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Deconstruction and Conservation of Roman Armour from the Millennium Excavations, Carlisle

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Summary

Soil blocks containing early second century Roman ferrous armour with associated organic material were excavated from anoxic waterlogged levels in Carlisle in 2000.

These were deconstructed to recover and stabilise the organic material. Fragments of the partly articulated armour were conserved, and associated mineralised organics examined and analysed.

Keywords

Conservation
Roman
Mineral Preserved
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Author's address
Department of Conservation, University of Durham, 46 Saddler Street, Durham DH1 3LE.
Tel : 0191 334 1139. E-mail : j.a.jones@durham.ac.uk

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Contents

Introduction

Excavations in front of Carlisle Castle, within the Roman fort of *Luguvalium*, were carried out by Carlisle Archaeology Unit (CAU) between November 1998 and March 2001. The excavation formed part of Carlisle City Council's Gateway City Millennium Project and took place prior to the construction of a footbridge over the Castle Way ring road, plus a new exhibition gallery for Tullie House Museum and a walkway beneath the road. The excavation was funded through a partnership between Carlisle City Council, The Millennium Commission and local businesses.

Lifting from Site

Five blocks containing early 2nd century Roman armour were recovered from anoxic, waterlogged levels in Trench 5 of the Millenium excavations, in late 2000.

Recognising the importance of the finds, the excavators kept the armour fragments intact and lifted them in blocks with the surrounding and overlying organics and soil. The blocks varied in size from 250x300mm to 800x900+mm. On site, the excavated material was placed on boards, on a layer of expanded polyethylene foam marked with a 100mm grid and the block’s orientation in the ground. The blocks were then wrapped in layers of cling film and medium and heavy duty polythene, sealed with duct tape to help prevent the organic material from drying out in storage.

X-radiography

As enough of the metalwork had been visible *in situ* for the excavators to suspect that they were dealing with important finds, once it had been lifted, arrangements were made for the material to be X-radiographed. Because of the dimensions of the blocks, it was not possible to use regular XR facilities, and the Royal Armouries (RA) conservation laboratory in Leeds was approached. The large-scale XR facility at the Museum was used successfully to produce 11 plates (340x450mm) of the material, either as whole blocks where possible, or in several sections. Records produced by Dr D Starley of the RA accompanied the X-radiographs, outlining results and procedure, and providing preliminary interpretation of the material.

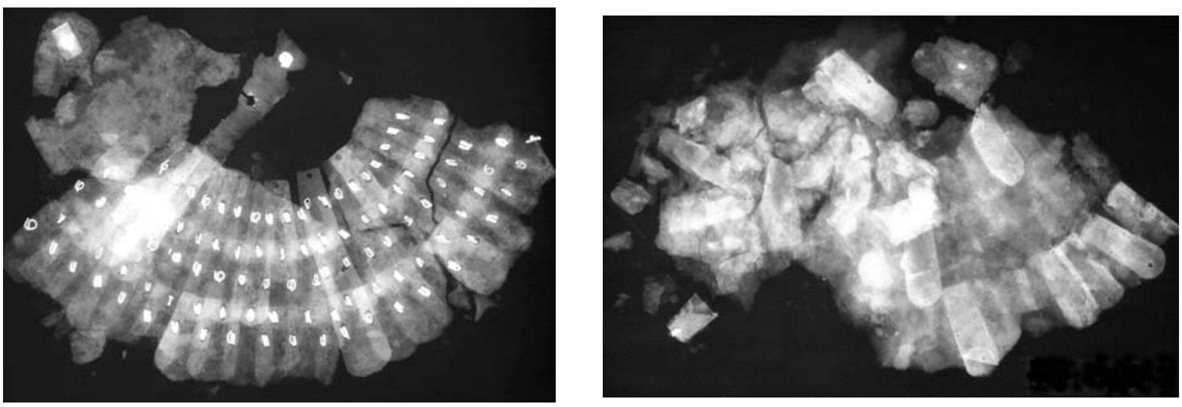

Fig 1 : 3416Δ and 3978Δ

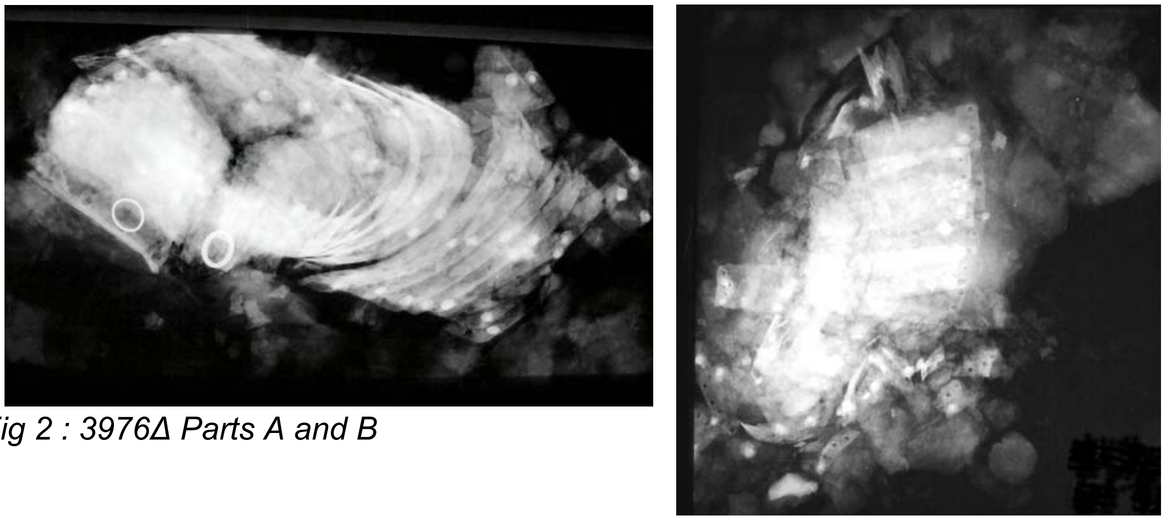

Fig 2 : 3976Δ Parts A and B

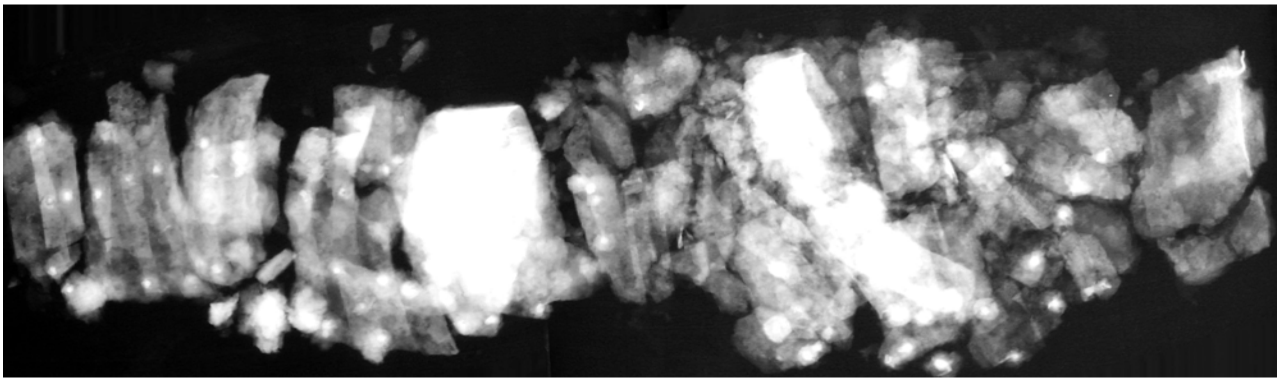

Fig 3 : 3979Δ

The X-radiographs confirmed that the material was armour, possibly still partly articulated.

