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Sidney Gilchrist Thomas

From an unfinished crayon drawing in the National Portrait Gallery

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Contents

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17th century ironmaking in south west Herefordshire

John van Laun

SUMMARY

Plentiful supplies of charcoal and abundant water for power lead to the establishment of a thriving iron industry in south west Herefordshire during the 17th century. Generally one furnace at St Weonards supplied three forges and in spite of distances up to13 miles separating the two processes much of the complex survived well into the 18th century.

For some time the complex formed part of the Foley Empire and reworking of Foley Family Papers give hints into the technology, production and costs involved at the time.

Little remains on the ground today of the furnaces or forges but an attempt is made to interpret the archaeology.

In South West Herefordshire lay an interesting ironmaking complex comprising the charcoal furnace at St Weonards and the forges at Llancillo, Pontrilas and Peterchurch. For much of their working lives the forges were dependent on St Weonards for sow or pig iron to work into bar or malleable iron. This was of course before the days of the coke fired furnace and Cort's puddling process.[1]

More unlikely places for heavy industry would appear to be difficult to find, but at the time, these were probably ideal situations. With an abundant source of wood for charcoal, and the heavy rainfall of the Black Mountains providing the rivers to supply the necessary power. Distance does not seem, surprisingly enough, to have concerned the early industrialist. St Weonards was a minimum of 6 miles from its nearest source of ore or cinder. Pontrilas Forge is 6 miles from St Weonards, Llancillo 8 miles and Peterchurch 13 miles. Glass was made at St Weonards between 1580 – 1620[2] and it is tempting to suggest that ironmaking followed glass-working. Certainly what attracted glassworkers to the place, namely the availability of charcoal, would also attract iron-smelters.

It is possible that the St Weonards Furnace was established by the Civil War. A delightful story recounted by Webb[3] describes a group of recruits ascending Llancloudy Hill to the south of St Weonards, in 1643, and being surprised by what they thought to be the enemy. It turned out to be a gang of carriers horses making for the woods for charcoal, presumably for the furnace. Webb[3a] also refers to a recollection of Mary Howells, who at the age of eighty six in 1834, remembers her great Aunt tell that her father Richard Kemble[4] was Clerk to Llancillo forge as well as St Weonards Furnace, at the time of the plundering by the Scots during the Civil War. In any case St Weonards Furnace is known to have been in existence by 1661 when it was leased to William Hall.[5]

Pontrilas Forge was established by the first quarter of the seventeenth century. On 9 April 1623 it was leased to Benedict Hall[6] by James and Walter Baskerville for twelve years at an annual rent of £60 –

'one Iron Mill or Ironwork called Pontrylas Fordge with all houses, buildings etc. and all manner of earth, turf and clay to be taken in and all lands and soil of the said James and Walter called Bradleyes leasowe or the Forge Leasowe or meadow for carriage of coall, wood Etc'[7]

An agreement of 12 March 1666[8] refers to an 'Ancient iron fforge called Pontrilas Fforge' (Because of its interest and illustration of the fierce competition for water rights this is reproduced as Appendix I and examined under Archaeology). At that time it was owned by Humphry Baskerville but still leased by an agreement of 25 July 1664 to Benedict Hall (the father of William, who inherited the agreement) for twenty one years. Llancillo Forge was leased to John Scudamore[9] by Thomas Cavendish of Madley and his wife Amy on 20 September 1637 for a term of three years at a Peppercorn rent. It is described at that time as an 'Ironworks or forge commonly knowne and called Llansillo forge'. The works consisted of weirs , ponds, dams, watercourses, houses, buildings and the lease gives the impression of a well established works.

In 1672 Paul Foley (1650–99) of Stoke Edith, Herefordshire, purchased the 'whole of the material of Kings Works'[10] in the Forest of Dean. This was to establish a new order in the organisation of ironmaking in Gloucestershire, Worcestershire, Staffordshire and Herefordshire. At about the same time he acquired a one half interest in the complex[11] comprising St Weonards Furnace and the three forges with William Hall. All the forges had been previously acquired by Hall, by lease or purchase.

On 1 March 1671 a lease was concluded between Robert Mynors[12] on the one part and William Hal and Paul Foley on the other. The partners would rent the 'ffurnace for the roasting or blowing of iron with the appurtenances' and water courses from 29 September 1671 for twenty one years for an annual payment of £70. The 8 March 1671[13] saw Henry Glover (? – 1689) (Paul's uncle) negotiating with Hall for the complex, which culminated in the formal agreement between Paul Foley and William Hall on 26 March 1672. The furnace at St Weonards and the forges at Llancillo and Pontrilas would be operated by Paul until the expiry of the existing leases and Hall's forge at Peterchurch (where he resided) would be leased to Paul for £20 per annum. A valuation was to be made of raw materials and iron extant at the time.

Charcoal at St Weonards was valued high at 30/– a load, at Peterchurch it was 20/– a load and Pontrilas and Llancillo 24/– a load (Brayses[14] was 4/– a load less to all places). Pig iron was valued at £6.10.0d a ton. The products of the complex were to be divided into equal shares after Paul had received 6 per cent of anything produced, he was to maintain two copies of detailed accounts for the partnership. Paul Foley was therefore bringing expertise to the concern and Hall the plant. If insufficient pigs were forthcoming from St Weonards then they were to be supplied from Redbrook in the first place and Bishopswood in the second.

A separate agreement for Llancillo forge was made between the owner John Scudamore and Paul Foley on 1st November

1672 at a rental of £55 per annum, and on 30 March 1673[15] it was agreed to extend the lease of a further ten years for this forge because of the great expense incurred by Paul in 'rebuilding of the said fforge fore bayes floodgates weirs or dams . . . also of making a new watercourse to the said fforge' (see Section on Archaeology).

A clause in the agreement gives an interesting side light into the state of roads at the time

> 'In case the Comon high way in the Parish of Langua shall during the said terme be much in decay that the said John Scudamore . . . will . . . at his owne proper costs and charges allow and gett out a good sufficient necessary and convenient way to the said fforge . . . for all horses waynes carts waggons and all other carriages'.

It is known that Paul Foley was in debt to his father Thomas (1617–77) for £60,000 and,as a means of repaying this, Thomas seems to have received a share of the works' profit.[16] (Account showing debts of Paul Foley to Thomas Foley. Pauls interest in stocks and debts at Pontrilas and Peterchurch is shown as £5,392.7.3½d on 25 March 1673).

By 1674 a situation had developed between Paul and his younger brother Philip (1653–1716) which demanded some rationalisation. Their father had divided his estate in such a way that Paul would control the furnaces of the Forest of Dean and Philip, the forges of the Stour Valley. The Forest furnaces provided 'tough iron' needed by Philip and, in spite of some pig iron production of his own, he was forced to buy from his brother. Both brothers had expanded their undertakings so that some form of trading agreement became essential. An agreement therefore took place in 1674 whereby Philip would be admitted to a third share in his brother's Forest works, including the St Weonards complex, in return for a guaranteed market for Paul's Forest pigs.[17] It was further agreed that they would jointly buy out William Hall but the agreement of 1672 seems to have been allowed to stay in operation.

Returns for 1677-8 exist for the complex[18] and, although no iron was made at St Weonards, there were deliveries to two of the subsidiary forges between 25 December 1677 and 28 March 1678 of sow iron and a credit for charcoal delivered to them (see under Production and Technology). The value of iron sent by all three forges to Monmouth storehouse in this year was £3,166.10.0d at £14.10.0d a ton – a total of 218 tons sent out of the 290 produced. Much of this finished iron made its way from Monmouth storehouse to Bristol.

In a letter dated 6 June 1678 referred to by Dr Schaffer, Paul wrote to Philip that 'after a short blast at St Weonards that furnace and its associated forges could be retired whenever Philip wished'. This was followed in 1683 by a draft agreement[19] by which Paul Foley would hand back to William Hall and his brother the forges of Llancillo and Pontrilas. Whether in fact this agreement was ratified cannot be ascertained. However it would seem that the complex was outside the 'Ironworks in Partnership' of 1692[20]. In this partnership John Wheeler was made 'Cashkeeper and Chiefe Agent' to the concern (equivalent to Managing Director).

St Weonards was blown out and Peterchurch and Llancillo continued to function drawing pig iron from Bishopswood or Redbrook furnaces. In 1700 Nathaniel Morgan of Llancillo received 93 tons from Bishopswood and 85 tons from Redbrook at £6.2.6d and he received a further 120 tons in 1701 from the latter. In 1704 William Hall at Peterchurch took 30 tons from Bishopswood and 20 tons from Redbrook and in 1705 a combined total of 50 tons from the two forest furnaces. The shortage of locally produced pigs for the two surviving forges led, no doubt, to the blowing in of St Weonards Furnace.[21]

On 2 July 1706 John Wheeler and another Foley partner, Richard Avenant, concluded a lease with Robert Mynors for St Weonards[22] for a term of twenty one years at £70 per annum, backdated to September 1705. Both had left the Foley partnership for a time, but in a campaign from 13 June to 8 August 1706, the furnace had produced 80 tons for the Partnership.[23] Perhaps the acquisition of St Weonards Furnace was a successful attempt to be re-admitted to the Partnership. The forges stayed outside the Partnership although Llancillo under Nathaniel Morgan was involved with St Weonards, taking 180 tons of pig iron in 1707-8 out of a total cast of 243 tons. From 1717-25 the furnace does not appear to have been part of the Partnership and in 1720 William Rea attributed the rebuilding of the furnace to himself (see Archaeology). Under the 1692 Iron Works in Partnership, William Rea[24] had entered the scene. Rising to become a partner in 1704 he succeeded John Wheeler as Managing Director, by 1710-11 he owned two and half shares out of the twenty five in the Partnership. He is generally referred to as of Monmouth where he later owned the forge.[25]

St Weonards and Llancillo were again associated with each other during this period. Llancillo taking 126 and 121 tons of pig during 1721-2, and 1722-3 respectively, the furnace having been put into blast shortly after the 1720 rebuilding. During the period 1723 to 6 June 1725 there was very careful monitoring of the production at Llancillo, but no monetary value is available for these quantities.[26]

This careful monitoring was in preparation for the re-admission of Llancillo into theFoley Partnership in 1725. An inventory of 1723 (see below) suggests that the forge until then had been operated by Nathaniel Morgan. 'Barr Iron at fforge greatest part of it being old stock had from Mr. Natt. Morgan'.[27]

Over this period the furnace continued to be leased to Wheeler and Avenant in spite of Rea's claim, because on 26 April 1726 it was leased by Robert Mynors to Thomas Foley (son of Paul) for twenty one years at the usual £70 rental.[28] In this agreement it is referred to as lately held by Wheeler and Avenant (presumably under the agreement of 1706). Production continued at the furnace until 1731. By 1732-3 the stock at the furnace was only 3 tons 19 cwts and this was so until 1736-7 when 7 cwt was sold.[29] From then no mention is made of St Weonards, the furnace having been blown out in 1730-1 and disposed of by 1736-7.

