EARLY IRON

The network for early iron technology

The manufacture of chain-mail

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Chain-mail is known in Europe as far back as around 300 BC. The method of manufacture is believed to have been discovered by the Celts, but the oldest remains discovered (in Denmark) are from the Hjortespring find on the island of Als, dated to around 350 BC (Rosenberg 1937). This find was excavated by Gustav Rosenberg in 1921-22 and today, there is almost nothing remaining of the material deemed to be chain-mail. Rosenberg describes several square meters covered with heavily corroded material. But there is doubt as to whether this was chain-mail, or a layer of natural iron separation formed around plant roots, the occurrence of which can often be in the form of rings.

The Romans adopted shirts of mail and they were subsequently used throughout the Middle Ages (Blair 1972:19ff, Robinson 1974:154) most often in the 12th and 13th centuries but small pieces of mail were used right up until the 17th century as a part of armor. Although shirts of chain-mail were used for nearly 2000 years, there has been surprisingly little interest in the manufacture of them. Since they are a very fine and without doubt a highly specialized craft, carried out over a very long period of time, they are an excellent object for studying technological development from the Iron Age to the Middle Ages.

The construction of chain-mail

A shirt of mail is a form of armor, made up of rings. As the rings can move in relation to each other mail is far more supple in relation to plate armor. Chain-mail is also lighter – the almost complete shirt from Vimose, displayed in the Danish National Museum weighs only 8 kg. But a shirt of mail represents much more work than sheet armor, such as the well-known 'Lorica segmentata'. In the Roman army, only the better-off legionnaires were able to afford a shirt of mail (Robinson 1975:164). We do not know how long it took to make a shirt of mail. In medieval German guild books we can see that a mail-maker's masterpiece was a shirt that would take him 6 months.

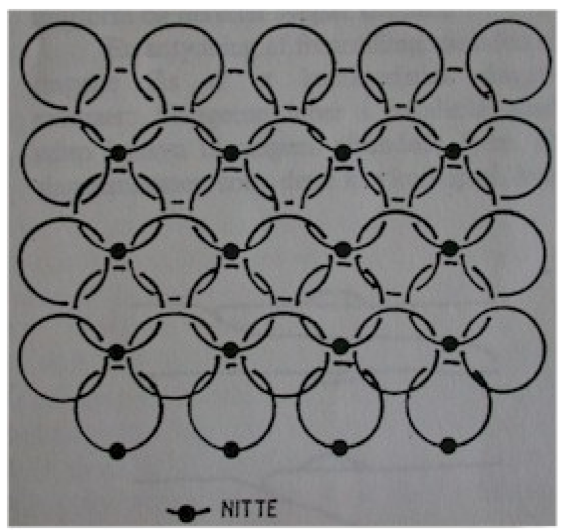


Fig. 1

Typical chain-mail construction. Rows consisting of jointless rings alternating with rows of riveted rings. Each riveted ring connects four jointless rings.

Common to all the types studied is that they consist of two ring types (1). The first is made of a wire that is bent, overlapped and connected using a rivet. The other has no visible joint. The two types always alternate in rows allowing each riveted ring to hold four jointless rings. Fig 1.

Ring size and appearance

In the four types of chain-mail studied, ring size varies greatly. The finest were found at Hedegaard, the rings of which had a diameter of around 5 mm and a wire thickness of around 0.95 mm. Somewhat poorer is the Brokbaer shirt, with a ring diameter of around 7.2 mm and a wire thickness of around 1.0 mm. A shirt with very similar rings was found at Vimose (Engelhardt 1869:12). The biggest mail rings were discovered at Vimose and Thorsbjerg: 10.5 mm and 12.5 mm respectively, with wire thicknesses of approx. 1.5 and 1.7 mm (Engelhardt 1863:59; 1869:12).