Following X-radiography, the wrapped blocks were brought to the Conservation Lab in Durham for storage until conservation could begin.

Storage & Assessment

For reasons beyond the control of both the excavators and the conservator, it became clear that conservation of the armour could not begin for some time. It was therefore important to arrange suitable short-term storage.

Objects containing both organic and inorganic elements such as the armour, pose particular problems for storage and for conservation. Wet organics and metalwork require very different storage conditions if they are to be kept as stable as possible until conservation can take place. And once conservation begins, it is usually not possible to successfully treat such different materials whilst keeping them in close association.

Storage of the blocks by freezing was the chosen solution. Freezing is effective as it locks up the high water content in the organic material and prevents it from being lost and causing collapse of the degraded cell structure. Freezing also greatly slows down corrosion of the metal by deactivating the effects of water and by restricting oxygen to the surface. For most of the material freezing was simple to arrange, as three of the four wet blocks (the fifth was received dry) fitted into an ordinary chest freezer.

The other block (3976Δ) was problematical, as its size (800x900mm) precluded storage with the rest of the material. Having failed to find an alternative freezer facility which could safely house this large and fragile object, it was decided to construct temporary frozen storage in the Conservation Laboratory at Durham.

Lengths of glass fibre roof insulation material were sealed inside polythene tubing, and then taped together to produce insulation 'blankets' of the required size. One blanket was placed underneath this largest armour block on its board, and another over the top. With an overlap all around the edges, the two blankets could be taped together. Layers of overlapping polythene bubble wrap and polyethylene foam were added over the insulating blankets, plus sheets of polythene.

Before sealing up the armour block in its insulation, it was frozen by carefully spreading 30kg of solid carbon dioxide (CO_2) pellets (at -79ºC) over the polythene-sheeted surface of the metal and organic spread. Obviously, a single application of pellets would only be effective in keeping the block frozen until all the CO_2 evaporated, and so the temperature inside the frozen block had to be constantly monitored. A temperature probe mounted on a retort stand was set up with the active end of the probe sitting in a small void among the metal/organics, and the insulating material was closely arranged around this. The temperature inside the block could then be regularly checked by attaching the probe to a hand-held monitor. It became clear that each application of CO_2 pellets would keep the block below freezing point for around 5 days before evaporation was complete. By applying CO_2 pellets twice a week, it was possible to keep the block permanently frozen.

This storage arrangement was intended to be temporary, but funding and other circumstances meant that the largest block had to be stored in this way for almost 18 months.

Towards the end of 2001, a collaborative assessment of the armour's significance and conservation requirements was produced by Oxford Archaeology North (OAN), This assessment included an outline of the intended conservation strategy and also conservation costings. With the production of the assessment, English Heritage (EH) funding for the conservation of the armour was confirmed in the Spring of 2002. The work was to form part of the Carlisle Millenium dig post-excavation analysis, which was being undertaken by OAN and funded mainly by Carlisle City Council, following the demise of CAU.

Conservation Strategy

Before conservation began, the relationship between the metal and organic elements in the armour blocks had not been defined. Despite close inspection by several interested specialists, while the material remained wet and untreated, it was only possible to speculate as to whether the visible leather and other organic material was actually part of the armour construction. The juxtaposition of the organics and the metal was one of the factors which made this find unique, so a determination of the role of the organics in relation to the ironwork was very important.

The first stage of the proposed conservation strategy was to separate the organics from the metal, in order to understand the relationship between the two materials, to stabilise the organics for further study, and to allow the fragile metalwork to dry out and so reduce the risk of continuing corrosion.

This was going to be a lengthy process, involving careful work to remove overlying soil etc and to separate the organic material from the metal, and then stabilise it. Once the organics were removed and stabilised, they could be passed onto the specialists for study.

Following the removal of the organics, the second stage of the conservation process would involve selective corrosion removal on some pieces of the dry metalwork from each armour block.

Deconstruction and Recording

The armour deconstruction process needed to be recorded as thoroughly as possible, to supply other specialists, who obviously could not be present throughout, with enough data to make sense of the spread of material.

Before beginning work on each block, its uncleaned surface was recorded on videotape. The tape is to be edited and will form part of the site archive.

Deconstruction was recorded using digital photography and drawings. Digital photographs were made to record each major feature encountered during the deconstruction, and also individual pieces of leather, wood and rope, if they were retained for stabilisation.

Because of the complex arrangement of the fragments of organic material, 1:1 drawings of the position of each piece were made on layers of Melinex (a polyester sheet), to show how the material lay in the blocks. This was done by placing the Melinex on top of a sheet of clear polycarbonate which was supported on wooden blocks, so that it was directly over the armour. The drawings concentrated on the organic material, though the metal elements were recorded schematically.

To make the drawings more usable, they were later digitised by EH illustrators, using AutoCAD. The results can be viewed as a composite, or used interactively with suitable software to separate out the various layers and see how they were positioned. Different colours were used in the digitised drawings for the different organic materials recovered, and the pieces were numbered as found.

Deconstruction proceeded with surface cleaning of the blocks, followed by the removal and recording of pieces of organic material from the top and around the edges of the metal. Most of this was leather, though wood and rope were also found in some of the blocks. The larger and less fragmentary pieces of leather were fairly easily removed, though few were found to be complete. Many pieces of leather were extremely fragmentary, however, and could not be removed from the supporting metal without disintegration.

To remove these, strips of a stiffer grade of Melinex were carefully inserted below the fragile pieces from several angles, to support them as they were lifted from the metal. The Melinex was left in place while the top surface of the leather was cleaned, and a further piece was used to allow the leather to be turned over for cleaning the underside. This method was also used for removing and cleaning fragile rope fragments.

Fig 4 : Lifting fragile leather using Melinex strips

Most of the wood, though fragile, could be removed from the blocks without difficulty. Some of it had clearly been worked or, though not artefactual, showed tool marks. These pieces were retained for stabilisation. Pieces of unworked wood and twig were disposed of. Retained organic material was double bagged and stored wet in the refrigerator to await stabilisation.

In three of the blocks (3976Δ, 3978Δ & 3979Δ), some of the organic material continued underneath the metal and could not be accessed from the top, meaning that the blocks had to be turned over.

It could be seen on the X-radiographs that many of the metal pieces were fragmentary or at least broken, and it was important not to displace them. In order to turn over the wet blocks safely, supporting moulds were made to keep the metal fragments in position.

Moulds were made by first creating a release layer over the metal by covering the surface with a layer of non-PVC cling film. Major unevenesses in the surface were also reduced by the use of wadded cling film. A layer of aluminium foil was placed over the cling film, making sure it conformed as closely as possible to the contours of the block, to provide maximum support for the metal fragments. Then the mould itself was made by painting on layers of liquid polyester resin, strengthened with pieces of fine fibre glass matting. When the resin had cured, the block on its board could be turned over in the mould into a suitable supporting container, to allow work on the underside.

Fig 5 : 3978Δ top, polyester resin mould

Fig 6 : 3978Δ turned over into mould

Following the removal of all the organics and soil from the underside, the metal in each block was allowed to air dry. Then a further polyester resin mould was made of the underside, and the block turned back to be stored in its mould until the second stage of the conservation process began. The wet blocks were kept frozen until they were worked on.

