The Civilisation of Iron

FROM PREHISTORY TO THE THIRD MILLENNIUM

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CHAPTER 3

Tradition and Innovation: Early Blast Furnaces in Central Europe between the Early and Late Middle Ages*

Albrecht Jockenhövel and Christoph Willms

The Westphalia University (Münster, Germany) has carried out two important archaeometallurgical projects which have achieved significant results concerning the technical and structural changes that occurred between the Early and Late Middle Ages in regions of central Europe noted for their iron metallurgy. It has been demonstrated that, in areas such as Dietzhöltzal, direct production of iron blooms continued until the 13th-14th century, and waterpower was used later with the adoption of the early high bloomery furnaces (or ***stucköfen***). At the same time, the indirect method appeared in other regions, especially in the Märkisches Sauerland where the early blast furnaces operated (***floßöfen***). The origins of this new technology are still not completely known, but it was certainly a revolutionary process.
From a chemical and metallurgical point of view, it consists of the change from the production of wrought iron (by the direct process) to that of cast iron (by the indirect process). In the Lahn-Dill region of Hessen, raw metal was obtained directly from enclosed bloomeries until the 13th-14th century (***rennofen*** or ***rennfeuer***), and later from high bloomery furnaces (***stucköfen***), that used waterpower to drive the bellows. From the 17th century onward, iron was obtained reducing the pig iron extracted from blast furnaces (***floßöfen***) that also used water-powered bellows. In all these cases, charcoal was used as the fuel. The use of water-powered bellows has modified the landscape and left traces that are still visible today.
The old bloomery sites, situated in hilly country, near springs and small streams, were abandoned; the new furnaces were built downstream, near larger rivers, whose waters were diverted by dams, canalised and regimented in basins. The earliest industrial districts (***industriegassen***) were located in these valleys, where they are still in part operating today.
The use of waterpower, wood and ore obviously was affected by the rights of land owners. Economically, the use of water-powered furnaces meant substantial financial investment for future profit. The concept of ownership was modified in these iron metallurgy sites and in their social structure as well. There are few written references to the vast changes that occurred in early ironmaking between the 10th and the 13th centuries in central Europe; in many cases, we have to rely on archaeological research, even up to the 16th century.
The interdisciplinary research in this area has progressed mainly thanks to the grants of the Volkswagen-Stiftung Hannover. The first results show that, while the direct production of iron in high bloomery furnaces reached a peak in many regions, in other regions blast furnaces

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equipped with water-powered bellows started to take their place in the course of the Middle Ages. The change took place gradually, differing from region to region in time as well as extent. Its complex technological and social implications are evident in these two projects (Lahn-Dill and Sauerland) of the University of Münster (Germany). They can be regarded as representative for central Europe[3, 2, 8, 12] (Fig. 1).

From the Early to the Late Middle Ages, three phases of ironmaking in the Lahn-Dill region may be distinguished.

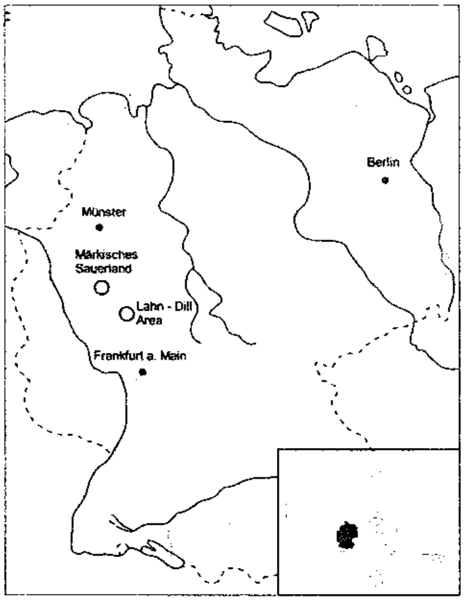

Fig. 1
Location of the two regions of Germany discussed.

Iron Metallurgy in the Lahn-Dill Area (Hessen)

Phase 1: Enclosed Bloomeries (*Rennöfen*)
of the Early Middle Ages (Ca. 12th-14th Century)

The region of the Lahn and Dill rivers, that comprises the old town of William of Orange, Dillenburg, was an iron metallurgy site until 1950 and the iron artefacts produced in ironworks there, such as Juno, Oranien or Buderus, were known worldwide. The earliest use of the local haematite (***roteisenstein***) for ironmaking can be traced back to Celtic prehistory. The clearest evidence refers to the High and Late Middle Ages, and consists of about 325 iron slag-heaps discovered in an area of 80 sq. km. The sites were near small rivers and springs, probably to guarantee an abundance of good quality clay needed for the construction and maintenance of furnaces.

