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TRADITION AND INNOVATION: NEW INVESTIGATIONS TO THE END OF THE BLOOMERIES AND THE BEGINNING OF HIGH FURNACES IN CENTRAL EUROPE DURING THE HIGH AND LATE MIDDLE AGES

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ABSTRACT

Two archaeometallurgical projects of the Westfälische Wilhelms-Universität Münster (Germany) in important regions of Central European iron production have provided exemplary results with regard to the technological and structural changes in the High and Late Middle Ages. It has turned out that in areas such als the Dietzhölztal direct iron production in blommeries continued to exist till late in the 13.-14. century A.D. Then with the introduction of water power as a new source of energy the first "Stucköfen" emerged about the time of the late 14. century A.D. At the same time indirect iron production was initiated in other regions, especially in the Märkisches Sauerland, Germany. The early blast furnaces ("Floßöfen") belong to this context. The origin of this new technology is still in the dark.

1. INTRODUCTION

In the High and Late Middle Ages iron-production in Central-Middle Europe underwent a revolutionary process of change. Its causes and impacts still remain partly in the dark. From the point of view of chemistry and metallurgy it is the transition from wrought-iron to pig-iron or from the traditional direct iron-production process in small bloomeries to innovative indirect iron-smelting in higher furnaces, which finally (from ca. 1600 A.D.) became the water-powered blast furnaces. Both processes are based on the use of charcoal as fuel. Due to the changes in the use and shaping of the landscape this advancement of technology was already visible to the contemporary people. The old bloomery-sites moved from the middle and upper hillslopes, from their locations near springs and small brooks ("Seifen") down to the larger valleys of small rivers.

These were changed into furnace sites as a result of the construction of water dams, water reservoirs and water channels. These valleys were the nuclei of the so called "Industriegassen" (industrial lanes) partly prosperous till today. Constitutionally the rights of the landowners with respect to the use of waterpower and the exploitation of woods and ore were touched. Economically this shift to water-powered furnaces primarily meant financial und personal investments with regard to future profit. This changed essentially the ownership of iron production facilities and the social structure. There are very few written records in Central Europe of this widely discernible advancement of early industrial iron-production in the 10. 13. century A.D. So in many cases we are dependent on archaeological investigations even up to the 16. century A.D.

Up to now recent interdisciplinary research in Central Europe has primarily been advanced through grants of the Volkswagen-Stiftung Hannover as part of a special programme promoting Archaeometallurgy. First results show that, while in the course of the Middle Ages direct iron-production in bloomeries reached its climax in wide regions, other regions existed where water-powered blast furnaces were already beginning to become established. This process of change

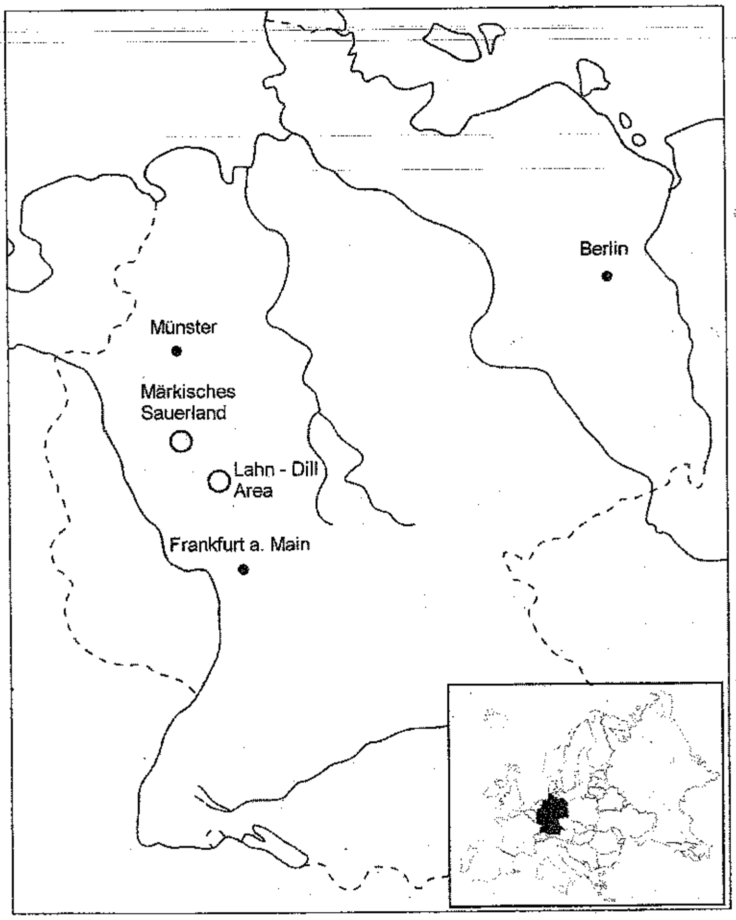

Fig.1 Map of Germany with the location of the two regions of research led by the Seminar für Ur- und Frühgeschichte Münster.

