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Ancient Monuments Laboratory
Report 89/97

METALLURGICAL STUDY OF A ROMAN IRON BEAM FROM THE 1959 BY-PASS EXCAVATIONS, CATTERICK, NORTH YORKSHIRE

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Summary

A 52 kg section of an iron beam from the excavated Roman bath house at Catterick was re-examined metallographically. An inventory of other British and Continental beams is included.

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The site of Catterick

Rescue excavation was undertaken between September 1958 and July 1959 on the site of the Catterick By-pass at Catterick Bridge, North Yorkshire. Amongst the structures uncovered was an incomplete 4th century AD bath house constructed on the remains of a 2nd century bath house. The broken half of the beam examined in this study was found built into the furnace walls of the earlier structure. Another beam, complete but damaged by use at its centre was found lying on a pile of refuse on the furnace room floor and was assumed (Wacher 1971) to be intended for re-use. Parallels for similar beams include the Stabian Baths at Pompeii, where beams survived in situ to show how they had supported water boilers and the metal extensions to the hot bath (*calderium*) which maintained its high temperature (Batty 1969).

Metallurgical significance

Iron bath house beams are unusual in Roman metallurgy in being amongst the very few iron artefacts which needed to be built up from the products of more than one bloomery smelt. Iron smelting in the Roman period was essentially a batch process. Operating below the melting point of pure iron or steel, the process had to be halted in order to remove the solid lump of iron (bloom) formed. After consolidation the bun-shaped blooms were probably widely traded in their own right, but archaeologically recovered examples are rare. Surviving Roman examples (Tylecote 1986 p186 & Starley forthcoming) vary considerably from 300g to 12 kg. Thus a complete beam, such as that from Catterick would require over 20 of even the largest individual blooms, demonstrating a considerable input in labour.

In early papers bath house beams are occasionally mis-identified as blooms or anvils. Given the difficulty in fire welding such large artefacts from smaller blooms the possibility of large composite blocks being constructed for trade can be dismissed. Smaller beam fragments are more easily confused with anvils, and their re-use for this purpose is quite likely. Several of the smaller fragments listed below were found in contexts far removed from bath houses (*eg* medieval Bayham Abbey and the Roman theatre at St Albans) but are thought likely to have originated as parts of bath house beams.

Previous investigation

The fractured beam from Catterick was investigated at the Research Department of Dorman Long (Steel) Limited (Wright 1960) and the results published (Batty 1969 and Wright 1972). As received the beam weighed 134.7 kg but 6.8kg of surface encrustation were removed after five samples had been taken. Analyses of these were interpreted as below, but provide little information on the beam itself:

1. A general corrosion product or deposit consisting of rust and clay.
2. A mixture of limestone and impure iron oxide in about equal proportions.
3. Iron-bearing sandstone.
4. A furnace product or cinder, consisting largely of silica and ferric oxide.
5. A type of iron ore, rich in ferric oxide and of low sulphur content.

With some difficulty the beam was sectioned longitudinally, and a sulphur prints made of the polished surface. The section was then given a macro etch of ammonium persulphate. This allowed 17 separately welded sections of iron to be identified. Each area was drilled for bulk chemical analysis. These showed a relatively consistent material averaging 0.138% carbon, 0.019% sulphur and 0.077% phosphorus. Macro hardness, measured on three of the areas, gave ranges of: 98.4 to 135H_v, 82 to 162H_v & 78.5 to 155H_v. The final sample, repeated after normalising at 900°C, gave a similar range of 78 to 147H_v. The very wide range of these values reflects the heterogeneous structure, including very soft ferritic iron. The similar hardness range between the normalised and un-normalised sample shows the absence of any quench hardening or work hardening of the structure.

After etching, micro-examination showed the presence of non-metallic inclusions, containing oxides and silicates. Five micrographs were presented by Wright (1972), showing very varied structures, from large (ASTM 2 to 3) ferrite grains to ferrite plus spheroidised carbides and hypereutectoid structures with cementite networks near weld junctions.

Wright concluded that "the ancient iron bloom can be classified as a porous mass of wrought iron, built up of several smaller pieces, which have been fire welded together. The smaller pieces of wrought iron were evidently produced by a production process direct from the ore. The low sulphur content of the iron suggests that charcoal was used as fuel during the reduction, refining and welding processes". Wright also pointed out the close similarity with the beam from Corbridge investigated by Bell (1912).

British and Continental beams and their examination

British finds of beams have been listed by Wacher (1971) and Tylecote (1986,165). These include:

Tylecote (1986) gives the dimensions of the other, complete, Catterick beam as 1.72m in length with a section of 18 x 18cm in the centre and 15x13cm at the ends and a weight of *c*250kg. This compares with original dimensions for the half beam, before sectioning of 0.89m length, 18 x 18cm and 15 x 16.5 cm section and 135kg weight.

