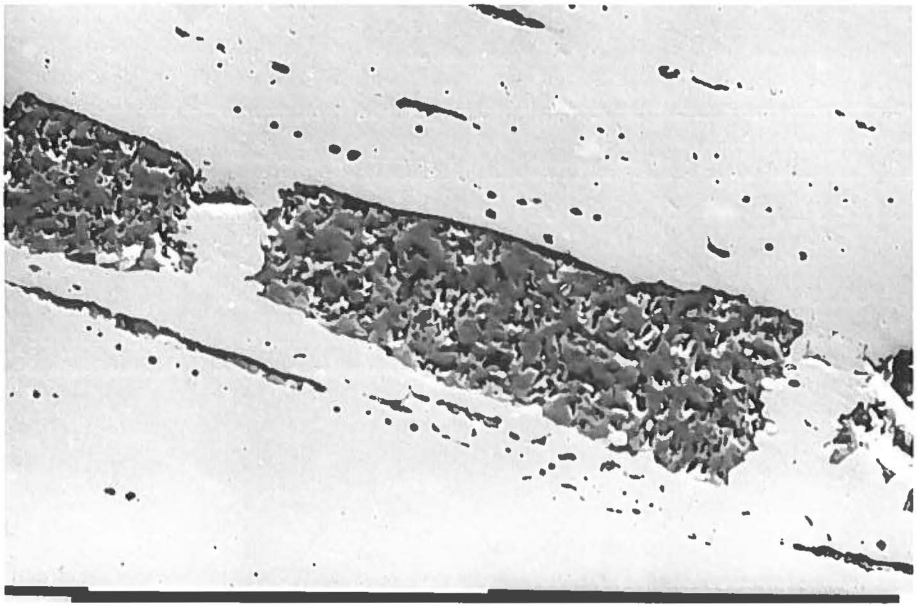

Fig. 73. Polished section through a supporting iron bar, Trinitatis Church, Copenhagen, mid 19th century. Puddled iron. The slag inclusions are thoroughly split due to the action of modern industry's heavy steam-forges or rolling-mills. A host of minute slag particles surround the larger ones. Scale bar 0.1 mm.

few years later his own expedition and surveyed the same coasts (Hayes 1867). Finally, Charles Francis Hall, in 1871 (Davis 1876; Dawes 1967) forced his way on the ship Polaris deep into Smith Sound and the Kane Basin. After Hall had died, in 1871, his crew erected in 1872 a cabin of boards from the wreckage of Polaris on Qallunatalik, a peninsula that may be the same as Kane's Life-boat cove mentioned above.

It is thus probable that the nails found at Qeqertaaraq in 1996 are relics from one of these expeditions. Further support for this supposition is the discovery of a can and two lids on the site (Appelt *et al.* 1998, Appendix 3). It is known that already these early expeditions carried canned food (Kane 1856).

On the hardness of iron alloys

A survey of the hardness variations in iron-carbon and iron-phosphorus alloys is presented in Fig. 74. The underlying causes for these variations are physically entirely different in the two alloy systems. Iron can only dissolve minute amounts of carbon (<0.02%) so if the alloy contains more carbon a new, hard phase, cementite, Fe_3C, appears. Pure ferrite has a hardness of, in practice, 80-90 HV. With increasing amounts of carbon, and thus cementite, the hardness increases to 225-275 at 0.9%C, somewhat dependent upon the detailed microstructure and its grain size. The smaller the grain size, the higher the hardness. At the eutectoid composition, 0.7%C, the structure is composed of about 85% ferrite and 15% cementite, displaying a delicate microscopic intergrowth, the socalled pearlitic microstructure. The appearance and hardness are, besides of the carbon content, also dependent of previous annealing treatments and final cooling rate, so the hardness can in this simplified treatment only be expected to fall inside a rather wide band, as shown in Fig. 74.

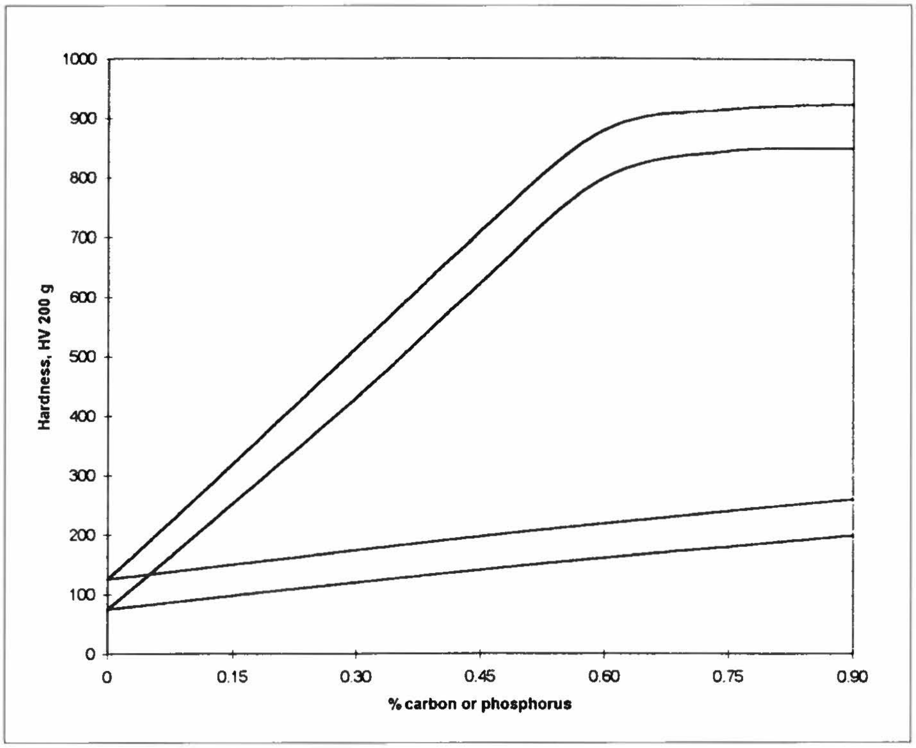

Fig. 74. The hardness of iron-carbon and iron-phosphorus alloys. Normalized and annealed Fe-C alloys are situated within the lower band. Here will also most iron-phosphorus alloys be found. The upper band illustrates the hardness of water-quenched, martensitic iron-carbon alloys.