took place gradually, differing in time as well as intensity from region to region. Its complex technological and social implications become obvious in the following two projects of the Westfälische Wilhelms-University of Münster (Germany) which may well be regarded as representative for Central Europe (Fig. 1) [1-4].

2. DIRECT IRON-PRODUCTION IN THE LAHN-DILL-AREA (HESSEN)

From the beginning of the Early Middle Ages to the end of the Middle Ages there are three phases of iron-production in the Lahn-Dill region can be distinguished [1, 3-4].

2.1 Phase 1: Bloomeries ("Rennöfen") of the High Middle Ages (ca. 12.-14. century A.D.)

The region of the rivers Lahn and Dill around the old William of Orange-town of Dillenburg as its centre was up to the 1950s a center of iron-production and namely the manufacture of iron goods in Germany. Factories like Juno, Oranien or Buderus acquired world fame. The roots of iron-production based on haematite ("Roteisenstein") were assumed to be found in Celtic prehistory, but this could not be proved. Instead in an investigation area of about 80 sqkm about 325 bloomery slag heaps dated in the High and Late Middle Ages. The analysis of bloomery sites showed a close proximity of the sites to water - small brooks or springs - probably because clay of sufficient quantity and quality for building and maintaining the furnaces was easily accessible there.

What does a bloomery site look like in the High Middle Ages? How is it connected to the environment, what is its internal structure, what kind of iron and how much was produced by whom?

The common elements consist of furnace, ore-dressing place, charcoal-store and slag heap (Fig. 2). In the simply constructed clay furnaces (Fig. 3) a mainly self-regulating smelting process [5] without additional supply of air by bellows produced a wrought iron bloom. The fuel - charcoal [6] - was probably made in pits by the bloomery workers themselves, who used wood from the surrounding forests. The ore, a high quality haematite ("Roteisenstein"), was transported over a distance of at least 10-15 km including some steep gradients.

Judging from the amount of slag finally found (around 10-30 tons per site) we estimate an iron-production of about 2-2.5 tons of raw iron bloom ("Luppe") per site in a year. For the years between 1150 and 1300 A.D. this would amount with reservation to a quantity of around 4000 tons. On a basis of an estimated 1600-4000 persons living in this small region that would mean a per capita production per year of 20-25 kg raw iron bloom or 10-12.5 kg wrought iron.

Taking into consideration all aspects of our archaeological field research the following model of direct iron-production with bloomery-technology can be developed, which may be regarded as valid up to the middle or end of the 13. century A.D. In each microregion an iron-smelter was