Peterchurch continued under the Hall s and occasionally traded with the Partnership. Peterchurch and Strangeworth, four miles west of Pembridge (SO 345 592) 'were linked through the name of Thomas Jukes, probably a Stour Valley man, who bought his pig iron from Bishopswood and Elmbridge'.[30] It may have continued up to 1736 although it was not in production at the time.[31] Pontrilas, because of its relatively isolated situation disappeared early on, probably around 1700, although mentioned in 1695 along with the rest of the complex.[32]

Llancillo was in a better situation to withstand the changes in technology that were about to take place. After 1725, being re-admitted to the Partnership, it received most of its iron from St Weonards, but also received small amounts of 'cold short' iron from Hanbury's furnace at Llanelly, Breconshire, (SO 231138) for blending, no doubt with the 'tough iron' of the forest. From 1725-7 it received totals of 20 tons from Llanelly and 38 tons from St Weonards.[33] After the closure of St Weonards, Llancillo forge must have drawn pig iron increasingly from South Wales, and as late as 1807, Luther Barnaby is referred to as of 'Llancillo forge',[34] and Duncumb writing before 1812[35] describes it as 'lately been destroyed'.

TECHNOLOGY AND PRODUCTION

The Furnace

The technology of the charcoal blast furnace has been dealt with elsewhere[36] but it is worth observing that the St Weonards furnace was probably built square in section internally and would have been similar to the Parkend Furnace[37] near Lydney, Gloucester. It is possible that the first round section furnace was built c.1652[38] but this was no doubt exceptional. St Weonards furnace was rebuilt in 1720 by William Rea (see under Archaeology) and it is fair to assume that by then it would have been rebuilt with a round section.

The situation of St Weonards was dictated by the large requirements of furnaces of the period, for charcoal.

> 'A charcoal furnace will consume from twenty-five to thirty thousand sacks in a year, each containing eleven to twelve bushels charcoal, the produce of at least one hundred and twenty acres of woodland. If the wood replaces itself fully in twenty years, then twenty-four hundred acres of land would be necessary to keep such a furnace at work'.[39]

The site was also fairly near to the Forest of Dean with its source of ore for making 'tough iron'. The accounts for the period 25 December 1677 to 28 March 1678 show 330 dozen bushels of 'Myne' (ie. ore) remaining and 130 dozen bushels of cinder (slag). The cinder left over from the bloomery era could have been obtained from near Monmouth or Whitchurch, 6 miles away[40] and would have required comparatively little ore to work into pig iron.

Production does not appear to be as high as that recorded for some earlier furnaces.[41] The initial eight weeks campaign of 1706 produced under 1½ tons each 24 hours, and an eighteen weeks period in 1707-8 yielded under 2 tons each 24 hours.[42] In 1707-8 2 loads 4½ sack of charcoal, 1 dozen bushels of ore and 2 dozen and 2 bushels of cinder was required to produce 1 ton of iron. The use of a flux is only mentioned in the accounts of 1728 and 1729 – 'flux mine' 550 dozens and 154 dozens respectively at 7/– a dozen.

In 1714-15, 2 loads 1 sack of charcoal, 2 dozen and 2½ bushels of cinder, and 1 dozen and 5 bushels of ore for a ton of iron. Most of this was cast into pigs but 3 tons in 1714-15 were 'Plates', 'Pallisades', 'Bowkes'.

Organisation at the Furnace

Fillers and furnace keepers (1727-8)[43] were paid £11.5.4d for the year. The cinders brought to the furnace needed cleaning and this cost £2.12.6d. There were separate coal baskets and mine (ore) (1725-7) baskets for carrying to the furnace and three ladders were required to heap the 'coles' which were supported from the ground by six horses.[44] To ensure the correct measure for cinders there was a 'cinder bushel' (1725-7). For replacing the hearthstone there were '2 roles' [wheels] and a 'Carriage to bring the hearth in'. The inventory of 1723 shows '3 Cast [fire] backs in Workmens houses' presumably 3 separate houses.

A number of other employees give further clues to organisation. Four colliers (for coaling wood). Ten carriers were paid from under £2 to over £12 per annum. Founders worked in the pig beds and repaired the hearth.

By 1731-2 there were no recorded expenses connected with the furnace, although it remained in the partnership for a few years longer.

The Forge

Two main types of pig iron were produced in Britain towards the close of the charcoal iron era – 'tough' pig iron produced from high grade non-phosphoric ores such as those found in the Forest of Dean and 'coldshort' iron produced from ores found in the coal measures of South Wales and the Weald. The former could be worked into the highest grade-merchant bar whilst the latter worked into an inferior and brittle metal but much in demand by nailmakers. The more malleable iron obtained from the Forest ores could be blended with those from the Coal Measures to make an intermediate quality known as 'best mill'.

The working of the pig iron from St Weonards would have taken place at 'the forge'. Here the carbon would have been burnt out in a charcoal fired finery by air was played onto the metal. The 'bloom' would then have been hammered under a water powered hammer and finally re-heated in the chafery and hammered into the shape finally required, normally bars. The iron produced at the three forges was of merchant quality and would have required charcoal as a fuel. As late as 1725-7 when coldshort iron was being used, Llancillo was still using charcoal to make 'best mill' iron.[45]

Within the relevant accounts and inventories a number of forge items are referred to, and an explanation of some of these follows based (in the main) upon H R Schubert, 'History of the British Iron and Steel Industry'.

The finery furnace (Fig 1) was constructed from a number of plates. At the bottom of the furnace was the *bottom plate* (terms in italics are mentioned under 'Technology at the Forge'). The *Tuyere Plate* was at the side through which the blast was introduced. Opposite the tuyere was the *fore spirit plate* which received the blast from the tuyere. Two other vertical plates completed the rectangular shape of the furnace. The *fore plate* over which the finer worked and the *hare plate* opposite. In the finery the pig was slid into the hearth over the hare plate, normally another hare plate rested on this to serve as a platform for the pig. The whole furnace was surmounted by a chimney stack and as the furnace was open on two sides this was supported by iron lintels termed. *morrisbars*. The chafery was larger and deeper than the finery. There was probably no second hareplate but there was a large plate resting on the wall opposite the tuyere plate the *Great plate in ye wall* of the 1723 Inventory. The 'bloom' or 'loop' was taken to the hammer over an iron floor, *loop plates* forming the way.

At the start of a make the hearth was lined with charcoal dust obtained by using *riddles*.

The foregemen (finers, hammermen etc) were paid by production although they may have received other small perquisites. In 1677[51] fining at Llancillo cost 8/6d a ton with hammering and drawing charged at 7/6d. At Pontrilas the 'forgemen' were paid 16/– a ton. Special iron such as