What did a bloomery site look like in the Early Middle Ages? What was its impact on the environment? What was its internal structure, what kind of iron and how much was produced from it and by whom?

The common elements are a furnace, an ore-dressing area, a charcoal store, and a slag heap (Fig. 2). In a simple clay furnace (Fig. 3), the smelting process was self-regulating[5], and it might produce blooms without using bellows. The fuel – charcoal[9] – was probably produced in pits by the ironworkers, who found the wood in the surrounding forests. The ore, a high quality haematite (***roteisenstein***), was transported over a distance of at least 10-15 km down steep slopes.

The amount of slag (about 10-30 tons per site) suggests a production of about 2-2.5 tons of lumps or blooms (*luppe*) per site per year. Between 1150 and 1300, this quantity increases to a total of about 4,000 tons. If we estimate that the population in this small region was between 1,600 and 4,000, then we can estimate a production of 20-25 kg of lumps (equivalent to 10-12.5 kg of wrought iron) per year per head.

After considering all the archaeological data we have collected, we have suggested the following model for direct iron production in shaft bloomery furnaces; it can be considered valid until the middle or late 13th century. In each microregion, an iron-smelter was busy throughout the

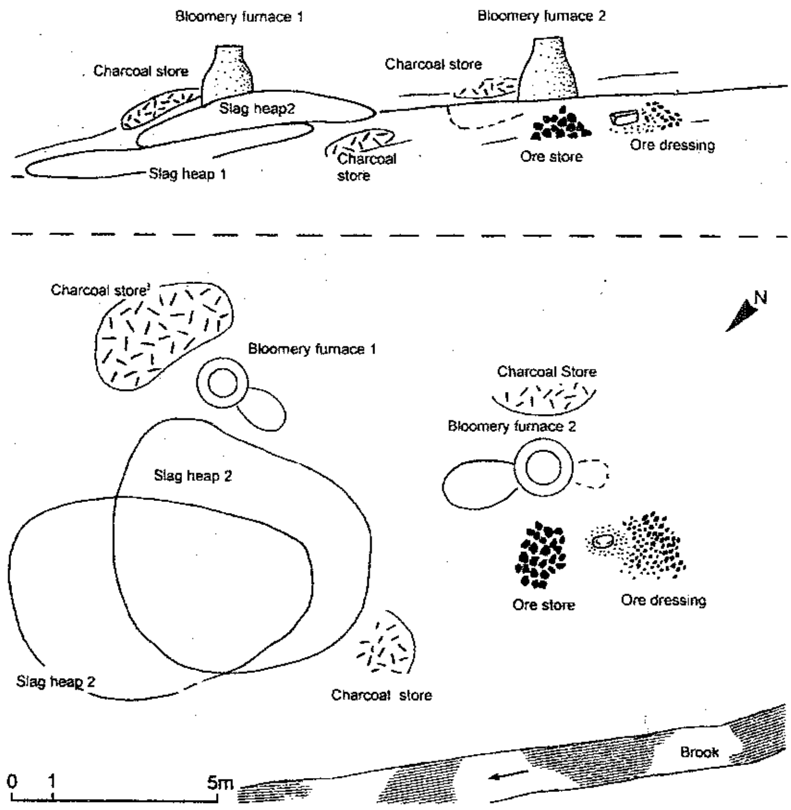

Fig. 2
Typical organisation and structure of a site with a shaft bloomery furnace using direct process (site A68) in the Lahn-Dill area (13th-14th century).

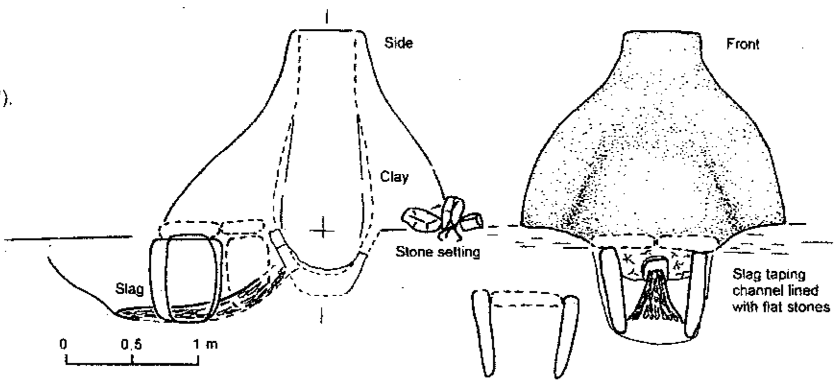

Fig. 3
Lahn-Dill area ("Dietzhölztal"). Reconstruction of a shaft bloomery furnace using direct process (site A68).

year (men A, B, C); every one or two years, once no more wood for charcoal was available[12], he had to change his production site (sites a, b, c).