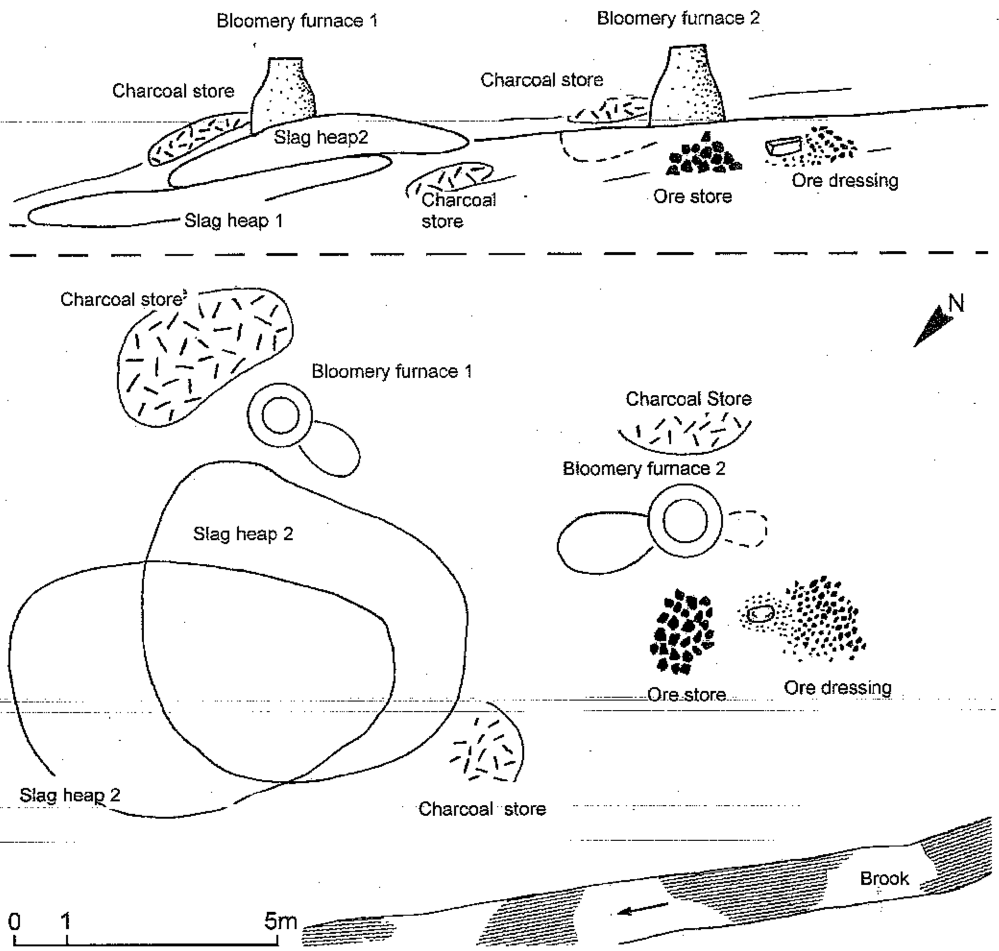

Fig.2 Organisation and structure of a typical bloomery site (site A 68) in the Lahn-Dill-Area (13./14. century A.D.).

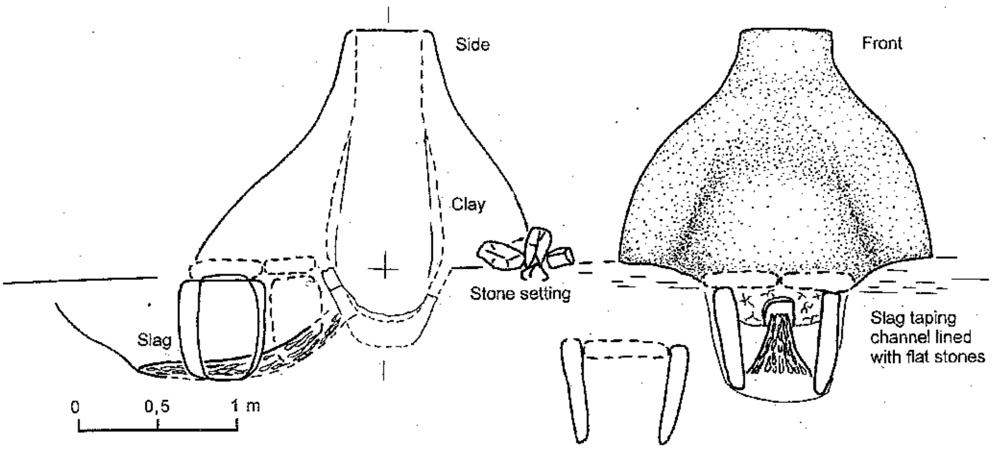

Fig.3 Lahn-Dill-Area (Dietzhölztal). Reconstruction of a bloomery furnace (site A 68).

busy throughout the year (person A, B, C). However he had to change his production-site (site a, b, c) every year or every two years because all wood for charcoal around his site would be used up [4].