Three from a furnace room at Chedworth villa (lengths 1.63m, 0.99m & 0.94m and weights 220kg, 161kg & 116kg) which the excavator, Fullbrook-Leggatt (1967) interpreted as blooms.

One broken example is reported to have been found during Kathleen Kenyon's excavation of the baths at the Jewry Wall site in Leicester. Surprisingly the object is not mentioned in either of her two reports on the site (Kenyon 1938 & 1948) but a letter from D. T-D Clarke, Keeper of Antiquities at the City of Leicester Museum and Art Gallery, dated 14 March 1962 records a conversation with Kenyon in which "she assured me that it was discovered there". The surviving portion measures 0.90m in length with a maximum section of 0.20 x 0.16m at its broken end thinning and broadening to 0.13 x 0.22m before ending in a forked terminal (see Appendix 1. Dimensions and sketch supplied by R. Clark, Leicester City Council SMR/planning archaeologist). This forked beam is unique in Britain, although on the Continent similar *Gabelkopf* (tops of forked beams) are known from Saalburg and four further (complete?) examples are reported to have been found in 1588 at Brittenburg, Netherlands (Baatz 1991). These are interpreted as the supports for a longer, square-sectioned beam which rested in the notch between the two forks. A sample from the Jewry Wall beam was examined by metallography (Jubb 1959) and found to be almost entirely ferritic with remarkably little carbide present. Entrapped scale was also noted during the examination.

At Corbridge, Northumberland in 1909 Forster and Knowles (1910) discovered a beam, which they assumed to be cast iron, standing upright in what was suggested to be a smelting furnace, adjacent to a bath house. This beam, now lost, was recorded as being about three and a half hundredweight (178kg). Louis (1910) gives the dimensions as 3 feet 4 inches [1.02m] long by 7 inches [0.18m] square at one end, "which was rough and rather spongy", tapering down to about 4½ inches [0.11m] square at the other. Chemical analysis and metallographic analysis was carried out by Louis who identified the low carbon nature of the beam; a metallographic sample cut from the beam was found to be ferritic but with occasional grains of pearlite towards the outer edge. Louis suggested that the block was used as an anvil associated with the smithing hearth. By contrast Stead (1912) thought that the beam had been under construction when abandoned. To determine how the mass had been constructed Stead had the beam sawn longitudinally, planed flat, polished and etched. Examination showed that lenticular slabs had been added, alternately from each side (see Appendix 2). A number of large cavities remained within the centre of the beam. Some areas of between 0.5 and 1.5% carbon were identified metallographically and confirmed by analysis. The upper central portion of the beam was recorded to be a mixture of iron and "cinder" composed of iron oxide rather than slag. This is interpreted as constructional rather than the result of use. More recently this interpretation of the structure in which the beam was found has been reconsidered (G. Plowright pers comm.) and it is suggested that the hearth/furnace was an associated part of the baths, used for heating water.

Wacher (1971) mentions a further fragment of a beam in Chesters Museum. The museum's current interpretation of this artefact (G. Plowright pers comm) is as an anvil. Tylecote (1986, p165) gives the following dimensions; weight c14kg, length 0.25m, and section (at end) 0.12 x 0.08m

A beam found during the excavation of a bath house at Llanfrynach, Powys in 1783 was recorded as "a bar of malleable iron four feet [1.2m] long, and six inches [0.15m] square, and so soft as to be marked by a stroke from a hammer" (Hay 1785). This beam does not survive in any museum collection and, despite recent investigations by Clwyd and Powys Archaeological Trust, the exact location of the baths is unknown.

One possible piece of beam weighing 13.6 kg and measuring 0.36m in length and 0.10 x 0.07m in section was excavated from Bayham Abbey. Despite the medieval context of the find, Tylecote (1979) suggests this object may be a piece of reused Roman bath house beam. Tylecote examined a sample of the object metallographically and refers to it as a typical piece of partly forged bloomery iron with "a good deal" of porosity and slag. The metal was reported to be mostly ferrite with a little pearlite (lamellar to spheroidal) but no cementite or graphite. A Vickers hardness of 140 H_V was interpreted as indicating low to moderate phosphorus content.

A large piece of iron found during the excavation of the Roman theatre at Verulamium was described as an iron counterpoise, used "presumably as part of the curtain raising mechanism" (Kenyon 1934). However it is now assumed (David Thorold pers comm.) that the object was a reused fragment of a bath house beam. The excavation report gives a weight of 69.9 kg, a date of soon after AD 160 and illustrates the object as a stubby fragment squared off at one end and with a concave fracture at the other. Tylecote (1986) gives the dimensions of the beam fragment as 0.43m long with the end section measuring 0.13 x 0.15m.