While iron hardly is able to dissolve carbon, it readily dissolves phosphorus, up to 2.1% at 1050°C. The phosphorus atoms occupy substitutional positions in the iron lattice without forming separate phosphide phases. This leads to the socalled substitutional hardening phenomenon. In ancient irons up to 0.6%P is often present in solid solution, leading to significant hardness increases as shown in Fig. 74. The carbon- and the phosphorus-curves almost coincide. Depending on cooling rate and phosphorus content the ghost structure (see p. 24) may assume various shapes. Also, the iron-phosphorus alloys may on low temperature annealing sometimes precipitate phosphide needles (Fig. 30), leading to slightly lower hardnesses. As for the carbon alloys the hardness values may therefore be expected to be somewhat variable for the same average phosphorus content.

Both Fe-C and Fe-P alloys may be strenghtened by coldwork, the hardness thereby increasing significantly relatively to the shown curves, while the ductility simultaneously decreases. An example of the hardness of steel and meteoritic iron as a function of coldwork has been presented by Buchwald and Mosdal (1985). Finally, the siuation is again different if the alloys are first heated to 800-1000°C, then quenched in water. The iron-phosphorus alloys suffer no essential changes, but the iron-carbon alloys form martensitic structures upon quenching, leading to very substantial hardness increases as shown in the upper curve band in Fig. 74.

Corrosion

Ancient iron in Greenland is rare, not because it has corroded away and has disappeared, but because it from the beginning has been a rare commodity. Iron will survive a very long time on the surface. It will become coated by rust, *i.e.* by various oxides and hydrated iron oxides, and rust will penetrate along cracks and crushed slag inclusions. The object will, however, survive in a recognizable shape for many centuries. The corrosion rate is low in the low average temperatures of Greenland, and in the North the climate is, in addition, pretty dry.

Most commonly the rust is composed of goethite, α-FeOOH, maghemite, γ-Fe_2O_3, magnetite, Fe_3O_4 and lepidocrocite, γ-FeOOH to which must be added amorphous, not yet crystallized ironhydroxides (Buchwald 1989). Hematite, α-Fe_2O_3, which is often reported as a corrosion product, does not occur except in rare cases under tropical conditions.

The scenario is quite different when the iron object is buried in the soil, where the conditions for corrosion are much improved. In the upper soil there is sufficient oxygen and humidity to continuously supply the necessary ingredients. The iron never has a chance to dry out as when exposed on the surface to sun and wind. Furthermore the situation is much aggravated by the presence of chloride in the pore waters of the soil. The chlorine is mainly supplied by rain which near the coast is enriched in chlorine from ocean salt spray. The chlorine ion destroys the natural passivity of the iron surface and forms metastable akaganeite, β-FeOOH with 2-5% Cl in the molecule (Buchwald and Clarke 1989). Akaganeite serves to store chlorine close to yet unattacked iron, and given the right temperature and humidity the corrosion attack may continue. When an earthfound object is transferred to the museum, the attack continues, especially if placed in a humid basement. The best way to stop the attack is to remove the culprit, the chlorine, which almost acts as a catalyst for the destruction of iron. Three methods are currently in use.

The old method of annealing the object for a few hours at 800°C has been in use for three generations (Rosenberg 1917). The chlorine is removed, but the structure of the iron is simultaneously destroyed so from a metallurgical point of view the method can not be recommended – at least not before all relevant metallographic analyses have been performed.

Since about 1960 wet extraction methods have been applied (Wihr 1972). The iron object is exposed to electrolysis in an alkaline soda solution for months followed by washing until the wash water is free of chlorine. The method does not interfere with the structural composition of the iron or the slags, but the process is slow.

In the last decennium a plasma method has been added. The object is

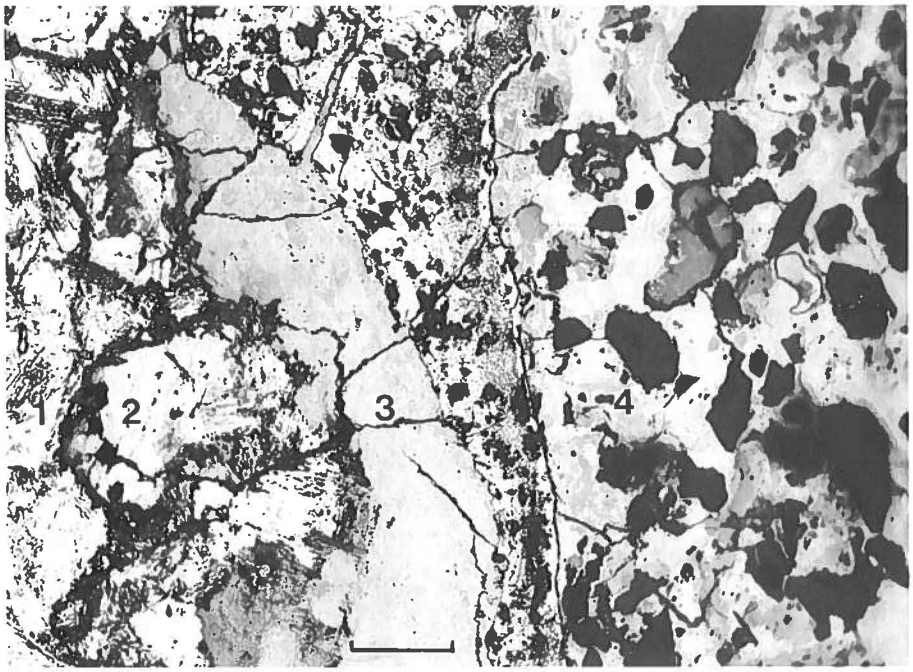

Fig. 75. Polished and etched section through the knife, no. 183, Nipaatsoq. To the left still unattacked martensite (1). Then follows a zone of active akaganeite (2), and a zone of fully oxidized, chlorine free goethite (3). A vertical white line of magnetite marks the original surface of the knife. The right part of the picture (4) shows the ironhydroxide-impregnated soil with embedded quartz particles (black). Scale bar 0.05 mm. From Buchwald 1989.

exposed to a hydrogen plasma at low pressure, about 1 mb, for a week while it is made the negative pole in a high tension field, *e.g.* 1500 V in a D.C.mode (Sjøgren and Buchwald 1991). The object does not suffer structurally, because its temperature does not increase above about 100°C, and the chlorine reacts with the hydrogen plasma and is carried away by slowly flushing with a hydrogen stream. The future of the plasma method appears quite bright.