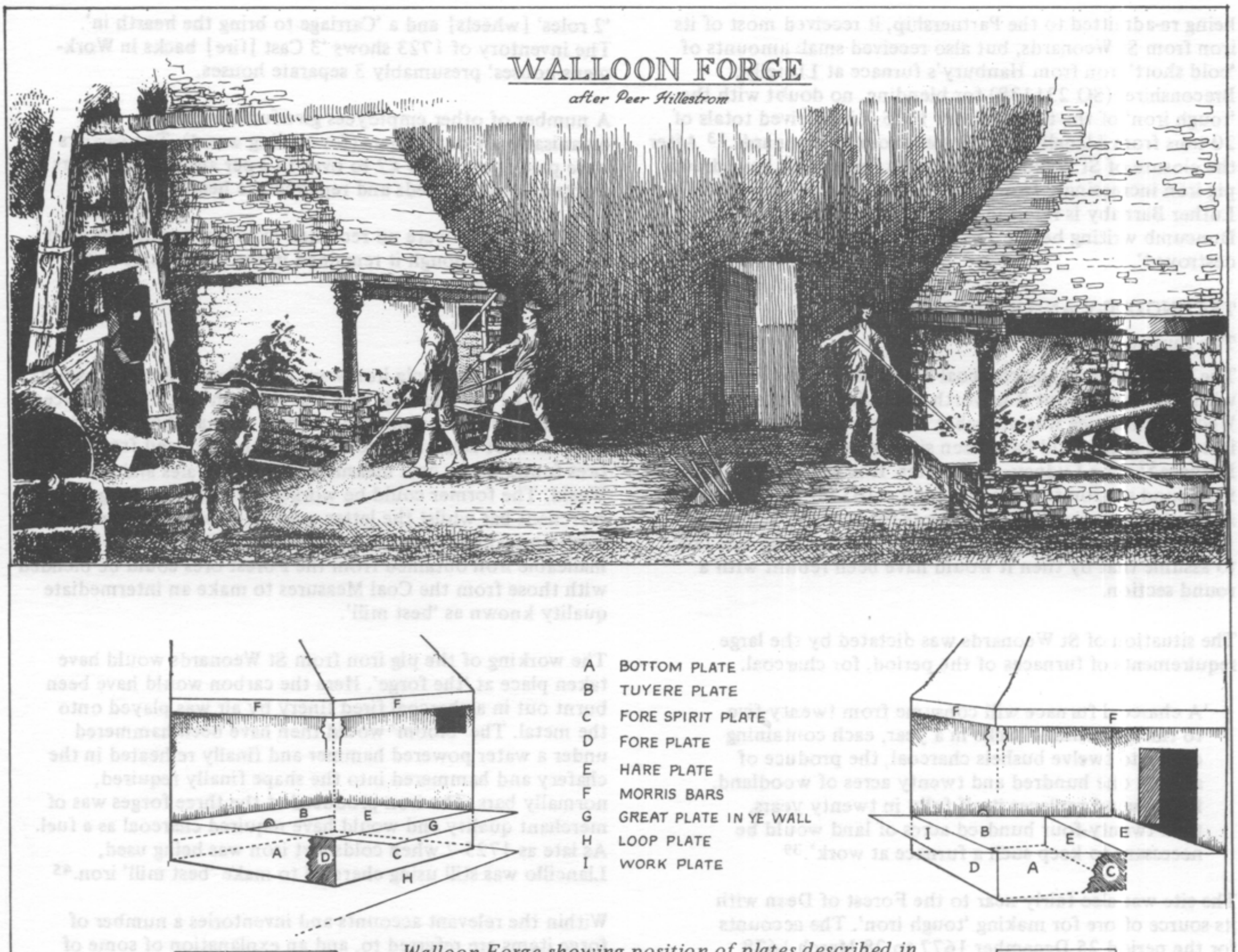


Fig I *Walloon Forge showing position of plates described in inventories (after Peter Hillestrom)*

'Osmund' cost £1.3.4d for just over a ton.[52] At Peterchurch, Hall charged 19/ a ton inclusive of administrative and other costs (see below). There was sometimes an increase in the yield from the hammer. In 1677 (Llancillo) 2½ tons onto 147 tons and in 1727–8, 4 tons onto 134 tons.[53] How this was arrived at is not clear.

The costs referred to above excluded the raw materials. Sow iron in 1677-8 came mainly from St Weonards. In the case of Llancillo (104 tons to help make 149 tons) and Pontrilas (66 tons to help make 88 tons). Peterchurch for that year relied entirely on its reserves to produce 53 tons. Iron varied in cost at the forge from £6.16.0d (Pontrilas) to £7.3.0d (Peterchurch). It required 25 cwts of sow iron to make a ton of bar iron at Llancillo and Pontrilas, and 27 cwts at Peterchurch in this period.

In the same years charcoal was around 23/– a load and in the case of Llancillo and Pontrilas, the supply of it is credited to St Weonards Furnace. In practice it came from Parry's Wood at Dulas (238 loads 10 sacks to Pontrilas and 239 loads 9 sacks to Llancillo). The balance used coming from William's Wood at Old Court in the case of Pontrilas (39 loads) and in the case of Llancillo mostly from William's (143 loads). At this time it required 2 loads 7 sacks to make a ton of bar iron at Llancillo and Pontrilas.

At this time 'Comon Charges' at Llancillo (including fining etc) came to £406 (£3.50 a ton).[54] At Pontrilas they came to £231 (£2.60 a ton). At Peterchurch which was operated for the Partnership by William Hall it is more difficult to arrive at operating costs per ton as charcoal is included in these charges. He was allowed £214 for 'charcoal and brayser' and administrative charges bringing his total charge to £296 (£8.66).

In 1677–8 final production costs at the forges were for Llancillo approximately £15.00 a ton, Pontrilas £14.13 and Peterchurch £17.95. Most of the iron produced at Llancillo and Pontrilas was sent to Monmouth Storehouse which was run by the Partnership, 137 tons from Llancillo, 77 tons from Pontrilas but only 3 tons from Peterchurch. At Monmouth irrespective of where the iron came from it was valued at £14.10.0d a ton. Iron sold off locally as at Peterchurch fetched between £13 and £18.13.4d a ton.

Transport costs were a major item of expense. Bar iron from Peterchurch to Monmouth cost 18/– a ton, but from Pontrilas it was between 10/– and 12/– and 12/– and 13/– from Llancillo. Much iron found its way to Bristol from Monmouth. Transport of 113 tons of Llancillo's iron cost approximately 5/– a ton to ship including handling charges. The different costs in land and water transport is well demonstrated by this. At one time in the period before 1663, a ton of Bar iron cost £11.16.5½d[55] to produce at Pontrilas. The selling price at Bristol was £13.10.0d allowing a profit of £1.13.6½d. Production at this time was expected to be 160 tons per annum. Sow iron was £4.10.0d a ton at 'Mr Kyres furness' with transport costs of 12/– a ton. 3 loads of charcoal at 14/3d were needed to make a ton of bar iron. The forgemen were paid 18/- a ton. Included in the costs is a proportion of the rent which was £80 per annum.

In the later period production was not dissimilar to that of the 1660's. In 1723–4 at Llancillo it took 2 loads of coal and 1 of brayses plus 27 cwts of pig iron to produce 1 ton of bar iron. A load of bray or brayses was used to approximately 8 sacks of charcoal and was used to line the sides of the finery hearth at the beginning of a heat.

Organisation at the Forge

In 1677 the management of the forges was, in the case of Llancillo and Pontrilas, in the hands of Charles Walvin for which he was paid £30 per annum. Nathaniel Morgan assisted him at Llancillo for his 'wage' of £23.6.0d. The Finer received £4 per annum and the Hammerman the same (Peterchurch). They each received a coat (value 10/–) at Llancillo but at Peterchurch they received a combined allowance of £1 for mending tools. At Pontrilas the Finer received a coat valued at 20/–, the Hammerman one valued at 10/–. The wages and perquisites received were not the only remuneration. At Pontrilas 'the forgemen' were paid 16/– a ton as mentioned above.

One ream of paper and ink were purchased for the stock-taker (Llancillo) who was paid 4/– a week for fifty two weeks for taking in stock. He seems also to have doubled as the carpenter and was entitled to a coat worth 15/–.

Heating for the work force was provided by the management 'All fyer for Clarkes and workmen' (Peterchurch). 'Ffuell viz. 9T of Stone Cole' (Pontrilas).

Peterchurch was entirely under the management of William Hall. He was credited for his services and debited with iron sold to him. He made his own arrangements for the provision of charcoal and it is not clear whether or not he received iron from St Weonards. Whereas the other forges sent the bulk of their iron to Monmouth, Hall sold most of his locally and only the remainder was sent to Monmouth.

Raw materials as well as the finished products were very carefully controlled with regard to weight and security. Sow iron and finished iron were weighed in tons/cwts/qts/lbs. Charcoal measured in loads and sacks (twelve to the load). Myne (ore) and cinders in dozens of bushels and bushels (sometimes 13 to a dozen). An 'Iron Beam', and Scales with chains' was to be found at all the forges and 'Sow Iron – on the pigg scales value 5 cwt at 1.16.0' shows a different accuracy for pig iron (Peterchurch). At Llancillo were four half-hundred weights fitted with lead and rings valued at 7/–.

The corder at Llancillo was paid £2 per annum for cutting the wood which was extra to his normal work. In one part of the works at Llancillo there was a problem with rats, as 'killing vermin in the Bay' at a cost of 4/– indicates.

Organisation for the later period is only available for Llancillo but shows very similar arrangements. In 1729-30 William Russell was paid £4.13.9d for producing 75 tons of 'anchonys' and John Maybury £5.12.6d for drawing them out. Thomas Powell, the stocktaker, was housed on the premises and he received £20.16.0d for the year. There were four colliers (charcoal burners) and fourteen carriers. The method of weighing is shown by the use of 'Pig beam & 10 wts' and one small beam and scales with "four and a half hundred" weights, thirteen "quarter weights" and sixteen "pound weights" with a total value of £1.12.0d.

Technology at the Forges

The layout of a seventeenth century forge is demonstrated by a plan of 1666–7 of Pontrilas Forge[56] (Fig. 2) lying at the confluence of the River Dore and Monnow. The works are served by a leat from the Dore (shown as 'Worme' on the plan) which feeds a large forge pond. A dam and cutwater direct the water into either the finery ditch or hammer ditch with the forge building between the two. At this time the axle for driving the hammer is shown crossing the hammer ditch. Both ditches discharge into the Monnow. No chafery is shown and it is likely that only 'anconies' were being produced at this time although by 1677-8 a chafery was in operation. A 'Coale hous' and 'Coale yard' take up a large part of the works to the west of the finery ditch. To the east is a storehouse and stable adjoining and slightly removed from the works area, three workmen's houses. The 'Clarkes Hous' is palatial by comparison, with a lean-to dairy and cellar beneath.

An inventory for Llancillo of the mid-seventeenth century[57] provides an insight into the technology at this period (see Section on the Forge).

'A true and perfect Note and Scedule of the Materialls instruments and implements which remayne within the Iron works or Forge of Llancillo or belong thereunto, vizt.
Imprimis [?one] hamer beame & hamer wheels
Item s [?ix] iron hoops upon the said beame
Item two iron gudgings in the ends of the said beame
Item one droome beame
Item one cheape sill
Item one popett & one doge
Item one rabbett
Item two leggs
Item two plumer blocks
Item two fynery chymneys two finery wheels
& two troughes thereto belonging
Item one chafery
Item one chafery chymney with one barr of
iron in the chmney & one chafery trough
Item one chafery wheele
Item one shaft with two iron wheeps upon it
Item two gudgings in the ends of the said shaft
Item one payre of bellows'

There were then two finerys and one chafery as well as a hammer. This arrangement was the case at the other two forges as appears in the accounts for 1677–8. At Llancillo each item of equipment was driven by its own waterwheel which was fed by a launder in the case of the fineries.