Continental Examples have been catalogued by Baatz (1991)

Gallia
Two nineteenth century references to ?swollen and spongy iron blocks from Mont Beuvrey (Bibracte) and Autun (Augustodunum)

Germania inferior
Xanten, Colonia Traiana. Nine fragmentary iron blocks.
Brittenburg bei Katwijk aan Zee (Netherlands). 5 forked beams.

Germania superior
Mainz, a 1 ½ Zentner (75kg) *eisenschlackenstücke* from the Legionary baths.
Frankfurt am Main. One *eisenblock* 1.2m long, another 0.18 x 0.2 x 0.6m
Zugmantel, 15.5kg *eisenblock* and broader, shorter *eisenbrocken* fragment.

Saalburg has produced the largest and most thoroughly studied assemblage comprising 43 broken beams and fragments. The larger straight and forked types suggest an arrangement comprising a horizontal bar supported at either extreme by two vertical beams as reconstructed by Baatz (1991). Each vertical beam has a broadened base for stability and a forked top to receive the horizontal beam. Jacobi's earlier publication (1897a, Tafel XXXXVII) illustrates the incorporation of the smaller fragments into masonry and as lintels and side supports for (?stokehole) openings. However it is suggested that this use was secondary and that they were originally anvils (Jacobi 1897b, 238). The full inventory of the Saalburg assemblage is given in Appendix 3.

These beams have been the subject of a number of metallurgical reports. An initial study by Krapp (1987) of beams S1112 and S1113 suggested that the beams contained cast iron. However, this is refuted in a subsequent study by Hauptmann and Maddin (1991) which showed beam S1112 to be ferritic *ie*, virtually free of carbon. Slag inclusions were large and abundant as in bloomery iron and the macrostructure was consistent with the piece being built up by forge welding. The most recent study of beam S1113, by Rehren and Hauptmann (1994), showed that the beam was built up of an inner core containing high concentrations of slag inclusions to which a much more homogenous surface layer had been applied, with a clear boundary visible between the two. Chemical analysis showed the central core to also have a significant phosphorus content (>0.2%) whilst the outer layer contained levels below detection (<0.02%). All the iron was ferritic with isolated cementite at the grain boundaries.

At Pompeii three beams were found *in situ* in the Stabian Baths. One had an exposed length of 56cm with a section of 0.12m by 0.09m, the other two showed exposed lengths of 0.67m (Tylecote 1986, p166). A cross section showing the position of the beams is illustrated in Mau and Kelsey (1899, p188) This shows how they supported a bronze water heater (*testudo*) for the hot baths (*caldarium*).

Re-examination of the Catterick beam

During the re-evaluation of the technological debris and artefacts from Catterick, prior to publication, the beams were seen to be of great importance. No micrographs survived from Wright's original study and it was decided that re-examination of the beam with the benefit of 37 years of subsequent archaeometallurgical knowledge would be worthwhile.

A section of the beam (Plate 1) is currently in the possession of English Heritage's Ancient Monuments Laboratory but it was unclear whether this is the same section studied by Wright or whether his work was based on the opposing half section. Certainly no samples had been cut or drilled from the section at the AML. The published plates are unhelpful as it would appear that either the photograph of the sulphur print or of the etched section had been reversed in the published reports to match each other. Thorough investigations failed to trace any other surviving portions of the beam. Its transfer to AML is undocumented though Batty (1969) states that at that time a half section was on display in the offices of the Iron and Steel Institution.

The surviving portion of the beam was found to weigh 51.1 kg. The section had a length of 0.89m, and maximum width of 0.18m, 0.53m from the unboken end. Its minimum width, at the unbroken end is 0.14m. Examination of the section surface showed it to be coarsely ground with slight superficial corrosion. Several large voids and areas of deeply penetrated corrosion were also visible. In an attempt to resolve the construction of the beam X-radiography of the artefact was attempted. Unfortunately even the AML's high powered Pantak X-ray unit failed to penetrate the beam.

Metallographic Preparation

Initially the surface was ground down using successively finer grades of abrasive paper, used dry, on a hand-held domestic sanding machine. The surface was then polished using one micron diamond paste. Considerable difficulty was found in achieving a scratch-free finish. The position of individual sections of iron (Figure 1) was found to correspond closely to the findings of Wright (1960). However the fractured end was too heavily corroded to be certain of the position of any weld lines in that region, though two possible weld lines are shown as dashed lines in Figure 1.