Most of the material examined in the present paper had been exposed to wet soil conditions for centuries and the iron was therefore rather ruined, many objects to a degree to inhibit metallographic analysis. Three typical examples of the corrosive degradation will be presented below.

Fig. 75 is a section through the knife blade no. 183 from Nipaatsoq, the Western Settlement (Table 10). It shows the corrosion attack as it has developed over some 700 years. To the left, zone 1, is the unattacked martensitic interior. Zone 2 is martensite under transformation to akaganeite with 5% Cl. Zone 3 comprises the fully transformed, "dead" and chlorine-free iron oxides, mainly goethite and magnetite. Finally, zone 4 is the surrounding soil, impregnated by amorphous iron hydroxides. Zone 4 is the crusty envelope around the "fossil" artefact, and quartz particles, black in the picture, clearly indicate the location and extent of the soil. A very fine line, probably of magnetite, indicates the original iron surface. When transferring the knife to a humid building, with say 60% relative humidity, the akaganeite of zone 2 becomes active, and corrosion continues along the boundary between zone 1 and 2. If unattended, the new corrosion products of the interior will force the exterior, rather solid crust to spall off.

Fig. 76 is a section through a piece of scrap iron, no. 175, from the Eastern Settlement (Table 5). Fig. 76a shows a slag inclusion with iron above and below, mapped by secondary electrons. Fig. 76b is a photograph of the same area mapped by X-rays from the element silicon. It is thus a map of the position of the silicon-containing slag. Figs. 76c and d map in the same way the location of chlorine and iron respectively. Pure iron is located above and below the inclusion, which in itself is almost devoid of iron. But note the intermediate, wide zone which is rich in both iron and chlorine. This is the mineral hibbingite, $Fe_2(OH)_3Cl$. The hydroxyl groups can not be mapped by X-rays. Hibbingite is an extraordinary corrosion product, containing iron in oxidation state 2, Fe^{++}, and having about 18 weight % chlorine. It usually forms in cracks and crevices in the "deep" interior, where access to oxygen is limited, but where chlorine-infested water may penetrate by capillary action. Hibbingite is homogeneous and surprisingly stable under museum conditions, transforming however within months to akaganeite, which then takes over as the active, corroding agent.

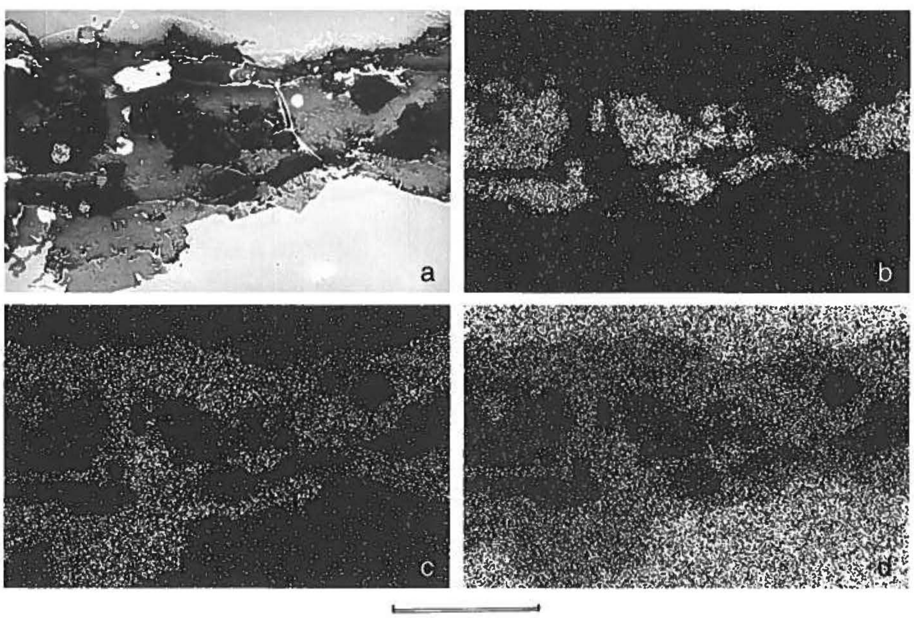

Fig. 76. Four pictures of the same corroded region in the scrap iron no. 175, Abel's Farm. Top left (a) mapped by secondary electrons, top right (b) mapped by silicon X-rays, below left (c) mapped by chlorine X-rays, below right (d) by iron X-rays. The location of the homogeneous corrosion mineral hibbingite, $Fe_2(OH)_3Cl$ with 18%Cl, is shown by the two lower pictures. Scale bar 0.1 mm.