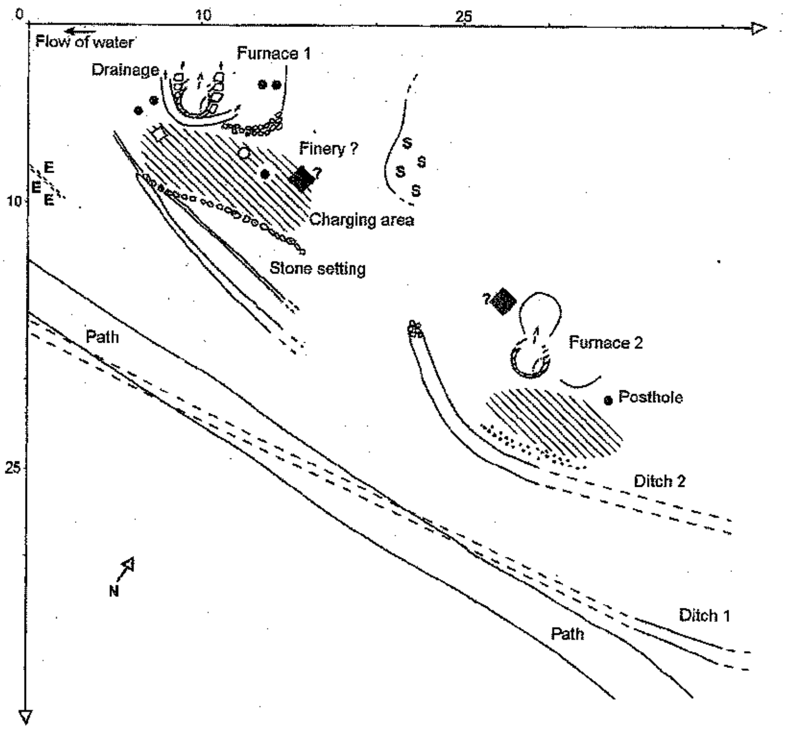

Fig.4 Märkisches Sauerland. Layout of site MSL−105 with two early blast furnaces (furnace 1, 2) and other internal structures.

The finds and the appearance of all sites are generally very similar at that stage. An exception is the site near Eschenburg-Wissenbach (site B 85) - remote from water but close to a settlement - with the stone-foundation of a permanent building used for the production of iron goods, a smithy, in the broadest sense. This smithy dates into the 13./14. century A.D.

2.2 Phase II: Stuckofen or intermediate Phase (ca. 14.-16. century A.D.)

In our research region on the rivers Lahn, Dill and Dietzhölze there are some indications suggesting that there was an intermediate Phase II with so called "Stuckofen" (or "Stückofen"; pl. "Stucköfen" or "Stücköfen") between the Phase I with bloomeries of wrought iron and the Phase III with blast furnaces of pig iron [4]. In German "Stuckofen" means a higher built furnace with water-powered bellows producing wrought iron in the direct process. The slags still contain ca. 35-45% FeO.

During our survey, sites with slag heaps were also found in the wider valleys of small streams, each with only a slight fall and with a breadth of the streamlets of 1 m or more. It is likely that most if not all of these sites belong in the time of the "Stuckofen" from about 1300 to 1600 A.D. when in other regions pig iron or cast iron was still made in a indirect process.

It is remarkable that there are some slagheaps behind millponds in the upper Dietzhölze-Valley.

The construction of these millponds may well reach back into the time of the "Stuckofen". What is striking is the close proximity to later built watermills and slag accumulations. Another indication is the name "Hüttenplatz" (= site of a large furnace), a place name quite often found.

Site A 12 provided a large quantity of slags. The geopysical (magnetometer) survey showed a mill-trench diverting water from the Langenbach probably to drive bellows and or a forging hammer. The smaller ones of the numerous (several hundred) round platforms in the forests of this region for the production of charcoal might also belong to this intermediate Phase II. The production of large quantities of charcoal remained an integral part of iron-smelting up to the transition to coke as the main fuel for blast furnaces. This transition from charcoal-burning pits (german: "Grubenmeiler") to charcoal heaps can also to be seen on an old illustration from Biringuccio (15. century A.D.).

2.3 Phase III: Time of the charcoal fired blast furnaces ("Hochofen") (16.-19. century A.D.)

We estimate that about 1520 sites in our research region date into the time of the "Stuckofen". They were certainly not all in operation at the same time. In post-medieval times these 1020 Stucköfen were replaced by four sites with blast furnaces. These numbers should not be taken as a sign of a declining productivity since the High Middle Ages, but of a concentration on fewer sites where larger quantities were continuously produced over a longer period of time, which in the long run led to an increase in production.

It was only in 1587 that the first blast furnace was lit in this region, others followed soon. These blast-furnace sites with their typical blue-glassy slags are farther away from the water sources. Specialisation and professionalisation already beginning during Phase II of the "Stucköfen" are further developed and become characteristics of related branches of production as well, like mining, with deep-mining starting in 1588/89.

It is remarkable that only from Phase III on starting in about 1600 all furnaces operated under the control of the Counts of Nassau who also forcefully promoted the introduction of a cyclic management of the low forests ("Haubergswirtschaft") aiming at the production of charcoal over a wide area.