Metallographic Structure

Viewed through an optical microscope, in the unetched condition, the structure was seen to contain significant but variable quantities of slag inclusions. The overall area occupied by these was probably about 2%, but without analysis it was difficult to differentiate slag inclusions from corrosion which had penetrated throughout the beam preferentially attacking both weld lines and inclusions as lines of weakness. Oxidation of the metal was particularly severe at the broken end, where more oxides were present than surviving iron.

Plate 1 Section of the Catterick beam after polishing and etching

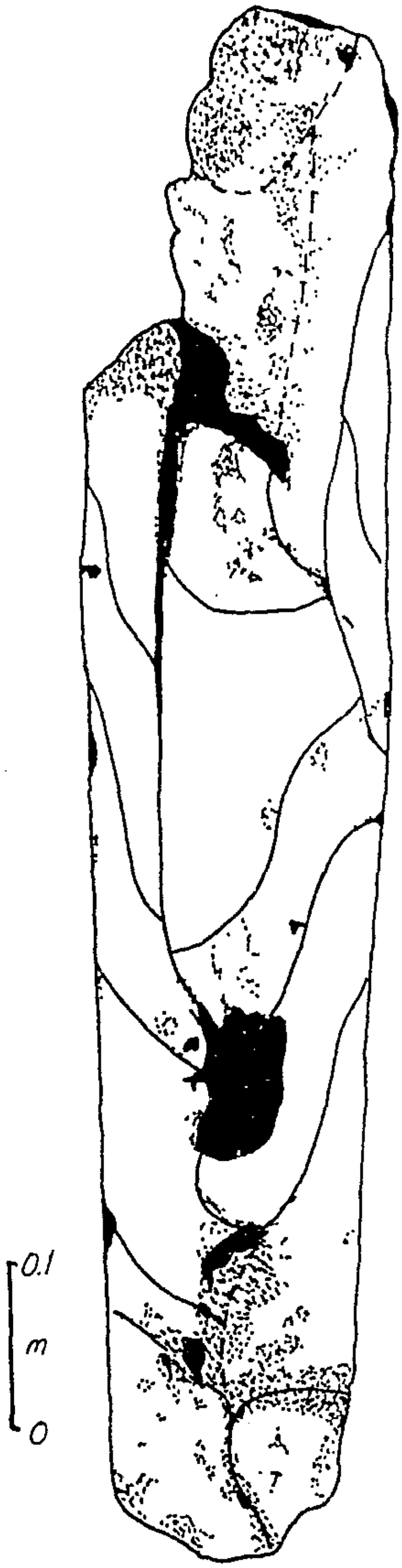

Figure 1 Schematic diagram of Catterick beam showing position of weld lines

Etching with nital (2% nitric acid in alcohol) revealed the crystalline structure of the iron. The vast majority of the beam (>95%) comprised coarse (typically ASTM 1) grains of ferrite (Plate 2), with little if any carbide at grain boundaries. Etch pits within the grains had resulted from the precipitation of carbides or nitrides at modestly elevated temperatures. Higher carbon regions were often associated with junctions between different sections, showing the preference for reducing conditions during welding operations, but one larger area was visible at the fractured end of the bar. The structures of these regions ranged from hypoeutectoid widmanstätten structure with ferrite and spheroidised pearlite (Plate 3) to an even higher carbon, hypereutectoid, structure of cementite plus spheroidised pearlite structure (Plate 4). The quality of welded joints varied considerably from voids to microscopically invisible joins. The weld line shown in Plate 5 is clearly distinguished by the higher carbon content of one component.

Interpretation of the Structure

The metallurgical structure reflects the conditions that would be expected of large pieces of bloomery iron being forge welded together *ie* highly elevated temperatures over long periods of time.

Cause of failure

The fractured end of the half beam was most heavily corroded, with penetration of oxides to the core of the artefact. Most of this probably occurred in use, as a result of high temperature, cyclical heating in heavily oxidizing conditions, of the most exposed middle section of the *in situ* beam. This allowed oxidation of the metal to follow weaknesses in the beam, particularly at weld lines between sections and through inclusion-rich areas within sections. Despite the considerable bulk of metal originally present, the beam appears to have eventually been weakened to the point of collapse under the aggressive conditions of the stoke hole.

Conclusions

Re-examination of this remarkable artefact confirmed the general findings of Wright (1960 & 1972). The iron used was largely ferritic with occasional areas of higher carbon, especially at the joints of the individual iron sections that had been forge welded together to make the beam. Like all beams investigated, the iron was the typical, slaggy product of the bloomery furnace. Its size which required a large number of individual blooms to welded together, in a crude, but metallurgically demanding procedure. The manner of construction of the Catterick beam had similarities with the "herringbone" structure seen on the Corbridge beam (Appendix 2), rather than the Saalburg example in which a homogenous outer casing had been applied to a highly porous core. Failure of the beam would appear to have been the result of gradual oxide penetration of the central portion of a complete (c 1.8m?) component, probably after many years in service.