The Accounts for 1677–8 give further details of all the forges of which the following is a summary.

The bellows to each were arranged in pairs, collectively worth £8 or £9. Maintenance on these required 'Hydes' with grease and tallow to keep them supple, which were kept nearby in a grease tub because of frequent use. Bellows 'bords' of wood provided the upper nd lower parts. Two bellows pipes (Llancillo) took air to finery or chafery tuyeres. The nailer for the bellows was paid 16/2d (Llancillo). Tinplate may

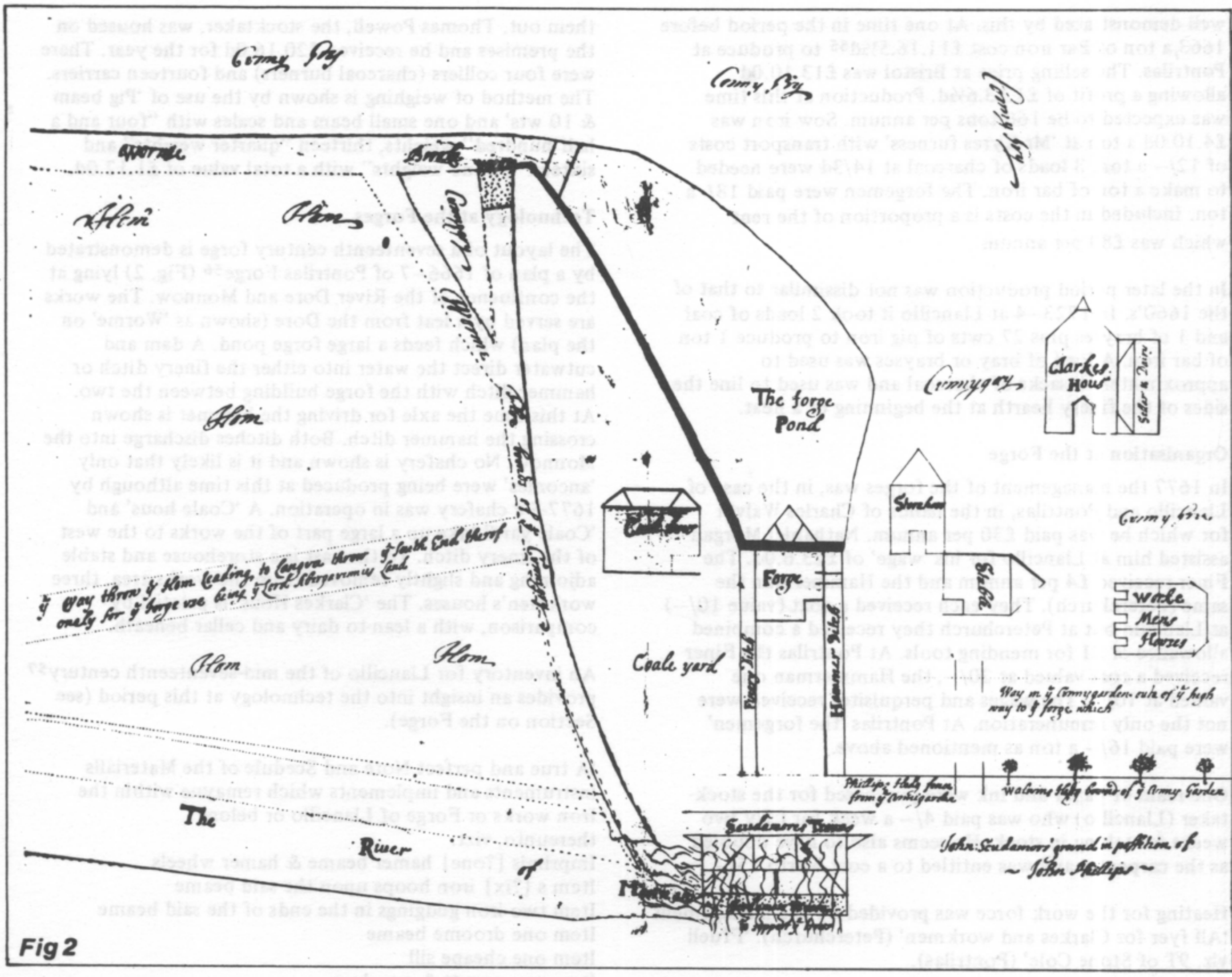


Fig 2

Pontrilas Forge in 1666 (Reproduced by permission of the National Library of Wales).

have also been used in the bellows, as '10 sheet Tynnplate 5/– and meale 11½', (Llancillo) appears with items of bellows maintenance. The chafery bellows were larger than those in the fineries (9 ft 9 ins by 2 ft 2 ins and 6 ft 10 ins by 2 ft 5 ins) and this is born out by maintenance costs of 4/– for the chafery and 3/4d for the finery.

Finery construction was of the traditional type 'making 2 Morrisbars 3/2d.' 'Laying a fin y gudgon 3/2' points to maintenance on a wheel driving the bellows to the finery. The weight of iron contained in a furnace is shown by the following 'Rec an old ffurnace from Mr Baskerville formly bought 8 cwt' (Pontrilas).

Sacks were used for carrying charcoal to the forge '2 pieces of sackcloth and Car [riage] there £3.7.4'. (These were normally without handles as 'Cole sacks [with] carrying handles' (Llancillo) are especially mentioned). 'Making and mending sacks & for Twyne 12/5' (Llancillo) 'Mending 20 sacks to carry coles to the ffurnace' (Peterchurch). At the finery baskets were used, and sieves and rakes to supply the materials to the furnace '2 rakes, 1 wheelbarrow, 2 ladders & 3 cole baskets' (Pontrilas). 'At the furnace 7 baskets, 2 riddles and chalke' (Llancillo) the last item, no doubt, for keeping a tally of materials used. 'Cole baskets 3 old ones, 2 cole rakes' (Peterchurch).

The hammer was a frequently mentioned item for maintenance. '2 hoopes on the Ham Beam 2 Collers & Bray on the helve and 2 hoopes on the Anvill Block besides what are to bee left' (Pontrilas), or 'ii helves and 12 pairs of arms & i Dayes Sawing [£4.4.9]' and a reference to iron 'hursts' weighing 6 cwt brought from Pontrilas for 9d. The hammers were equipped with 'rabbets' (Llancillo & Pontrilas) to send the hammers down onto the workpiece with increased force. At Llancillo were 'Crooks for a Ham Wheele' worth 10/–.

Other items of maintenance for the year include the weir and buildings. An indication of the type of building is suggested in the following 'mending [a] Bay & Tyling the Storehouse & for Lyme & Hayre for them' (Llancillo) demonstrates a stone roofed half timbered construction.

Forest iron was unsuitable for forge hammers and anvils being too pliable. These were imported to many forges in the Forest of Dean from Hales Furnace in the Stour Valley[58]. The three forges were no exception as the accounts 1677–8 show, Llancillo and Pontrilas received from Tintorne(sic) 'Hales Hams' weighing 1 ton 5 cwt plus. Peterchurch received a slightly greater weight (1 ton 9 cwt). This is shown to have been carried from Monmouth at 20/– per ton and from Tintern to Monmouth for only 6/–, by river.

Technology at the forge in the 1720's was similar to the earlier periods as it domonstrated by 'An inventory of Stock left at Llancillo fforge' dated 14 October 1723 from which comes the following extract

	T C Q lbs
Working Tools	00. 09. 2. 00
2 Cast Plumer blocks 0.10.0.0.00	
3 New hammers	
17 Old hammers	
7 Anvils	
1 Smiths Anvil	
4 Hursts	
6 Boyts	
5 Hammer Gudgeons	
5 Hammer Braysers [brasers]	
4 Ffinery do in work	Pigg beam & Scales
4 Gudgeons D^{to}	and wtc 10C
2 Chaffery Brasses	Iron beam & scales
2 D^{to} Gudgeons	Wts 2C 2q
In Chaffery Plates	Timber left
1 fforeplate 1 ffore Spirit	1 New hammer beam
1 Hare 1 Tuironplate	a new hutch for hamr.
1 bottom plate 1 Cinder hold	Wheel
5 ffinery bottoms	2 Rabbets
1 Great plate in ye wall	10 Helves
In ffinery Uppr.	
12 plates of all sorts	21 Arms
Lower 9 plates D^{to}	Greece and tallow 50 lbs
In the ffllor 5 Hares 1 bottom	New Cole Sack 3 doz
1 Chaffery Tuironplate	old 1doz: ½
10 ffinery bottoms	4 doz: of New Cole baskets
15 Tuironplates	4 doz yt has been used
1 fforeplate 1D^{to} at Nat. Morgans	6 Horses to keep up coles
4 Rakes, Meeseplate	2 Grindstones
2 Meese plates under Anvile	3 Ladders
3 Loop plates	
1 Cole tub	

From this it will be seen that there were the two finerys, an upper and lower and the one chafery on the old principle. During the same period are one pair chafery bellows, two pairs finery bellows with one old finery beam. This suggests a system of counter-balances to work the bellows.

