The Anglian Helmet from Coppergate

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Fig. 408 (pp. 942–5) Four views of the helmet as reconstructed (a–d)
cheek-piece, and is almost identical to the right cheek-piece hinge, except that it has three slots instead of four, forming four projecting loops which engaged with the slots on the opposing half of the hinge. The rear loop is roughly broken away. The brass edge binding is identical to that on the right cheek-piece, ranging from 3·1mm to 3·7mm in width and between 2·7mm and 2·9mm in thickness, including the thickness of the iron of the cheek-piece. The metal from which the binding is made must originally, therefore, have been less than 1mm thick. The binding is held in place by four rivets. One is just in front of the hinge, and two are closely spaced, only 4·1mm apart, just behind it. The fourth rivet is placed 67·7mm below the front upper corner of the cheek-piece. These rivets vary from 1mm to 1·6mm in diameter (Table 75).

From the rear edge of the cheek-piece develop four loops intended to link the cheek-piece and the mail. They are identical in form to those on the right cheek-piece. Loop 5 is placed 8·5mm from the rear upper corner of the cheek-piece and is 14·5mm long and 3·9mm wide (Fig.460). Loop 6 is 32·4mm below this and 14·3mm long by 3·9mm wide (Figs.460-1). Loop 7 is 29·1mm below loop 6 and 15·1mm long by 5·4mm wide (Fig.461). Loop 8 was 32·9mm below loop 7, but had been completely lost when the helmet was discovered, leaving only the rivets and the mark where it crossed the edge binding to indicate its position. A modern loop now occupies this position. The dimensions of the individual rivets holding the loops in position are recorded in Table 75.

X-ray fluorescence analysis of the rivets demonstrates that some are made of brass and others, perhaps slightly cruder, of bronze (pp.1017-19), suggesting repair or replacement, a subject discussed in more detail below, p.1029.

As with the right-hand cheek-piece there is a rivet placed 32·5mm below the hinge, just to the rear of the vertical axis of the cheek-piece. It is 2·3mm in diameter and has a flat head on the outside and a slightly domed head on the inside where it holds in place a subcircular
washer, 5.7mm in diameter (Fig.459c–d). Again this probably represents the point of attachment for a tie.

**The mail curtain**

**By Sonia A. O’Connor**

The mail curtain at the rear of the helmet is formed mostly of iron rings which have an external diameter of 8mm and are made from a circular wire with a diameter of 1mm. They are of very high quality as the shape and size of the rings are very consistent. The mail was originally hung from the U-shaped suspension strip at the base of the cap by way of a row of copper alloy rings, which are themselves held in the slots of the strip by an iron wire (Fig.462). These suspension rings are unlike any of the rings in the mail proper, being both larger and thicker. The edges of the curtain were held by the copper alloy loops on the cheek-pieces. When the helmet was partially dismantled in antiquity the rings attaching the mail to the cheek-pieces were probably cut, resulting in some loss at both ends of the curtain. Most of the rings in the first row of the mail were probably also removed in this way, but the job was left incomplete and the curtain was still attached to the rings of the suspension strip of the helmet at the right-hand end of this row prior to conservation (Figs.389 and 599s).

The surviving portion of the mail curtain consists of 1947 rings arranged in 28 horizontal rows, the longest of which is now 81 rings long. The rows alternate between welded, and lapped and riveted rings. The body of the mail is structured in a conventional manner. Each ring passes through two rings in the row above and two in the row below. Within a single row adjacent rings do not interconnect, but both pass through a common ring in the rows above and below. The overall visual effect is of vertical lines of alternating crescents curving
Fig. 462  Diagram of the suspension strip and mail

Fig. 463  An idealised area of the mail showing the vertical lines of alternating crescents curving to the right and left
to the right or the left (Fig. 463). This technique produces a material which is flexible but anisotropic. If such mail is hung incorrectly, so that the rows run vertically, the weight of the mail pulls the rings apart as far as they will go, extending the area covered by the mail but giving a very open structure with little depth. Hung in the correct direction the downwards drag on the mail acts to pull the rings of each row close together to form a densely packed armour. Figure 600s is a schematic representation of the mail from which each ring can be identified by an alphanumeric code; the letter indicates the row and the number indicates the position of the ring within the row. The surviving mail of the curtain is approximately 105mm from top to bottom, but its width depends on how compacted or stretched it is when measured. When fully extended sideways the mail is 470mm at its widest, but it would not have been stretched this far when it was hung.

**Suspension of the mail curtain**

Figure 599s shows the rings which attached the mail to the helmet when it was excavated. The copper alloy suspension rings are slightly larger (between 8.0mm and 8.5mm external diameter) and thicker (between 1.2mm and 1.4mm wire diameter) than the rings of the mail. They are circular and made from a circular cross-section wire. They are very well-preserved with smooth surfaces, but neither visual examination nor X-radiographic study revealed the method by which the rings were closed. It is difficult now to determine exactly how the mail was distributed around the back of the helmet as only six lapped and riveted rings of the first row (row A) have survived. The first three of these at the right-hand end are atypical of the mail, being large, between 10mm and 12mm in diameter. These rings are hung from pairs of suspension rings but have been pulled open at their rivets, perhaps during the dismantling of the helmet in antiquity. In Fig. 600s the first ring on the right has been designated A73/75 as it was linked through B73, 74 and 75. Although the next ring to the left was only linked to B72 and the next was no longer linked with the bulk of the mail, they have been labelled A70/72 and A67/69 on the assumption that they too were originally linked to these rings in row B below. To the right of A73/75 there is room for a fourth large ring of similar function and a number of rings in row B are available to connect with this and the top attachment loop of the cheek-piece. The fullness created by this gathering of the mail immediately behind the cheek-piece would have allowed movement of the cheek-piece, reducing the strain on the attachment loops, particularly when the helmet was being put on or taken off. The next two surviving rings are the same size as the rings in the bulk of the mail and hang only from single suspension rings. It is possible that they may also originally have hung from pairs of suspension rings as one of the rings of the mail is open and one of the suspension rings is missing. If the rings of row A between these two rings and the last of the large rings (A67/79) were all of this smaller size and were linked to the rest of the mail on a one-to-one basis, these two rings can be reasonably identified as A63 (which is copper alloy) and A61. The only other ring in this row (A26) is still attached to the mail but not to the rings of the suspension strip. It appears to be slightly smaller and thicker than any of the other rings and also to have a butt join, but since it is heavily corroded it is difficult to be sure that this is not a break.
If all of the above assumptions are correct, it is possible to suggest how the mail might have been distributed. Behind the right-hand cheek-piece the first ring of row B might be involved in a linkage with the cheek-piece and the next twelve gathered into four large rings of row A (Fig.464). Moving round to the left each standard ring would be linked one-to-one with the suspension strip, taking up a further 38 rings to the mid-point of the back of the cap. The last ring would be directly above B29 and, if the same pattern were mirrored across the missing half of the suspension strip, row B would require another 51 rings to reach the left cheek-piece and falls short by 26.

It is possible that the standard size rings in row A were originally linked to pairs of suspension rings, as are the surviving larger rings. By substituting this into the calculations, row B ends up with a surplus of eleven rings. Another possibility is that the relationship of suspension rings to rings of the mail was more random and that a piece of mail was used that did not precisely fit the helmet. This latter idea, however, does not fit well with the level of care and craftsmanship generally observed on every detail of the helmet. In the current reconstruction the mail has been rehung with very little addition of new rings. This has resulted in the mail being stretched sideways too far, producing a very open structure which reduces its protective function.