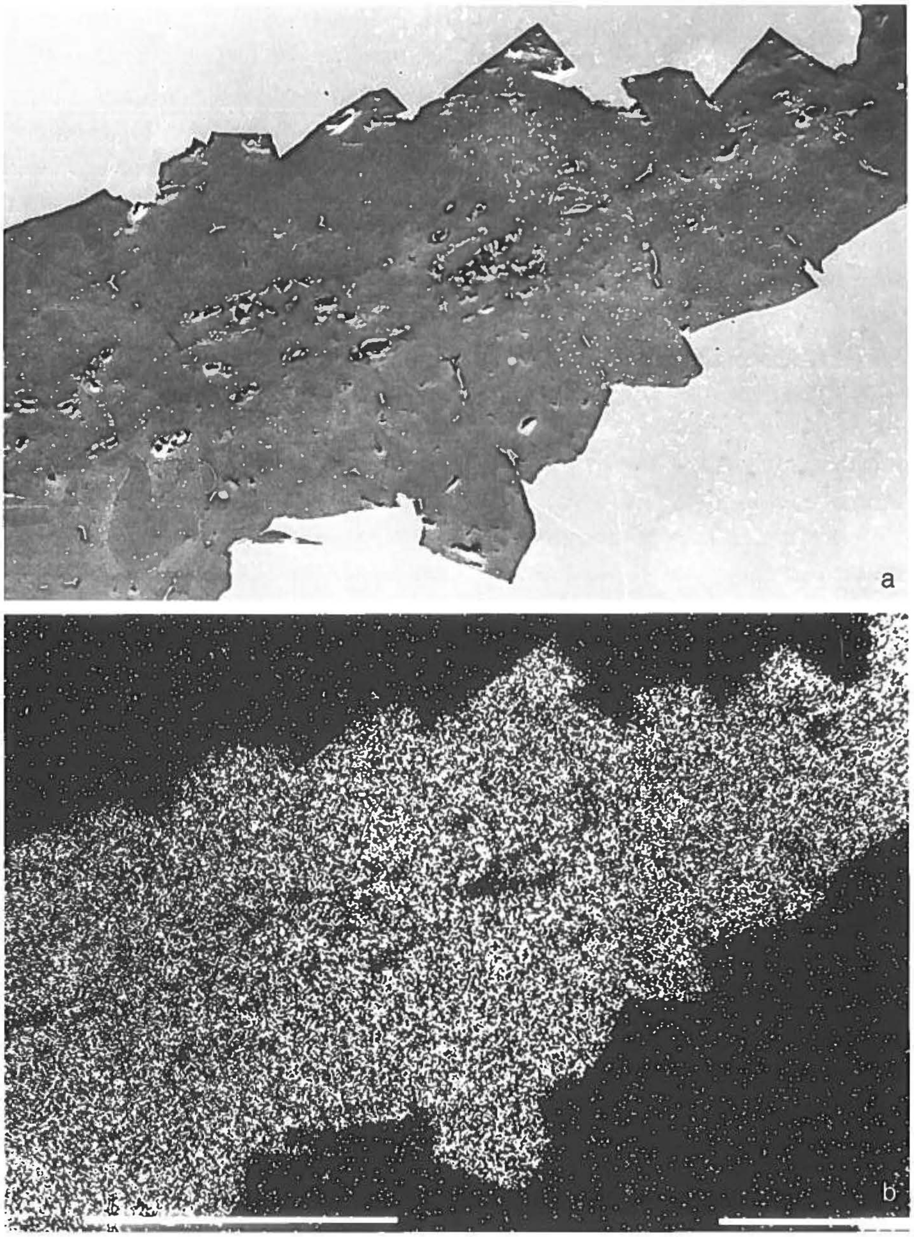

Fig. 77. Two pictures of the same corroded flat piece of iron, no. 992, from the Western Settlement. The top picture (a) taken by secondary electrons. White is iron, grey is homogeneous hibbingite with very small slag inclusions. Note the geometric attack of the iron phase. The lower picture (b) is mapped by chlorine KαX-rays. Black is unattacked iron and slag particles. White is chlorine, indicating the location of hibbingite. Quantitative analysis reveals about 18 weight% chlorine in the hibbingite. Scale bar 0.1 mm.

Fig. 77 is a section through a severely corroded flat piece of iron from the Farm beneath the Sand in the Western Settlement, no. 992 (Table 5). In the center of Fig. 77a is a minute crack along some inconspicuous slags. Along this crevice chlorine-infested water has penetrated and formed a rather extensive cake of hibbingite. Fig. 77b shows its homogeneity with respect to chlorine, and the angular, sharp boundaries against still unattacked iron. On a polished section, hibbingite appears black with a greenish tint. It is stable enough to survive wet metallographic grinding and polishing. Upon etching with Nital it aquires a rough surface with parallel, microscopic striations. On long exposure to humid air it loses its blackish-greenish luster, slowly transforming to orange-reddish akaganeite.

There are other corrosion products, such as vivianite, but they are rather rare and of limited interest to the deterioration of the material. The chlorine containing minerals are, however, a curse.

On the production of iron in Greenland

From the analytical details of the present paper (Tables 6-12) it is clear that the iron material excavated on Norse settlements in high probability can be interpreted as of Norwegian origin. It is certainly different from Danish material. The problem whether it might come from iron production sites in Iceland could not be solved, because insufficient comparative material from Iceland was available. However, in medieval time the trade between Iceland and the Norse settlements appears to have been utterly limited. The major trading routes were those from Bergen and Trondheim directly to Greenland (Gad 1965).

It has been maintained that the Norsemen themselves were able to produce iron on basis of local bog iron ore. This supposition appears to be based solely upon slag examinations by Nielsen (1930, 1934, 1936). While his slag material is no longer available, it is possible to reexamine his detailed reports. These reveal that most of his slags were very small, 2-7 cm in diameter, sometimes of a fragmentary, blistery nature, and sometimes more compact. They commonly contained metallic grains up to 1 mm in size and some charcoal. Most importantly, they were usually reported to contain foreign bodies, stone fragments and quartz grains, smelted in, and in at least four cases remains of animal bones were noted. The largest slag was from Sandnes, it weighed about 300 g and had a diameter of 8 cm. On the whole, Nielsen found that his material was very heterogeneous and had relatively many inclusions of foreign bodies.

The description leaves little doubt that all his slags were either entire plano-convex purification slags or fragments of these. The presence of foreign inclusions of quartz, rocks and bone material are typical for purification slags. They rarely occur in production slags. Although the slags bear witness to activities related to iron handling, they do not belong to the production step, step 2 in Table 1, but from the later steps 3 and 4, and mainly from step 3, the purification of imported blooms. As blooms are heavy, 5-15 kg, they may have served as ballast stones on the Norwegian trading ships. They may have arrived as solid *blastrjarn*, blooms, or perhaps as *fellujarn*, the individual splits of a bloom, or as *teintjarn*, short bars of less than poundweight. The cleaning and forging of this material in the Norse settlements would result in much needed iron, leaving some minor slag fragments as a waste product. Repair work on worn iron objects would result in very minor slags of cinder character, step 4 B of Table 1.

A glimpse of the smithing activity in the *landnáma* period, about 1025 AD, is provided by Fostbrødre Saga (1838: 317, 329): "A man named Bjarne lived with Skuf (at Stokkanes opposite Brattahlid in Eriksfjord). Bjarne was a clever man and much esteemed for his abilities, particularly as a blacksmith ... Bjarne forged for Thormod, after his desire, a broad axe. The top of the axe was straight to the very edge. The edge was not rounded at all, but nevertheless very sharp." Thormod Kolbrunarskjald knew how to wield an axe and killed several of his opponents in Greenland in revenge acts. Finally he found his death in 1030 AD when defending king Olaf at Stiklestad. Bjarne was evidently a cunning smith, and had probably learned his trade in Iceland or Norway before arriving in Greenland. But later generations with limited fuel resources would hardly be able to acquire the same experience in the blacksmithing art.