Corrosion to the shirts from Hedegaard and Kastenskov has caused the rings to swell, making it difficult establish the original thickness. The Brokbaer shirt is also heavily corroded, but it is possible to see that the jointless ring had a flat side in towards the hole and a more rounded exterior. The clearest cross-section of the jointless ring can be seen on the shirts from Vimose and Thorsbjerg. Once again, the inside is flat and the exterior more rounded and a groove can be seen all the way round on one side of the rings. On the small Vimose shirt, the edges of the groove actually form burrs of 0.5 – 1.0 mm.

The cross-section of the riveted rings is in every case more rounded, although the wire thickness can vary. These rings are not as uniform as the jointless rings, but have a tendency to be oval and with much greater variation. The overlap at the rivet is always flattened, but least on the Brokbaer shirt, where only a canted cut is apparent with an overlap of 1.5 – 2.0 mm.

The biggest overlap is found on the Vimose shirt, where there is up to 7.0 – 8.0 mm and on the same shirt, the overlap consistently follows the same direction, Fig. 2.

The rivet heads are nicely rounded in contrast to the rivets used in some cases for repairs where hammer marks can be clearly seen on the rivet heads.

Metallurgical study

<u>The jointless rings:</u> A plane-section was made across the jointless rings and a series of cross-sections of the wire were taken (2). The plane-sections showed that the rings are made of carbon-free iron. Only a few rings from the Thorsbjerg shirt were found to contain up to 0.3% carbon. The iron is generally quite homogenous and contains almost no slag – in other words, it is high quality. The rings of the Hedegaard shirt contain 0.2% phosphor. There is no sign of weld joints, which may be expected if the rings were made of wire bent into a ring shape and then welded.

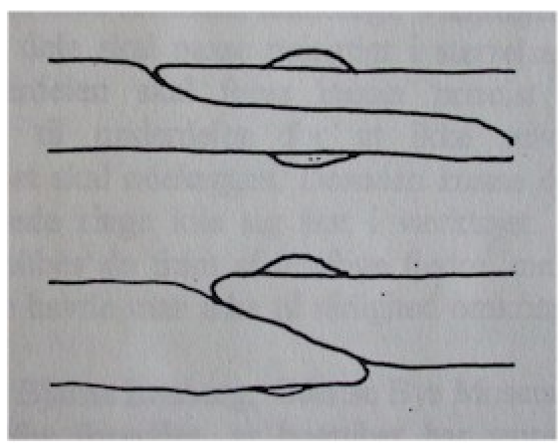


Fig. 2

The overlap of the riveted ends differs, from 1.5 – 2.0 mm to 7.0 – 8.0 mm. The overlap is always in the same direction within the same mail-shirt, but can be both ways.

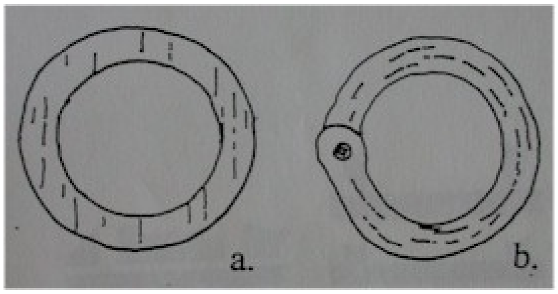


Fig. 3

Plane-sections of jointless and riveted rings show different slag structures. The origin of the jointless ring structure is best explained by theorizing that these rings were cut from a thin iron sheet. If they had been formed by drawn wire, the structure would be similar to the form found in riveted rings.

Some hint of the method of manufacture can be gleaned from the characteristic slag pattern, which runs in parallel bands regardless of the rounded shape of the ring. A slag pattern of this nature can only occur if the ring is made of a thin, beaten sheet and not if the ring (as previously assumed) was made of welded wire. Fig 3a.

Cross-sections of the whole ring also show a very characteristic slag pattern. The structure is clearly deformed, as the material has been forcibly depressed at the sides. This explains the burrs that even with the naked eye can be seen on many of the rings. These are the remains of grooves such as those that can still be found on the small Vimose mail shirt. On the rings of the Thorsbjerg shirt, the large Vimose shirt and possibly the Brokaer shirt, the groove on the inside of the rings is very visible whilst the outside is more rounded. Only a trace of an outer groove can be seen.