The layout of these sites and the finds from them are very similar in this phase. An exception is the site near Eschhenburg-Wissenbach (site B85) – far from water but close to a settlement – where the stone foundations have been found of a permanent building used for the production of iron objects, probably a smithy. It dates back to the 13th-14th century.

Phase 2: High Bloomery Furnaces (*Stucköfen*) (Ca. 14th-16th Century)

In the area under investigation, between the Lahn, Dill and Dietzhöltze rivers, there is some indication that there was an intermediate Phase 2, with the so-called ***stucköfen*** (or ***stückofen***), between Phase 1 with enclosed bloomeries and Phase 3 with blast furnaces.

In German, the word ***stucköfen*** indicates a high bloomery furnace that uses water-powered bellows and can be operated to produce iron by the direct method. The slag still contains about 35-45% of FeO.

During our surveys, slag heaps were also found in wider valleys where small streams were flowing, each with a small waterfall and a riverbed of a metre or more. It is likely that the most of the sites, if not all of them, belong to the period of the ***stucköfen*** that lasted from 1300 to 1600, while in other regions, pig iron, that had to be refined, and cast iron were already being produced by the indirect process.

Slag heaps have been discovered behind millponds in the high valley of Dietzhöltze. The construction of these millponds can be traced to the period of the ***stucköfen***, but the close proximity of water-mills and slag heaps is surprising.

One site (A12) provided a large quantity of slag. A geophysical survey (with a magnetometer) showed the existence of a channel that diverted the water of the Langen stream, probably in order to drive bellows and/or forge hammers.

Even the smallest of the numerous round platforms, used for the production of charcoal in the forests of this region, might belong to this intermediate Phase 2. Large quantities of charcoal were necessary for ironmaking until coke became the main fuel for blast furnaces. The transition from charcoal burning pits (***grubenmeiler***) to charcoal heaps is shown in an illustration of the *Pirotechnia* of Biringuccio (1540 – Third Book, pp. 63 and 64).

Phase 3: Charcoal Blast Furnaces (*Hochofen*) (16th-19th Century)

We estimate that about 15-20 sites situated in the area of investigation date to the period of the ***stucköfen***, but it is certain that they did not all operate at the same time. In post-medieval times, the number of sites had declined to four. This number should not be interpreted as a sign of the decline of iron production from the Early Middle Ages, but as a concentration in fewer areas of plants that produced more iron for longer; they consisted of blast furnaces, which meant a general increase in production.

Only in 1587 did the first blast furnace became operational in this region, although it was soon followed by others. Their sites are some distance from water and are characterised by a typical blue glassy slag. Specialised skills of the workers, already noted during Phase 2 (***stucköfen***) were further improved and this became typical of other production sectors, such as mining, that became intensive activities from this period.

It is notable that from Phase 3 onwards, around 1600, all furnaces were under the control of the Count of Nassau, who introduced the cyclic management of low forests (***haubergswirtschaft***), thus distributing charcoal production over a wide area.

Indirect Iron Production in the Märkisches Sauerland

The second region covered by our research, the Märkisches Sauerland, is located in the northern border of the Rheinisches Shiefengerbirge. Historically, it is the southern core of the former old county of Mark, with the towns of Altena, Lüdenscheid and Meinerzhagen.

Besides the Bergisches Land, with its well-known towns, such as Remscheid and Solingen, this was one of the first and most important metallurgical regions of Europe, the nucleus of the area later named the *Ruhrgebiet*, developed by the firms of Krupp, Hoesch, Thyssen, etc.

Thanks to the surveys made by Manfred Sönnecken and Hans Ludwig Knau, a complete documentation is available for this region. Sönnecken was able to demonstrate that pig iron was already being produced at Haus Rhade in the 13th century, when enclosed bloomeries ceased to exist in the region.