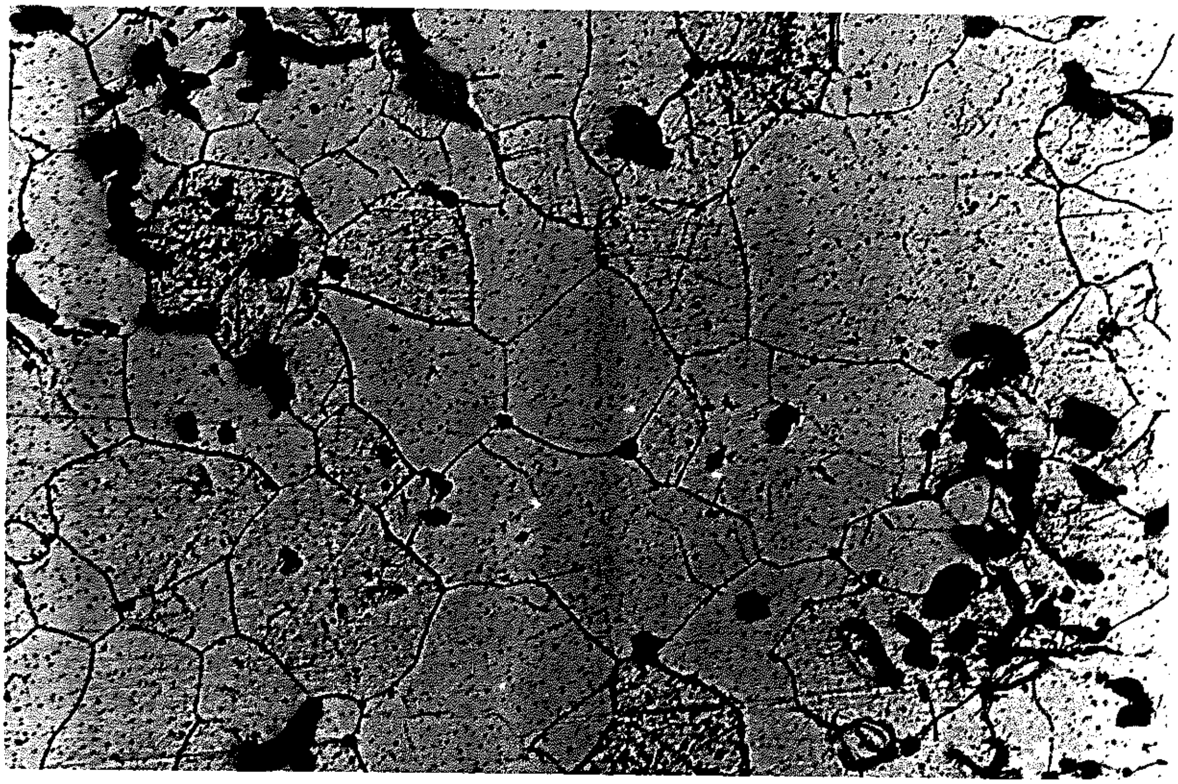

Plate 2 Micrograph of etched (2% nital) Catterick beam. x60.
Coarse ferrite grains, corrosion penetration and etch pits.

Plate 3 Micrograph of etched (2% nital) Catterick beam. x120
Widmanstätten structure with ferrite and spheroidised pearlite.

Plate 4 Micrograph of etched (2% nital) Catterick beam. x60
High carbon region. Spheroidised pearlite with grain boundary cementite