The riveted rings: A horizontal section of the rings shows that they are also made of carbon-free iron. The phosphor content in the Hedegaard shirt rings is 0.1 – 0.2%.

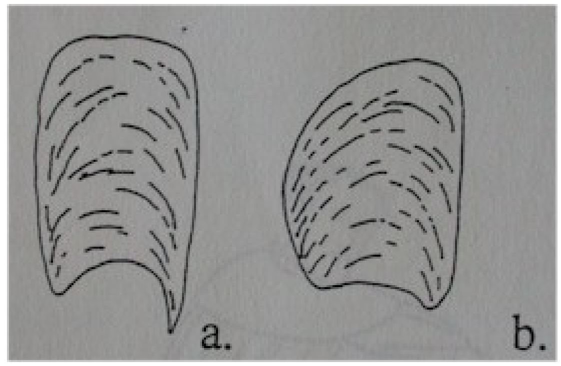


Fig. 4

A cross-section of jointless rings shows a typical deformed structure where the material at the sides has been forced downwards (a). In some mail-shirts the outside of the rings are rounded, probably by deliberate grinding in order to remove sharp edges (b).

The riveted rings have an entirely different slag pattern to the jointless rings: The slag pattern runs parallel with the surface of the ring. Cross-sections reveal no depressed structure.

The manufacture of the rings

The observations noted here can be interpreted as follows:

The jointless rings: The raw material used for the rings was a 1.0 – 2.0 mm thick sheet of almost carbon-free iron. The rings were either produced using a single stamping process or in two steps, using hollow punches. Stamping would seem to be the most logical process for the manufacture of very large numbers of uniform rings, but a stamping tool must have been difficult to produce given the technology of the time. The individual components of the tool must have been exactly the same size and the upper part must be placed accurately in relation to the lower in order to avoid damaging the tool itself. Additionally, the newly stamped ring could get stuck in the tool. Today, they are

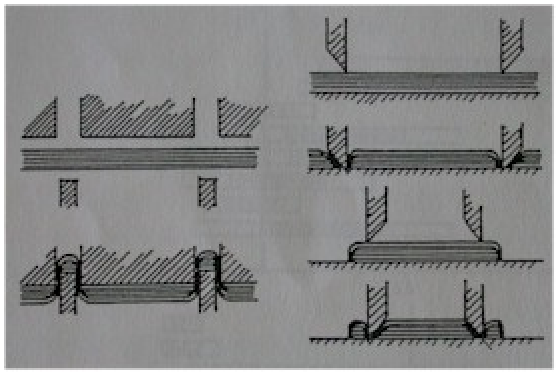


Fig. 5

The rings can be formed either by a stamping machine or by first punching the outer rim and the hole with hollow punches.

pushed out using powerful springs but such things would not have been available around the year 0.

