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PIT METALLURGY?

ARNE ESPELUND

Institutt for materialteknologi, NTNU, 7491 Trondheim, Norway

ABSTRACT

Small pits in the ground are often encountered as secondary elements at excavations. In Norway most attention has been paid to flagstone-lined pits named /hellegryte/ with small amounts of slag at Møsstrond in Telemark, assumed to represent primitive ironmaking around year 600. However, a careful materials balance shows that this is wrong. Another type is represented by cooking pits, found in great numbers after the removal of top soil by machines has become a regular practice. Slag has been found at some of them. After a presentation of the problems of bloomery ironmaking the author claims that these elements may have been used for a /pretreatment/ of bog iron ore, in order to create the iron silicate fayalite from wustite and silica as a separate step. It remains to prove this allegation in practical experiments.

Key words: pits, pretreatment, fayalite

INTRODUCTION

During excavations of graves, housegrounds etc. in Scandinavia certain small pits, mostly lined with stones, are often encountered as secondary elements. Their function is not always evident as normally only cracked stones and remains of charcoal are present. They are mostly defined as “cooking pits”, used for dry cooking of meat, probably also fish end vegetables. The practice seems to have consisted of two variants: heating of stones in the same pit prior to addition of food to be cooked, or heating in a separate fire of stones, which were subsequently transferred in the hot state to the cooking pit. The cooking of meat in this way is nowadays common among field archaeologists on festive occasions, creating a good mood and possibly some afterthought.

A great survey of such pits has just been published by the University Museum in Oslo (Gustafson & al. 2005), with 20 papers by archaeologists from Norway, Sweden and Denmark. Apart from examples from the three Nordic countries there are presentations of cooking of food in similar pits in New Guinea, Polynesia, Australia and New Zealand, Tonga and America. A majority of such pits seem to have been in use during the Early Iron Age in Scandinavia. Martens (2005) points out that the pits dominate in the area from Lower Saxonia and Mecklenburg, Germany in the south to Trøndelag, Norway in the north. It is laudable that attention by archaeologists is paid to simple objects of this kind, in a profession much concerned about ornaments, typology and aestetics. It is clearly linked to new methods used in excavations, such as careful removal of top soil with modern machines, thereby opening much larger areas than by the use of conventional methods. Above all this has led to new impressions of house grounds and whole farms. In “my” province Trøndelag much insight has been gained about such patterns in fertile parts near Trondheim in the Early Iron Age. By using this method, cooking pits are easily seen as rounded, black areas below the top soil. The number of pits revealed by this method has increased drastically.

It seems that most archaeologists think that some cultic rituals were associated with cooking of food in these pits. It is quite conceivable that people gathering for a common meal took part in some ritual.

FLAGSTONE-LINED PITS (*HELLEGRYTE*)

However, heating in pits is also typical for the flagstone-lined and dug-in furnaces, by archaeologists named *hellegryter* . This name was first given to such furnaces found in Gudbrandsdalen by T. Dannevig Hauge. At the site Skrautvål in Valdres he describes a furnace lined with 6 stones, about 45 cm deep and with a cross section of 50 cm in the bottom, about 60 cm in the top (Hauge 1946:82-83). No inlet for air was found. Very large quantities of slag characteristic for the early iron age (pieces weighing up to 50 kg) were found at the site, obviously created in a furnace with slag pit, characteristic for the region and the period in question. The large furnace and the pit existed side by side. By giving it the name *blestergrop,* it is clear that Hauge associated also the pit with ironmaking.

This type of find has caught much more attention at Møsstrond in Telemark, a place well known in Scandinavia for ironmaking as a result of professional archaeology in the years about 1960 – 1980, well presented in a large book (Martens/Rosenqvist 1988). 9 finds of *hellegryter* are presented in the book (:70), with hearth diameter from 45 to 70 and height 30 to 40 cm. The shape and proportions, as well as the use of flag stones remind of the find by Hauge, at a place some 300 km north of Møsstrond. Some of the furnaces have a hole used as an air inlet, others not.

The new ^{14}C-dating was successfully tested at Møsstrond. The *hellegryte* was found to have been in use during the period AD 550-800. At each site with this type of pit only small amounts of slag were found. By means of a few analyses the co-author A.M. Rosenqvist claimed that the output of smelting had been very low due to poor technology in this early period. A drawing from the 1970s of an interpretation of their use is shown in fig. 1.