The largest block (3976Δ) caused some problems. Throughout the deconstruction process, the organic material, and consequently the metal, would have to be kept wet. Deconstructing 3976Δ was complicated and would take the longest time, and it would have been unwise to allow the whole wet block to remain exposed to the air throughout. Examination of the X-radiographs showed a ‘path’ through the block where there seemed to be no metal. To minimise the block’s exposure to the atmosphere, it was decided to split 3976Δ into two parts along this path, to allow one half to remain frozen until deconstruction. Another advantage of this was that the resulting smaller blocks then fitted in a domestic freezer. The fragments of leather between the areas of metal in 3976Δ - most of which were small pieces overlying each other - were carefully separated, and the block split into two parts – A and B (see below).

During deconstruction, a written log of the process was kept, which will form part of the site archive.

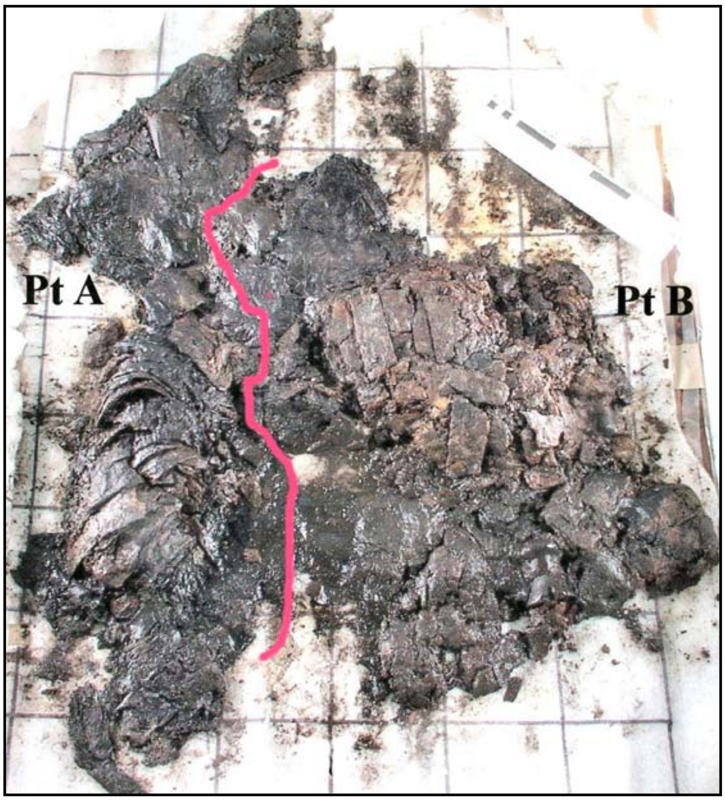

Fig 7 : 3976Δ before deconstruction, showing line of separation into Parts A and B

Deconstruction Findings

3416Δ This block was received dry, and associated organics were preserved as mineralised material.

3976Δ PtA Seventeen pieces or groups of fragments of leather were recovered, including fragments of stitched edgings and strap, (Leather BL and BJ). Fourteen pieces of worked wood, 16g dry weight of wood working debris and two pieces of rope (BI and BO) were also retained and conserved.

Fig 8 : 3976 PtA leather BC

3976Δ PtB 23 bags or pieces of leather were recovered from the deconstruction. Most were fragmentary, but some had seams and visible stitch holes, (eg Leather U and AW, which also had a small Fe tack *in situ)*. Part of a wooden ?handle (Wood AM) was also recovered at the NW limits of the block, unfortunately truncated by the lifting process. Most of this material was recovered from a dense area of organics towards the southern edge of the metal spread (see Fig 9). Also found were 3 pieces of very degraded rope (AT, Z, AD), possibly of two different sorts, 49g dry weight of wood working debris and 22 other pieces of worked wood. These were retained and stabilised.

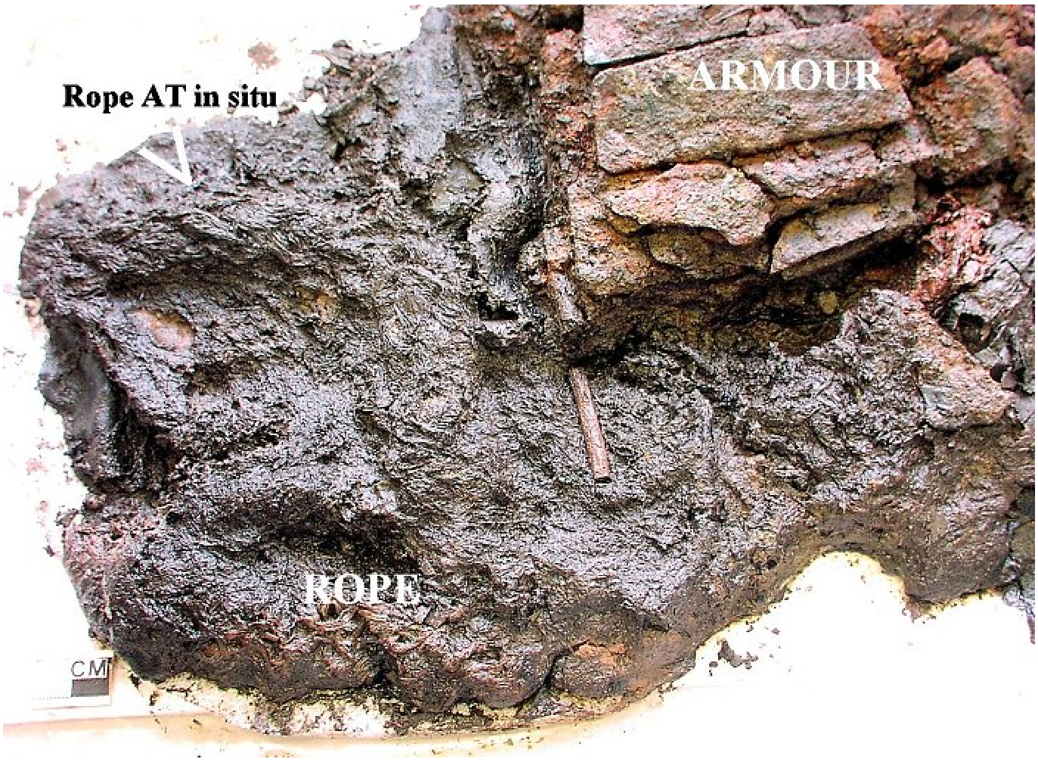

Fig 9 : Area of 3976B containing many of the recovered organic fragments

3977Δ This block was composed entirely of organic material, mainly leather. There were 25 pieces or groups of fragmentary leather, including a piece of edging with a loop (Leather H), a strap fragment (Leather K), and a complex of small pieces with a stitched circle (Leather W). There was also 12.5g dry weight of wood working debris. One piece of vitreous slag and one fragment of bone were also recovered.

Fig 10 : 3977Δ leather H

3978Δ As well as two bags of very small leather fragments, 40g dried weight of wood working debris was recovered from the deconstruction of 3978Δ. There were also 2 wooden objects or offcuts (Wood 2 & 3), plus 2 very thin rectangular pieces of alder, each around 50x70mm.. A piece of bone was also recovered, with a worn and abraded point, which may have been used as a tool.

Fig 11 : 3978Δ bone tool?

3979Δ Few organics were removed during the deconstruction of 3979Δ. Sixteen grams dry weight of wood working debris and fragments, closely associated with the metal, were removed from the underside.

Stabilisation of the organics

Following deconstruction, the fragments of retained leather and wood were supported on a net frame and carefully washed under running water, using soft brushes, The more fragile pieces were conserved on Melinex strips which were used as a support to turn the pieces during cleaning.