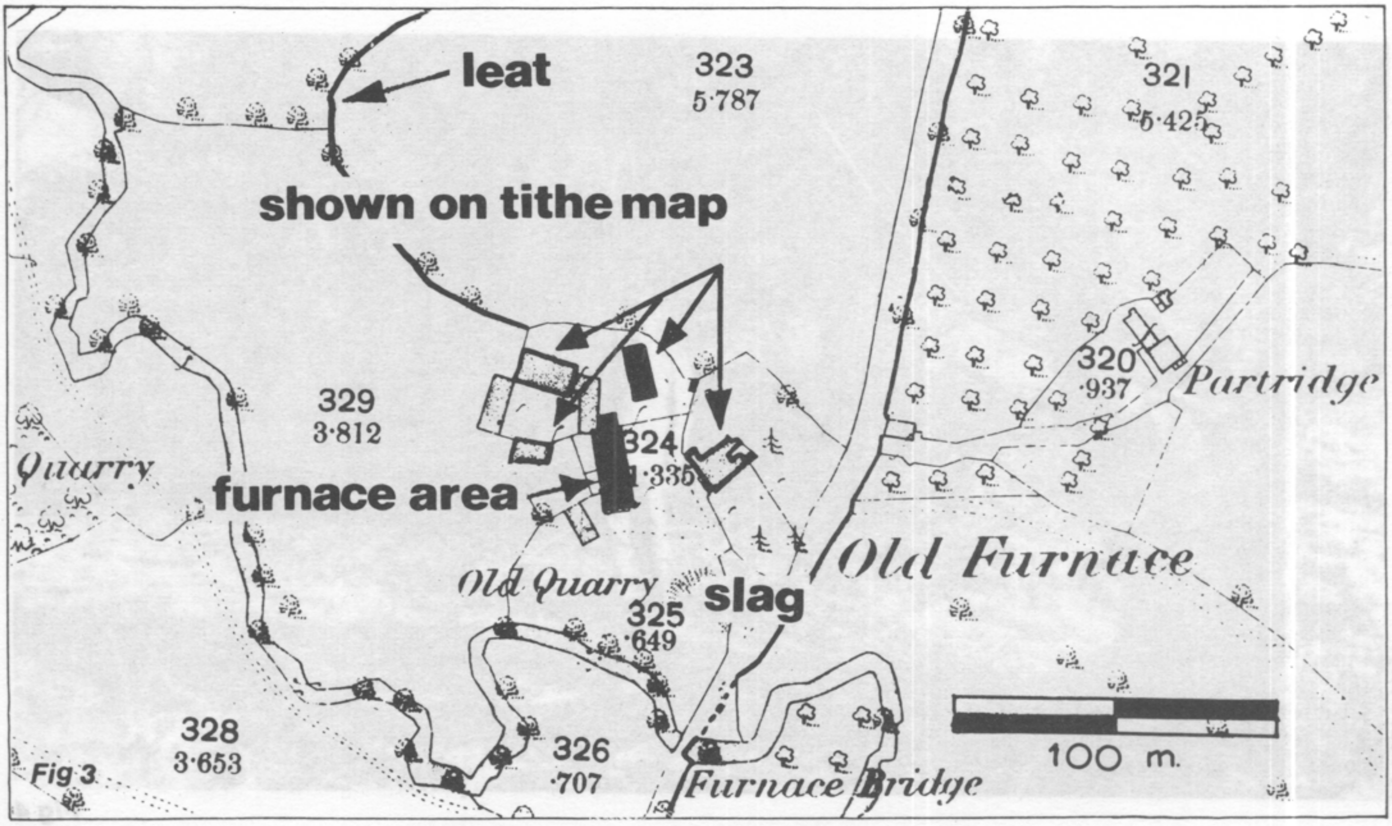
ARCHAEOLOGY

St Weonards Furnace (SO 492234)

The furnace was sited near the Garron Brook and the OS maps mark the location as 'Old Furnace'. To the west lies Furnace Wood. By 1835 Bryant[59] was showing the area as 'Old Furnace' (Fig 3).

A three storey building with dentils and brick lintelled door and windows (SO 4918 2341) was probably associated with a paper mill in existence in 1808[60] and although it contains a sandstone plaque inscribed 'This furnace was rebilt by William Rea Gen in 1720', it is undoubtedly of later date than the furnace. At the north end of this building is an older stone wall from which springs an arch to another old wall. It is suggested that in this area was contained the bellows house with the wheel on the west side, above would have been the preparation floor which became the drying loft of the later paper mill. The ground is sloping here, but the necessary height to the furnace top (approximately 24 feet) would only be obtained by projecting out from the top of the bank. The furnace then would have been in the area of the three storey building but not occupying the whole site. The remaining space might have been taken up by the casting house but this would mean the front of the furnace being opposite the tuyeres. Nevertheless it is significant that the area immediately to the south is covered with heaps of slag. The fact that the stone plaque was rebuilt into the new building supports the theory that it was near at hand.

A leat meanders some 20 feet above the course of the Garron and can be followed from near the west side of the furnace



St Weonards Furnace (reproduced from the Ordnance Survey Map of 1888.

site to 4925 2360. It does not connect with the nearest bend in the little river but probably continues to follow its erratic course keeping to the 250 foot contour line to where it joined the river at 4878 2416. It crossed the road at 4923 2414 and again at 4905 2415.

The lease of 1672 by Robert Mynors to the Hall and Foley Partnership mentions watercourses and gives the impression that they would pass through Mynors' land at Treago. The course described for the leat would in fact do this.

Llancillo Forge (SO 376252)

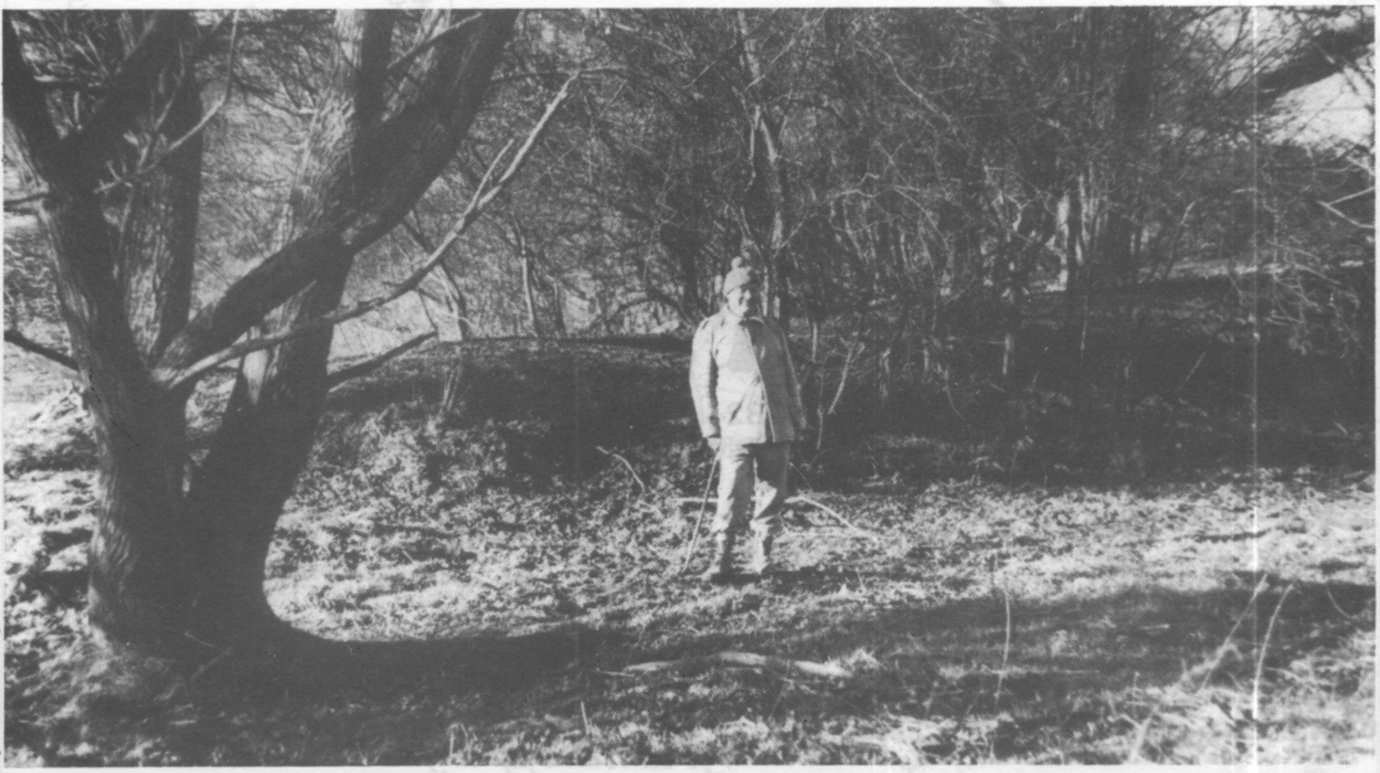
Bowen's map of 1778 shows the forge but by the time of the Tithe map (1839) the forge has obviously not been working for some years. A number of buildings are shown on the site which is marked 'Forge'. The 'Forge Stream' is extant but the pond is marked as waste. The leat is long and incorporates a small stream running through the settlement of Llancillo. This leat represents the extensive work carried out by Paul Foley, making use of a former bed of the River Monnow. In the bed a series of holding ponds were constructed. A low dam at SO 3707 2514 (Fig. 4) indicates the site of the pond to the west, whilst there is another pond from SO 3707 2514 to SO 3722 2521. The take-off point for the leat would have been at SO 3692 2493 and it is suggested that no weir existed at this point. Instead a weir across the Monnow at the forge site caused a back up in the main river which divered water into the holding ponds. The First Edition of the 25 inch Ordnance Survey map (1889) (Fig. 5) shows the course of the leat which now discharged directly into the River Monnow. The forge pond is not identified but would have been in the area shaded on the extract. The Tithe map shows that the whole site was still in the ownership of the Scudamore family of Kentchurch (John Lucy). Only one building can be identified now. A stone building with openings on the north side only, built on a slag tip. A wall remains to the north west of this building which now forms part of a modern farm building. Many tons of slag were sold to Rhymney Iron Works[61] presumably because of its high iron content.

From a combined use of the Tithe map and 1889 map it is possible to determine that the forge itself would have been approximately 50 metres due east from the building mentioned above (SO 3768 2522).