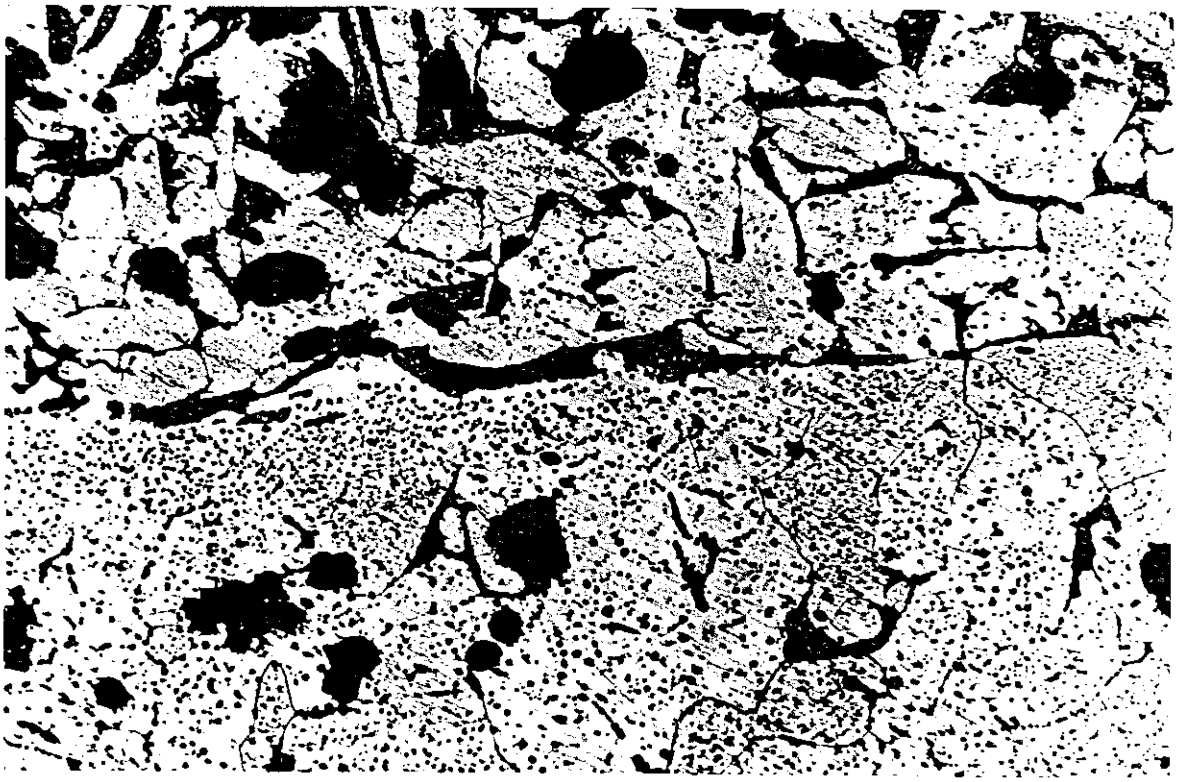

Plate 5 Micrograph of etched (2% nital) Catterick beam. x60
Weld line, distinguished by the higher carbon content of the upper component.

Acknowledgments

Many thanks to the many individuals in numerous institutions who responded to my requests to search memories, archives and databases to bring to the surface information on the beam from Catterick beam and those in other collections:

Jake Almond, Historical Metallurgy Society
Sally Bell, British Steel, Teeside Technology Centre Library
Richard Brewer, Brecon Museum
T. Gordon Brown, University of Sheffield, Engineering Materials
Richard Clark, Jewry Wall Museum
Ralph Jackson, British Museum, Department of Prehistoric and Romano British Antiquities
Maureen Johnston, Institute of Materials
Duncan MacCallum, British Steel, Teeside
Bill Manning, University of Wales
Georgina Plowright, Hadrians Wall Museums, English Heritage
Mark Redknapp, National Museum of Wales
Diana Tapley and John Powell, Ironbridge Gorge Museum Trust
David Thorold, Verulamium Museum