Before freeze drying, the leather was impregnated with 20% polyethylene glycol (PEG) 400 for 2 weeks, then frozen and freeze dried. The wood pieces and wood working debris were impregnated with 10% PEG 400 plus a further 30% of PEG 4000 added incrementally over a period of 8 weeks, then frozen and freeze dried.

Throughout deconstruction and conservation, groups of particularly fragile pieces of leather were not separated, but cleaned and stabilised as a group (eg 3977Δ Leather W below). It seemed likely that the very fragile pieces would disintegrate further if separated, and the specialists needed to see them before this happened.

Fig 12 : 3977Δ Leather W as recovered

The wet rope was especially fragile and prone to disintegration. It was supported on pieces of Melinex throughout the conservation process to minimise loss of shape and fibres. Though the twist of the rope was usually clearly visible in the freshly recovered material, it was very easily disrupted and 'blurred' by any kind of physical intervention. This made the removal of adhering soil and debris very difficult, as under X16 magnification it could be seen that the rope had a great deal of extraneous material trapped between the fibres making up the ply of the twisted lengths. In order not to destroy the twist of the rope, much of the debris trapped between the fibres had to be left, and cleaning was largely confined to the surface.

There seem to be two different sorts of rope present – one type is very dark in colour post-conservation, and feels quite hard and fibrous to the touch (3976ΔA BI and 3976ΔB Z). The other type is lighter in colour, softer and more flexible (3976ΔA BO and 3976ΔB AD & AT). Initially the rope was conserved with a similar pre-treatment to that used for the wood and leather – a mixture of grades of PEG. While this produced a good colour and retained flexibility, the rope was still extremely fragile and prone to disaggregation. Following freeze drying, a 1:20 solution of Primal WS24 (an acrylic colloidal dispersion) was applied to the dry rope, using a dropper, to improve cohesion of the rope fibres.

The stabilised leather fragments were packed in polythene bags, with polyethylene foam inserts, and passed onto the specialists for study. The wood and rope were similarly packed.

Conservation of the Metalwork

Once the organic material had been removed and the metalwork had dried, a consultation meeting was held at Durham, involving representatives from OAN and other interested specialists, to plan the best use of the rest of the available conservation time.

It was clear that there would not be sufficient time or resources in the conservation post-excavation programme to work on all of the armour. Also, conservation ethics require that some part of an artefact or assemblage remains 'unconserved' (albeit correctly stored) to allow for future analysis.

Those present at the consultation meeting helped to decide which part of each block of armour fragments would be conserved. Conservation was to focus mainly on facilitating study of the material, not on its possible future display. It was planned to work on pieces from each of the blocks to provide specialists with information on the armour's construction, its surface finish and associated mineralised material.

Proposed Conservation Strategy

3416Δ X-radiographs showed this (the only block received dry) to be quite well-preserved and possibly almost complete, although broken into several (apparently joining) fragments. Closely associated with the main piece of armour were two further unknown objects, which required investigation. As the piece was not large, it was decided that the whole block would be air abraded.

3976AΔ Although the initial impression was of an intact artefact, close examination of the X-radiographs of 3976AΔ showed that many of the pieces making up the shoulder guard were broken and/or incomplete. The central area and pieces towards the north end of the complex were particularly damaged and disarranged. Both ends of the piece appeared to be possibly original and complete, though broken – a rolled edge could be seen at the N end. There were also two possible rings in the construction which required investigation, plus a large number of rivets. It was decided to work mainly on the N and S ends of the piece, leaving the more damaged central section unconserved.

3976BΔ The proximity of this area to the shoulder guard suggested that it could be part of the same piece of body armour, and it was therefore important. However X-radiographs showed that large areas were damaged and disarranged, and might yield little evidence. It was decided to begin conservation with the less damaged plates on the upper surface, and then to conserve only the more complete pieces from the layers below.

3977Δ There was no metal from this block.

3978Δ This piece of scale armour appeared to have both unadorned iron scales and also copper alloy-plated iron scales. The NW part of the block appeared to be quite well-preserved, while the more SE area was obviously very disturbed. It was decided to concentrate on the well preserved area, leaving the other part unconserved. The possible plating of the scales would be investigated, as would the manner of joining the scales together.

3979Δ This length of *manica* (arm guard) was received with its inside surface uppermost. It was composed of parts of several pieces of joined or riveted curved iron bands, and at least one of the ends appeared to be original and complete, with a possible hook. Traces of possible mineralised leather could be seen on the inside surface. It was decided to concentrate on some adjacent, possibly joining pieces from each end of the *manica*, leaving the central section unconserved.

Examination, Corrosion Removal and Consolidation
Fragments for conservation were carefully removed from the block, and photographs taken before and after the removal of each piece. Each conserved piece was numbered and the number added to the relevant photograph, with the aim of showing the exact location of each (often displaced) fragment in relation to the others in the block. The annotated photographs were later used successfully by OAN illustrators.

Most corrosion removal was done using air abrasion. An air abrasive system delivers a stream of compressed air mixed with a fine abrasive powder (in this case 53 micron grade aluminium oxide) through a nozzle in the hand piece. All air abrasion was under X10 magnification, and work was carried out inside a glass-fronted cabinet to reduce dust hazard. It had been decided that pieces selected for conservation would have all overlying obscuring corrosion products removed as far as possible, to reveal the dark layer of iron oxide (magnetite), where present. If carefully revealed, this layer can hold as much of the original surface detail as has survived. Corrosion removal down to the magnetite layer would allow researchers to examine 'original surfaces' of the armour fragments, and might also reveal evidence of manufacturing technology. Several pieces from each block would remain unconserved to be available for future conservation or analysis.

Before air abrasion began, X16 microscopic examination was used to assess the condition of the fragments, and surface features were defined and elucidated by limited soil and corrosion removal using hand tools. This examination also indicated areas where mineralised material might be preserved *in situ*. Close examination of the relevant X-radiograph could show the location of rivets and perforations, but the orientation of some fragments as X-radiographed in the blocks could also obscure such information. This preliminary microscopic and X-radiograph work was used to inform the air abrasion strategy for each piece.

Most of the fragments were robust enough to be worked on unsupported inside the air abrasion cabinet. More fragile pieces were held on contoured pads of polythene bubble wrap or acid-free tissue, covered with polythene cling film.

Low pressure, low powder air abrasion was used first to remove soil and grit cover, revealing areas of mineralised material, and also showing the depth of iron corrosion products to be removed. Following preliminary air abrasion, the fragments were examined again under X16 magnification to assess the extent of the mineralised material. Then air abrasion at higher pressure was resumed to remove all obscuring corrosion from the object surface, while leaving mineralised material in place.

Thickness of soil cover and obscuring iron corrosion products varied from piece to piece and from block to block. In general, however, these were not voluminous (usually <5mm), and the general outline of the piece was usually visible before corrosion removal began. Sometimes the position of rivets and perforations could also be seen, though fine surface detail was invariably obscured.

Fig 13 : 3976AΔ/7 before and after corrosion removal, with obscured copper alloy rivets and overlapping iron plates revealed

Many of the highly corroded armour pieces were found to have a surviving metal core – many fragments only 1mm thick had metal remaining below the corrosion, particularly away from the more corroded edges. Metal was sometimes visible below the magnetite layer, where this was thin or uneven, or could be detected by passing a magnet over the surface of the object. Some of the better-preserved, strongly curved pieces from 3976Δ, for instance, still retained some 'spring' and flexibility.