A further problem with all these hypotheses is that ring A63 is unbroken and none of the rings in this region of row B is broken or missing. This suggests that A63 was never directly
linked with row B. It is possible that a partial row of rings was inserted between rows A and B to compensate for the distortion caused by having rings of two different sizes in row A. This would mean that the rather odd ring A26 does not belong to row A but is the sole survivor of this partial row. Another explanation could be that A63, which is not iron but copper alloy, is an additional ring hanging free; perhaps a talisman. There are only three other copper alloy rings in the entire mail, AA46, AA48 and AB48, and they are the only representatives of the lowest two rows (Figs. 469, 600s). They are of similar size to the iron rings, those in row AA being lapped and riveted and that in AB being solid. It is not known how the latter ring was fabricated. It may be that there was a trim of two complete rows of copper alloy rings at the bottom of the mail, or these three isolated rings may also have been a talisman. Copper alloy talismans are found in medieval European mail and edgings of two or three copper alloy rings are frequently seen at collars, cuffs and lower edges of mail shirts and other items.

Understanding the attachment of the mail to the cheek-pieces is no less fraught with problems. Each row of the mail curtain would have to be longer than the one above in order to follow the curve of the cheek-piece. Mail with a straight edge will tend to hang with a taper, as the weight of the rings pulling downwards tends to draw the edges in. This effect would lead to the mail hanging away from the attachment loops producing vulnerable gaps in the protection afforded, even though the mail was shaped to the curve. This problem could be overcome by the insertion of a wire, bent to follow the curve of the cheek-piece, through the rings at the edge of the mail as demonstrated in the restoration of the helmet (Fig. 461). It cannot be determined to which rows the attachment loops were connected, as the original length of the rows is unknown and the more the mail has to be stretched sideways to reach the loops the shorter the mail becomes.

The rings of the mail

The characteristics of the lapped and riveted rings and the welded rings are very consistent within each type and there are several points of similarity between the two types. Both ring types are circular, made from circular cross-section wire, and planar — quite flat when viewed edgewayes on. The diameter of the wire is between 0.9mm and 1.2mm, and the external diameter of the rings is between 7.8mm and 8.2mm. Measurements taken from the rings are presented below.

The wire of the lapped and riveted rings spiral in an anticlockwise direction, i.e. with the lap at 12 o'clock the right-hand end of the wire passes over the left-hand end. The ends of the wire overlap approximately 4mm and are flattened and tapered into a simple leaf shape. The rings are circular and the flattening of the wire, to about 1.5mm thick, only affects the internal diameter of the ring (Fig. 465). At the overlap the front-to-back thickness of the ring gradually increases from 1mm to 1.5mm and in cross-section this bulge is symmetrical. The centre of the lap is pierced with a circular hole, 0.8mm or 0.9mm in diameter, into which the rivet has been introduced. This method of closure creates a weak point at the rivet as only a very thin narrow strip of metal survives either side of the hole. On rings broken at this
point it is possible to see, on one internal surface of the overlap, that as the hole was made the metal was deformed producing a little raised collar around the hole (Fig.466). This feature suggests that the rivet holes were punched through the lap, but the metallographic evidence from a single lapped and riveted ring indicates that the holes were drilled (p.1023). The rivet and the rivet hole taper very slightly from the head to the tail. The rivet is circular and the head and tail are slightly domed but are apparently flush with the surface of the ring.

The welded rings were first identified using high-definition micro-focus X-radiography. From visual examination of the conserved rings it was clear that these were not simply butt-welded as no gap could be discerned between the ends of the wire. This observation was confirmed by conventional radiography which also showed that the rings had not been soldered closed, as such material would have appeared as bright (more radio-opaque) lines across the wires. Conventional radiography techniques produce a 1:1 scale image which can be viewed under lenses to magnify the image to a certain extent, but the resolution of the
Table 56 Randomly selected measurement data describing internal ring diameter and wire thickness

<table>
<thead>
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<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>n</th>
<th>Coefficient of variation</th>
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<td></td>
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<td></td>
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<td>0.43</td>
<td>10</td>
<td>7.84</td>
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<tr>
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<td>0.28</td>
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<td>5.05</td>
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<tr>
<td>Wire thickness:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>riveted rings</td>
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<td>0.12</td>
<td>10</td>
<td>11.14</td>
</tr>
<tr>
<td>welded rings</td>
<td>1.16</td>
<td>0.16</td>
<td>10</td>
<td>13.64</td>
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image is limited. However, the high-intensity micro-focus radiographic equipment which was subsequently used did provide magnified images, up to ×20 linear. Figure 467 is a high-definition X-radiograph of a group of rings on the left-hand edge of the mail. This clearly shows the features of the lapped and riveted rings and, on ring L2, a dark transverse line flanked by dense bands in the iron. This was tentatively interpreted as a weld line, although not identified in this way before, and was later confirmed by metallographic examination (p.1024).

Following conservation of the mail, measurement data of the diameter of the rings and the thickness of the wire were randomly selected to determine whether the two types of ring were significantly different in internal diameter, and thus made on different mandrels, and whether the wire used to make the two ring types differed in thickness. Ten riveted rings and ten welded rings were measured using vernier calipers and recording measurements to the nearest 0.01 mm. The results are presented in Table 56.

Table 57 Selected measurement data describing external ring diameter and wire thickness

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<thead>
<tr>
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<th>Mean</th>
<th>S.D.</th>
<th>n</th>
<th>Coefficient of variation</th>
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</thead>
<tbody>
<tr>
<td>External ring diameter</td>
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<td>1.75</td>
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<td>Wire thickness</td>
<td>1.05</td>
<td>0.09</td>
<td>10</td>
<td>8.88</td>
</tr>
</tbody>
</table>
The data confirm that the two different ring types have mean internal diameters similar enough to suggest that they could have been made on the same mandrel. Mean wire thickness appears to differ, the welded rings having a greater mean wire thickness than the riveted rings. This measurement could have been made inaccurate by measuring areas with a thin crust of superficial corrosion or corrosion pits. The high coefficients of variation (11.14 for riveted rings, 13.64 for welded rings) would be consistent with this kind of variation.

A second series of measurements was taken, purposely selecting rings where surfaces bearing original surface details within replacement corrosion could be recognised. This series contained both riveted and welded rings. These data are presented in Table 57. The very low variance of the external ring diameter (coefficient of variation = 1.75) indicates that both ring types were specifically made to have the same external diameter. The standard deviation and coefficient of variation for the wire thickness are lower than those given in Table 56. These results confirm that at least some of the variance seen in the original data resulted from the inclusion of superficial corrosion and that the wire used for both types of ring does not differ significantly in diameter.

The data show a marked consistency in ring and wire size, confirming the high degree of craftsmanship manifested in the mail.

**Quality of the iron wire**

On the high-intensity micro-focus X-radiograph images some of the rings showed dark bands running parallel to the long axis of the wire (Figs. 467–8). These features in iron are usually caused by slag inclusions or areas of deep corrosion, indicating that the iron is very heterogeneous. Some of the rings had split longitudinally as a consequence. The metallographic study of the rings (pp. 1023–4) sectioned L2, which was welded, and M2, which was lapped and riveted. Both wires contained inclusions but these were more extensive in L2. These faults in the rings were also visible on the conventional radiographs of the mail which, with the use of a ×8 loupe, could be mapped. This quickly showed that the faults were concentrated in the wire of the lapped and riveted rings. For each ring the fault was recorded as a possible trace, severe or absent. Of the 1938 iron rings examined, 1011 were welded and 927 were lapped and riveted. Only 32 of the welded rings showed any sign of the fault and only three of these were classed as severe, while 583 of the lapped and riveted rings were identified as having the fault and 468 of these cases were severe.