However, for the calculation of output she used analytical values for manganese oxide, with 0.18% in the ore and 0.25% in the slag as evidence. Due to a removal of iron an increase in *percentage* is to be expected for oxides remaining in the slag. The values quoted are very small, so that analytical errors may play a role. By using as an alternative the values for silica SiO_2, present in much greater amounts, a decrease is found. A calculation of output based upon iron and silica leads to a *negative* value, which expresses that the *hellegryte* definitely was not used for iron production (Espelund 2004). A schematic presentation of mass balances for bloomery ironmaking is shown in fig. 2.

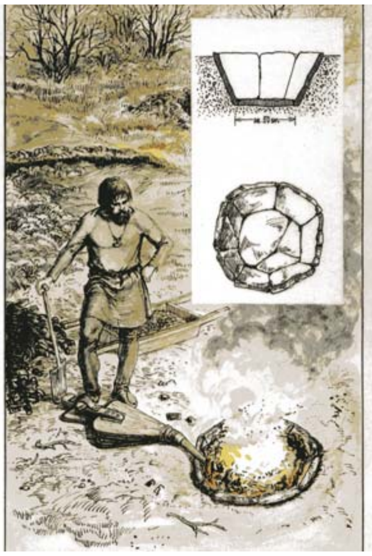

Fig 1 - The bloomery ironmaker at Møsstrond operating his hellegryte, *as conceived by archaeologists in the 1970s. Drawing Ø. Hansen. In Hagen (1975)*

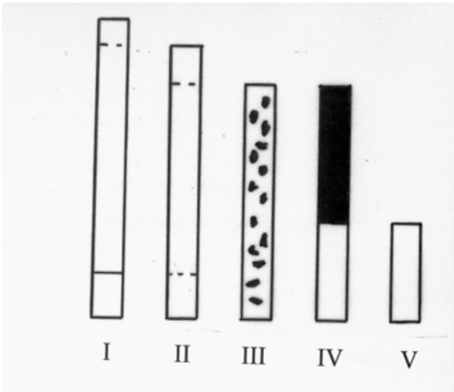

Fig 2 - The development with respect to weight when going from ore to metal and slag: I – composition of roasted ore, with SiO_2, MnO and Al_2O_3 in the lower part, major part Fe_2O_3., II – loss of weight due to possible pre-reduction of Fe_2O_3 to FeO III – formation of Fe from FeO IV – separation of metal and slag V – remaining slag containing FeO (about 60%), SiO_2 (about 24 %), MnO and Al_2O_3, after removal of iron

On the other hand, the area is known for a very large production of bloomery iron in the period 1100 –1275 AD, possibly about 20 tons per year (Espelund 2004). Along the shores of Lake Møsvatn where flooding as a result of dam building has washed away the peat large amounts of small pieces of brown bog iron ore are still found among gravel and stones. It is an exception as this resource has been consumed at most places with early ironmaking in Norway.

This early interpretation needs a revision as during the last 10 – 20 years a very large and professional production of bloomery iron during the Roman Iron Age in Norway has been documented. It is summarized by this author, who also has taken part in the excavations around Trondheim (Espelund 1999/2005). The furnace of the period was a shaft furnace with slag pit, apparently of two different types. Careful mass balances have proven that the output of smelting was between 1 and 1.5 kg of metal for each kg of slag (Espelund 2005). Therefore the alleged small amount of iron obtained in the *hellegryte* is an anachronism. The raw material bog iron ore was abundant at Møsvatn, and a successful technology had been in use in large parts of Norway at least since the turn of the millennium and during some 600 years.

The explanation for the lack of early, successful ironmaking by the people living in Møsstrond appears to be connected with the *type of wood* in the area. Lake Møsvatn lies at about 1000 masl and is surrounded by large swamps and groves with birch. Botanists agree that pine hardly was growing in the area during the last 2000 years. The furnace with slag pit, in use in Norway from Pre-Roman time and up to about 600 AD, was namely fired with pine, which has a large content of resin and tar. Such wood was evidently put directly into the shaft of the early furnaces. When in operation, the wood ignited immediately. Combustion took place in two steps: in step 1 inflammable gases were evolved and created a chimney fire mainly above the rim of the shaft. Air was sucked into the furnace through holes, placed just above the ground. At the same time charcoal was created. It sunk as a part of the charge, was ignited and burned in step no. 2 in the normal combustion zone. *No bellows were needed.* This explanation seems to explain why so many bloomery sites from the Roman iron Age – Migration period are found near the forest line. The slow-growing pine contains much resin and tar, more than pine at lower altitudes.