The excavations made by Sönnecken and Knau, in 1992, in the basin of the Jubach river, brought to light the ruins of a large blast furnace (*floßöfen*) in rough stone as well as refining hearths that were probably part of the same complex. The metallurgical conclusions are clear: contrary to former opinion, this furnace produced only pig iron.

There is no evidence for the substitution of bloomeries by blast furnaces for steelmaking.

In the course of the research in the University of Münster (sponsored by the Volkswagen-Foundation Hannover), excavations were also made at three other sites where blast furnaces were erected[2, 12].

The results given here are provisional ones only, as the final reports, particularly on metallurgy, have not yet been completed.

Site no. 105 is situated in the basin of Kerspe (Fig. 4). When this was emptied after maintenance work, excavations brought to light the ruins of two important furnaces.

The older furnace is dated by radio-carbon measurements to the second half of the 13th century. They were in good condition, with the inside walls partially melted and covered with slag; they are still located in their original position, reaching a height of 1.75 m. One of the two furnaces still had openings for nozzles *in situ* in the side wall (Fig. 5 and Fig. 6). The internal parts of both furnaces – the "well" (the German word is *gestell*) – are still in good condition. Unfortunately the front face, important for the construction and operation of the furnaces, was badly damaged.

The bellows were driven by a water-wheel whose housing (*radstube*) was easy to identify as well as the mill-trenches. The latter carried the water in a slight fall to a distance of about a hundred metres down the side of the valley.

Compared to the other blast furnaces (*floßöfen*) of this region, relatively few stones were used. Mostly, they were built of clay, as was the case with the older and smaller enclosed bloomeries. The technical necessity of keeping opposing elements – such as fire (for smelting) and water (to drive the wheel that, moving the bellows, blew air into the well where the temperature could reach 1,300 °C) – so close together, required a complex construction. To drain off ground water from the inside of the most recent furnace, several drainage channels had to be built in its foundation. It is probable that most larger furnaces had a similar drainage system. Such a system used below a furnace was first described about 100-200 years later by Georgius Agricola who called it *abzucht* in his *De Re Metallica* (1556).

Similar results were obtained from the furnace of site no. 90 on the upper Wipper river, not far from the town of Marienheide (Fig. 7). This site can be dated back to the 14th-15th century. The

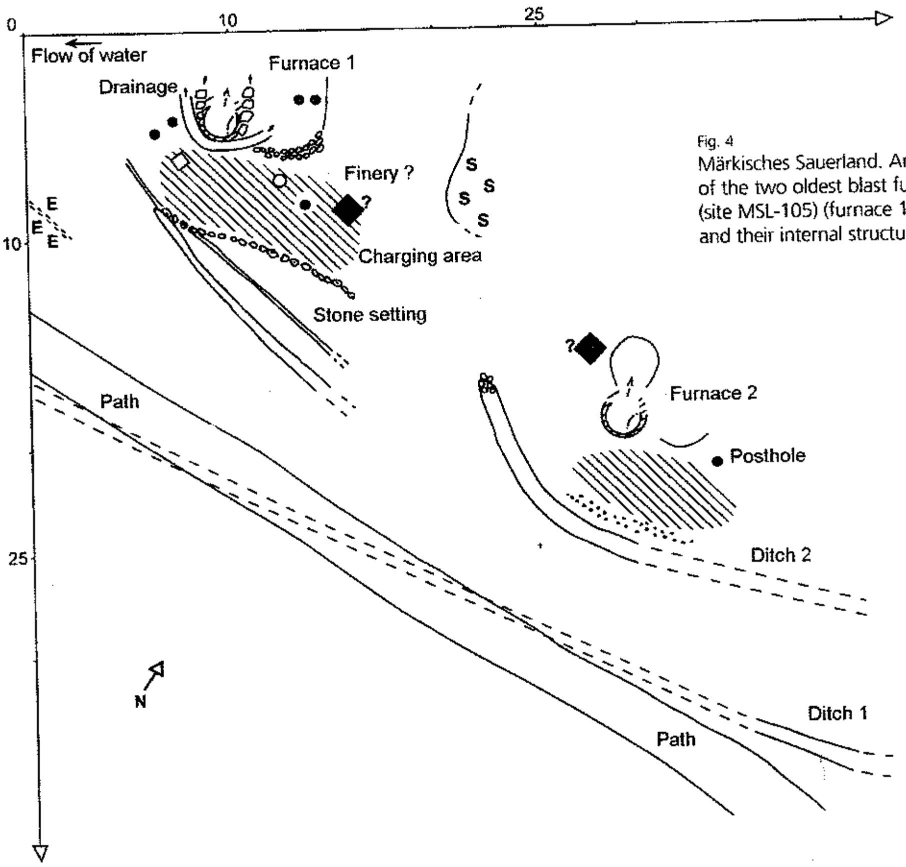

Fig. 4
Märkisches Sauerland. Arrangement of the two oldest blast furnaces (site MSL-105) (furnace 1, 2) and their internal structure.