This result indicates that the wire for the two types of rings came from different stocks; that used for the welded rings was much cleaner and more homogeneous than that used for the lapped and riveted rings. This may indicate that the two types of rings came from different sources, although the results of the statistical study of measurement from both types of ring (Tables 56–7) suggest that this is unlikely. It is possible that a higher quality
Fig. 467 High-intensity micro-focus X-radiograph showing the welded ring M2 (M), the lapped and riveted ring L2 (L), and the wire fault (F). Magnification ×5
Fig. 468 High-intensity micro-focus X-radiograph showing the wire's internal faults. Magnification ×9
iron was favoured or even necessary for the production of welded rings. In practical terms a small amount of slag could be useful in the welded rings as it would act as a flux for the weld. When iron is heated its surface rapidly oxidises and a layer of oxide or scale prevents the weld being formed. At welding temperatures the slag liquefies and flows on to the surface of the iron inhibiting the formation of the oxide layer and facilitating the weld. However, experimental work on the method of production of welded rings (pp.1064–71) was successfully done using good quality, modern, soft iron wire, without the use of a flux.

Evidence for wear

There is a small number of rings missing within the body of the mail. Some of these may have been lost during the useful life of the helmet, but some were the casualties of extreme corrosion during burial. Rings E73, W49, W50, W51 and Z6 are all misshapen and not as neatly made as the rest of the mail. The three deformed rings in row W are grouped above one lapped and riveted ring (X50/51) which has been used instead of two welded rings (Fig.469). Similarly, the lapped and riveted ring M56/57 has been used in place of two lapped and riveted rings (Figs.470, 600s). These features have been interpreted as repairs and were possibly carried out hurriedly, in the field, with limited equipment and, perhaps, by someone with lesser skills than the original mail maker.
Technology and dating of the mail

By Sonia A. O’Connor

An historical perspective

Mail armour occurred quite widely in Europe from the late Iron Age through to the 18th century when, with most other forms of body armour, it effectively dropped out of use. In Britain the mail shirt from the cart burial at Kirkburn, North Yorks., is probably the earliest occurrence of mail, attributed by Stead (1991) to the 3rd century BC, and its mail is thus broadly contemporaneous with the earliest known examples of iron mail from elsewhere in Europe. The rings were all butted, between 8-2mm and 9-2mm in external diameter, and made from a wire 1-5–1-9mm thick. The Kirkburn mail was constructed in the manner which seems to have been very widely utilised, where each ring passes through four others. Other pre-Roman Iron Age finds of mail from Britain and comparative material from Switzerland, Denmark, Romania and Czechoslovakia are noted in Stead (1991). This material includes examples of mail made completely from butted rings, alternating rows of butted and riveted rings, solid and riveted rings, and an example of a very unusual densely constructed mail where each ring passes through six others. Stead suggests that the solid rings may have been punched from iron sheet (Stead 1991, 54–6).

Whether the Romans adopted the wearing of the mail shirt from the Celts or vice versa is open to debate, but there is considerable documentary, sculptural and archaeological evidence of Roman use of mail from before the 2nd century BC onwards. In the 1st century AD a mail with small scales attached to the rings was developed. Fragments of iron and, occasionally, copper alloy mail of a variety of ring types and sizes are found on archaeological sites, but usually their corroded state restricts the amount of detailed information which can be gained (Robinson 1975, 164–73). Mail was used alongside plate, segmented and scale armour. As the Roman helmet developed it acquired more complex and elaborate protection for the face and neck, but these were rigid plate constructions and mail was never employed.

Finds from sites of the 5th–10th centuries AD generally do not give a clear picture of the development of mail. Fragments of iron mail are widely found but few are published in detail, again largely due to their corroded state. The 7th century grave at Sutton Hoo contained a mail shirt but, as noted below, pp.1094–5, the helmet has a solid iron face mask, cheek-pieces and neck guard (Bruce-Mitford 1978) (Figs.530–1). The 6th–7th century Spangenhelme, below pp.1082–3, have defensive iron mail curtains, and in reconstructions they are typically shown with hinged plate cheek-pieces and mail neck guards. Evidence for the cheek-pieces has survived, but that for the mail is usually far more circumstantial. Both the Frankish helmets from Morken (Pirling 1974, no.21) and Cologne, Germany (Doppelfeld 1961–2), have well-preserved iron mail guards possibly secured to the caps by leather thongs, although the Cologne helmet is not a standard Spangenhelm form. Other Spangenhelme have been found in association with mail; the associated object
from Gammertingen, Germany (Gröbbels 1905), is perhaps a whole mail shirt. Many of these helmets have perforations along their lower edge which are commonly interpreted as being for the attachment of mail. However, this explanation seems unlikely for, where preservation allows, as on the Gammertingen helmet, it can be seen that these holes are punched along the entire circumference, around eye arches and along the edges of the cheek-pieces. The alternative explanation is that the holes were made to take thongs which secured a leather lining. This suggestion is supported by the fragments of leather surviving inside the Gammertingen helmet (ibid.).

From helmets of the Vendel period in Sweden (Table 61) there is far more direct evidence for the use of mail in the form of suspension strips (Fig.550), similar to that on the Coppergate helmet, neck guards and fuller protective curtains (Fig.553); however, there is an equal amount of evidence for more rigid neck guards made of hinged suspended strips. Arwidsson (1934, 254) suggests that these strips might have been used on the simpler forms of helmet and the more ‘costly’ mail was reserved for more complex higher quality work. Although the helmet from Vendel XIV (Fig.539) does not fit this pattern, she suggests that the lack of mail is explained by its early date and draws a parallel with the rigid neck
protection on Late Roman helmets. Remains of mail shirts were also found with many of these helmets, including Vendel XIV, but that from Valsgärde 8 is unique in having mail over the shoulders and strips of iron down the body and upper arm (Fig.503).

Viking Age helmets are extremely rare and fragmentary but the one from Gjermundbu, Norway (Grieg 1947), is the most complete and was found in association with a mail shirt. The helmet may have had a mail neck guard suspended from rings on its lower edge, although the wide spacing of the surviving rings might be better suited to supporting a leather neck guard (Munksgaard 1984) (Fig.560b). From Birka, Sweden, a few rings of mail of various sizes have been found but only the rolled up remains of one mail shirt (Mann 1958, figs. 34, 38). The original shape and length of all the mail shirts mentioned is not known as a result of folding and subsequent corrosion, even when they appear to be more or less complete. A more detailed discussion of the mail contemporary with the Coppergate helmet is given below, p.1076.