The survival of metallic iron in fragile artefacts of such antiquity is due to the corrosion-inhibiting effects of an undisturbed anoxic waterlogged burial environment. Context 6419, which produced blocks 3976Δ, 3977Δ, 3978Δ and 3979Δ was described by the excavators as 'a layer of mid grey/brown organic silty clay', and context 6205 which produced block 3416Δ as 'a black organic silty clay' (*Zant 2001*). (Though 3416Δ was received dry, it came from a waterlogged context, but was not immediately recognised as armour).

Rivets made from iron and copper alloy were also revealed by air abrasion. 3976Δ had mainly copper alloy rivets, with just a few made of iron - thought to be repairs. 3979Δ, however, had iron rivets. All the rivets were used to hold a leather lining or straps in place, not to join the armour plates together (see below).

As received, many of the copper alloy rivets were covered by a thick, uneven or bubbly layer of an unusual 'brassy' coloured corrosion product, sometimes with an overlying white layer, which formed a hard shell over the rivet. Samples of this corrosion product were analysed using XRD (see Analysis section). Below the corrosion shell, the copper alloy rivets were found to be in good condition, though the surfaces were sometimes etched. A programme of EDXRF analysis was carried out on some of the copper alloy rivets, and the results can be found below**.**

Fig 14 : 3976AΔ/16 showing copper alloy rivet obscured by corrosion 'shell' and revealed by air abrasion

Fig 15 : 3979BΔ/9 showing iron rivet

The surfaces of the iron bands revealed by air abrasion were not undamaged. Some pieces had areas of magnetite which were almost continuous, and preserved very fine detail (e.g. 3976ΔA/5/12, 3976ΔB/9)**,** but the majority of fragments had uneven surfaces, with blisters and pitting. Edges were found to be damaged, and fragile surfaces were perforated in places (eg 3976ΔA/16, 3978Δ/4). To strengthen the fragile pieces and preserve revealed mineralised material, all pieces were consolidated following air abrasion. Paraloid B72 (an ethyl methacrylate copolymer), diluted to 7.5% in acetone/toluene with added matting agent was applied with a brush.

'Restoration'

Many of the armour fragments, both plate and scale, were very thin and fragile (usually 1-1.5mm thick). As far as possible, consolidation alone was used to strengthen them, and the fragments were joined with a reversible adhesive (Paraloid B72), where necessary.

Occasionally, however, this was not enough to make them safe for study and handling. Some pieces required extra conservation work to support or infill damaged or weak joins, or to make the reassembled fragments easier to understand and interpret. 'Restoration' work of this kind was mainly used to fill joins between reassembled fragments, where part of the joining edge was damaged and provided little support (eg 3976A/1, 3978Δ).

The area to be filled was first backed or filled with fragments of non-woven Japanese tissue or aluminium mesh, tacked in place using Paraloid B72 adhesive. The void was then filled from the front or from both sides, using a paste made from 20% Paraloid B72 in acetone, mixed with silver sand to give texture, and coloured with Artists' powder Pigments. When the fill had dried, it was colour-matched to the surrounding corroded surface using Artists' acrylics. The intention was for the fill to blend in with the surrounding metal surface and not attract the eye, but to be easily seen when the piece was closely examined. (eg 3979Δ/4, 3976ΔA/1).

Pieces from **3979Δ/4** were 'restored' in this way. As recovered, **3979Δ/4** was in three pieces (see below), which were air abraded and then joined using Paraloid B72 adhesive.

Fig 16 : 3979Δ/4 as recovered and with the fragments air abraded, consolidated and joined

The pieces joined together well, but missing fragments left a void. To strengthen the piece, a fragment of aluminium mesh was cut to size and tacked in the void. The void was then filled, back and front with the paste as described above. When dry, the area was overpainted to blend in with the surrounding surface.

Fig 17 : Aluminium mesh tacked in place with Paraloid B72

Fig 18 : Filled with a paste of Paraloid B72, silver sand and Artists' pigment

Conservation Findings

3416Δ : The whole of this block was conserved. It was received as 5 closely associated fragmentary sections made up of small iron scales joined by copper alloy wire. The air abraded sections were reassembled using adhesive, with poor joins occasionally filled for strength as described above. Evidence for mineralised leather was found on the back of the metal (see below).

Corroded to the back of 3416Δ was a piece of unrelated copper alloy, riveted to a fragment of iron plate. Because of the overall fragility of 3416Δ, this piece of copper alloy was left *in situ*, as its removal might have seriously weakened the piece.

Fig 19 : 3416Δ conserved

Closely associated with 3416Δ were two fragments of shaped iron, which joined and proved to be part of a helmet cheek piece. There was a copper alloy rivet still *in situ*, and caught below this were the remains of a layer of metal foil with a high silver content, which had evidently been clipped away prior to disposal. EDXRF analysis was carried out on the copper and silver alloys used (see below).

Fig 20 : 3416Δ/6 iron cheek piece, with detail showing copper alloy rivet with silver foil caught below it

3976ΔA : 35 partial plates and fragments were conserved from both ends of this shoulder defence, leaving the middle section unconserved. All the pieces conserved were incomplete, and some were strongly curved. Copper alloy rivets, most still *in situ*, had been used to attach a leather lining, and many of the plates also had perforations, probably for lacing. Evidence – sometimes extensive – for mineralised leather was found on the back of 28 out of the 35 pieces conserved (see below).

Fig 21 : Conserved pieces from 3976ΔA

3976ΔB : 53 mostly fragmentary plates were conserved from this part of 3976Δ, most either flat or slightly curved. Only pieces from the top layer were at all complete, with those below being severely damaged and displaced. It had been intended to leave part of this block unconserved, but as most of the pieces were not found in their original positions, it was decided to conserve all but the smallest fragments. Both copper alloy and iron rivets were used in the construction. There were lacing perforations, and evidence for mineralised leather on the back of 38 out of the 53 pieces conserved (see below).

Fig 22 : Conserved pieces from 3976ΔB

3978Δ : The better preserved area of this block was worked on, which consisted of 6 fragmentary but joining sections made of iron scales, some plated with copper alloy. The scales were joined by thin iron wire. The air abraded sections were reassembled with adhesive and filled as necessary, and the rest of the block was stored unconserved. Evidence of mineralised leather was found on the back of 3 of the conserved sections of metal scales (see below). EDXRF work was carried out on the copper alloy platings (see below).

Fig 23 : Conserved pieces of 3978Δ, with detail showing fine iron wire joining the scales

3979Δ : 6 of the 7 pieces conserved from this arm guard were adjacent, and after conservation could be fitted together, though they were not joined with adhesive. They consisted of fragmentary, curved iron plates, the best preserved piece

(3979Δ/5) being very distorted. The seventh, non-joining conserved piece was evidently the end of the arm guard, and had one rolled edge with an iron hook riveted to it. The rivets in 3979Δ were made of iron. All seven pieces had evidence of mineralised leather on the back (see below).

Fig 24 : Conserved pieces from 3979Δ, with detail of rolled edge and hook

Mineralised Material

One of the aims of the conservation work was to look for evidence of the leather component in the armour's construction. As mentioned above, the majority of the rivets did not join the plates of armour together, but were used to hold a leather lining or straps in place. Rivets were invariably inserted with the head on the inside of the metal, and there was a gap (of around 2-3mm) between the rivet head and the armour surface. As many of the plates and scales were found semi-articulated, but were not riveted together, the leather component must have been largely intact when the armour entered the burial environment. The 3mm gap probably represents the thickness of the lining or strap.