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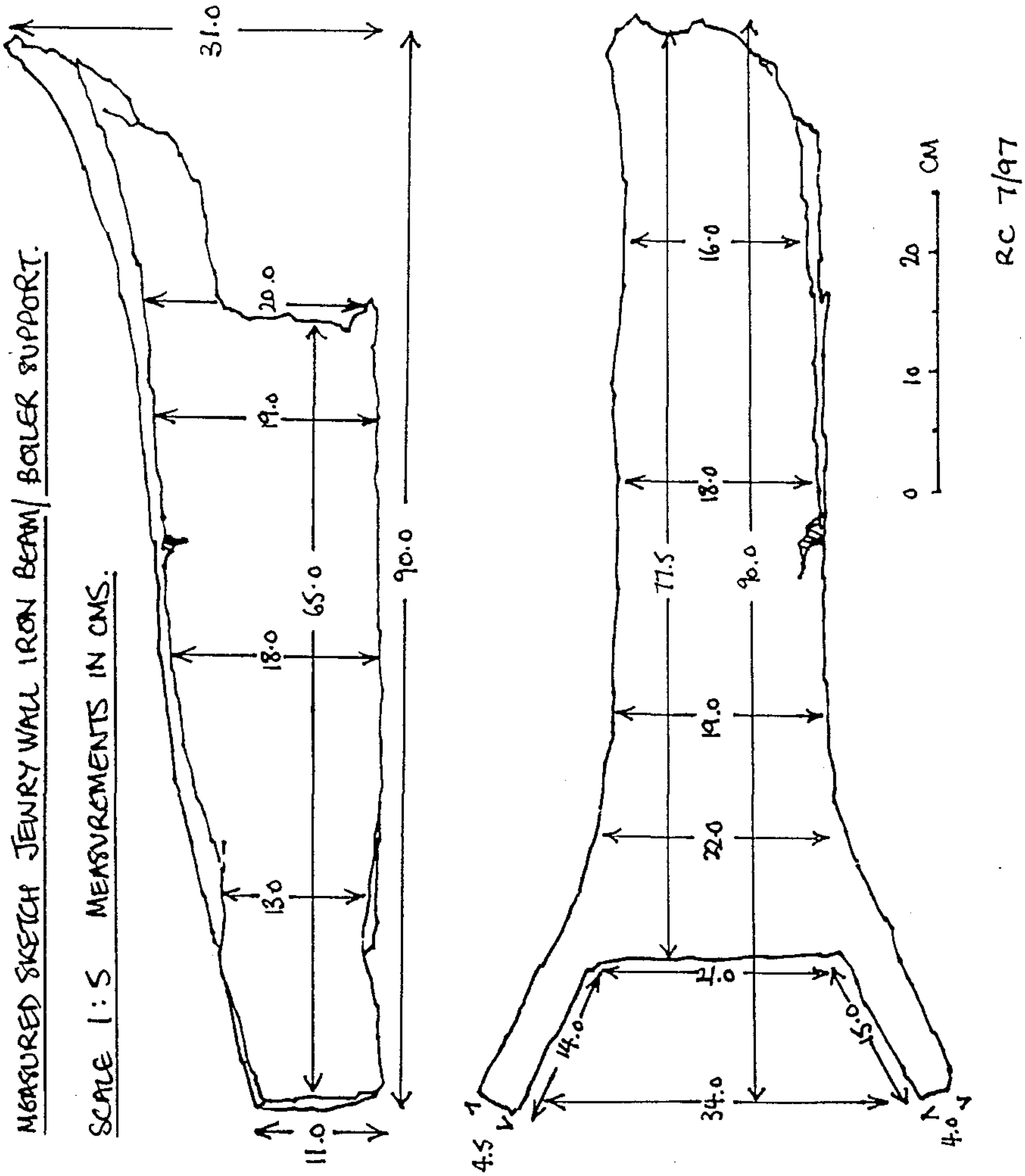
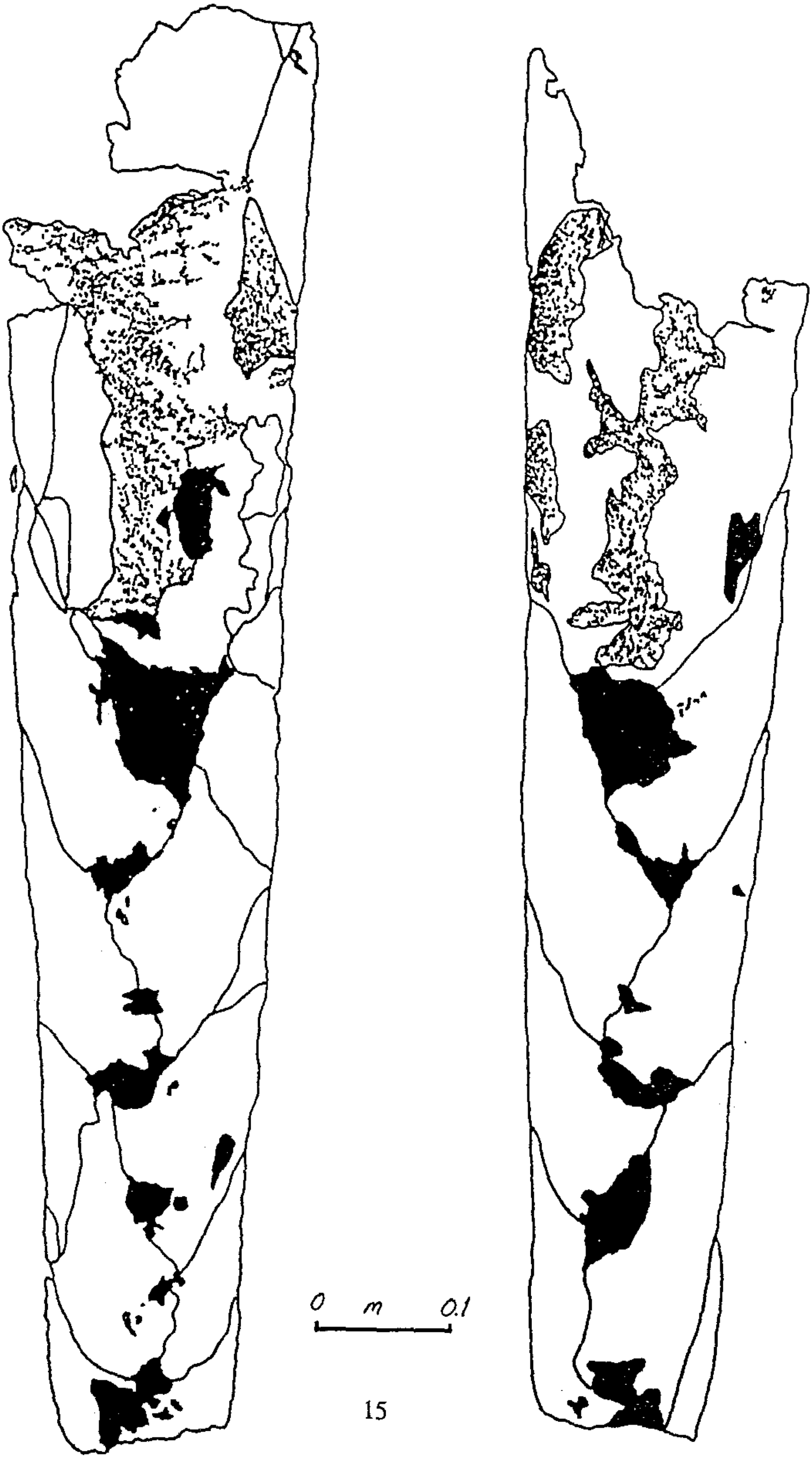
Appendix 1 Dimensions of Jewry Wall site forked beam