The more substantial finds of mail are generally from high status burials and may not truly reflect the garment forms or ring types in more general use; other forms of evidence, however, suggest that the mail shirt or byrnie was more widely available. Mail-clad warriors are depicted in Vendel art, on the 8th century Franks Casket, and are suggested on decorated panels on the Sutton Hoo helmet (Bruce-Mitford 1978, 237–8). The wearing of mail is alluded to several times in the poem Beowulf. Three Anglo-Saxon wills also deal with mail, all dated in the early years of the 11th century. The will of Wulfsige (AD 1022–43) leaves one coat of mail (Sawyer 1968, 1537), the will of Ælfwold, Bishop of Crediton (AD 1008–12) leaves six coats of mail (ibid., 1492), and Archbishop Ælfric of Canterbury bequeaths 60 coats of mail (ibid., 1488). As noted below (p.1169), this represents, with 60 helmets and a ship, the arms of the ship’s company. The Laws of King Cnut lay down heriots for the greater nobles. For an earl the heriot included four coats of mail, and for a king’s thegn one coat of mail. The implication is that lesser thegns and those of lower rank would not have mail coats, but the wording is ambiguous (II Cnut 71; Whitelock 1955, 465). Mail is a very durable commodity and, with a fairly constant rate of production, the amount in circulation would have gradually accumulated. Mail was considered commonplace enough in the 10th century to feature in a riddle which appears in The Exeter Book, AD 975 (Scott 1979, 155).

Blair, in his standard work on European armour from the mid 11th to the 18th century, divides armour into three groups; soft armour, mail armour, and plate armour (Blair 1958). Other than soft armour, made of leather or quilted fabrics, mail was probably the most commonly worn body defence until 1250 and continued in general use well into the 15th century. The construction was almost invariably based on each ring passing through four others and was either made entirely from lapped and riveted rings or alternating rows of these and solid rings. The use of solid, e.g. welded, rings is rarely encountered after 1400 and the bulk of the mail which has survived is all riveted. Butted rings are only found in Oriental armour, modern reproductions and forgeries.
There is little mention of mail on helmets but close-fitting mail hoods or coifs were worn over caps or under helmets. These coifs are depicted in the 11th century Bayeux Tapestry both as discrete items and made into one with the mail shirt, the hauberk. The latter form may well have had a ventail which was a fitted flap that could be drawn across the mouth. Some of the figures also appear to be wearing mail leggings called chausses. These are the main items for which mail was used until it was overtaken by plate armour.

Between the 11th and 14th centuries there are various changes in the types and detail of the mail garments, but the appearance of the mail itself remains little changed. Mail was hung from some forms of later medieval helmets and appears to have been designed to be removable for cleaning. Scale or lamellar armour in one form or another was probably used throughout this period, but it is only at the end of the 12th century that plate armour begins to appear and not until the middle of the 13th century does it come into general use. It was well into the 14th century before it was adopted universally, and then only as an added protection for the legs, knees and elbows. By the 15th century the use of mail was overtaken by the further development of plate armour. The wearing of complete mail shirts beneath plate armour gradually disappears in the 16th century but mail was still used into the 17th century for collars or mantles and to protect areas, such as the armpit and groin, where greater flexibility was needed.

**Manufacturing techniques of the Coppergate mail**

Despite Wilson's dismissive statement that 'It is hardly worth pursuing the very simple process of manufacturing chain-mail . . . .' (1976, 264–5), examination of the Coppergate helmet mail shows that its manufacture must have been a far from simple process. There would have been over 2000 rings in the mail when it was complete. A rough calculation based on 1940 8mm diameter rings demonstrate that around 49m of 1mm diameter wire was used to produce the surviving portion of the mail alone. The circular cross-section of the wire, its unvarying diameter and the smoothness of the surface on the best preserved rings raise the question of how it was manufactured. Further questions are raised concerning the method of manufacture both of the lapped and riveted rings and the welded rings, and the order and method of the construction of the mail curtain from the rings.

**Production of the wire**

It seems, on the face of it, doubtful if wire of this quality and consistency could have been produced other than by drawing. The hand making of iron wire pre-dates drawing, but the techniques used were laborious and the results were of variable quality. There is much controversy as to the date of development of wire drawing and its application to iron. It has been suggested that mail would not have been developed if drawn wire was not available, for if wire was not fairly easy to make it would not have been used on such a scale when other material was available for defensive armour (Burgess 1953a). Oddy (1977, 81) is in no
doubt that the changes in wire drawing technology, which appear to have occurred in the 14th century, would have been stimulated by increasing demands for products such as mail.

The process of wire drawing involves the reduction of a metal rod to a wire by drawing it through a series of successively smaller holes. Gold, silver, copper and some of their alloys are drawn cold. Iron would normally be heated to a relatively low temperature (black heat) although soft iron wire also can be cold drawn (P. Gardner, pers. comm.).

A rod is first drawn down from the stock iron by hot working. Drawing down iron in the forge is done by hammering on the anvil or by fullering between a pair of chisel-like tools with rounded ends at near-welding heat (CoSIRA 1952, 20). The temperature for this varies depending on the carbon content of the iron, but at 0.3% carbon this occurs at about 730°C (Alexander and Street 1972, 158). The rod becomes work-hardened and brittle and needs to be softened by annealing at red heat and cooled very slowly. The surface scale of oxide is removed and one end is pointed by hammering or filing.

The pointed end of the rod is inserted into a hole, in a drawplate or swage block, which gradually tapers along its length to a diameter slightly smaller than that of the rod. The point protruding from the narrow end of the hole is gripped with pliers and the rod is pulled through in short lengths by hand and longer lengths using a windlass. As the wire is drawn it is reduced to the size and takes up the shape of the hole and becomes longer. A drawplate has a series of holes of descending size (Fig. 504) and an adjustable swage block has two
dies, one or both of which are cut with tapered grooves, which could be brought together progressively. The wire is drawn through these holes until it reaches the desired diameter. Modern dies and drawplates would be cut in hardened steel, but Thomsen and Thomsen (1976, in Oddy 1977) have shown that wire can be formed through dies of the same metal and Burgess (1953a) claims that soft iron could even be drawn through hardened bronze.

It might be expected that the final product would be work-hardened and brittle, like the hot-worked rod, and require annealing after, and perhaps during, the drawing process but this is not necessarily the case. S.W. Goodyear, an experienced wire drawer, writing in the journal *The Blacksmithing and Wheelwright* in the late 1880s, states that drawn wrought iron wires can be 'bent, flattened, riveted and otherwise treated in a way to test their tenacity, without showing any sign of having had the tenacity removed or destroyed but on the contrary greatly increased . . . .' (Richardson 1978, 54–8). His explanation for this improvement over hot or cold hammered iron is that the reduction in size has been achieved by gradual and gentle compression, evenly distributed, rather than by 'shock and violence' which produces an unequal compressive effect.

The use of drawplates is first mentioned in the early 12th century in the treatise *De Diversis Artibus* by the monk Theophilus (trans. Hawthorne and Smith 1979, 87–9). But iron drawplate-like objects have been found from as early as the Merovingian period on archaeological sites (Petersen 1951). Unfortunately it is impossible to be sure that wire drawing was their function and many of the published examples could equally well be bolsters for forming the heads on nails or rivets. Corrosion inevitably obscures the shape and surface detail of these objects, just as it destroys the wire which may have been produced by them. It is argued that the wire products which have been found cannot therefore be drawn wire because no drawplates have been identified beyond question. The only way to break this circular argument is to look for evidence of drawing on the wire itself.

Drawn wire has a very even cross-section and may be circular when produced with a drawplate, but if a swage is used the wire may be somewhat flattened. The surface of the wire exhibits many parallel striations running down its length, caused by contact with the drawplate or die, which are visible under low magnification or even by eye (Fig.505). Oddy (1977, 80) states that these striations are exclusive to drawn wire and maintains that in their absence the assertion that a wire is drawn cannot be proven.