Some time between 600 and 800 AD a new technology with smaller, side-tapped furnaces was introduced. It was in use until about year 1300 AD, at a few places until 1500 (Rolfsen 1992, Espelund 2004). The number of furnaces from this second period, also including Møsstrond, may reach 10 000. They were no longer charged with wood, but with charcoal and fired with forced air from bellows. Now the type of wood no longer seems to play a role. Pieces of charcoal of birch and pine, as well as spruce have been recovered at such sites, evidently equivalent for iron production when first transformed into charcoal. The enormous iron production at Møsstrond after about year 1000 is clearly connected with the new type of furnace and the use of birch, a local resource. There are numerous charcoal pits in the area.

Conclusion: Based upon general features, and also some analyses, it is strongly indicated that the hellegryte at Møsstrond and Skrautvål, Valdres was not used for extraction of iron, in the way done at normal bloomery sites during the first six centuries AD.

We must look for an alternative function. We can start with a second look on analytical values.

As a single value for bloomery slags % SiO_2 is most significant. A normal slag after extraction of metal contains about 25% SiO_2, irrespective of country, period and process (Espelund 2005). For the hellegryte type of slag at Møsstrond the average is 10.0 % (:171). It therefore reminds of the composition of ore while the appearance is like that of normal slag. *Could it represent a pre-treatment of ore*? In case, such a treatment must be based upon some experience rooted in the metallurgy of the process.

THE METALLURGY OF THE BLOOMERY PROCESS

The general picture of the process is based upon combustion of charcoal, thereby creating a temperature around 1100 ^{o}C and a CO-rich gas. When the operation is successful, this gas mixed with nitrogen has to reduce the iron oxide to a solid bloom of iron, that could be forged, i.e. with a carbon content between 0 and about 0.7% C. The gangue minerals of the ore, containing mainly SiO_2, MnO and Al_2O_3 must be separated from the metal and removed as a liquid, fluxed by remaining FeO.

The main problems are how to avoid too much carbon in the metal, and to achieve fluxing of the gangue minerals. For a moment let us turn our attention to the blast furnace process, in use in Scandinavia from about 1300 AD until present day, where liquid pig iron containing about 4.5% C as well as slag are tapped from the furnace. The metal is brittle and can only be used as cast iron or transformed into steel by oxidizing refining. The slag is practically FeO-free. Fluxing of the gangue minerals is done with CaO, added to the charge. The relations between metal and carbon are read from the iron-carbon diagram, which shows a eutectic (low-melting) temperature of 1145^{o}C and a composition about 4.5% C in the metal.

This diagram also expresses that saturation with carbon below the eutectic temperature of 1145 ^{o}C will lead to about 2% C in the metal, also a metal that hardly could be forged. The question is how the carbon content can be limited. The answer is by using the chemical equilibrium between carbon in the metal and FeO in the slag, in short *slag control*. This is expressed by the reaction FeO + $\underline{C}$ = Fe + CO, and illustrated in fig.3.

The problem of the bloomery process is not reduction to metal, the problem is *slag formation.*

The main phase in solid bloomery slag is fayalite Fe_2SiO_4 , therefore the required reaction can be written

$$2\ FeO + SiO_2 = Fe_2SiO_4.$$

It is likely that Fe_2O_3 while sinking in the shaft of the furnace will pass through the steps

Fe_2O_3 – Fe_3O_4 – FeO and end up as fragments of solid and carburized metal, together with unreacted silica. This is illustrated in fig 4.

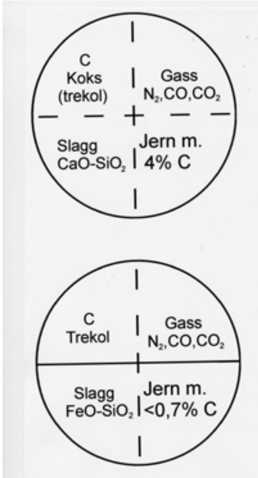

Fig. 3 - Schematic illustration of the phase relations in the bottom of the blast furnace as well as the bloomery furnace. The four phases carbon, metal, slag and gas are allowed to be in chemical equilibrium, thus making the blast furnace process in principle easy, while the bloomery process requires a separation between metal and slag on the one side, and carbon and gas on the other. It is shown as a heavy line. A total equilibrium is not permitted. In short this expresses the difficulty for the bloomery process, demonstrated by the limited succsss of numerous modern experiments.