The waterlogged leather found surrounding and covering some of the armour (eg 3976Δ, 3978Δ) was examined by specialists and found to be unrelated to the armour itself, being composed largely of scrap – though many pieces had military associations. Although fragmentary and fragile, this leather was flexible and showed no signs of mineralisation. However, the leather lining and straps which formed part of the armour's construction were preserved only through mineralisation. While a degree of mineralisation might be expected in such circumstances, it was significant that none of the unrelated leather was mineralised, even when found lying directly on top of the metal, while nearly all the leather components of the armour itself were completely mineralised. As all the leather had been subject to the same burial environment since deposition, this disparity in preservation would suggest that a different dressing was used for the leather in the armour's construction, which has not survived as well as the (presumably) vegetable tanned leather. This may have been an oil-tanned leather, frequently used nowadays in armour reconstructions, as it has a longer life when in close contact with metal. Oil tanning produces a soft and supple leather, which would be suitable as a lining material, but which needs regular oiling to maintain its suppleness and waterproofing. Once the leather has entered the burial environment, however, the preserving qualities of the oil are lost, and if conditions are right, mineralisation will occur.

There was abundant evidence for mineralised leather, though this was often frustratingly ephemeral and discontinuous, and not found in the clear and precisely defined locations that researchers had hoped for. Most was present as areas of orange or orange-brown powdery and sometimes profuse iron corrosion products, the colour and texture of which was variable but very distinctive to those accustomed to examining archaeological artefacts. The edges of the mineralisation were usually not well defined, with their limits merging into adjoining areas of very similarly-coloured iron corrosion. The colour and positioning - on the back but not the front of the plates and scales - all strongly suggested that this was a mineralised organic material. The discovery of a few surviving fibrous areas confirmed this, and also identified the material as leather However, the discontinuous nature of the mineralisation unfortunately made it difficult to draw conclusions about the exact role that the leather had played in the construction of the different types of armour.

Careful low pressure air abrasion with little or no abrasive powder was used to reveal the extent of the mineralised leather, and occasionally fragments of original surface or structural details were detected. Traces of possible pores in the leather surface were observed on the back of 3416Δ/5 and 3976ΔB/36. On the back of 3976ΔB/47 a distinct edge to the mineralised leather was visible, and the back of 3976ΔA/15 had the remains of what appeared to be a leather washer surrounding a CuA rivet head.

Evidence for mineralised leather

3416Δ : A piece of scale armour, with the scales joined by copper alloy wire. The remains of a thin layer of leather on the back lay close to the metal surface. Pieces 1 and 5 showed possible pores in the mineralised leather surface.

Fig 25 : 3416Δ/5 back – possible pores in the mineralised leather

3976AΔ : Mineralised leather was found on 28 out of the 35 pieces conserved. It was present discontinuously on the back of the metal plates, occasionally surviving almost to the full depth of the copper alloy rivets (eg 3976ΔA/20). Traces of a fibrous structure were seen on 3 of the pieces, including 3976A/15, which also had the remains of a possible leather 'washer' around the rivet head.

Fig 26 : 3976ΔA/15 back – leather 'washer' surrounding copper alloy rivet head

3976BΔ : Thirty nine of the fifty four conserved pieces had evidence of mineralised leather, with seven retaining traces of a fibrous structure. Two pieces were of particular interest –

3976ΔB/Frag A (a piece selected by Dr D Sim for metallographic analysis) had a few non-mineralised fibres among the mineralised material found on the back of the metal, close to an iron rivet head. A sample was examined using scanning electron microscopy (SEM) (see below).

3976ΔB/18 had a substantial area of mineralised hair or fur on the back of the metal, the pattern of the tufts being visible without the aid of a microscope. This was also sampled for SEM work (see below).

Fig 27 : 3976ΔB/14 back – mineralised leather retaining fibrous structure

***3978Δ* :** Another scale construction joined by iron wire, this piece had traces of a thin layer of mineralised material on the back, close to the metal surface. It was detected on 3 of the 6 pieces conserved.

***3979Δ* :** The length of *manica* or arm guard, appeared to have traces of straps running along the inside of its length when first viewed - as would be expected from the method of construction and intended usage. This was not disproved by conservation work, but the mineralised leather seemed to be present over a much wider, and less well-defined area than would have been expected from straps alone. Perhaps the arm guard had a lining of leather as well as the strapping, which was used to keep the iron plates in position and to allow them to articulate. Samples were taken for SEM examination (see below).

Fig 28 : 3979Δ/2 inside, showing the extent of the orange/brown mineralised leather

Storage

All the conserved pieces from 3976ΔA and B and those from 3979Δ were placed individually in pierced polythene bags with polyethylene foam inserts, and stored in air-tight polythene boxes with active silica gel.

The conserved pieces of 3416Δ and 3978Δ, and the unconserved areas of 3976Δ**,** 3978Δ and 3979Δ required more complex storage. All had to be stored in a way which would allow researchers to examine both sides with the minimum amount of handling, particularly of the unconserved pieces.

A series of more robust containers was made, with an inner cushioned mould intended to protect the fragments against physical damage and to hold them in position, placed inside a more rigid outer casing.

Fig 29 : Construction of the cushioned mould, with silicone rubber curing inside a plasticine dam

The inner cushioned mould was made from silicone rubber. The armour pieces were covered with a layer of non-PVC cling film brushed with talc as a separator, any major unevenesses or undercuts in the armour surface having been padded out with wadded cling film. A 'dam', to contain the silicone rubber while it cured, was created around the armour, either using plasticine modelling material or plasticine plus Correx (a fluted polyethylene construction material) for the larger, more three-dimensional pieces. The silicone rubber was then poured over the cling film. When the rubber had cured, the mould plus armour was turned over, and the dam rebuilt around it. The armour was again covered with a layer of talced cling film, and more silicone rubber was used to mould the other side. The silicone rubber moulds, (sometimes with some cling film wadding), held the fragments in position very well, but were not sufficiently rigid to prevent damage and movement in long-term storage.

Pourable epoxy resin was used to make rigid containers to surround the silicone rubber moulds. Suitably-sized Correx boxes (comprising base and sides) were constructed to contain the silicone moulds and act as formers for the epoxy. The Correx box edges were secured with duct tape, and the inside surfaces lubricated with Renaissance wax (a hard wax of fossil-product origin). A thin layer of two-part pourable epoxy resin potting compound, mixed with vermiculite (an expanded lightweight micaceous mineral product) which was used to reduce the weight of the finished mould was poured into the Correx box, and one half of the silicone rubber mould immediately positioned on top of it. More epoxy was then added to the top of the silicone rubber. When this had cured, the Correx box was removed from around it, and the procedure repeated for the other half of the silicone rubber mould. The flatter containers were made in this way, but where it was feared that the two halves of the silicone rubber might be difficult to align (3976Δ, 3979Δ), the second part of the epoxy mould was poured on top of the existing cured part, (separated by a layer of polythene which was later removed), allowing the two halves of the silicone rubber mould to be precisely aligned.

The cured epoxy/vermiculite mix was rather sharp-edged, so a further thin layer of epoxy alone was added to the outer surfaces of the moulds. The moulds were finished by filing and hand sanding the edges, and the two halves joined using small brass hinges, drilled, screwed and epoxied in place. The moulds were fastened with brass hooks and eyes, and stored in air-tight polythene boxes with active silica gel.

Fig 30 : Correx box former, with curing epoxy/Vermiculite mix surrounding the silicone rubber inner mould

The epoxy moulds can be opened with either face of the armour fragments uppermost, to allow for examination without handling.