Although Oddy's paper is primarily concerned with non-ferrous wire production, gold in particular, he surveys both the historical and archaeological evidence for wire drawing and, more usefully, the possible ways in which wire can be made and the criteria by which these techniques can be distinguished.

There are four ways of hand-making wire besides drawing: hammering, block twisting, strip drawing and strip twisting. The latter two techniques produce hollow wires from strips of foil and are not relevant to the production of iron mail. Hammered iron wire is simply produced by repeatedly forging and annealing a rod until the required diameter is obtained. The resulting wire will have a solid but less than circular cross-section with a variable diameter. The surface of the wire tends to be faceted and may exhibit longitudinal grooves.
or creases, a few millimetres long, caused by the hammering. Block-twisted wire can be formed from square-section hammered wire or from square-section strips cut from forged sheets. In either case the wire is tightly twisted. The twisting produces a fold through the centre of each surface so that the wire is encircled by four spiralling grooves. Soft, non-ferrous, block-twisted wire would then be rolled smooth between wooden boards, but it is more likely that iron would have to be hot worked to smooth its surface. Block-twisted wire will have a more constant diameter, circular cross-section and smoother surface than hammered wire, but the spiral grooves would persist in places. Both hammered and block-twisted wire could be swaged to improve their appearance and manipulate their cross-section.

The wire from the Coppergate mail has a solid cross-section and despite some corrosion is circular, smooth and consistent in its diameter. It shows none of the surface characteristics specific to hammered or block-twisted wire and most closely resembles drawn wire. The metallographic sections made of the wire of the welded and riveted rings showed features which could have been formed by hammering or drawing (p.1024). Unfortunately, even the best preserved rings have suffered some surface corrosion and the striations observed during conservation (p.929) could well be caused by this corrosion enhancing elongated inclusions at the surface of the metal. However, it is possible that with careful searching, areas of replacement corrosion may be found where the characteristic striations survive, confirming beyond doubt that the wire was drawn. Acetate peels were taken of some of the rings for study by SEM, but these have not yet yielded results. The slag inclusions, so clearly shown in the X-radiographs (Figs.467–8), may have caused the wire to snap frequently during drawing, but this would not necessarily have been seen as a problem as even a short length of wire would have produced several rings when coiled and cut.

Manufacture of the rings

The techniques of manufacture of mail rings were first discussed by Burges (1881, 564–6). The production of butted, riveted and solid rings are described and he assumes that the first two types are made from drawn wire. Burgess (1953a) takes this work further by
making lapped and riveted rings from drawn wire, using a set of simple tools. First he coiled the wire, cut it into individual rings, overlapped the ends of the wire, flattened the overlap between dies, punched in the rivet hole and cut the rivets. The rivets were inserted and closed as the mail was assembled. The possibility that the rivet holes might have been drilled rather than punched is not addressed. Burgess, like Burgess, believed that the solid rings which were often alternated with the rows of riveted rings were punched from sheet and then clipped or filed to shape or cut with a double punch. Neither author has identified or discussed the method of manufacture of solid welded rings. Smith (1959), in his metallographic study of rings from sixteen pieces of mail of the 14th–16th centuries, found evidence for a wide range of metalworking techniques, including the use of split sheet and hammered wires, but his results are largely consistent with Burgess' sequence of operation. Interestingly, all the rivet holes examined proved to have been drifted with a punch, and not drilled as the mail of the Coppergate helmet appears to have been, but all the solid rings in Smith's study were welded wire and not cut from sheet metal. These rings had flattened cross-sections and appeared to be made by welding two or three turns of wire together rather than having a small area of overlap welded. Smith believes that some of these welded rings have been individually finished by filing, but he has not considered that the surface loss he is seeing may in fact represent wear during use.

Experimental work on the rings

The metallographic study of the Coppergate mail showed clearly that the riveted rings differed in detail from those produced by Burgess and that the solid rings were heat- and pressure-welded. In order to understand the techniques involved, attempts were made to reproduce both types of ring. Peter Gardner provides the following report on this experimental work.

This work was carried out using modern drawn soft iron wire of 1.6mm diameter. It was the closest wire commercially available to that used for the Coppergate helmet mail. The initial work of forming the rings closely follows the process described by Burgess (1953a) and was identical for both types of ring.

An iron mandrel of 8mm diameter was held in a drill chuck and one end of the iron wire was held in a slot cut into its end. The free end of the wire was held with pliers and the mandrel was slowly turned, winding the wire into a tight spiral around the mandrel (Fig.506). The coil formed was cut along its length to form individual rings with an external diameter of 11.4mm. The cutting was done in two ways, using a sharp knife-edged chisel along the length of the mandrel, and by slipping the coil off the mandrel and cutting down the side with a pair of snips. The chisel gave the wire flat cut ends, whereas the snips produced V-shaped ends (Fig.507). To overlap the ends the diameter of the rings had to be reduced by forcing them through a tapered hole in a steel plate. This was done using a special punch with a stepped off-set end (Fig.508). This step was placed over the cut ends of the ring to push them out of alignment as the ring was forced down the taper. The ends of the ring were squeezed past each other as the ring was pushed through the hole resulting in a ring of 10mm external diameter with an overlap of approximately 4mm (Fig.508).
Fig. 506  Wire being wound on the mandrel

Fig. 507  Iron rings cut with chisel (a, side view, b, top view) and snips (c, side view, d, top view) (wire D.1 6mm)
Experiments were first made in order to close the rings by fire-welding. Fire-welding items as small as mail rings requires careful judgement of the temperature since the metal reaches the required temperature rapidly. Conversely, the metal begins to lose its heat very quickly once withdrawn from the fire. The co-ordination required in removing the ring from the fire, placing it on the anvil or stake and hitting the weld with the hammer requires some practice.

A small coke-burning hearth, with an electrically driven blower providing the air blast, was used for the welding. Each ring had to be heated individually and held during the entire process to avoid over-heating such a small object. Available tongs were too large for this purpose and initially stainless steel artery forceps were used; subsequently, a pair of tongs were specially made. As these forceps were only 20mm long the work had to be carried out uncomfortably close to the fire. The ring was held at a point opposite to the lap and heated until it had reached welding heat, which took a matter of seconds. This point was judged as having been reached when the iron was white and sparkling. As soon as the correct temperature was achieved the ring was removed from the heat, and, with the tip of the forceps resting on the edge of the anvil, the lapped portion was hit with a single blow from a six ounce hammer to produce the weld (Fig.509). If the ring was left in the fire for even a few seconds too long it became too hot and eventually burned to nothing; if the weld was not achieved within a second of removing it from the fire the wire was too cold for the weld to form. If the lap of the ring was held against the anvil the weld was usually unsuccessful as the heat was instantly drawn away into the cold anvil. It was found that with practice it was possible to hold the ring just off the surface of the anvil so that welding heat could be maintained until the hammer struck.
The welded joint was made without the use of a flux, such as silver sand, which is normally needed to remove scale or oxide which has formed on the surface of the iron during heating. Such a layer would normally inhibit the formation of a weld but it may be that the small size of the rings and the speed with which they reach welding heat results in very little oxide being formed. The resulting welded rings remained circular but were thickened at the weld which ended with an obvious step on both sides (Fig.509), whether the wire had been chisel-cut or snipped. These rings were not planar but were laterally distorted, when viewed edgeways on, due to the hammering of the weld.