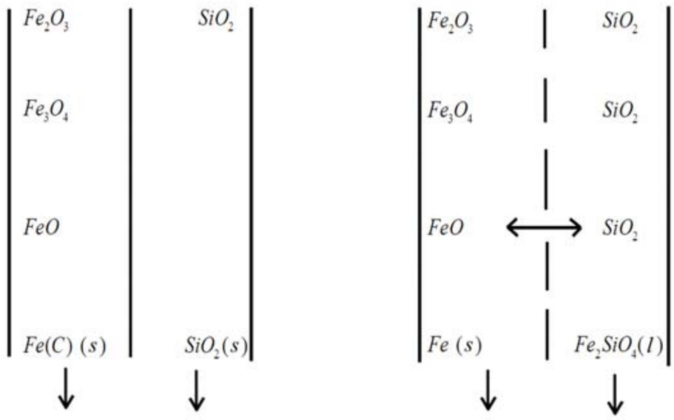

Fig. 4 - Schematic illustration of successful smelting to solid iron and liquid slag (right), with ample contact between FeO and SiO_2, and a full reduction to carburized metal and unreacted, solid silica (left).

Formation of fayalite would be enhanced by a long retention time at moderate temperature. Also one must expect a tendency for formation if iron oxide and silica are intimately mixed. Finely disseminated silica can be formed by precipitation from superheated water.

Of course formation of silica by pre-treatment of ore seems to be a genial way to solve this problem. If the raw material added to the bloomery furnace contains silica as fayalite, in addition to free FeO, the running of the furnace should become very simple. As will be shown, this appears to have been the case at Sjøholt, Sunnmøre and also at Møsstrond.

Evidence for pre-treatment.

The first evidence for a pre-treatment of ore was found for slag-like samples from Sjøholt, Sunnmøre (Espelund & al., 2005).

	FeO	Fe_2O_3	MnO	SiO_2	Al_2O_3	P_2O_5
Sample no. 6	84.5	(93.9)	0.64	7.55	4.0	0.17

This is an excellent raw material for bloomery ironmaking. Phase studies by XRD revealed presence of wustite FeO, fayalite Fe_2SiO_4 og goethite FeOOH.

A sample was cut, polished and studied by the microprobe. It showed as expected a fine-grained mixture of FeO in a matrix of silicate, mainly fayalite.

A micrograph of a similar sample from the site Nystaul is shown in fig. 5. The grains of FeO are much larger than in the sample from Sjøholt.