3. INDIRECT IRON PRODUCTION IN THE MÄRKISCHES SAUERLAND

The second region of our research, the Märkisches Sauerland, is located on the northern edge of the Rheinisches Schiefergebirge. Historically it is the southern core of the former old county of Mark with the towns of Altena, Lüdenscheid and Meinerzhagen. Together with the adjacent Bergisches Land with the world wide known towns of Remscheid and Solingen it was one of the important regions of early iron in Europe, the nucleus of the later "Ruhrgebiet" formed by Krupp, Hoesch, Thyssen etc.

Thanks to the surveys that were made for several years by Manfred Sönnecken and Hans Ludwig Knau this region is one of the most thoroughly documented ones. Sönnecken was able to show with his excavations at Haus Rhade that the production of pig iron (hard, high-carbon iron) started here als early as in the 13. century A.D. That was also the the end of the bloomeries in the region.

A rescue excavation by Sönnecken/Knau in 1992 unearthed a mighty, coarse stone furnace ruin ("Floßofen") in the water reservoir of the river Jubach with the refining hearths probably belonging to it. The metallurgical analysis is clear: contrary to former opinions only pig iron was made. There was no switching between the production of wrought iron and pig iron.

In the course of the research of the University of Münster (also sponsered by Volkswagen-Stiftung Hannover) three other blast furnace sites were excavated [2, 4]. In the following I am going to present some of the provisional results, since the final reports especially on the metallurgy (Prof. Dr. Ingo Keesmann, Mainz) have not yet been finished.

Site Nr. 105 is located in the Kerspe water reservoir (Fig. 5). When the reservoir was emptied due to repair works we were able to excavate two impressive furnace ruins. They were found in good condition, the inside walls of the furnaces partly molten and slag covered were still in their former places up to a height of 1.75 m. One furnace had the openings for the bellows (tuyeres) in situ in the sidewall (Fig. 6, 7). The interior construction the well (the German term for well is "Gestell") of both furnaces had been preserved in good condition. Unfortunately the frontside, important in view of the construction and operation of the furnaces was badly damaged in both cases. The bellows were driven by a waterwheel, its housing ("Radstube") as well identifiable as the mill-trenches. Those trenches carried the water in a slight fall over a distance of several 100

Fig.5 Märkisches Sauerland. Blast furnace Nr. 1 (1 drainage channel made of stones [Abzucht]; 2 hole for the bellows).

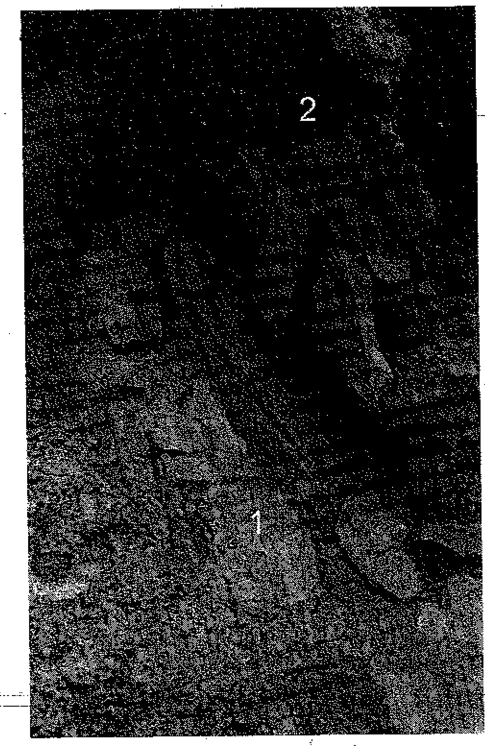

Fig.6 Märkisches Sauerland. Detail of blast furnace Nr. 1 (1 opened drainage; 2 hole for the bellows).

metres along the sloping side of the valley. Compared to the other blast furnaces (Floßöfen) in this region relatively few stones were used for their construction. They were mainly built with clay like the older and smaller bloomery furnaces of this region.

The technological necessity of keeping the opposite elements of fire (for smelting) and water for driving the waterwheel and moving the bellows (to reach a temperature of well over 1300°C) in close neighbourhood required cleverly devised constructions of the furnace builders. So in order to keep away the groundwater from the interior of the furnace a system of diverse draining channels was built into the foundation of the younger furnace. It can be assumed that most of the bigger substantial furnaces had some similar kind of drainage. In this case, for the first time a drainage system under a furnace was found that was described by Georgius Agricola about 100200 years later (ca. 1550) who called it the "Abzucht".