Pontrilas Forge (SO 399264)

The site of the forge is at the confluence of the Rivers Dore and Monnow. The Barn ('Old Forge Bn' on Bryant's map 1838) at SO 4018 2624 can be identified with the storehouse and stable of the 1666–7 map.[62] Futher, a piece of ground some 100 metres to the north east is possibly the site of the workmen's houses of the same map. The extract from the 25 inch Ordnance Survey map of 1889 (Fig. 6) shows the conjuctural course of the leat which ran from the River Dore but discharged into the Monnow. At the take off point the river is dammed by a natural fall, or rock step, also for the first 100 metres the land is waste and level as shown on the extract. The course of the leat from this last point could follow an old field boundary to enter the pond (via a gap) shown as waste in 1889 but now ploughed. The shape of the pond can be discerned from the waste area and this corresponds to the pond shown on the 1666–7 map. The forge area itself is clearly seen on the site by a dark area of slag. Neither the finery nor hammer ditch can be identified. There are very large lumps of slag or hammer scale spread by ploughing over the whole area, some weighing over 25 lbs. The site is bounded on the east by an old river terrace, the forge site occupying the flood plain. In the bank of the terrace charcoal can be recovered adjacent to the forge area itself, but not on the side shown for the 'Coalhous' and 'Coale yard' of the 1666–7 map. The site of the forge is marked 'Conny Gry' – a rabbit warren. Today much of the site particularly the bank is taken up with rabbit burrows.

The agreement reached between the owners of Kentchurch Mill and Pontrilas forge is shown as Appendix I. 'Scudamores Trows' (troughs), which caused an interruption to the flow from the forge wheels, were probably located near SO 401262. The leat which these troughs feed can be



Llancillo Forge – dam of holding pond forming part of works executed by Paul Foley.

Fig 4

Technology at the forge in the 1720's was similar to the earlier periods as it domonstrated by 'An inventory of Stock left at Llancillo fforge' dated 14 October 1723 from which comes the following extract

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Working Tools	00. 09. 2. 00
2 Cast Plumer blocks 0.10.0.00	
3 New hammers	
17 Old hammers	
7 Anvils	
1 Smiths Anvil	
4 Hursts	
6 Boyts	
5 Hammer Gudgeons	
5 Hammer Braysers [brasers]	
4 Ffinery do in work	Pigg beam & Scales
4 Gudgeons D^{to}	and wtc 10C
2 Chaffery Brasses	Iron beam & scales
2 D^{to} Gudgeons	Wts 2C 2q
In Chaffery Plates	Timber left
1 fforeplate 1 ffore Spirit	New hammer beam
1 Hare 1 Tuironplate	a new hutch for hamr.
1 bottom plate 1 Cinder hold	Wheel
5 ffinery bottoms	2 Rabbets
1 Great plate in ye wall	10 Helves
In ffinery Uppr.	
12 plates of all sorts	21 Arms
Lower 9 plates D^{to}	Greece and tallow 50 lbs
In the ffllor 5 Hares 1 bottom	New Cole Sack 3 doz
1 Chaffery Tuironplate	old 1doz: ½
10 ffinery bottoms	4 doz: of New Cole baskets
15 Tuironplates	4 doz yt has been used
1 fforeplate 1D^{to} at Nat. Morgans	6 Horses to keep up coles
4 Rakes, Meeseplate	2 Grindstones
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A leat meanders some 20 feet above the course of the Garron and can be followed from near the west side of the furnace

St Weonards Furnace (reproduced from the Ordnance Survey Map of 1888.

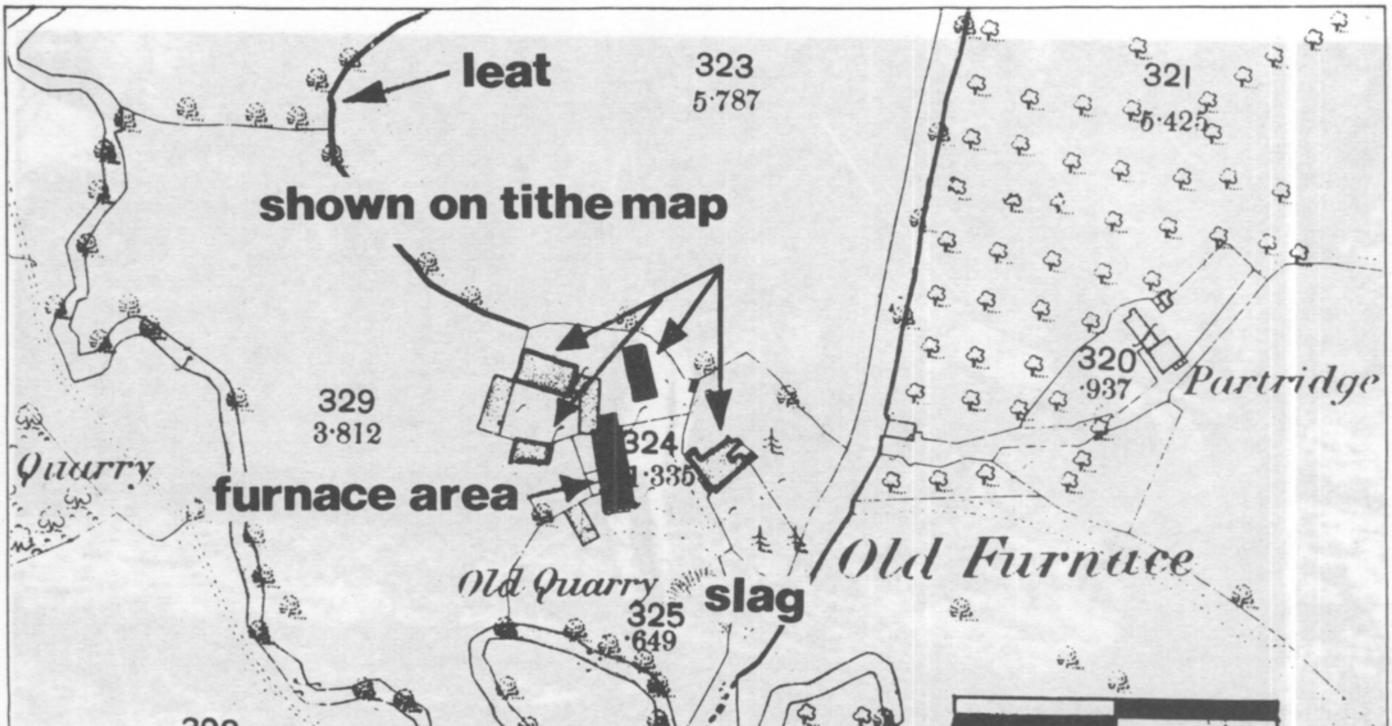
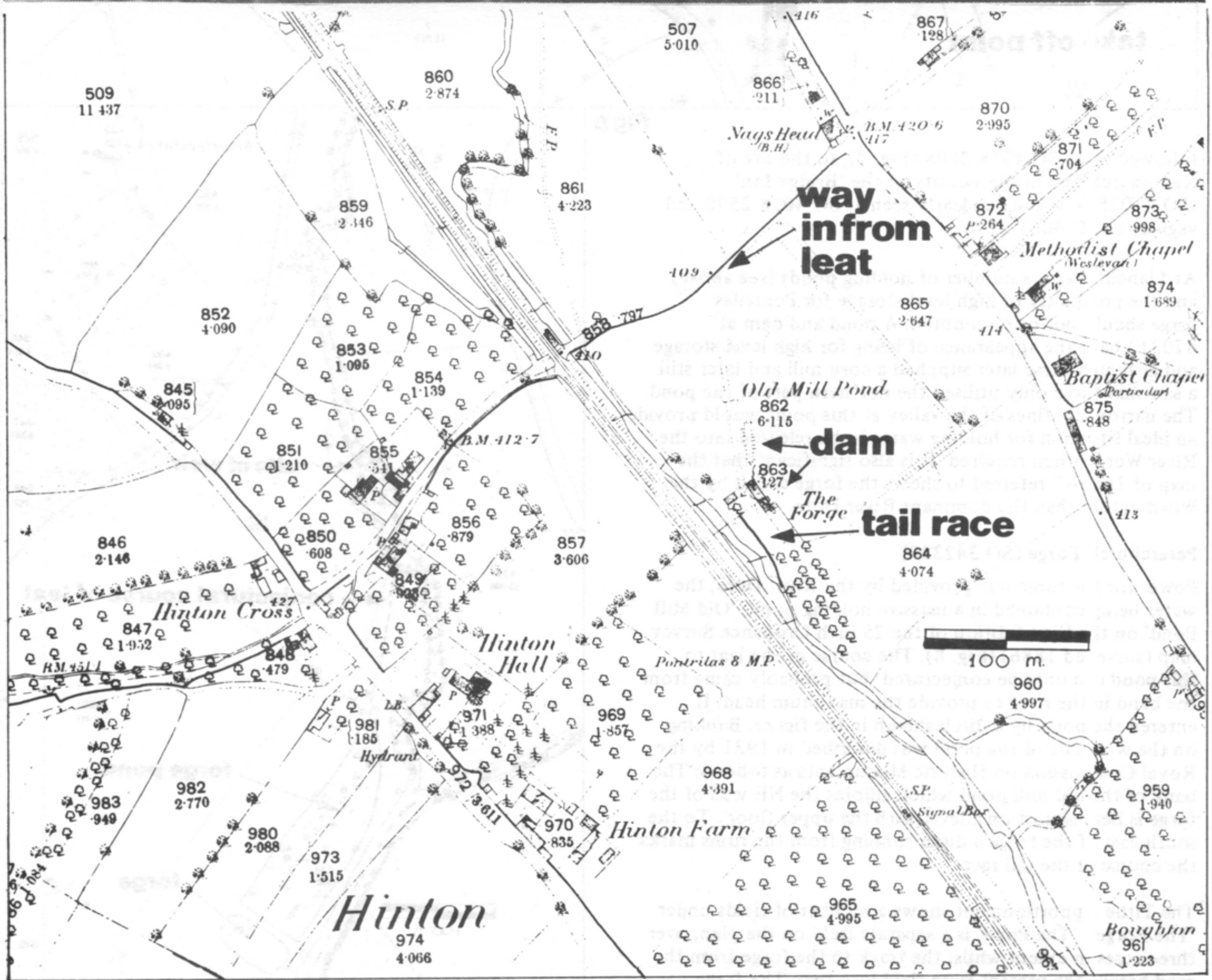


Fig 3

Fig 7 *The leat to Baskerville's Kentchurch Mill*



Peterchurch Forge (reproduced from the Ordnance Survey Map of 1889 25" to the mile) **Fig 8** itself is shown as a barn and orchard. The field to the north west of the site and adjacent to the east bank of the river is shown as part of the forge, presumably because it contained the leat. The whole site is in the ownership of John Gwynn and occupied by his son.