During this experiment it was found that, with a little initial practice, between 25 and 30 rings could be welded in an hour. A craftsman using this process continually could possibly double this output. The work would also be made easier if certain tools were purpose made for the forging of the rings, such as small tongs, a hammer and a headed stake set at the correct working height for a seated operator. If charcoal was used as the fuel, a very small fire could be constructed which would easily reach welding heat; perhaps in a hearth only 0.2m in diameter with hand bellows providing the blast. The small scale of this hearth would enable the operator to have the anvil or stake very much closer to the centre of operation, increasing the efficiency of the process.

The welded rings produced do not have the characteristic shape of the welded rings in the mail from the Coppergate helmet, but it is feasible that with carefully cut swage blocks their shape could be modified in one simple operation to something very similar. On the other hand, if the wire coil was cut spirally (Fig.510), in the opposite direction to the
winding of the coil, the ends of the rings would have a taper which would reduce the bulk of the material in the overlap and would produce a weld with a smoother profile (Fig. 511).

Lapped and riveted rings were successfully produced by the method described in detail by Burgess (1953a). The lapped rings were annealed and the laps were swaged between a pair of dies cut in silver steel to press the lap together and give it its final form (Fig. 512). After annealing, the rivet hole was formed using a specially made punch (Fig. 513), and the rivet was hammered in. The punch was made from square-section, silver steel rod, ground to a point, and the rivets were made from the same wire stock as the rings, reduced to a 1 mm square cross-section in a rolling mill and then annealed (Fig. 514). If the wire could have been reduced by drawing to retain a round cross-section, a circular-section punch would have been fabricated.

The finished rings (Fig. 514) look very much like those produced by Burgess (1953a) but are very clumsy when compared with those of the helmet mail. The laps are bulky and end abruptly. It is possible that if the coiled wire were cut spirally, as suggested above, the tapered end to the wire might, after swaging, produce a neater lap with a rounded point. The rings produced by Burgess also have the very characteristic 'water shed' line on the
Fig. 512 The dies in the swage were used to press the lapped ends of the ring together. Inset shows resulting shape of the lap of the swaged ring.
Fig. 513 Rivet hole being punched in the ring with hammer and punch
lap, a ridge running either side of the rivet head concentric to the ring, which is commonly
seen in medieval armour. The shape of the laps of the riveted rings from the Coppergate
helmet mail have a more sinuous form and could probably have been created using
simpler equipment than that described by Burgess. Indeed, during the welding
experiments some of the rings failed to weld, because their temperature had dropped
before they were hit with the hammer, but the form of the ring produced would have been
perfectly suitable for riveting although no longer planar.

One of the major problems encountered in this work was in keeping the punches for
the rivet holes in a working condition. Very quickly the points bent or snapped and had to
be replaced. Another area of difficulty was initially cutting the dies for swaging the lap. The
volume of the space cut into the two dies must be just sufficient to contain the volume of
metal in the lap as it is flattened and shaped. The shape of the die must also match the
diameter of the wire either side of the lap so that it is not bent, flattened or cut by the edge
of the swage. Several trial pieces may need to be swaged, using a soft, non-ferrous wire of
the same diameter as the rings, during the cutting of the dies. The tolerances of this system
are very small and, as Burgess comments, it is difficult to imagine how a consistent result
could have been gained without the use of drawn wire stock.
Construction of the mail

There are two basic methods for systematically constructing a mail item linked in the manner of the Coppergate mail. The first is based on a five ring unit, a central lapped and riveted ring passing through four welded rings, which can be handled in one of two ways. A single lapped and riveted ring can be passed through pairs of welded rings in adjacent units to build horizontal bands of mail three rows deep (Fig. 515). These bands can then be joined together using more lapped and riveted rings. The first of these rings passes through the first and second rings in the band above, and the first and second in the band below. The next ring overlaps the first, passing through the second and third in the row above and below. In this way each successive ring overlaps with the previous ring. Alternatively, the mail can be developed in a more organic way, from a single five ring unit around which eight more units are added ensuring that each ring passes through four others (Fig. 516).

The second approach is to build up the mail in successive rows (Fig. 517). The first row, of welded rings, might be held in place on a wire. Working from one edge, this row would be linked to the next row of welded rings via a row of lapped and riveted rings. The first lapped and riveted ring would pass through the first and second rings in the rows above and below, the second one would pass through the second and third rings in the rows above and below, and so on, to the other edge. The next row of welded rings would be attached in the same manner until the item had reached its required height. The length of the rows could be adjusted as required either by stopping short of the previous row or extending beyond it.

![Diagrams showing successive stages in construction of mail]

*Fig. 515 Successive stages in construction of mail, made by forming bands of five ring units*
Fig. 516 The successive stages in mail construction using a central five ring unit

Fig. 517 The construction of mail one row at a time
Fig. 518. Rings of different size and form used in the construction of an early 16th century German mail cape: a, lapped and riveted rings form the body; b, rings with expanded laps form the collar; and c, smaller rings are used to keep the edge of the collar firm and tight. Scale 1:2 (after HM Tower of London III 1423)

Whichever approach is adopted, the mail-maker must work very methodically from one side of the mail only, so that all the rivet heads are on one surface and all the rings in alternate rows lie to the right and then to the left throughout the mail. In mail of alternating rows of riveted and solid rings, the solid rings usually slope back into the mail to the left when viewed from the outside. The consistency of the finished mail might well be dependent on the ease with which a right-handed riveter could link the mail together and close the rivets in the anticlockwise lapped rings. The rivet heads are usually on the outside of the garments as these can be quite prominent, whereas the tails are usually flattened against the lap and consequently cause less wear on the underlying garments. Shaping can be introduced into a mail garment and the techniques involved in this are detailed by Burgess (1953b) who also sets out a method for recording the linked structures. The speculation by Burgess (1953a) that the completed mail might have been finally case-hardened, a technique which hardens the outer surface while maintaining the inner toughness of the metal, cannot be supported by either the Coppergate mail or any of the samples in Smith’s study (1959).

Rings of different size and shape are commonly used in a single garment. Progressively smaller rings may be introduced down the length of a sleeve to produce a smooth taper, and a row of very small rings can be applied to a garment edge to stop it from stretching or deep bands of them may be used to form cuffs. Rings of different shapes or different metals are
also inserted to form decorative motifs or edgings (Fig. 518). The reasons for combining welded rings with lapped and riveted rings, as found in the Coppergate mail and many other early examples, is less obvious. As the laps and rivets of the Coppergate mail are not particularly obtrusive it would not have looked very different if it had been constructed entirely of riveted rings. Obviously if only welded rings were used some would have to be welded closed as the mail was constructed. Although this is how modern mail gauntlets and other protective garments are made, electric arc rather than heat and pressure welding techniques are used. It is difficult to estimate the relative cost of production of the two types of rings. The initial manufacturing stages of both types of rings are very much the same, but the lapped and riveted rings require a more complex technology to produce the finished item, greater capital outlay for the production of precision equipment and possibly a high turnover of tools such as punches or drill bits. On the other hand the welded rings may have required the use of a better quality iron stock and more highly skilled workers, and resulted in a higher failure rate. The welded rings are stronger and more durable than the lapped and riveted rings, as borne out by the number of the latter which are missing from the body of the mail, have lost their rivets, or have broken across the rivet hole. Combining the welded rings with the lapped and riveted rings does not lead to a stronger construction than one made from lapped and riveted rings alone, but it does make this stage of the construction faster as half the rings come already closed. It is also possible that the use of welded rings in alternate rows was purely a matter of fashion (Blair 1958, 20).