The older one of the two furnaces is dated by radion-carbon to the second half of the 13. century A.D.

Comparable results were obtained from the furnace site no. 90 on the upper river Wipper not far form the town of Marienheide (Fig. 4). Characteristics of this site is the use of more stones for building the furnace and the draining system. A highlight of this furnace is a wood lined channel used to carry the water back from the drainage and the waterwheel to the river. This site is esti-

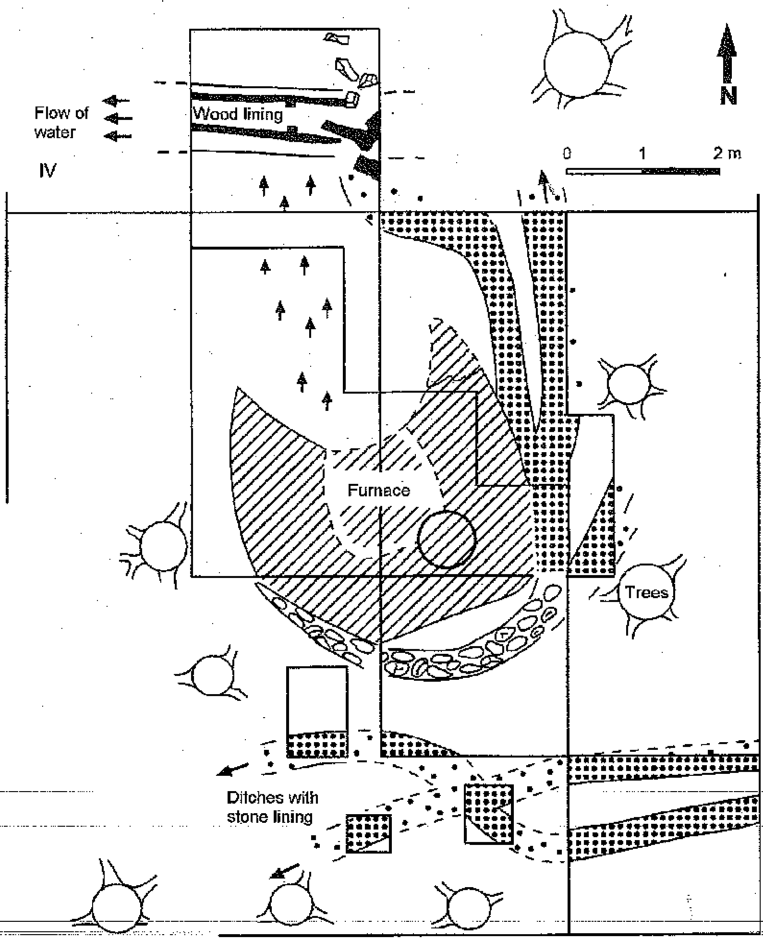

Fig.7 Märkisches Sauerland. Layout of an early blast furnace site (MSL–90).

mated to have its beginnnings in the 14./15. century A.D. Site no. 90 is located in a very prominent section of the Wipper-valley. Since there was no later activity the remains of the former iron industry are comparably well preserved. The furnaces were remote from the rural and urban settlements. Consequently numerous channels and mill-ponds can still identified.

Because the charcoal fired blast furnaces (Floßöfen) were laid out for continuous operation over a period of at least some weeks or months (german: „Hüttenreise") there had to be a crew sufficient in number for all activities during that time. Before starting iron smelting extensive preparations had to be made: water-channels and the wheel-housing had to be dug and lined with wooden boards, the waterwheel and the bellows were probably made by special carpenters. The construction of the furnace itself was specialized work of experienced iron-workers who were often hired for this task from farther away. Ore-miners, charcoal-burners and transport had to be organized in advance. Contracts had to be made, sufficient capital was needed. So it took some time before the iron-production itself was started and profit could be gained. The records show that many times the stage of gaining profit was never reached due to the numerous difficulties that could arise with regard to blast-furnace operation. Nevertheless, some of the lower local nobility like the Lords of Neuhoff engaged in the late medieval iron-production.