That iron nails must have been very scarce is proven by the record (Sturlunga Saga 1904: 141) of Asmund Kastanraste who in 1189 arrived to Iceland from Greenland in a ship which was assembled by wooden nails alone and reinforced by strong ropes of (seal)skin. Asmund had been on his way to Norway, but had by heavy weather been forced to land in Iceland. Next year the miserable ship was wrecked.

It is thus likely that the bulk of all iron tools, nails, and weapons were ready made in Norway and shipped as finished items. The slag analytical method is unfortunately not able to distinguish whether a particular object was finished on the production site in Norway or, later, in a forge in Greenland from imported bloomery iron. The very limited evidence of forging activities in Greenland, the awkward methods employed by unskilled blacksmiths (Nørlund and Stenberger 1934) and scattered notes in the literature suggest that most Norse iron objects arrived in finished shape from Norway. Revealing is the contemporary lament from about 1250 AD: "All what is necessary in supporting the Norse population must be purchased in other countries, both iron and construction wood for house building" (Kongespejlet 1926: 50).

On the contact between Inuit, Norsemen and whalers

On ancient Inuit sites, contemporary with the Norse settlements in southern Greenland, there have at various occasions been identified items of Norse origin. In the present paper was reported a Norseman's knife, L3.12673 (Table 17) from Nuulliit in the Thule district and probably from the 13th or the 14th century. In House 4 on Ruin Island two objects of Norse origin were found, a comb and rusted links of chain mail from the same centuries (Holtved 1944, plate 44). The material was rather deteriorated and could not be subjected to metallographic analysis (Buchwald and Mosdal 1985). Mathiassen (1958) reported among other things from a Thule culture settlement at Sermermiut, Disko Bay, two Norse ornamented pieces, a bronze spoon hammered to a wedge, and half a pair of sheep shears of iron. He explained these objects as the result of bartering with Norsemen, travelling to the Disko Bay area in the 14th century. Chess pieces, bronze fragments and combs have been retrieved from other Inuit sites. The direct contact between Inuit and Norsemen is also witnessed by the small wooden figures of Norsemen carved by Inuit in the period 1200-1500 AD (Meldgaard 1977). What the Norsemen acquired through trading with the Inuit is perhaps a little more difficult to identify. Possibly it was in particular furs, meat, walrus tusks, caribou antler and soapstone. Vebæk (1993:80) identified a few small Palaeo-Eskimo items in the early Norse settlement (1000-1100 AD) at Narsaq. It was fragmentary implements of rock crystal, a small arrowhead of quartzite and a knife of grey slate. At one occasion the Norsemen at Nipaatsoq must have acquired the meteoritic arrowhead, Nipaatsoq nr. 162 (Table 14) since it is unlikely that the Norsemen ever extended their Northern voyages to the Thule district, which is the only known finding place for meteoritic iron. The shape of the arrowhead (Fig. 54) is somewhat puzzling, since it is neither typical Inuit, nor Norse. Since the Inuit, however, were the only craftsmen who knew how to work the meteoritic iron occurrences, it is most likely that the Norsemen received a finished, coldworked arrowhead. The Norse blacksmith would not be familiar with coldhammering practice. On the contrary, in Medieval time forging and finishing processes were intimately associated with the charcoal fired hearth.

The presence of iron on late Inuit sites, after the Norsemen had disapeared, has created many speculations. On the basis of observations by David Danell who in 1652-54 made three expeditions to West Greenland it has been suggested that many of these iron objects were of Norse origin and had been obtained when the Inuit scanned house ruins at abandoned Norse settlements (*e.g.* Meldgaard 1977; Gynther and Meldgaard 1983). While this is entirely possible, the present analyses (Tables 17-18) do not contain a single Norse iron but point to other sources, viz. to iron obtained by trading with the whaling ships. Surveys of the history of whaling in Greenland waters may be found in *e.g.* Scoresby (1820), Lubbock (1937), McCartney (1984) and Gad (1986).

The interaction between Inuit and the large ships might take several forms, whether it was an expedition ship on its way to discover the Northwest Passage, a Hudson Bay Company supply ship (Parry 1824: 504) or a ship hunting for seal, walrus and whale (McCartney 1984). The Inuit were eager to obtain knives, needles etc. and could by bartering easily acquire finished items from the sailors. Petersen (1999) even suggests that certain Dutch ships that repeatedly visited Kangaamiut, Paamiut and the Disko Bay region were on very friendly trading terms with the Inuit, decades before Hans Egede in 1721 arrived in Greenland. The Dutch sailors would know the needs of the Inuit and bring the required items ready made from the Netherlands. Evidently, those are among the items now investigated.

On the other hand it is also likely that a casual meeting resulted in the ship's blacksmith assuming the task of manufacturing a tool, *e.g.* an ulo, after the Inuit's wish and design. Many ships carried a blacksmith's forge and iron bar stock in order to manufacture tools and repair faults while at sea. Already Frobisher's inventory lists in 1578 show that this was the case (Fitzhugh and Olin 1993). When Ross (1819) prepared for his search of the Northwest passage he was most meticulous in listing his ships' crews and provisions. He also listed specifically "the presents to the natives on the West Coast of Greenland: 24 brass kettles, 300 knives, forks and cases, 150 butcher knives, ... 2000 needles, ... 2 cwt (about 90 kg) iron hoops, 129 gallons of English gin, ... and 40 umbrellas (!)." The iron hoops – for the reinforcement of barrels – were a soft quality of band iron from which could easily be forged the appropriate fittings and tools.

Direct evidence of the Inuit's interest in obtaining iron is, *e.g.* provided by Parry (1824:210) who was forced to interrupt his search for the Northwest Passage near Winter Island in the Foxe Basin. Here he met with a group of Inuit: "There was nothing which seemed to impress them so strongly with a sense of our superiority as the forge, and the work which the armourer performed with it. The welding of two pieces of iron especially excited their admiration ..... desiring to have some spearheads fashioned out by this means".

Conclusion

The slag analytical method has been employed on a multitude of ancient iron objects retrieved by archaeological excavations in Greenland. They come from Norse settlements in the south and from Inuit sites all along the west coast, from Qaqortoq (Julianehaab) in the south to Washington Land, 2000 km further north. The results may be summarized by selecting the few samples presented in Table 19. The iron has been derived from many countries, Norway, Sweden, The Netherlands and the United States (or possibly England), and both telluric iron from the Disko Bay area and meteoritic iron fragments from the Cape York shower area north of Melville Bay have been used at times.