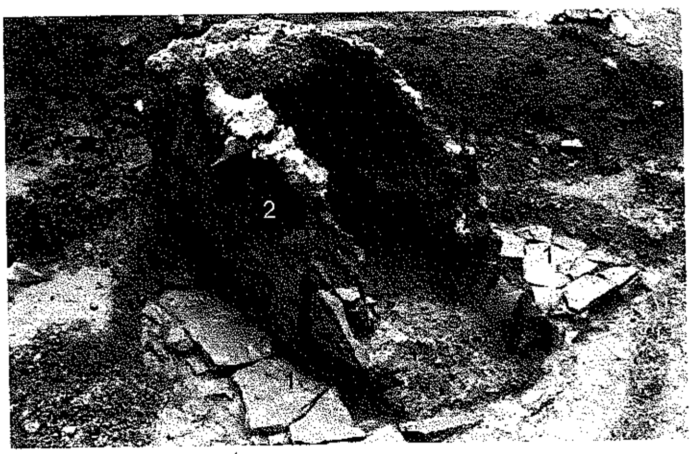

Fig. 5
Märkisches Sauerland. Detail of the furnace no. 1 (1. Detail of the drainage; 2. Opening for the nozzle).

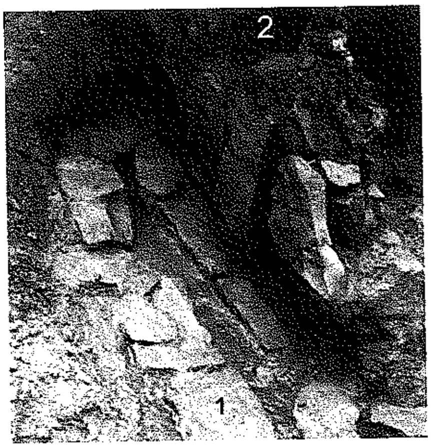

Fig. 6
Märkisches Sauerland. Furnace no. 1 (1. Stone drainage channel [*abzucht*]; 2. Opening for the hammer).

use of larger stones for the construction of the furnace and the drainage system is typical of this site. Another peculiarity of this furnace is the presence of a wood-lined channel to lead off water, from the drainage and the water-wheel, back to the river. Since there was no further activity on this site, the remains of the former metallurgical activities are relatively well-preserved. The furnaces were far from the urban and rural settlements, consequently many channels and millponds are still visible.

Charcoal blast furnaces (***floßöfen***) had to operate continuously for campaigns that might last for several weeks or even months (in German, ***huettenreise***), so it was necessary to have a large team of technicians to undertake all the activities for the entire duration of the production cycle. Before starting smelting campaign, various important tasks had to be completed: water-channels for the mill-race were dug and lined with wood boards, while the waterwheel and the bellows were built by skilled carpenters. The construction of the furnace itself was put into the hands of skilled metalworkers who might also have to have been imported. Miners, charcoal-burners, furnace masters and transport had to be engaged in advance. Contracts were drawn up, capital was raised. Even some of the lesser nobility, such as the Lords of Neuhoff, were