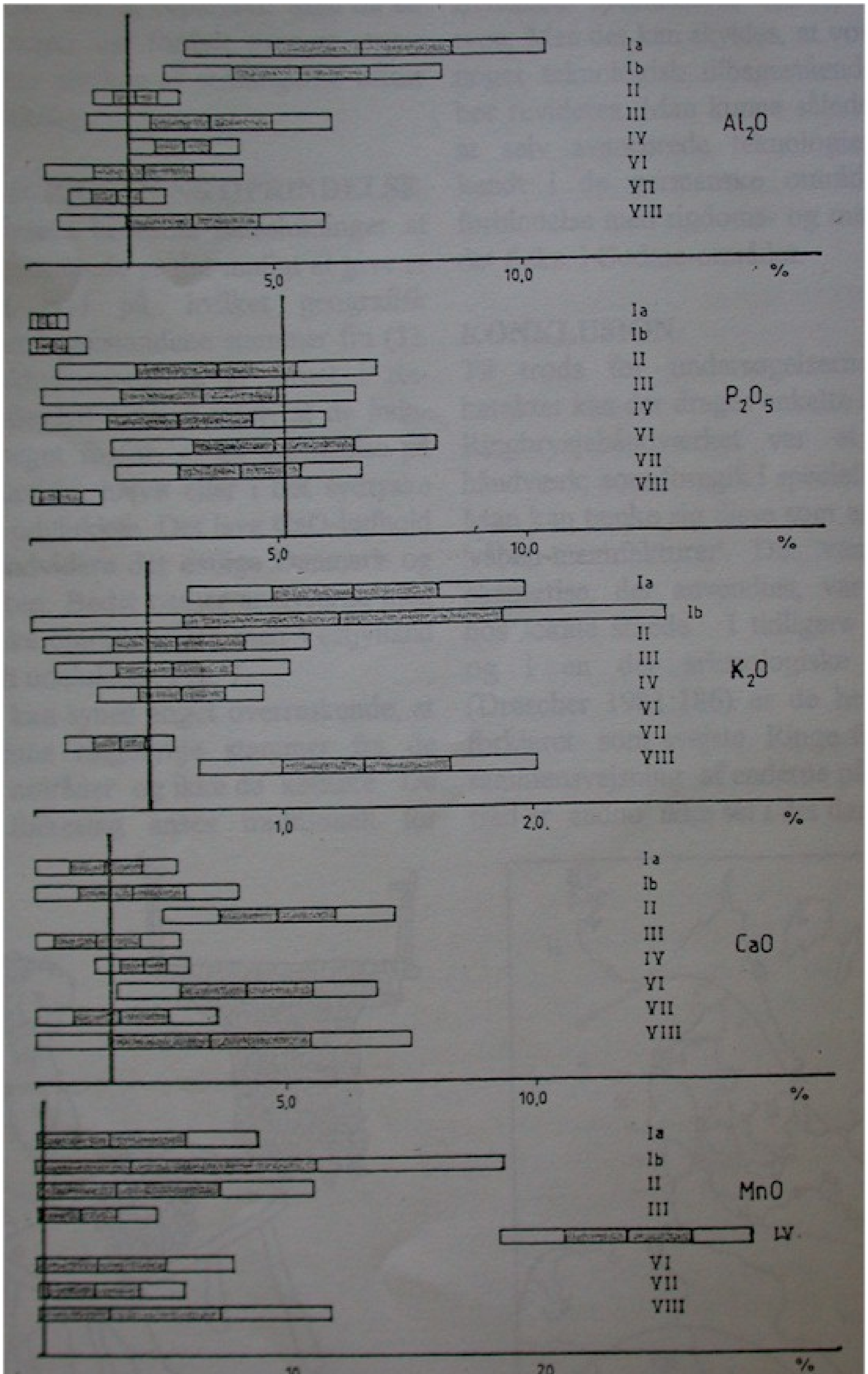
Bjarne Lønborg, of the City of Odense Museums has therefore suggested that hollow punches have been used (personal opinion). Such punches were used in the Iron Age for the preparation of various metals – although not iron. But since pure iron is soft, in fact, softer than bronze, it is certainly possible that it can be cut with punches made of steel. The rings could then have been ground after punching which would explain the rounded exterior. This would be done to remove abrasions and sharp edges, which could otherwise wear through a leather vest worn underneath – not to mention the wearer's own skin. Grinding could have been achieved in the way described by a German handwritten text from the 15th century.

<u>The riveted rings:</u> The round cross-section of the wire and slag pattern indicates the wire was drawn. This involves first forging the iron into a thin rod which is then drawn through a series of holes of decreasing size in a steel plate until the desired thickness is achieved. This is still the most common method used today. Wire making is a very

Fig. 6

A ringmaker finishing rings. The rings are strung on the bowstring and then drawn through a hole in a wooden block. Grinding media may have been added to the block (Treue 1965).

old technology and has been known in the Middle East since around 1000 BC. It is presumed that drawing plates from the European Iron Age could only have been applied to silver, gold and copper (Johansen 1953:172). But wire could also be drawn from pure, soft iron. The wire was wound around a dowel and cut into rings. The ends of the rings were laid over each other, pressed flat and a rivet hole made with a sharp implement. This was only done once the ring had been passed through its four jointless 'neighbors'. Finally, the rivet wire would be passed through the hole and the rivet head formed. Another common method of wire production was cutting, in which a very thin plate was forged and then using tin shears to cut a narrow band off the edge. This gave the wire a slanted cross-section.