It is remarkable that no wrought iron can be referred to a Greenland production site. It is still true what Nørlund and Stenberger (1934: 130) emphasized: "no smelting-place has yet been found in Greenland". The scattered slags are few and small and have been found in association with smithies. The present examination of typical slags (Table 12) clearly support the conclusion that they are smithing slags, not production slags. They are mostly of the type purification slags, though a few slags of the manufacturing type are

	Century		Type and Locality	Table	Figure	Origin
Meteoritic iron	12-14th	Inuit	Lancehead, Washington Land	14	53	Cape York
Meteoritic iron	13-14th	Norse, West. Settlem.	Arrowhead, Nipaatsoq	14	54	Cape York
Bloomery iron	13-14th	Inuit	Knife, Nuulliit, Thule District	17	61	Norway
Fined wrought iron	11-13th	Norse, East. Settlem.	Iron bar 230, Abels Farm	9	26-27	Sweden
Bloomery iron	11-13th	Norse, East. Settlem.	Iron 245, Abels Farm	8	22-24	Norway
Bloomery iron	11-14th	Norse, West. Settlem.	Nail 2302, Farm beneath the Sand	11	46-47	Norway
Telluric iron	14-16th	Inuit	Ulo, Uummannaq			Disko
Walloon iron	17th	Inuit	Adze, Kangaamiut	17	69	Belgium
Walloon iron	17-18th	Inuit	Arrowhead, Lc 297, Uummannaq	17	62	Belgium
Walloon iron	1721	Danish	Nails, Haabetz Colonie	16	58	Belgium
Fined wrought iron	19th	Inuit	Ulo, Greenland Trading Comp.	17	70	Sweden
Puddled wrought iron	19th	Expedition debris	Nails, Hatherton Bay	18	71-72	USA/ England

Table 19. *A dozen examples on the use of iron in Greenland in ancient time.*

also present (Table 1), steps 3 B and 4 B. The purification slags of the plano-convex type (*kalotslagge*) develop when a bloom, *blastrjarn, klimp* or *klode* is processed in an open-hearth forge. Their presence demonstrates unambiguously that the Norsemen to some extent imported semiproducts from Norway, otherwise purification slags could not have been formed. When in later times fined wrought iron and Walloon iron was imported no more purification slags formed. They belong uniquely to the bloomery iron production method.

Theoretically some bloomery iron and iron manufacture could have been imported from Iceland. The present examination has not been able to deal with the problem, because no authentic Icelandic iron objects were available for comparison. It is believed, however, that Iceland had little bloomery iron or manufacture to offer, because they had difficulties enough with fulfilling their own needs. The bulk of the provisions for the Norsemen came, no doubt, directly from Bergen, Norway.

The ancient iron objects enclosed in this study are of a humble nature, being nails, knife fragments and scrap iron. The more conspicuous items, such as lanceheads, shears and full knives have been reserved for museum purposes and future studies. The study does, however, not suffer from this limitation. On the contrary, it has been possible to cut and sub-cut the material without regard to possible exhibition viewpoints, whereby a wealth of metallographical and slag-analytical problems as well as corrosion problems could be attacked.

A total of 76 iron fragments from Greenland were examined. They were compared to more than 40 other iron objects from well-documented European sites. About 80% of the Greenland irons could be totally analyzed and identified with some European production site. The rest was either too corroded or too small to carry the necessary analytical information. The corrosion products akaganeite and hibbingite were present in many samples. If the objects be not treated by electrolytic or plasma conservation methods these objects are threatened with total disintegration.

The quality of the examined irons was good. The knives had been hardened by water-quenching, but the optimal hardness of say above 500 HV was not always attained, because the blacksmith had not recognized the sometimes low and insufficient carbon content. Many items, particularly on Inuit sites, had acquired additional hardness by coldworking processes, mainly overhammering with stones. Perhaps this is the most unique characteristic of all Greenland iron items. They have, after forging elsewhere, in Greenland been coldhammered very much, perhaps in an attempt to give the tool a different shape for a function different from what it was originally intended for.

Scandinavian wrought iron is, on the other hand, always hot forged to the final shape, and if alterations were required, the object was again heated and hot forged. The reason for the different approach being, of course, the shortage of fuel and skilled blacksmiths in Greenland.

The phosphorus present in a great many of the objects confers a natural hardness. This does not require water quenching. While unalloyed pure iron in the annealed condition attains hardnesses of 80-90 HV, phosphorus increases the hardness to 200 HV with about 0.6% P in solid solution. Carbon also increases the hardness, to about 225-275 HV with 0.9% C. Quench-hardening of iron with more than 0.6% C may ultimately develop hardnesses of 900 HV (Buchwald 1976), not met with, however, in this study.

Eleven iron objects from Inuit sites after 1500 AD (Table 17), were shown to have nothing to do with irons from the Norse settlements. The slag analytical method revealed that the Inuit had acquired their iron from an entirely different source, the explorers and whalers, that from the late 16th century in ever increasing numbers visited the Greenland coasts – and named them. It appears that most of the irons were derived from the Walloon district around Liège, Belgium. The ship outfitters in Antwerp and Amsterdam relied heavily upon the Walloon iron masters.

The slag-analytical method has its limitations. First, it is necessary to cut and prepare a metallographic section, which in some cases may be undesirable from the point of view of a museum. Second, there are cases when the sections are too small or happen to be too poor in slag inclusions for a meaningful analysis to be performed. Third, the material may be too corroded. Sometimes apparently sound slag inclusions are already under transformation. Some ion-exchange process may be altering the slag composition. In general, if chlorine is detected, the analysis must be rejected, and better preserved slags looked for. With these precautions in mind the slag analytical method should be a helpful instrument in the future.