Appendix 2 Schematic diagram of Corbridge beam sections showing position of weld lines (after Stead 1912)



Appendix 3 Inventory of beam fragments from Saalburg (after Baatz 1991)

No	Description	Weight (kg)	Length (m)	Cross section (cm)	Saalburg code No.
1	Balkenende (end of straight beam)	99	0.75	16x16-14.5x14.5	S 109a
2	Gabelkopf (top of forked beam)	140	0.92	17x18- 6x18	S 1111
3	Gabelkopf (top of forked beam)	70	0.40	16x17-5.5x16	S 1114
4	Gabelkopf (top of forked beam)	21	0.26	15x?-15x4.5	S 009
5	Fußstück (foot of beam)	132	0.80	16x17-17x26	S 1109b
6	Fußstück (foot of beam)	128	0.89	16x16-16x27	S 1110
7	Fußstück (foot of beam)	69	0.39	18x18-18x27	S 1112
8	Fußstück (foot of beam)	12	0.22		S 012
9	Fußstück (foot of beam)	76	0.40	17.5-17.5	S 1113
10	Bruchstück (fragment)	48	0.53	18x?	S 002
11	Bruchstück (fragment)	42	0.50	19x?	S 002
12	Bruchstück (fragment)	30	0.42	18x?	S 003
13	Bruchstück (fragment)	49	0.52	18x19	S 004
14	Bruchstück (fragment)	37	0.37	21x?	S 005
15	Bruchstück (fragment)	32	0.32	23x?	S 006
16	Bruchstück (fragment)	37	0.57	-	S 007
17	Bruchstück (fragment)	23	0.44	14x15(?)	S 008
18	Bruchstück (fragment)	12	0.36	-	S 010
19	Bruchstück (fragment)	8	0.21	-	S 011
20	Bruchstück (fragment)	33	0.43	13.5x13.5	S 013
21	Bruchstück (fragment)	18	0.28	-	S 014
22	Bruchstück (fragment)	24	0.24	16x?	S 015
23	Bruchstück (fragment)	15	0.31	-	S 016
24	Bruchstück (fragment)	18	0.26		S 017
25	Bruchstück (fragment)	11	0.22		S 018
26	Bruchstück (fragment)	12	0.18		S 019
27	Bruchstück (fragment)	7	0.27		S 020
28	Bruchstück (fragment)	6	0.32		S 021
29	Bruchstück (fragment)	6	0.31		S 022
30	Bruchstück (fragment)	14	0.24		S 023
31	Bruchstück (fragment)	6	0.25		S 024
32	Bruchstück (fragment)	6	0.26		S 025
33	Bruchstück (fragment)	5	0.22		S 026
34	Bruchstück (fragment)	5	0.21		S 027
35	Bruchstück (fragment)	4	0.20		S 028
36	Bruchstück (fragment)	3	0.14		S 029
37	Bruchstück (fragment)	4	0.18		S 030
38	Bruchstück (fragment)	3	0.20		S 031
39	Bruchstück (fragment)	2	0.20		S 032
40	Bruchstück (fragment)	1	0.12		S 033
41	Bruchstück (fragment)	1	0.10		S 034
42	Bruchstück (fragment)	1	0.11		S 035
43	Bruchstück (fragment)	1	0.09		S 036