Ia
Ib
II
III
IV
VI
VII
VIII
Al_2O
5,0
10,0
%
Ia
Ib
II
III
IV
VI
VII
VIII
P_2O_5
5,0
10,0
%
Ia
Ib
II
III
IV
VI
VII
VIII
K_2O
1,0
2,0.
%
Ia
Ib
II
III
IV
VI
VII
VIII
CaO
5,0
10,0
%
Ia
Ib
II
III
IV
VI
VII
VIII
MnO
10
20
%

Fig. 7

The mean value of slag inclusion analyses from the Hedegaard chain-mail compared with reference analyses (mean value with confidence limits between 66% and 95%) from the eight main areas (I-VIII). The phosphorous-oxide (P205), calcium-oxide (CaO), Aluminium-oxide (A1203) and potassium-oxide (K20) content shows that the origin of the iron must be sought within the area VII – although area III cannot be excluded.

Repairs to mail-shirts were made using rings made of cut wire. Perhaps they were carried out by a local smith who did not have the necessary equipment to draw wire. Cutting would also have been a much quicker and easier way of making all the small lengths of wire needed for repairs.

Fig. 8

The mail-maker at his workbench. He is using a pair of tongs, probably for riveting (Treue 1965).

These various operations were probably performed with special tongs. No archeological find known has included any type of riveting tool or a chain-mail tool for that matter. A German Medieval handwritten text shows a ringmaker using tongs for riveting. The rivets were always made of cut wire, often with a much

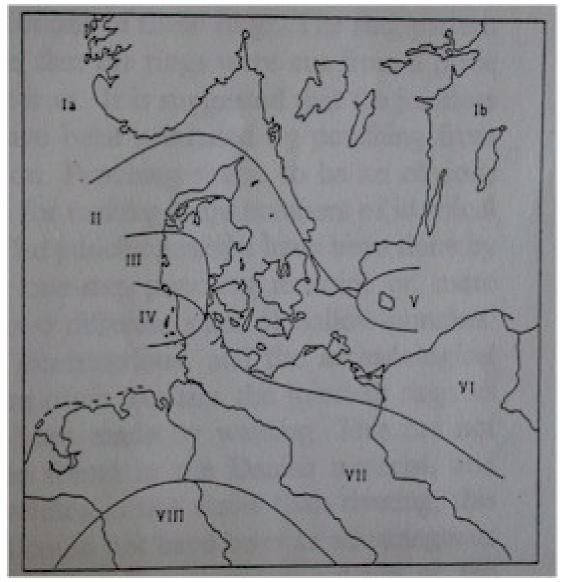


Fig. 9

Based on bloomery slag analyses, Northern Europe may be divided into eight main areas, each having its own unique chemical characteristics.

smaller dimension than the rivet hole. They must have been relatively weak joints and only the riveted rings have been repaired. But since most of the strain would be distributed over a large number of rings, the strength of the joints was usually sufficient.

Hedegaard mail-shirt's origins

By analyzing the tiny elements of slag embedded in the iron, it is possible to give a well-substantiated estimation of which geographic area the iron originates from (3). A slag inclusion analysis of the rings in the Hedegaard mail shirt shows that they contain so much phosphor that the Scandinavian peninsular and the south of –

Germany can be ruled out. The low CaO content also rules out the eastern part of Denmark and the Baltic Sea coastline, The analyses match best the north of Germany (VII), but the west of Jutland cannot be excluded. Fig 7.

It can seem surprising the rings in this shirt originate from Germany and not the Celtic areas. The Germanic peoples are traditionally regarded as not being in possession of sufficiently advanced technology and organization to be able to produce such specialized handiwork of this type. But it could be that our view of the somewhat technologically-backward Germans should be revised. If so, it could be imagined that even advanced technology has been known in the Germanic areas, perhaps in connection with centers of wealth and power such as around Gudme.