4. DISCUSSION

The reason for the increasing iron-production in High and Late Middle Ages in the regions named above and all over mountainous Central Europe from Thüringen (Central Germany) to the Lorraine/Ardennes (East of France) lies in the increasing demand for iron [7, 8]. Iron was needed for building the numerous towns and castles which were founded in that time. Local and regional conflicts between feudal rulers required the supply of arms and armour. The beginning monetary trade made iron and steel sought after merchandise. Whole towns specialised in the trade with iron ("Eisenstädte") and based their wealth on it.

A 1610 painting by the famous painter Jan Breughel the Elder called "Hütte im Walde" (= Iron-work in a Forest), now to be seen in the Galleria Doria in Rome shows very well what a charcoal fired blast furnace in the forest looked like (Fig. 8). Such furnace sites were widely spread over Europe at this time.

At the beginning of the 1990s just two regions were known where the invention> of the blast furnace and the indirect process of ironproduction could reasonably be assumed to have taken place: The Märkisches Sauerland between the rivers Rhein, Lenne, Sieg and Ruhr in the west of Germany and in Central Sweden around the city of Norberg. From 1989 to 1995 in a research

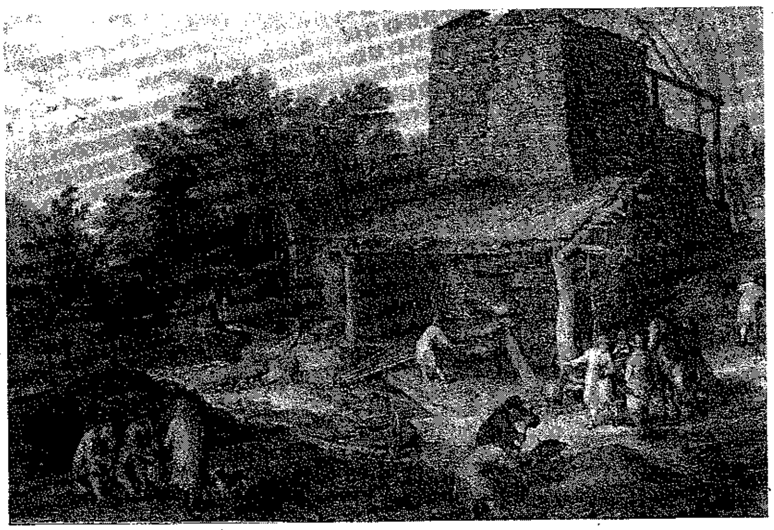

Fig.8 Jan Breughel the Elder (1568~1625), around 1602, "Ironworks in the Forest" (Galleria Doria, Rome).

project sponsored by the Volkswagen-Stiftung Hannover mentioned above the Landesdenkmalamt of Baden-Württemberg was able to locate in the foreland of the Schwäbische Alb (Southwest Germany) as a further region with a probable early production of pig iron rooting in the 12. century A.D. [9]. Another newly found site is the blast furnace of Dürstel (Kanton Basel-Land, Switzerland) dating to the end of the 13. century A.D.[10]. This site, which has not been fully published yet, was excavated from 1996 to 1997. It also had a drainage system under the furnace and for the first time a refining hearth ("Frischherd") surrounded by stonework. In the region around Norberg in Central Sweden (north-west of Uppsala) there is a dense concentration of about 85 furnace sites. The socalled "Floßofen" (water powered blast furnace) at Lapphyttan has nearly completely been excavated since the late 1970s. However, it has only been published in some preliminary reports so far. Its radio-carbon and ceramic finds date to the 13. 15. century A.D. [11].

If we chart these early finds together with some documentary evidence form central and upper Italy on a map, there is a south-north track for the 13. 14. century A.D. from central Italy over the western Central Alps to the Rheinland and Sweden. On the eastern (Austrian, Poland, Slavic kingdoms etc) and western (Western France, Iberian Peninsula, British Isles) side of this track there is no evidence known of the early introduction of the indirect process of iron smelting until the late 16. century A.D.

So, as to the early use of the indirect process it is still too early to assign priority to a single region of Europe. There is a need for research in other core regions whose innovative influence in the Late Middle Ages must be regarded as more important, in my view, compared with the Grafschaft Mark or Central Sweden. Here we are particularly thinking of the flourishing city republics of Central and Upper Italy, the more and more powerful kingdom of France or the self-confident duchy of Burgundy. Due to a mobility characteristic of that period, which can be observed in many other fields as well, the new iron-technology spread fast over late-medieval Europe. [7, 8, 12]. We assume it spread in connection with dynastic alliances, the foundations of monasteries by the Cistercians, pilgrimage over long distances and the high mobility of craftsmen and artisans. Whether additional extra-European influences existed, which found their way from the East (Levante; Middle Asia) into Europe in the course of the medieval crusades or oriental trade must be left open here.