Fig 31 : Conserved parts of 3978Δ in its support mould

Analysis

X-Ray Diffraction (XRD)

Several samples of interesting or unusual corrosion products discovered during investigative work were analysed using XRD, the analysis carried out by Roger Wilkes at Fort Cumberland in Portsmouth. Only one sample (from 3978Δ/3) produced usable results, however.

Many of the armour's copper alloy rivets, and some of the copper alloy platings (as in 3978Δ, see Fig 32 below) were covered with a thick layer of a hard, dull gold-coloured corrosion product, often present as a 'shell' over the copper alloy below. This was sampled for XRD analysis. Similar corrosion products have previously been observed on artefacts from other excavations in Carlisle, and they have also been noted by conservators elsewhere (*Duncan & Ganiaris 1987*). The corrosion product is characteristic of copper alloys excavated from anoxic waterlogged environments.

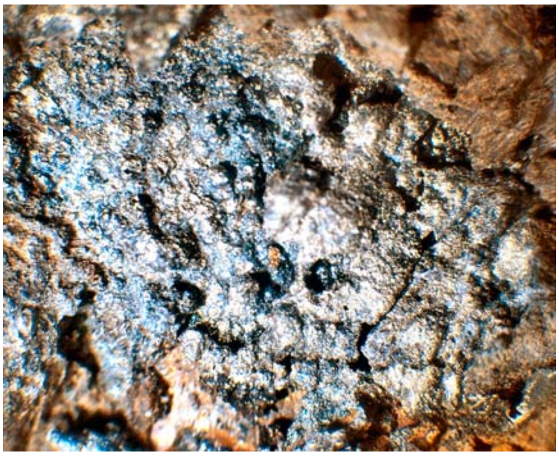

Fig 32 : 3978Δ Chalcopyrite corrosion over copper alloy

XRD analysis confirmed the findings of other researchers, and identified the corrosion product as chalcopyrite - an iron copper sulphide. The source of the sulphur is hydrogen sulphide produced by the sulphur-reducing bacteria, present in abundance in waterlogged anoxic environments. The iron and copper components derive either from the metals of the artefacts themselves, or from precipitation of ions present in solution in the soil.

Scanning Electron Microscopy (SEM)

SEM was used to try to positively identify the mineralised material found extensively on the back of the armour plates and scales. As mentioned above, mineralisation was very variable, both in colour and texture, and it was largely the characteristic form, context, extent and positioning of the material which suggested that it was leather. Occasionally small areas apparently preserving a more fibrous structure and/or a hint of an original surface were observed, and it was from here that samples were taken for SEM examination.

Under high-powered SEM (c X3000+), the structure of leather can be seen to be composed of bundles of long collagen fibres, arranged in a distinctive three-dimensional but rather variable pattern *(Haines, 1981)*. It was an identification of such structures which would confirm that the mineralised material was leather.

Samples were mounted on adhesive carbon discs on aluminium stubs, then sputter-coated with gold to make them conductive, and viewed using an SEM facility belonging to Durham's University's Earth Sciences Dept.

Under SEM, only one sample of mineralised material showed any characteristics which could be positively identified as leather. This sample was taken from the back of 3976ΔB/14A, a fragmentary piece of iron scale armour, which had an area of mineralised material with a visible fibrous structure, surrounding and covering a large

(13mm diameter) iron rivet head. Under SEM, traces of a bundled structure could be seen along the edges of the sample.

Fig 33 : 3976ΔB/14A SEM showing the bundled structure characteristic of leather

SEM examination of the non-mineralised hair found among iron corrosion on the back of 3976ΔB Fragment A found this to have a scale pattern consistent with calf skin, although a positive identification was not possible.

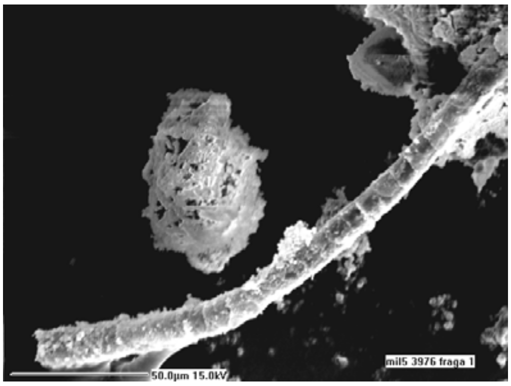

Fig 34 : Scale pattern on non-mineralised hair from 3976ΔB Frag A

The mineralised hair or fur from the back of 3976ΔB/18 showed casts of animal fibres with a scale pattern. Under SEM, these scales looked different to those found on Fragment A, with more curved or undulating boundaries. Their appearance was similar to wool fibres, an identification which would be consistent with the ‘tufted appearance’ of the mineralised material.

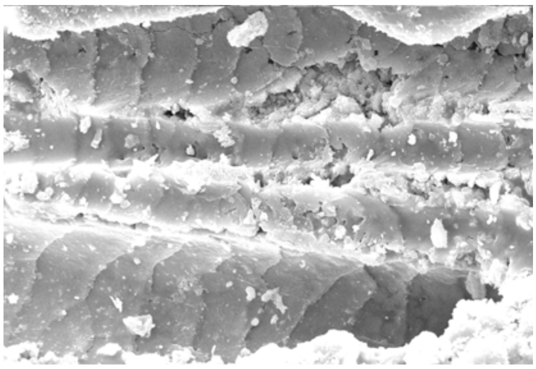

Fig 35 : 3976ΔB/18 with SEM of wool

Most of the samples examined under SEM proved disappointing, however. Leather does not have such a well-defined and rigid microscopic structure as wood, and its identifying characteristics are therefore more easily damaged and distorted. This is particularly true of mineralised material, which is essentially composed of inorganic powdery material (in this case iron corrosion products), with all organic components from the original material lost. The sampling process, carried out with a scalpel as the material is usually too soft to allow a fragment to be broken off, may destroy most of the surviving structure.

Another problem when viewing archaeological material under high magnification is the presence of fungal hyphae and mineral fragments from the soil. Even when the sample is taken from below the surface of the deposit and appears ‘clean’ when viewed using light microscopy, when the high magnifications of SEM are applied, an abundance of extraneous debris can be seen coating and obscuring identifying features. With more robust SEM specimens, it is possible to remove most of this debris prior to examination using various cleaning methods, but this is rarely possible with fragile archaeological material, and impossible with mineralised samples.

Wood identification
Only five identifiable wooden artefacts (as opposed to pieces of worked wood) were recovered from the armour blocks. From 3978Δ came a small turned disc (Fig 36, left), made from fruitwood *(Pomoideae*).

There were also two very thin (<1mm) flat rectangles of alder (*Alnus* sp. *1 & 2)*, both with some original edges. The thinness of these pieces suggested ink writing tablets, though they were perhaps rather large. To check for ink writing, they were examined under an infra-red light source, but were found to be blank. There were faint saw cuts and chisel marks visible on both pieces, and it is possible they were cut as veneers, although alder is not an obvious choice for such a use, as it does not have any decorative figuring. The thinness of the pieces, presumably cut by hand, is remarkable (Fig 36, right).

Fig 36 : Wood from 3978Δ

From 3976AΔ came a small chunk of wood with a wedge-shaped end (Wood AX), made of alder. The incomplete handle from 3976BΔ (Wood M, Fig 37), was found to be made of hazel (*Corylus* sp.).

Fig 37 : Wooden handle from 3976ΔB, truncated by the lifting process

For identification purposes, the artefacts were sampled wet, with three sections (transverse, radial and tangential) cut by hand using a razor blade. The sections were examined and identified using transmitted light microscopy, at magnifications up to X400.