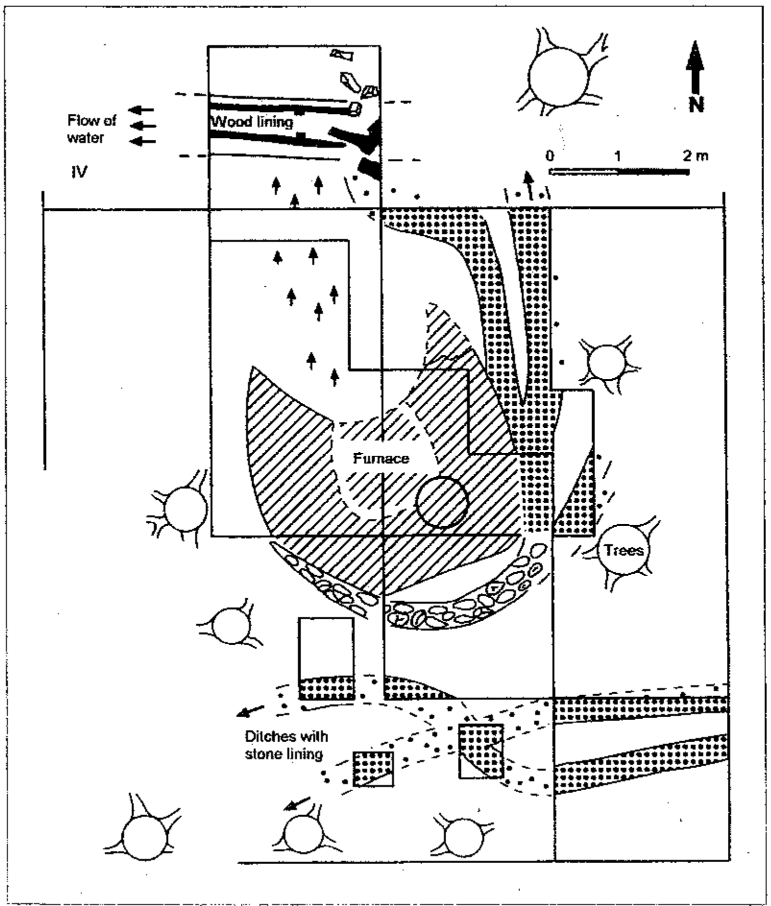

Fig. 7
Märkisches Sauerland. Illustration of the oldest blast furnace (site MSL-90).

engaged in metallurgical activity. Much preparatory work and considerable expenses would have been incurred before any profit could be realised. It is recorded that profit was never realised because of the numerous difficulties that arose especially during the smelting campaign.

Conclusions

Ironmaking increased in extent during the Early and Late Middle Ages in the regions discussed here, as well as in all the mountainous areas of central Europe between Thüringia and the Ardennes, because of increased demand[4, 10]. Iron was used to supply arms and armour to the armies of the feudal lords so often in conflict with each other, iron tools were used in agriculture and industry, and for the construction and expansion of the numerous towns and castles established then. Entire towns specialised in iron trade (*eisenstädte*) and based their economical wealth upon it.

A painting (1602) by Jan Breughel the Elder, called *Hütte im Walde* (Ironwork in the Forest) (Fig. 8), now on show in the Galleria Doria, Rome, shows clearly what a charcoal blast furnace located in a forest looked like. Such furnace sites were widespread throughout Europe at that time.

At the beginning of the 90s of the 20th century, we knew of only two regions where the invention of the blast furnace and indirect iron production might probably have occurred. Märkisches Sauerland between the Rhine, Lenne, Siegh and Ruhr rivers in western Germany and in central Sweden around the town of Norberg. From 1989 to 1995, research (sponsored by Volkswagen-Foundation of Hannover) and led by the Monuments Office of Baden-Wuettenberg, brought to light a third area where the earliest pig iron production probably dates back to the 12th century, in the territory adjacent to Schwaebische Alb (south-eastern Germany)[1].

Yet another recently excavated site is the furnace of Dürstel (in the canton of Basel, Switzerland), dating back to the end of the 13th century[11]. Under the furnace, there is a drainage system and for the first time a refining hearth was found (*frischherd*), surrounded by a stone wall.

In the region around Norberg, in central Sweden (north-west of Uppsala), there is a dense concentration (about 85) of furnace sites. The charcoal blast furnaces with bellows driven by waterwheels (*floßöfen*) of Lapphyttan had been almost completely excavated by the end of the 70s. The ceramic finds and radio-carbon measurements date it to between the 13th and 15th centuries[7].

For this period (13th-15th centuries), using these recent finds as well as some Italian documentary evidence, we can trace on the map a band of intensive metallurgical progress starting from central Italy, continuing through the central Alps, going through the region of the Rhine and ending up in Sweden. To the east of this band (Austria, Poland, other Slavic countries) and also to the west (western France, the Iberian Peninsula, Britain), there is no evidence of the adoption of the indirect process for ironmaking prior to the 16th century.