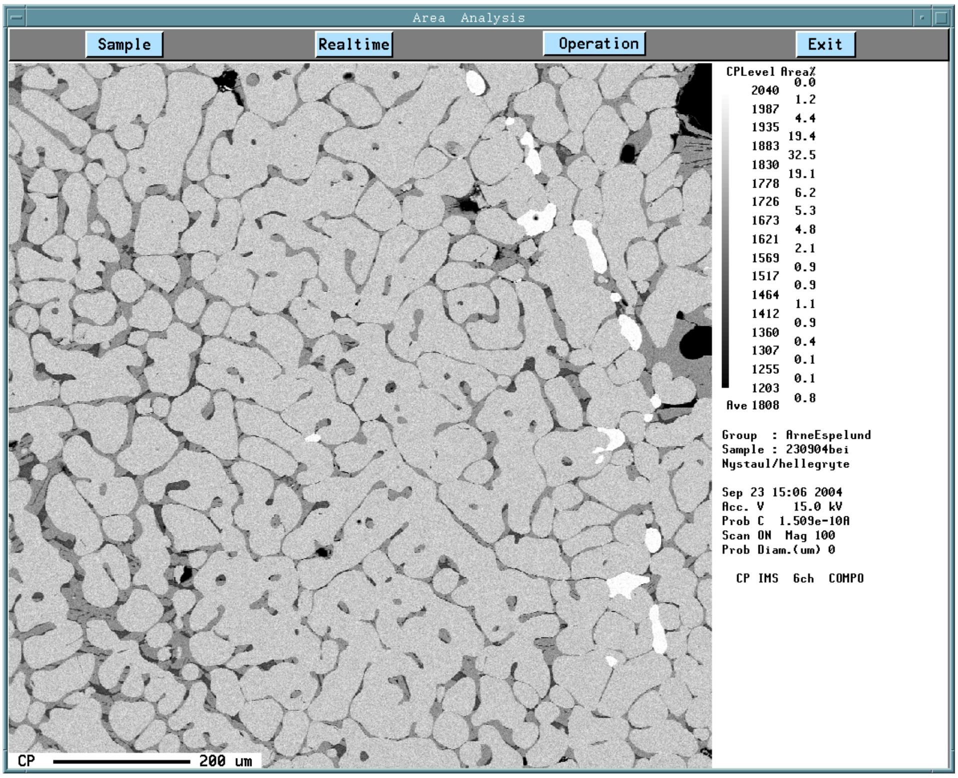

Fig. 5 - SEM-analysis of slag-like sample from Nystaul, Møsstrond. Chemical analysis in w.%: FeO 90.5, SiO_2 6.33, MnO 0.25, Al_2O_3 0.63, P_2O_5 0.138 %. White metallic iron, light grey FeO, matrix silicate slag.

It is strongly indicated that bog iron ore was exploited at Møsstrond during the period 550-800 AD. However, only a pre-treatment of ore in pits named *hellegryte* was undertaken. The semi-product, a type of sinter, was brought to some other place with pine and used as a raw material for conventional smelting in the typical bloomery furnace of the period: a shaft furnace with slag pit. This type of furnace has been found at e.g. Fitjan in the community Tokke, about 20 km from Møsstrond.

This seems to prove that our forefathers, by splitting it into two consequtive processes were masters of bloomery ironmaking, and organized it in a genial way. Most likely, once established, bloomery ironmaking became simple when one difficult process was replaced by a pretreatment which gave an excellent raw material for the smelting proper and resulted in solid metal and liquid slag.

Hurdalen – another example?

In the large publication about cooking pits, only the author J. Bergstøl mentions slag as a part of the find material, after excavations in Hurdalen (Bergstøl 2005). He therefore also refers to ironmaking and/or processing. At this place some 3000 m^2 were unearthed. In fig. 6 the excavated area is shown. Out of 126 registered pits slag was found in 22, in addition a shaft furnace with slag pit and a few smithing hearths. In the near future the present author will ask for permission to analyze some slag pieces, in order to find out if the slag represents pretreated ore or the final slag after extraction.

Fig. 6 - The excavated area in Hurdal, according to Bergstøl (2005). Crosses mark smithing hearths, a triangle the shaft furnace, grey points cooking pits with slag, black points cooking pits without slag

It is normal that the field archaeologist will search for elements that fit into established patterns. Because of obvious advantages, it is not likely that Møsstrond and Sjøholt were the only places where the first step of two was performed. At future excavations emphasis should be put also on small amounts of slag. Large amounts are not to be expected as it was a valuable semi-product, to be used in the reduction furnace.

While step I is documented as a separate process during the early iron age, probably performed in pits, a pre-treatment is also conceivable in the characteristic Medieval furnace, by using a large surplus of ore relative to charcoal. This appears to be a part of the “bloomery story” at places like Gråfjellet in Østerdalen, where large-scale excavations were performed during the years 2002-2005.

CONCLUSION

After the introduction of new methods in Norwegian archaeology, large areas have been cleared of the top soil. Thereby new elements, such as small pits with cracked stones and charcoal are found. They are named cooking pits, but the large number indicates that they also served a second purpose, such as cultic ceremonies.

The use of pits for heating purposes has also been revealed by excavations in areas known for ironmaking. They were at first conceived of as reduction furnaces. However, the present author has shown that this function is unlikely. Instead it is suggested that they were used for pretreatment of ore, in order to create the important slagforming constituent fayalite Fe_2SiO_4 and facilitate the smelting in step No. 2. The chemical analysis as well as a study by the scanning electron microscope supports this interpretation. In the paper a sample from the site Nystaul at Møsstrond, is shown.

Of the many reported sites with cooking pits slag has been found in Hurdal only. It is not unlikely that some of the cooking pits were used for pre-treatment of ore. This may also be the case at other places, not revealed hitherto as archaeologists are not familiar with this question and a possible third function.

In a simple experiment two months ago in a pit reminding of a *hellegryte,* a maximum temperature of $800^{o}C$ was measured. The ore had been transformed into Fe_3O_4 and an incipient formation of fayalite could be observed.

We Scandinavians know that man-made iron was first made in or near Asia Minor, now Anadolu. But we know little about the early method. It took some 1000 years before ironmaking was introduced in the Nordic countries. Perhaps the two-step process outlined in this paper can explain how iron was made in

Continental Europe. Perhaps the main secret was linked to such a two-step process.

It is striking that a two-step process was also required for the successful production of copper from a raw material containing next to copper also iron and sulphur, with the common mineral chalcopyrite $CuFeS_2$.

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