The Forge building was destroyed by fire but stone-walls and fallen beams remain. The Royal Commission on Historic Monuments describes the building as 'The Cottage is of two storeys with attics. It is of stone with the lower storey wall as a cattle shed . . . the building is probably of late 16th or early 17th century date. It is of unusual type and its original purpose is doubtful[!]' Figures 9 and 10 illustrate the building in September 1970 before destruction.

Slag can be found on the site, much of it removed from the vicinity of the dam.

CONCLUSION

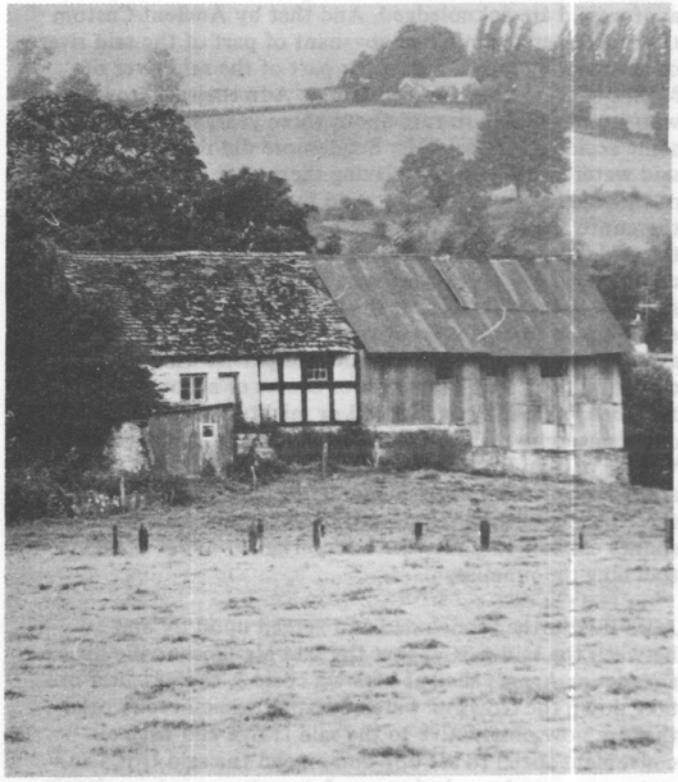
Initially the prime reason for the location of the furnace and forges was the abundant sources of wood for cording. With regard to the forges their location may too have been dictated by the fact that there were relatively few sites available where water power could be used, as the more suitable ones had already been taken up by corn mills. In the case of Llancillo and Pontrilas forges, both appear to have been started by large landowners (Scudamore and Baskerville respectively) with surplus capital to invest.

Throughout their lives, possibly with the exception of Llancillo, the forges were providing bar iron, using 'tough iron' made from Forest ores or cinder. They seem to have been taken on and shed according to the needs of the Foley Partnerships which was finally forced to rationalise the complex by keeping St Weonards in blast to supply Llancillo and Monmouth. The position of Peterchurch is interesting. It seems largely to have become part of a Foley enterprise at the instigation of Paul Foley's uncle, Henry Glover, but William Hall maintained an independent attitude throughout. He obtained pig iron from a number of sources and his finished product was probably sold locally and little found its way to Monmouth Storehouse for onward transmission to Bristol. It was, then, the dictates of the various Partnerships that maintained all or part of the complex. Poor communications in the area and of course the rise of new technology led to the abandonment of the charcoal furnace at St Weonards. The remaining forge at Llancillo, because of its nearness to South Wales and iron produced from Coal Measure ores, was probably stimulated to adopt new methods, and survived into the new eara. It is interesting to note that all three forges including Llancillo were of the old type with two fineries and one chafery to the end.

ACKNOWLEDGEMENTS

I am indebted to Mr A T Foley for permission to quote from the Foley Papers and to Miss Meryl Jancey, Deputy County Archivist for Herefordshire and Worcestershire for her help with these. Archivists from the Record Offices concerned have provided much,help in particular Mr W Tudor Barnes of the National Library of Wales who has responded with great forbearance to my repeated requests.

Professor Tucker brought my attention to valuable material on Llancillo and Pontrilas Forges and Michael Blackmore drew the illustrations of the Walloon Forge. I am also grateful to Mr H W Paar who read this paper and made many helpful suggestions.



Peterchurch Forge Building in September 1970 from the east

Peterchurch Forge Building in September 1970 from the west

Figs 9 and 10

APPENDIX I

Articles of agreement Indented made, concluded and agreed upon the twelvth day of March in the eighteenth year of King Charles the Second [1666–7] over England etc Between John Scudamore of Kentchurch in the County of Hereford the elder Esqre. on the one part and Humfrey Baskerville of Pontrilas in the County of Hereford Esqre. on the other part as follow.

1. I promise whereas there is an Ancient Watercornmill called Kentchurch Mill now driven by the river of Monnow now of right belonging unto the said Mr: Scudamore: And whereas there is an Ancient iron fforge called Pontrilas fforge now driven by the said river of Worme lying higher than the said watercornmill, which now of right belonging to the said Mr:

Baskerville, and whereas the full right of both these parties as aforesaid are acknoledged, And that by Ancient Custom the said watercornmill had covenant of part of the said river of Monnow by trows over other part of the said river of Monnow neere unto the said fforge, Adn the said trows and watercourse falling to ruin about three years last past by some accident, the said Mr: Scudamore did remove the said watercourse & trows placing them over another part of the said river of Monnow, And by raising of supports thereunto the river of Monnow begotte an obstruction to the said fforge Whereupon of late there was a suite commenced in His Ma..jes Court of Kings Bench by the said Mr: Baskerville against the said Mr: Scudamore and his eldest sonne Now it is hereby covenanted concluded and agreed upon by and between the said parties That all controversies Lawsuites accon or causes of accon which have been allready commenced or might for the future be commenced by reason of the obstruction of the river of Worme passing from the said fforge called Pontrilas fforge are from henseforth concluded determined released & fully agreed upon both in relation to the said parties or to any sonnes concerned under the said parties or either of them touching the premises

2. Allso it is further concluded and agreed upon by and between the said parties that the said Mr: Baskerville his assignes or Agents shall at his own costs & charges alter or take down the trows or watercourse or whatsoever works that are now obstructive to the said fforge and with all convenient speed to set upp and amend the said trows and watercourse and see during one & twenty years to maintain and preserve them and so leave them

3. Allso it is further agreed upon by and between the said parties that the said Mr: Scudamore shall give full libty of ingress egress and regress to the said Mr: Baskerville his assignes agents serb:ts over the land of the said Mr: Scudamore adjoining to the said trows and watercourse during one & twenty years for the amending scouring & cleansing the said trows or watercarriage, and also to cleans the river of Monnow in any other place neer adjoining the said fforge that shall any wise obstruct the said fforge within the current of the said river of Monnow not wasting the banks of the said river:

4. Allso it is lastly concluded declared and agreed upon by & between the said parties that nothing in these Articles of agreem..t specified shall at any time hereafter bee expounded or declared to predjudice the Ancient right of either of the said parties to these presents to and in the said Mill or fforge

5. And whereas there is a time intended to bee for the alterting and now erecting of the said works for the water-carriage over the said river it is hereby consented & convenanted that two months bee allowed to the said Humfry Baskerville for the said works and in case of any further impedement, that for every week afterwards the said works not performed, the said Mr: Baskerville to pay to the said Mr: Scudamore or his heires the some of ffive shilings weekly, and in case of future accidents two weeks and noe more at one time are allowed to Mr: Baskerville without any damage paid by him to the said Mr: Scudamore In Witness whereof the said parties to these present have interchangeably putt to their hands and seals the day & year first above written

APPENDIX II

Production in Tons

(Sources B L C Johnson 'The Foley Partnerships' and Foley Account Books and Accounts).

	St Weonards	Llancillo	Pontrilas	Peterchurch
1677/8	NIL	150	89	54
1706/7	80			
1707/8	239			
1708/9	175			
1709/10	686			
1710/11	168			
1711/12	733			
1712/13	NIL			
1713/14	NIL			
1714/15	293			
1715/16	251			
1716/17	519 300*	130*		50*
1718	212 1/3 ***			
1722/23	278			
1723/24		48		
1724/25	To June	27		
1725/27	193	61		
1727/28		138		
1728/29	230	120		
1729/30	407	76		
1730/31	201	33		
1731/32	NIL			
1736		100** (200)		

* from M.S. of John Fuller and his son, Gunfounders, Heathfield, Sussex (E Wyndham Hulme, Trans. Newcomen Soc. Vol. IX)

** 'The Interest of Great Britain in Supplying Herself with iron Impartially Considered' Anon 1736 'Have made' in brackets

*** H R Schubert 'History of the British Iron and Steel Industry' 1957 p.351.

REFERENCES AND NOTES

1. The reader will note that the period covered by this paper takes us beyond 1700. The writer feels justified in this as the methods of organisation and technology are of those of the seventeenth century, throughout the period covered.

2. N P Bridgewater 'Glasshouse Farm, St. Weonards'. **Transaction of the Woolhope Naturalist's Field Club.** 1963, 37 (3), 300-315.