Acknowledgments

The author would like to thank Inger Søndergaard, Department of Metallurgy, The Technical University of Denmark, for her competent assistance with the scanning electron microscope. Gerda Møller, Edith Johannsen, Toni Larsen and Annelise Steffensen were helpful in selecting, preparing and photographing the metallographic sections. I also thank my former polytechnic students, Claus Traulsen, Gert Mosdal, Arne Jouttijärvi, and Lise Hobbs for their early work with archaeological, metallic artefacts. Samples have been provided by many museums, in Denmark, Greenland, Norway, Sweden, Belgium and England, where the curators have done a great job selecting proper material for examination. While most material has been returned to the appropriate museums, a representative selection of metallographical sections have been registered and permanently stored at The Conservation Department, The Danish National Museum, Brede, for which operation I am most grateful to the curator, Birgit Sørensen. My pleasant sojourn in Eisenbibliothek, Georg Fischer Stiftung, Schaffhausen, Schweiz, in

search of records on Wallonian iron production was amicably supported by the chief librarian, Annette Bouheiry.

References

Andreasen, C. 1980. Nordbosager fra Vesterbygden på Grønland. – *Hikuin* 6:135-146.

Andreasen, C. 1982. Nipaitsoq og Vesterbygden. – *Grønland* 5-6-7:177-188.

Appelt, M., H. C. Gulløv and H. Kapel 1998. The gateway to Greenland. Report on the field season 1996. – In: J. Arneborg and H. C. Gulløv (eds.). *Man, Culture and Environment in ancient Greenland*, pp. 136 -191. The Danish National Museum and Danish Polar Center. Copenhagen.

Arneborg, J. and H. C. Gulløv (eds.) 1998. *Man, Culture, and Environment in ancient Greenland*. The Danish National Museum and Danish Polar Center. Copenhagen.

ASTM 1990. *Standards for Hardness Measurement E 92 (Macrohardness) and E 384 (Microhardness)*. American Society for the Testing of Materials. New York.

Berglund, J. 2000. The Farm beneath the Sand. – In: W. Fitzhugh and E. I. Ward (eds.). *Vikings: The North Atlantic Saga*. Smithsonian Institution Press, Washington.

Berntsen, A. 1656. *Danmarckis oc Norgis fructbar Herlighed*. Bergen. (Reprint edition by Selskabet for udgivelse af kilder til Dansk historie, 1971.)

Björkenstam, N. and S. Fornander 1985. Metallurgy and technology at Lapphyttan. – *Jernkontorets Forskning* H 34:184-225. Stockholm.

Bruun, D. 1918. *The Icelandic colonization of Greenland and the finding of Vineland*. Meddelelser om Grønland 57:1-228. Copenhagen.

Buchwald, V. F. 1975. *Handbook of iron meteorites*. Vol.1-3. University of California Press, Berkeley.

– 1976. En metallografisk undersøgelse af en vikingetidsøkse fra Sønder Onsild. -*Årbøger for Nordisk Oldkyndighed og Historie*, pp. 96-123.

– 1989. Mineralogi og reaktionsmodeller ved korrosion af jordfundne jerngenstande (meteoritter og oldsager). – *Dansk Metallurgisk Selskabs Årbøger*, pp. 41-71.

– 1992 a. On the use of iron by the Eskimos in Greenland. – *Materials Characterization* 29:139-176.

– 1992 b. *Meteoritter, nøglen til Jordens fortid*. Gyldendal, Copenhagen.

– 1997. Grundrids af jernets historie indtil år 1900. – *Dansk Metallurgisk Selskabs Årbøger*, pp. 225-253.

– 1998. Myremalm. – *Geologisk Tidsskrift* 1:1-26.

– 1999. Blæsterjern, kloder og klimpjern. – In: P.H. Jensen (ed.). *Klimp og kloder, jern i middelalderens Danmark*. Blicheregnens Museum, Thorning, pp. 28-62.

Buchwald, V.F. and R.S. Clarke 1989. Corrosion of Fe-Ni alloys by Cl-containing akaganeite (β-FeOOH). – *American Mineralogist* 4:657-667.

Buchwald, V.F. and G. Mosdal 1985. *Meteoritic iron, telluric iron and wrought iron in Greenland.* Meddelelser om Grønland, Man and Society 9. Copenhagen.

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

Davis, C.H. 1876. *Narrative of the North Polar Expedition. U.S.Ship Polaris, Captain Charles Francis Hall Commanding.* U.S.Government Printing Office, Washington.

Dawes, P.R. 1967. Historical records and relics from the North Greenland coast. – *Arctic, Journal of the Arctic Institute of North America.* 20(3):203-212.

Eriksen, E. and S. Thegel 1966. *Conservation of iron recovered from the sea.* Tøjhusmuseets Skrifter 8. Copenhagen.

Erngaard, E. 1973. *Grønland i tusinde år.* Lademann, Copenhagen.

Fitzhugh, W.W. and J.S. Olin 1993. *Archaeology of the Frobisher voyages.* Smithsonian Institution Press, Washington.

Fostbrødre Saga 1838. – In: *Grønlands Historiske Mindesmærker. Vol. 2.* (Reprint edition, Rosenkilde and Bagger, Copenhagen).

Gad, F. 1965. Sjældent farer mænd did. – *Grønland* 3:81-91.

– 1967. *Grønlands historie 1. Indtil 1700.* Nyt Nordisk Forlag, Copenhagen.

– 1969. *Grønlands historie 2. 1700-1782.* Nyt Nordisk Forlag, Copenhagen.

– 1976. *Grønlands historie 3. 1782-1808.* Nyt Nordisk Forlag, Copenhagen.

– 1986. Hvalfangstsituationer ved Holsteinsborg omkring 1820. – *Grønland* 5:125-135.

Godard, C. 1931. *La fabrication des clous forgés à la main.* Enquêtes du Musée de la vie wallone. 3, no. 25-28:55-107. Liège.

Gulløv, H.C. and H. Kapel 1979. *Haabetz Colonie 1721-1728.* Publications of the National Museum, Etnographical Series. 16. Copenhagen.

Gynther, B. and J. Meldgaard 1983. *5 kapitler af Grønlands forhistorie.* Grønlands Hjemmestyre, Pilersuiffik, Nuuk.

Hayes, I. I. 1867. *The open polar sea.* Hurd and Houghton, New York.

Holm, G.F. 1894. *Beskrivelse af ruiner i Julianehaabs distrikt, der er undersøgte i aaret 1880.* Meddelelser om Grønland 6(3):57-145. Copenhagen.

Holtved, E. 1954. *Archaeological investigations in the Thule district.* Meddelelser om Grønland 146(3):1-137. Copenhagen.

Kane, E.K. 1856. *Arctic explorations. The second Grinell expedition. Vol.1-2.* Childs and Peterson, Philadelphia.