At any rate further intensive investigations are necessary of the regional and supraregional networks which helped to spread the knowledge of the indirect production of iron in the early charcoal blast-furnaces. On the other hand the reasons why in many regions this innovative technology was not able to prevail over the traditional bloomery process at that stage should be researched with equal intensity. In this context the advantages and disadvantages of both processes should be considered carefully as well (Fig. 9).

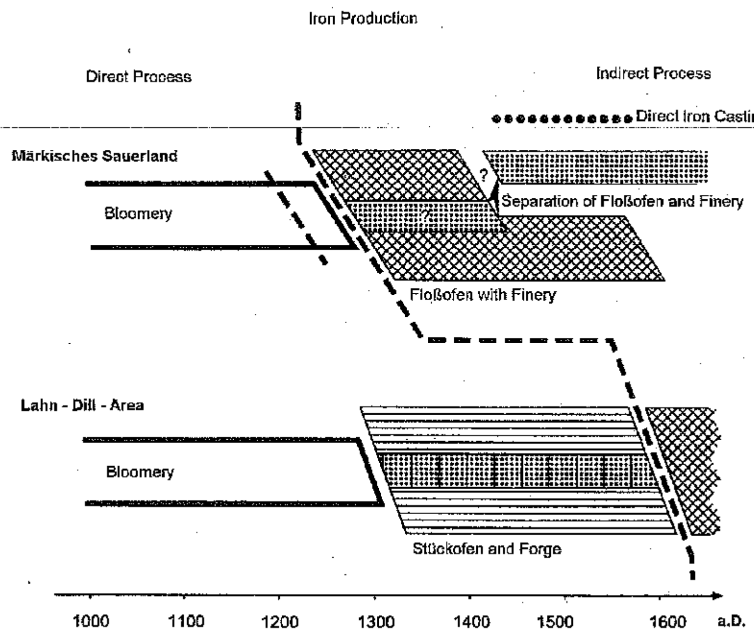

Fig.9 Changes in the medieval iron production of Central Europe from ca. 1000–1600 A.D.

REFERENCES

1. B. Pinsker, ed., Eisenland - Zu den Wurzeln der nassauischen Eisenindustrie (Begleitkatalog zur Sonderausstellung der Sammlung Nassauischer Altertümer im Museum Wiesbaden 29. Januar - 23. Juli 1995) Wiesbaden (1995).
2. A. Jockenhövel and Chr. Willms, Neue mittelalterliche Hochöfen im Märkischen Sauerland. Der Anschnitt. Zeitschrift für Kunst und Kultur im Bergbau Vol. 50 (1998), 131-133.
3. A. Jockenhövel, ed., 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 Wirtschafts-geschichte. Beiheft 121, Franz Steiner, Stuttgart (1996).
4. Chr. Willms, Frühindustrielle Landschaften nördlich von Dillenburg und im Märkischen Sauerland. Siedlungsforschung; Archäologie - Geschichte - Geographie Vol. 16 (1998) 339-362.
5. A. Kronz, Phasenbeziehungen und Kristallisationsmechanismen in fayalitischen Schmelzsystemen-Untersuchungen an Eisen- und Buntmetallschlacke, Bielefeld (1998).
6. M. Speier, 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).
7. R. Sprandel, Das Eisengewerbe im Mittelalter, Anton Hirsemann, Stuttgart (1968).
8. H. Kellenbenz, ed., Schwerpunkte der Eisengewinnung und Eisenverarbeitung in Europa 1500 - 1650. Kölner Koll. z. intern. Sozial- u. Wirtschaftsgesch. 2 , Böhlau, Köln/Wien (1974).

9. M. Böhm et al., Beiträge zur Eisenverhüttung auf der Schwäbischen Alb. Konrad Theiss, Stuttgart (1995).
10. J. Tauber (Kanton Basel-Land, Switzerland), pers. comm.
11. G. Magnusson, Lapphyttan. En medeltida masugn i Karbennings socken. Karbenning en bergslagssocken, Norberg (1984).
12. K.-H. Ludwig, V. Schmidtchen, Metalle und Macht, Propyläen-Technikgeschichte 1, Ullstein, Berlin (1992).