Conclusion

Despite the provisional character of this study, some conclusions can be drawn. The craftsmanship of mail-making was very specialized, performed in special workshops. We can imagine these as being part of a more extensive 'arms-manufacturer'. The tools and expertise used was not available at the local smithy. In previous studies and in a number of archeological publications (Drescher 1981:186) the jointless rings are often described as being welded. Rings manufactured by welding the ends of a bent piece of wire have not yet been seen in the Danish material.

Welding of wire only millimeters thick is a difficult job, as the heat in such small pieces of metal is hard to control. It tends to recede very quickly when the object is removed from the fire.

An essential requirement for the jointless rings was that they had to be quicker and easier to manufacture than the riveted ones otherwise, all rings would be riveted. Such mail only appears first in the Middle Ages. This makes stamping or punching more logical. The forging of thin sheets would be no problem for an experienced smith and stamping would be much quicker and easier than drawing wire followed by welding.

Notes

(1) This article is based on a study of two mail shirts: The first from the pre-Roman Iron Age from the burial site at Hedegaard (HOM 151x1054) and the second from Brokaer (ASR C 3281) dated to the late Roman period. The studies were later supplemented by material from the finds at the Thorsbjerg (NM 19503) Vimose (NM 24219) and Kastenskov (NM C 13527) bogs.

(2) Samples for metallurgical analysis were taken from the Hedegaard and Brokaer mail shirts supplemented by loose rings from Thorsbjerg and Vimose, Since there are a lot of common features, despite the different dimensions of the rings, the results of the study are therefore described in general terms.

(3) A method developed over recent years by the author of this article.

Summary

Pieces from five different mail-shirts have been examined, all dating to the Late pre-Roman Iron Age and the Roman Iron Age. These finds include one from a Late pre-Roman burial at Hedegaard in central Jutland, two bog finds from Vimose in Funen, and from Thorsbjerg in south Jutland, and from a find in Brokaer near Ribe in western Jutland.

The mail-shirts all consist of alternating rows of riveted, and apparently jointless rings. The sizes of the rings, however, are very different, ranging from 5.0 mm to

12.5 mm in outer diameter. The wire-thickness is 0.95 mm to 1.7 mm. Cross-sections of the wire show that the jointless rings have a flat inside and a more rounded outer side. A characteristic groove is seen running around the lwer side of the rings, its edges sometimes forming burrs up to 1 mm wide. The structure of the jointless rings has been heavily deformed, the material being forced downwards at the inner and outer edges. No sign of any joint has been seen in the plane-sections of these rings. The slag pattern indicates that the rings were cut from a piece of sheet-iron. Punching seems to be an obvious method for making large numbers of identical rings. The punching might have been done by using a one-step punching machine or, more likely, two different sizes of hollow-punches. Earlier examinations, and the archaeological literature often explains the jointless rings as having been made by welding. This has not yet been found in the Danish material, and since welding is not easier than riveting, this method could not have been as advantageous as punching. The rounded outside of the rings might have been deliberately made by grinding. This removed the burrs and would have protected an underlying leather garment. Riveted rings are made of almost circular wires. The slag-pattern in the plane-sections are more or less parallel to the surface of the wire. This suggests that drawn wire has been used. The overlap at the rivets is always somewhat flattened and varies in size from 1.5–2.0 mm to 7.0-8.0 mm. Consequently, the overlap is in the same direction within one mail-shirt, but can vary in different mail-shirts. Wire cut from sheet-iron was only seen in rings inserted as repairs. All of the rivets seem to have been made of cut-iron wire. The riveting might have been done with special tongs.

Analyses of the slag inclusions in the rings in the mail-shirt from Hedegaard, compared with analyses of bloomery slags, has given information as to the origin of the iron. The iron has apparently been produced within the geographical area which covers the middle part of Germany and the southern part of Poland.

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