Kongespejlet. 1926. Danish translation by Finnur Jonsson. Gyldendal. Copenhagen.

Krogh, K. J. 1967. *Viking Greenland.* The National Museum, Copenhagen.

– 1982. *Erik den Rødes Grønland.* Sagatekster H.Bekker-Nielsen. The National Museum, Copenhagen.

Lorenzen, J. 1882. *Kemisk undersøgelse af det metalliske jern fra Grønland.* Meddelelser om Grønland 4. Copenhagen.

Lubbock, B. 1937. *The arctic whalers.* Brown, Son and Ferguson, Ltd, Glasgow.

Magnusson, G. 1985. Lapphyttan, an example of medieval iron production. – *Jernkontorets Forskning* H 34:21-57. Stockholm.

Mathiassen, T. 1931. *Ancient Eskimo settlements in the Kangamiut area.* Meddelelser om Grønland 91. Copenhagen.

– 1936. *The eskimo archaeology of Julianehaab district.* Meddelelser om Grønland 118(1). Copnehagen.

– 1958. *The Sermermiut excavations 1955.* Meddelelser om Grønland 161(3). Copenhagen.

McCartney, A. P. 1984. History of native whaling in the Arctic and Subarctic. – In: Jacob, Snoeijing and Vaughan (eds.). *Arctic whaling.* University of Groningen, The Netherlands.

– 1991. *Canadian arctic trade metal. Reflections of prehistoric to historic social networks.* MASCA Research Papers in Science and Archaeology 8, part II.

McDonnell, J. G. 1984. The metallurgy of Anglo-Scandinavian knives. – In: Scott, B.G. and H. Cleere (eds.). *The crafts of the blacksmith.* p.87-89.

Meldgaard, J. 1977. Inuit-Nordbo projektet. – *Nationalmuseets Arbejdsmark,* p. 159-169.

Nielsen, N. 1930. *Evidence of the extraction of iron in Greenland by the Norsemen.* Meddelelser om Grønland 76(4). Copenhagen.

– 1934. *Samples of slag from Brattahlid.* Meddelelser om Grønland 88 (1). Copenhagen.

– 1936. *Evidence of iron extraction at Sandnes in Greenland's West Settlement.* Meddelelser om Grønland 88 (4). Copenhagen.

Nilles, P. 1997. The Walloon immigration and the Swedish steel industry. – In: B. Berg and K. Fernheden (eds.). *Iron and Steel – today, yesterday and tomorrow.* 3: 59-74. Jernkontoret, Stockholm.

Nørlund, P. 1929. *Norse ruins at Gardar.* Meddelelser om Grønland 76(1). Copenhagen.

– 1967. *De gamle nordbobygder ved Verdens ende.* The National Museum, Copenhagen.

Nørlund, P. and M. Stenberger 1934. *Brattahlid.* Meddelelser om Grønland 88(1). Copenhagen.

Parry, W.E. 1824. *Journal of a second voyage for the discovery of a North West passage.* John Murray, London.

Peary, R. 1898. *Northwards over the "Great Ice". Vol.2.* Stokes, New York.

Petersen, R. 1999. Hvalfangernes tid. Missionærerne. Handelen. – In: B. Gynther and A. Møller (eds.). *Kalaallit Nunaat, Gyldendals Bog om Grønland,* p.187-206. Gyldendal, Copenhagen.

Pringle, H. 1997. New respect for metal's role in ancient arctic cultures. – *Science* 277:766-767.

Rosenberg, G.A. 1917. *Antiquité en fer et en bronze.* The National Museum, Copenhagen.

Ross, John 1819. *A voyage of discovery, made under the orders of the Admiralty, in his Majesty's ships Isabella and Alexander ....* John Murray, London.

Roussell, Aa. 1936. *Sandnes and the neighboring farms.* Meddelelser om Grønland 88(2). Copenhagen.

– 1941. *Farms and churches in the mediaeval Norse settlements of Greenland.* Meddelelser om Grønland 89(1). Copenhagen.

Scoresby, W. 1820. *An account of the Arctic regions with a history and description of the Northern whale-fishery.* Vol. 1-2. (David and Charles Reprint edition 1969).

Sjøgren, A. and V. F. Buchwald 1991. Hydrogen plasma reactions in a D.C. mode for the conservation of iron meteorites and antiquities. – *Studies in Conservation* 36: 161-171.

Sturlunga Saga 1904. I dansk oversættelse ved K. Kaalund. Vol.1. Gyldendal, Copenhagen.

Sørensen, Søren A. 2000. *Hørup, en sjællandsk værkstedsplads fra romersk jernalder.* Museet Færgegården, Frederikssund.

Vebæk, C.L. 1963. Kolonisation af Grønland. – In: *Kulturhistorisk Leksikon for Nordisk Middelalder,* Vol. 8:650-658.

– 1992. *Vatnahverfi. An Inland district of the Eastern Settlement in Greenland.* Meddelelser om Grønland, Man and Society 17. Copenhagen.

– 1993. *Narsaq- a Norse landnáma farm.* Meddelelser om Grønland, Man and Society 18. Copenhagen.

Wihr, R. 1972. Elektrolytische Metallentsalzung. *Arbeitsblätter für Restauratoren.* Heft 2, Gruppe 1 : 31-48.

Yernaux, J. 1939. *La métallurgie lîegoise et son expansion au XVIIe siècle.* G. Thone, Liège.

MONOGRAPHS ON GREENLAND

PUBLISHED BY THE DANISH POLAR CENTER

Iron was probably never produced in Greenland, neither by Norsemen nor by Inuit. However, objects of iron have been found in archaeological excavations. How was this iron traded into Greenland?

It is shown in this book that the Norsemen depended on ready-made iron tools imported from Norway, and also forged minor items from blooms smelted in Norway.

The Inuit had access to three types of iron: meteoritic, native and wrought iron. After about 1600 A.D. their major source was wrought iron provided by whaling ships and research expeditions. It is shown here, that much of this iron was produced in the Netherlands by the Walloon method.

Vagn Fabritius Buchwald, born 1929, is a retired lecturer in metallurgy at the Technical University of Denmark. He has introduced the slag analytical method for characterizing ancient iron objects and is also an expert on meteorites. He has recovered numerous meteorites, among them the 20 tons Agpalilik mass from Cape York.

Printed in Denmark by Special-Trykkeriet Viborg a-s