We still cannot assign to any particular European region the earliest use of the indirect process. Thanks to a high degree of mobility, noticeable in other sectors at that time, the new iron technology spread quickly in late medieval Europe[1, 6, 10]. Dynastic alliances, the foundation of

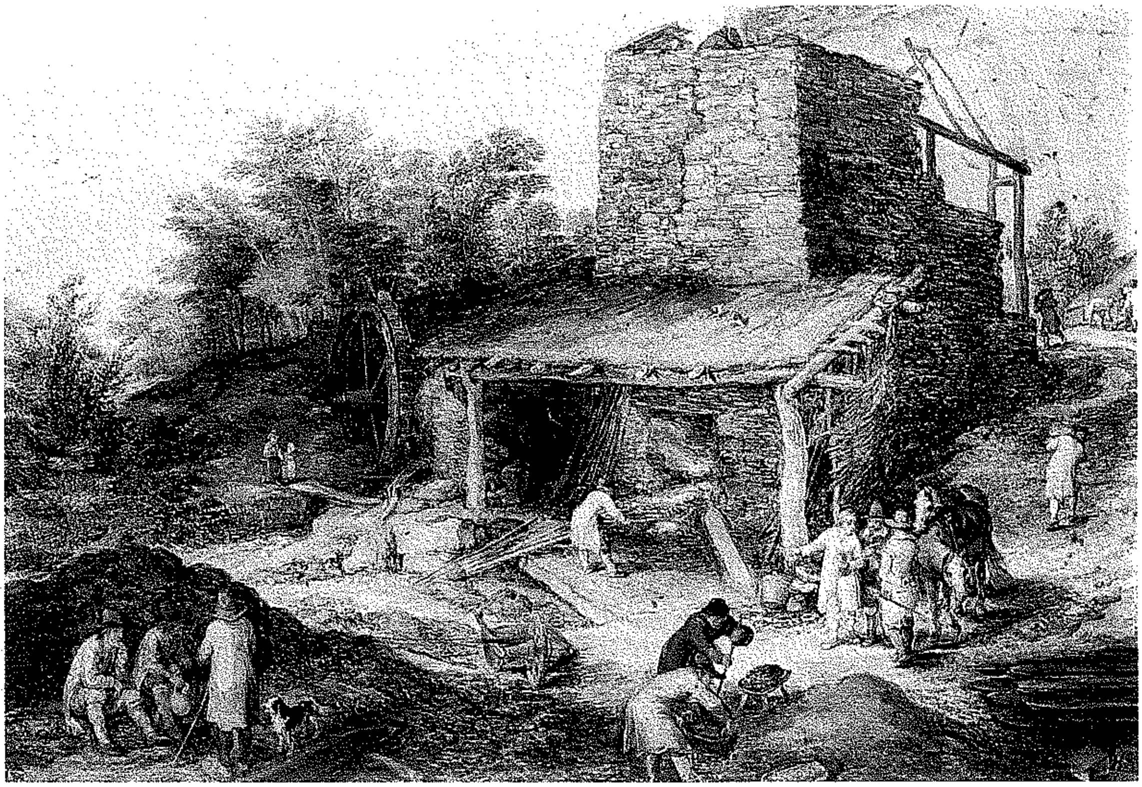

Fig. 8
Jan Breughel the Elder, (1568-1625),
Hütte im Walde (1602).
(Galleria Doria, Rome.)

monasteries by the Cistercians, long-distance pilgrimages, and the mobility of technicians and craftsmen all favoured this spreading. The question of extra-European influences, which might have been initiated by the Crusades and then fostered by the commercial exchanges with the Near and Middle East, remains an open one.
Certainly, more detailed researches are necessary to investigate the relationships that, whether on a regional or an extra-regional scale, helped to spread the techniques of indirect ironmaking with the first charcoal blast furnaces (Fig. 9).