Conclusion

The mail of the Coppergate helmet is probably the most expensive single element in its construction, being both time consuming to produce and requiring specialised skills. As neither ring type contains appreciable amounts of arsenic, in contrast to the plates and rivets of the helmet cap (pp.1021–4), this would indicate a separate ore source for the iron of the mail. The metallographic analysis (p.1026) showed only traces of arsenic, leading to the conclusion that the smith who produced the cap was probably not aware of the presence of the arsenic or of the properties it conferred on the iron. It is unlikely, then, that one craftsman would use different sources of iron for the cap and the mail, so the components of the mail were almost certainly not made from wire produced by the smith. A possible explanation for this is that the smith was buying in wire made by techniques he did not use himself. This suggestion could be used to support the argument that the wire was drawn. There is plenty of evidence, however, to suggest that mail was not that uncommon at this period (p.1059) and it would be quite reasonable, therefore, to conjecture the existence of specialist mailmakers at this date. The differences between the iron of the riveted and welded rings (p.1006) suggest they were made from different wire stocks. Either the mailmaker was using two different sources of wire or was ‘buying in’ one of the ring types prefabricated, perhaps from a ringmaker specialising in welded rings. At the least, the evidence points to the work of a specialist mailmaker, but the picture could be even more complicated in reality and involve one or even two ringmakers and possibly wiremakers as well.
Comparative material

In contrast to the wealth of detailed information gained from the Coppergate helmet mail (pp.999–1011), very little is forthcoming from the comparative material. All the surviving European mail even loosely contemporary with the Coppergate helmet is from archaeological sites, much of it reported in publications without the aid of conservation or even radiographic examination. Most of the material was excavated and published long before the potential of mechanical cleaning of corroded iron was appreciated, and certainly before the widespread use of the Airbrasive, which is the most effective tool for salvaging detail from heavily corroded iron. Even when other iron objects on a site may be quite well preserved, the high surface-to-volume ratio of mail will cause it to be in a much more advanced state of corrosion. Because of the obscuring corrosion crusts which usually form, accurate measurement is difficult and it is easy for the observer to see the expected. It is, therefore, difficult to evaluate the validity of the statements made in the literature unless supporting material, such as photographs, drawings and X-radiographs, is included.

Visual examination of corroded mail can be very misleading and an example of this is furnished by the mail shirt from Sutton Hoo. Prior to X-radiographic examination it was thought to be made entirely of butted rings and was published as such by various authors including Mann (1958), who saw it as unique in European armour and an inferior structure. In 1969, Oddy and Werner undertook more thorough scientific examination, including standard and stereo radiography, metallographic and compositional studies of the mail (Bruce-Mitford 1978, 240), which revealed that the rings were all about 8mm in diameter and some were riveted with copper rivets. Bruce-Mitford (1978, 237) interprets this as indicating that the mail was constructed from alternate rows of riveted rings. However, despite this rigorous examination it was still not possible to ascertain the actual shape of the mail garment, to locate any original edges, to determine the size of the rings more accurately, to determine the wire diameter and cross-section, to give details of the rivets, or to show how the non-copper riveted rings were closed.

The publication of the mail from the Swedish Vendel and Valsgärde material is no more detailed. Mail was found in graves at Vendel spanning the entire chronology of the Vendel period, from c. AD 520/30 to 800, and there was Viking period mail from grave VIII. Apart from the drawings of selected fragments in Stolpe and Arne (1927), which indicate that some of the mail from grave XII was of a smaller ring size than the rest, there is little information to be gleaned from the text except for the numbers of fragments. Some of the fragments from graves XI and XII may be from helmet neck guards (Arwidsson 1934, 253–4) and are of the larger ring size. The material from Valsgärde is also very corroded and the mail from grave 6 is typical of the general state of preservation. The cheek and neck guard to the helmet from this grave was in the form of a cylinder. Although very corroded and folded it had 34 rows of rings at the front and seventeen or eighteen at the back. The rings were about 10mm in diameter and made from a round-section wire of 2mm diameter. The method of closure was not determined and X-radiographic study gave no further information. The mail was suspended from an iron wire through the uppermost rings, which was attached here and there to the rim of the helmet (Arwidsson 1934, 244–5).
The two Frankish helmets from Cologne and Morken are preserved well enough to allow reconstruction, but the published detail of the iron mail curtains is still sparse. The Cologne mail consists of nineteen rows of 29 rings with an external diameter of 15mm and 2mm thick wire, but the method of closure is not clear. Doppelfeld (1961–2) states that they are clearly not soldered or riveted. The Morken mail consists of fourteen rows of rings which, although much rusted, are reported as being simply bent closed (Pirling 1974, no.21). If both these mails are examples of butted ring structures they are very different from any other material of this period.

These results present a depressing prospect to those faced with the task of studying mail, but not all finds are so completely corroded and even when no metal has survived the conditions of burial may have stimulated less disruptive corrosion mechanisms, preserving varying degrees of detail. A survey of mail based on direct observations of Scandinavian material was carried out by this author in 1985. Subsequently, some of this mail was conserved by the author and the extra data gained were incorporated. This survey is inevitably incomplete, but it does indicate the range of variation in the material. A catalogue of this material appears below on pp.1183–7.

No clear picture of the development of the mail emerges from these studies of the contemporary material. Alternating rows of lapped and riveted rings and solid rings or mail of all lapped and riveted rings can be found throughout this period. The mail is mostly in iron but both iron rings with copper rivets and even copper alloy rings with iron rivets have been identified. Corrosion on most of the material makes it impossible to speculate as to the method of wire production. Most of the cross-sections, often observed at breaks in the rings, are circular, but there are examples of subcircular section and even flattened rings. The ring and wire diameters are positively correlated, but more than one size of ring may be found on a single site or even within a single item of mail. Each sample examined, where detail could be discerned, was unique in some way (e.g. the form of the lap and rivet joint), which perhaps reflects the work of individual craftsmen as much as function, provenance, or date of manufacture. From their cross-sections, none of the solid rings from Norway and Sweden appeared to have been punched from sheet, but neither butt joins nor solder was observed on the X-radiographs. Without metallographic studies, however, it cannot be suggested that the rings were welded, but it is unlikely that even the best preserved examples have enough metal surviving for such a study. Unfortunately the Vendel and Valsgärde mails, which might be most usefully compared with the Coppergate mail, are among the worst preserved.

**Dating mail**

It is Blair's opinion that mail is the most difficult type of armour to date as its construction varies so little whatever the period or provenance (Blair 1958). Most of the changes which he identifies are in the style of the garments, not the form of the rings or the construction of the mail. The date of introduction of some items of mail, such as the tippet, a short cape to cover the shoulders, is fairly well established, in so much as they can be attributed to half of a particular century, but examples may exist which are almost entirely
made of rings reworked from an older, very different garment. Earlier work dating mail is often based on the shape and size of the rings, but these typologies must be regarded with caution.