As already mentioned, much of the fragmentary wood recovered during the deconstruction of the blocks was made up of small chips, often with visible tool marks, which appeared to be woodworking debris. There was not time for all these small pieces to be identified microscopically, but they were examined after conservation. Many of the pieces examined were made from oak (*Quercus* sp.), but alder and ash (*Fraxinus* sp.) were also identified.

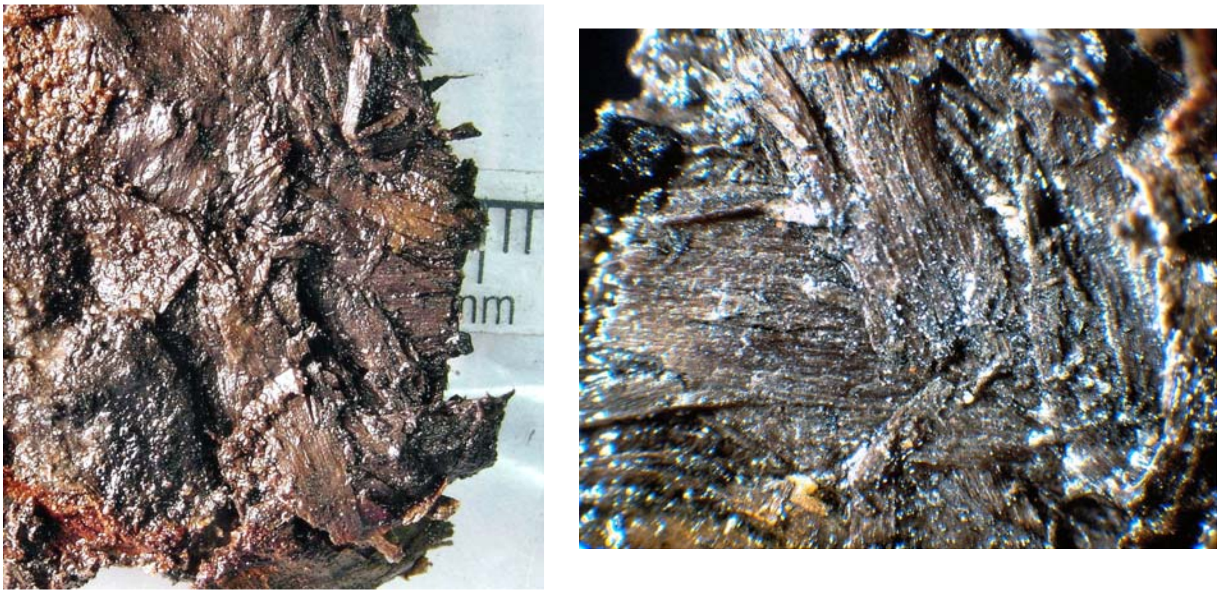

Fig 38 : Wood working debris from the deposits surrounding the armour

Fibre identification

There appeared to be two different sorts of rope present – one type very dark in colour and quite hard and fibrous to the touch (3976A∆ BI and 3976B∆ Z). The other type lighter in colour, softer and more flexible (3976A∆ BO and 3976B∆ AD & AT). The ropes appeared to be made from plant bast fibres, but an identification was not immediately possible. Both types were sampled and sent for examination to OAN's archaeobotanist (E Huckerby).

Fig 39 : Rope Z and Rope AT before stabilisation

Energy Dispersive X-Ray Fluorescence (EDXRF)
A programme of EDXRF analysis was carried out on some of the copper alloy rivets and coatings/platings. Some rivets could not be analysed because of time constraints or difficulties with positioning the pieces inside the EDXRF system. The analyses used a Link Analytical XR200 system and a pre-set 'method' formulated to detect a suite of elements present in copper alloys and platings. The method normalises the results to 100%, and therefore the analyses should be regarded as being semi-quantitative only. All were surface analyses.

Surface analyses are generally considered undesirable if comparisons are to be made between sets of results, because of preferential deposition of some of the elements from the alloy into the surface corrosion products (*Oddy & Bimson 1985*). However, as the armour was recovered from an anoxic burial environment, the usual layers of surface copper corrosion products were generally absent. Once the shell of chalcopyrite had been removed, analysis was effectively carried out on an uncorroded metal surface.

3416Δ : 9 analyses
Copper alloy wire joining iron armour scales (3 analyses): brass
Copper alloy wire joining copper alloy armour scales: brass
Copper alloy armour scales: brass
Associated piece of copper alloy and copper alloy rivet corroded to the reverse of 3416∆ : brass.
Fragment of white metal sheet on fragmentary ironcheek piece (3416∆/6): high silver/copper alloy
Copper alloy rivet holding silver/copper sheet: bronze

3976ΔA : 27 analyses
Copper alloy rivets (23 analyses): all bronze, with low levels of added tin(range 0.11%-2%), 7 also having traces of lead(<0.5%)

3976AΔ/18 (ring): leaded bronze
3976AΔ/25 (ring, rivet and tag): ring leaded bronze, rivet brass, tag bronze with trace of zinc.

3976ΔB : 10 analyses
Copper alloy rivets (9 analyses): 2 copper, 4 copper with traces of zinc and/or lead, 3 bronze including 1 with trace of zinc)
3976BΔ/35A (loose copper alloy sheet frag): brass with trace of tin

3978Δ : 4 analyses of decorative copper alloy plating on iron armour scales
3987Δ/2, plus one unconserved plating: both are brass, with a trace of tin
3978Δ/3, plus one unconserved plating: both bronze

The semi-quantitative EDXRF analyses showed the use of a range of copper alloys in the armour's construction. They also showed quite a high degree of variability among the copper alloy used in the same piece of armour. This was particularly evident in the alloys used for the rivets of 3976ΔB. This variability may be evidence for extensive repairs, carried out either by different workers, or possibly by the owner himself in the field. One end of the copper alloy rivet would have been visible on the outside surface of the armour, and therefore it would be expected that at least the colour of the rivet would be consistent, regardless of its composition. This was not always the case in 3976ΔB, however, where some of the iron plate fragments (45 & 49) had rivets which were different from the majority in both composition and colour.

Fig 40 : 3976ΔB frags 45 and 49

Evidence for the use of different copper alloys to produce a decorative effect was seen in 3978Δ, where some of the iron scales were plated with copper alloy sheet. Both brass and bronze were detected as plating materials, and EDXRF analysis of both the conserved scales and also two other scales from the unconserved area of the armour, suggest that the different alloys were used on alternating rows. In its unadorned state, each alloy would have been slightly different in colour when new, and it is possible that the bronze sheet was also originally surface coated with tin, as was found among the material excavated at the Roman fort at Newstead *(Curle 1911*). Plating could not be detected here using EDXRF analysis, because of tin present in the composition of the copper alloy sheet.

The choice of different alloys for different purposes was evident in 3976ΔA/25 (Fig 41), an iron plate fragment with attached copper alloy ring, tag and rivet, where each component of this small assemblage was found to be different in composition (see above). This demonstrates the sophistication of the Roman metalworking industry, and also the wide range of both raw materials and (possibly) ready-made components available to the armourer.

Fig 41 : 3976ΔA/25

Metallographic analysis

Several pieces of the armour were included in a research project being carried out by the University of Reading, which was looking at the production of Roman Ferrous armour. Pieces of the Carlisle armour were sampled for metallographic analysis, by Dr David Sim, and the results of this research are soon to be published (*Fulford, Sim and Doig 2005*).

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