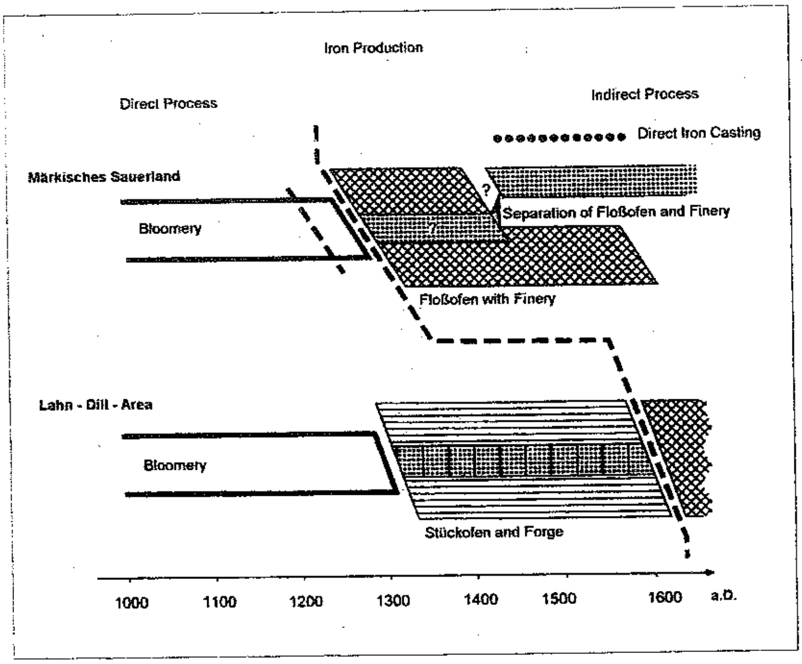

Fig. 9
Changes in ironmaking in central Europe from 1000 to 1600 AD.

Bibliography

[1] Böhm M. *et al.*, *Beiträge zur Eisenverhüttung auf der Schwäbischen Alb. Konrad Theiss*, Stuggart, 1995.

[2] Jockenhövel A. (edited by), *Bergbau, Verhüttung und Waldnutzung im Mittelalter – Auswirkungen auf Mensch und Umwelt. Ergebnisse einer Internationalen Workshops (Dillenburg, 11-15 Mai 1994, Wirtschaftshistorisches Museum "Villa Grün")*, Vierteljahrschrift für Sozial- und Wirtschaftsgeschichte, 121, Franz Steiner, Stuggart, 1996.

[3] Jockenhövel A., Willms C., "Neue mittelalterliche Hochöfen im Märkischen Sauerland", in "Der Anschnitt. Zeitschrift für Kunst und Kultur im Bergbau", 50, 1998, pp. 131-133.

[4] Kellenbenz H. (edited by), *Schwerpunkte der Eisengewinnung und Eisenverarbeitung in Europa 1500-1650*, Kölner Koll. z. intern. Sozial- u. Wirtschaftsgesch, 2, Böhlau, Köln – Vienna, 1974.

[5] Kronz A., *Phasenbeziehungen und Kristallisationsmechanismen in fayalitischen Schmelzsystemen – Untersuchungen an Eisen- und Buntmetallschlacke*, Bielefeld, 1998.

[6] Ludwig K.-H., Schmidtchen V., *Metalle und Macht*, Propyläen-Technikgeschichte 1, Ullstein, Berlin, 1992.

[7] Magnusson G., *Lapphyttan. En medeltida masugn i Karbennings socken*, Karbenning – en bergslagssocken, Norberg, 1984.

[8] Pinsker B. (edited by), *Eisenland – Zu den Wurzeln der nassauischen Eisenindustrie*, Begleitkatalog zur Sonderausstellung der Sammlung Nassauischer Altertümer im Museum Wiesbaden 29 Januar – 23 Juli 1995, Wiesbaden, 1995.

[9] Speier M., *Vegetationskundliche und paläoökologische Untersuchungen zur Rekonstruktion prähistorischer und historischer Landnutzung im südlichen Rothaargebirge*, Abhandl. aus dem Westfäl. Museum für Naturkunde, Vol. 56, 3/4, 1994.

[10] Sprandel R., *Das Eisengewerbe im Mittelalter*, Anton Hirsemann, Stuggart, 1968.

[11] Tauber J. (Kanton Basel-Land, Switzerland).

[12] Willms C., "Frühindustrielle Landschaften nördlich von Dillenburg und im Märkischen Sauerland", in "Siedlungsforschung; Archäologie – Geschichte – Geographie", 16, 1998, pp. 339-362.

INDEX

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She has conducted research on objects from many great international institutions, including the British Museum, Ägyptische Sammlung of Münich, the Royal Ontario Museum of Toronto, Römisches Museum of Augsburg, the Louvre, Antikensammlung of Münich, Mestni Muzej of Ljubljana, Römisch-Germanisches Museum of Cologne and other museums and Soprintendenze Archeologiche in Italy.
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In addition to other honours, he was awarded the title of Honorary Professor by the University of Beijing and of Distinguished Senior Research Fellow by the Alexander von Humboldt Stiftung.

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