Persistence in the use of mail may seem surprising when the superior protection afforded by plate armour was known and available as witnessed by the continuous use of plate in the form of helmets. Mail gave good protection against the cutting edge of a sword but the force of a small projectile, such as an arrow head, could split a ring and penetrate the mail. Experimental work using Iron Age style bows and arrows showed how the mail impeded the arrows. The arrow head was less likely to pass through the flesh and instead remained embedded in the target. The injury was also more serious as fragments of the shattered mail were pushed into the wound (Nielsen 1991). A mace would break the limbs beneath the mail because the flexibility of the mail presented no resistance to the blow. Rigid plate armour gave much better protection in all these instances. A mail shirt could weigh 15–20kg, nearly as much as an entire suit of plate armour. Because the mail was flexible the entire weight of a shirt would be carried by the shoulders, and garters below the knee or thongs at the wrists were employed to improve the fit. The rigidity of plate armour meant that it could be tailored to distribute the weight, some of it being supported at the waist for instance.

The advantages of mail, however, must have considerably outweighed these deficiencies. Mail was a durable item and easier to repair in the field than plate armour. A temporary repair could be made with wire and pliers or a rent garment could even be laced together. Its flexibility allowed for free and natural movement, which was never possible with full plate armour. Individual tailoring was unnecessary as one garment could be stretched or gathered up with laces to fit a wide range of body shapes. A mail shirt was expensive to originate but the ring structure lent itself to alteration and the shirt could finally be cut to produce several smaller items. This versatility meant that, although the initial outlay in materials, time and skill for mail was high compared to plate, mail could be stored and re-used or reworked repeatedly until the rings were worn to breaking point.

It is the very versatility of mail that makes it virtually impossible to date even a substantially complete piece. The pieces which have survived are few and not necessarily typical of the period. Many are prestigious items deliberately buried with other high-status grave goods or dedicated in churches. The well-preserved hauberks of St Wenceslaus, Prague Cathedral, Czechoslovakia, first appears in the Treasury inventory in 1354, although the Saint reputedly died in 935. Using accepted criteria, the date of the hauberks cannot be pinned down with any degree of confidence to within 400 years (Blair 1958, 24). It is not surprising that most of the extant mail in collections is just as problematic, being generally less well documented and provenanced. Archaeological finds are generally obscured or degraded by corrosion. Mail was rarely discarded or buried with the dead from a battle as it was a valuable and re-usable material. This is illustrated in scenes from the Bayeux Tapestry where the dead are being stripped of their mail with great vigour (Fig.519). A notable exception to this is the mail from Visby, Sweden, where in 1361 the defenders of Visby were slaughtered by Danish invaders. Excavation of the mass graves revealed evidence which
suggested that the fallen were not immediately stripped, but lay clothed and rotting for some time before burial. When they were eventually buried many were still partially clothed and armoured, perhaps because they had become so foul with decay that recovery of items even as valuable as mail and plate armour was deemed undesirable. The mail items from these graves, including some 185 coifs, twelve or thirteen mail shirts, and possibly two mail gauntlets, although heavily corroded and often very fragmentary, have been studied and published in detail (Thordeman 1939). The preservation is good enough to allow the approximate size and shape of some items to be recorded and the decorative use of copper alloy rings to be traced. Unfortunately no details are given about the iron rings themselves beyond a general statement about the size range, the variation in the wire cross-sections and that some of them appeared to have been riveted. Thordeman explains that it is due to the covering of iron corrosion that so little information has been gleaned. However, it is clear from some of the plates that careful removal of these crusts would have revealed much detail.

It is difficult to make even general statements about the provenance or development of mail from the evidence available. It has been suggested (Laking 1920, 173) that the shape of the rivet establishes the provenance of the mail, triangular rivets being a European feature, circular rivets Eastern, and Thordeman (1939, note 94, 441) maintains that copper rivets in iron rings are a ‘pronounced Oriental feature’. Burgess (1957) goes to great lengths to try to explain how solid rings with an angular, subcircular cross-section, in a medieval shirt, might have been punched from sheet, as he considered welding to be an Oriental technique of relatively recent date. These assertions are patently incorrect in the light of the evidence now available from Sutton Hoo (p.1076) and Coppergate. Many features, like high domed rivet heads, may not be functional but purely decorative, a matter of style which may come into or go out of fashion at different times in different places quite independently, or they may be
the longstanding trade marks of particular mailmaking workshops. Oddities such as welded rings stamped with imitation rivet heads, U-shaped clamps used to form double rivets, rings with stamped decoration, names and other non-functional details, have all been reported but are rare.

It is well established that mail composed of all riveted rings predominates after c.1400 and Burgess (1958) speculates that improvements in riveting and wire drawing techniques may have overcome many of the drawbacks of all-riveted mail. This change in mail also probably reflects the rapid development of arms and other armour at this period. The denser the mail the better the protection it affords. The density of the mail, however, is not dependent on the ring size so much as the ratio of the wire diameter to the ring diameter (Fig.520a, b and c). As the wire gets thicker in relation to the size of the ring, the space through which the rings must be passed when the mail is constructed is restricted. This reduces the flexibility of the mail and also makes the linking and riveting processes more difficult. When mail of alternate rows of solid and riveted rings is constructed, the riveted rings must be passed through four solid rings before riveting, and in very dense mail access to the riveting point becomes very restricted. However, in all-riveted mail each ring need pass through only two other rings before it is closed so the rings can be more easily manipulated for riveting. The development of disc-like rings, with wire of flattened cross-section, may also have been for practical reasons; a denser mail is produced without the consequent increase in weight (Fig.520d). Such rings were probably produced from round-section wire which was swaged flat after the overlap had been formed. Greatly expanded laps on relatively thin wire rings can be so large that they cannot pass through the
rings on either side and so present a rigidly ordered and dense appearance whilst still maintaining flexibility (Fig. 521).

Burgess’ (1953b) approach to the recording and constructional analysis of historic mail is thorough and systematic, dealing with every aspect from the overall form of the garment and the techniques employed in shaping the mail to the finest detail of the rings. His records include sketches, photographs, minute plaster casts and simple but effective diagrammatic representations of shaped areas of the mail to show their construction. Although Burgess was dealing with more or less complete historical items, the application of his recording system to archaeological material is valid even if some of the metrical and non-metrical information may not be obtainable even after conservation.

Only through such detailed and consistent recording, followed by a selective programme of radiography, conservation, metallographic study and analysis, can the problems of dating and provenancing mail be resolved. From the data gathered it may eventually be possible to identify trends which will lead to a radical re-evaluation of the criteria on which dating is currently based. The occurrence of drilled, as opposed to punched, rivet holes in mails of known date may show drilling to be a feature of earlier mails, a technique made redundant, perhaps, by improvements in the manufacture of hardened points for the punches. Where sufficient metal survives, metallographic and compositional study of the rings may produce more information relating to the history of the technology of their production, reveal which solid rings have been punched from sheet and which welded, push back the dates for the introduction of such techniques as wire drawing and help in the detection of forgeries.

It is impossible to ascribe a date or provenance to the Coppergate mail on typological grounds. Even though it is attached to the helmet, it is possible that the mail may have been re-used from another garment and may pre-date the helmet by a considerable, and unquantifiable, number of years. This seems unlikely given the prestigious nature of the helmet but, as the helmet shows evidence for prolonged use and wear, the possibility that this mail is a later replacement for a damaged original must also be borne in mind. Whatever the case, the mail had been damaged and roughly repaired and was almost completely detached from the helmet before it was deposited. It may be that this was not the first stage in the systematic dismantling and salvaging of the helmet but that the intention was to refurbish the helmet with a new mail curtain.