3. J Webb **Memorials of the Civil War in Herefordshire** 1879, 1, 252.

3a. Webb. op. cit. Vol. 2 p.395.

4. John Kemble, the Catholic Martyr was born at Rhyd y Car farm in 1599 (1600) just over a mile to the North West of the furnace. The Kembles were a well known recusant family in this strongly Catholic district. It is not therefore surprising that there should be a hint of Royalist leanings. Captain Richard Kemble,

nephew to John (it is not known if he was the same Richard who was Clerk to the furnace and forge) helped the future Charles II escape from the Battle of Worcester. Richard was not the only Kemble associated with ironmaking. George Kemble started to rebuild Whitchurch Furnace in 1632 and Newmill Forge in the same parish the following year.

5. Mynors family records. The family, whose home is at Treago Court, still hold the furnace site.

6. Of High Meadow, Newland, in the Forest of Dean.

7. Gloucestershire County Record Office Gage MS (D1677 GG684)

8. National Library of Wales. Kentchurch Court No 689

9. National Library of Wales. Kentchurch Court No 888

10. B L C Johnson, 'New Light' on the Iron Industry of the Forest of Dean'. **Transactions of the Bristol and Gloucestershire Archaeology Society**, 1953, 72, 129-143.

11. R G Schafer 'Genesis and Structure of the Foley Ironworks in Partnership of 1692'. **Business History** 1971, **13** (1), 19-38

12. Herefordshire and Worcestershire County Record Office, (Hereford) Foley Papers F/VI/DBC

13. Ibid

14. Brayses (Breeze) – small charcoal normally unsuitable in a furnace but used at the start of a heat.

15. H & W CRO Foley Papers, F/VI/DBC

16. Ibid Account etc

17. R G Schafer op cit and H & WCRO Foley Papers F/VI/DCc/1 11 July 1674

18. H & WCRO Foley Papers F/VI/DC (General Accounts 2677-8)

19. H & WCRO Foley Paper F/VI/DCc6

20. R G Schafer 'Ironworks in Partnership of 1692'

21. H & WCRO Foley Papers 'The Acco^{t} of the Forest Ironworks in Partnership'

22. H & WCRO Foley Papers F/VI/DFC, E12/F/P5

23. H & WCRO Foley Papers 'The Acco^{t} of the Forest Ironworks in Partnership'

24. Mayor of Monmouth 1727 and took active part in agitation for protection 1736 (Commons Journal XXIII pp 109H). Probably supplied John Fuller, Gunfounder, Heathfield, Sussex (see Appendix II).

25. B L Johnson – 'The Foley Partnerships. The Iron Industry at the End of the Charcoal Era' **Economic History Review** 1951–2, 2nd series, 4(3), 324-340.

26. H & WCRO Foley Papers Accounts

27. H & WCRO Foley Papers Inventory 14 October 1723

28. H & WCRO Foley Papers F/VI/DGc

29. H & WCRO Foley Papers – Partnership Accounts

30. Johnson 'New Light' . . .

31. E Wyndham Hulme 'Statistical History of the Iron trade of England and Wales 1717-50' **Transactions of the Newcomen Society, 1930, 9,**

32 John Lloyd, **Papers relating to the Wye & Lugg**, 1873

33 H & WCRO Foley Papers – Partnership Accounts

34 British Transport Historical Records. Brecknock and Abergavenny Canal Committee Minute Book. 26 September 1807. N L W Kentchurch Court No 901 29 April 1778 refers to the 'Ironworks or Forge'.

35 John Duncomb – **Collections towards the History and Antiquities of the County of Hereford** (Hereford) 1812

36. H R Schubert **History of the British Iron and Steel Industry circa 450BC – AD1775** London, 1957.

37. H R Schubert 'Kings Ironworks in the Forest of Dean' **Journal of the Iron and Steel Institute** 1953, **173**, pp 159-161 under 'the Furnace'

38. M M Hallett and G R Morton 'Yarranton's Blast Furnace at Sharpley Pool, Worcestershire' **Journal of the Iron and Steel Institute**, 1968, **206**, 689-692

39. **Encyclopedia Britannica**. Edinburgh, 1824, **5**, 119.

40. Johnson 'New Light' . ... map. Also Foley Papers Partnership Accounts 1714-15.

41. Schubert 'Kings Ironworks' . . . page 162.

42 H & WCRO Foley Papers 'Partnership Accounts'

43 Refers to the year in the accounts (Foley Papers)

44. H & WCRO Foley Papers Inventory 22 October 1723

45. Johnson 'The Foley Partnerships . . .'

46. H & WCRO Foley Paper F/VI/DC (General Accounts 1677-8)

47. H C B Mynors 'Iron Manufacture under Charles II'. **Transactions of the Woolhope Naturalist's Field Club**, 1952, **34**, 3-9.

48. British Library Scudamore Papers add.11052 ff.62. These papers cover the period 1600-1663 but in the opinion of P M Jones, research assistant, this item dates 1630's or 1640's.

49. H & WCRO Foley Papers. Partnership Account F/VI/DEc

50. H & WCRO Foley Papers. General Accounts 1667-8

51. Ibid

52. Osmond iron was produced in a smaller hearth. How the forge at Pontrilas was adapted for this is not clear.

53. H & WCRO Foley Papers, Partnership Accounts

54. Calculations from accounts decimalised by Author

55. Scudamore Papers add. 11052 ff.60 see note (48) above

56. N L W Kentchurch Court No. 1873. I am grateful to Miss Pamela Wright for drawing my attention to this valuable plan.

57. N L W Kentchurch Court No. 10120

58. Johnson 'New Light' . . . page 132

59. Bryant A Map of the County of Hereford from actual survey in the years 1832, 1833, and 1834 London, 1835.

60. Information kindly supplied by Mr Inett Homes

61. John Duncumb Collections towards the History and Antiquities of the County of Hereford (Hereford). Hundred of Wormelow by John Hobson Mathews 1912 'There are two forges on the Kentchurch lands. Many tons of half-smelted ore were sold by Colonel Scudamore to Rhymney Iron Works'. Mathews appears to have grouped both Pontrilas Forge and Llancillo Forge in the same Hundred but it is clear that he is referring to Llancillo as this was owned by the Scudamores.

62. N L W Kentchurch Court No.1873.

Notes on contributors

John van Laun runs Northamptonshire's centre for outdoor education on the South Wales Border. In addition he is heavily committed to part-time lecturing in Industrial Archaeology particularly in South East Wales.

Stig Blomgren graduated in metallurgy at the Royal Institute of Technology in Stockholm and spent nine years with the Forging Research Laboratory in Eskilstuna, belonging to Sveriges Mekanforbund, until it was closed in 1970. One of his main tasks there was an in-depth study of steel scaling. Since he has been a cooperator in the Rinman Laboratory in Eskilstuna and he has specialized in microscopical work on ancient iron and steel as well as on slags from bloomeries, blast furnaces and similar objects.

Baron Elias Hermelin graduated in metallurgy at the Royal Institute of Technology in Stockholm. After some years with the ball-bearing industry (SKF) and the steel industry (Fagersta) he was for thirty three years with the Royal Rifle Manufactory in Eskilstuna as head of its laboratories.

He has devoted a life-long interest to the History of Metallurgy, Technology and Natural Science, being also a corresponding member of the Royal Academy of Letters, History and Antiquities, and he has been president of the council for the Town Museums of Eskilstuna.

Erik Tholander graduated in metallurgy at the Royal Institute of Technology in Stockholm and spent twenty years with industries producing special steels in Soderfors, Bofors and Vikmanshyttan. After that he organized the Forging Research Laboratory in Eskilstuna, belonging to Sveriges Mekanforbund, and served there as laboratory director for fourteen years until it was closed in 1970. Since then he is a senior master of material and mechanical production techniques at the Rinman High School in Eskilstuna. For more than fifteen years he has devoted as much time as possible to the study of early metallurgy and forging techniques and he has again entered into the R.I.T. as a research student on ancient iron ore reduction metallurgy. Together with Mr Stig Blomgren he operates the Rinman Laboratory on a voluntary basis.

Gordon Van Praagh first became interested in Metallurgy during World War II. Later, as a member of the Nuffield Science Teaching Project, he introduced some simple metallurgy into the GCE Chemistry syllabus. From 1975-78 he was Associate Professor in Science Education at the Universiti Sains Malaysia, where he carried out his investigation into White Brass.

A prehistoric Nickel-alloyed Iron Axe

Elias Hermelin, Erik Tholander and Stig Blomgren

Introduction

One summerday in 1930 one of the authors (EH) walked with his father, the late Baron E M Hermelin, along the woodland ridge, Kjulaas, east of Eskilstuna in Sweden. The district is known as part of a very old route of communication in north and south directions through the province Sodermanland and was probably used from early prehistoric times. At a small farm named Nybygget Baron Hermelin observed a piece of iron shaped like a socketed axe lying on the stonework below the cowhouse. The farmer mentioned that he had recently found the rusty but in its shape well-preserved axe when digging a ditch in the sandy ground in the vicinity. The axe was bought because of its interesting shape and the relatively little rusting compared to similar artefacts known elsewhere. The purpose was to make a scientific examination of the axe.

The appearance of the axe as found is shown in Fig 1 and the sketches in Fig 2. The weight was later found to be about 0.75 kg.

Axes of the same type are reported to have been found earlier in Sodermanland in at least three places (in Halla, Lunda and Tuna parishes). For typological reasons they have been dated to the period of the first four centuries of the Christian era. A similar age estimation was then considered reasonable for this axe.

One side of the axe blade was ground and etched. It had a characteristic structure pattern which is seen in Fig 3.

In 1931, the first chemical analysis was made by E Hammarberg of Fagersta, which, surprisingly, revealed the presence of nickel and cobalt as shown in Table 1.

Table 1 Chemical analysis of the Kjula axe

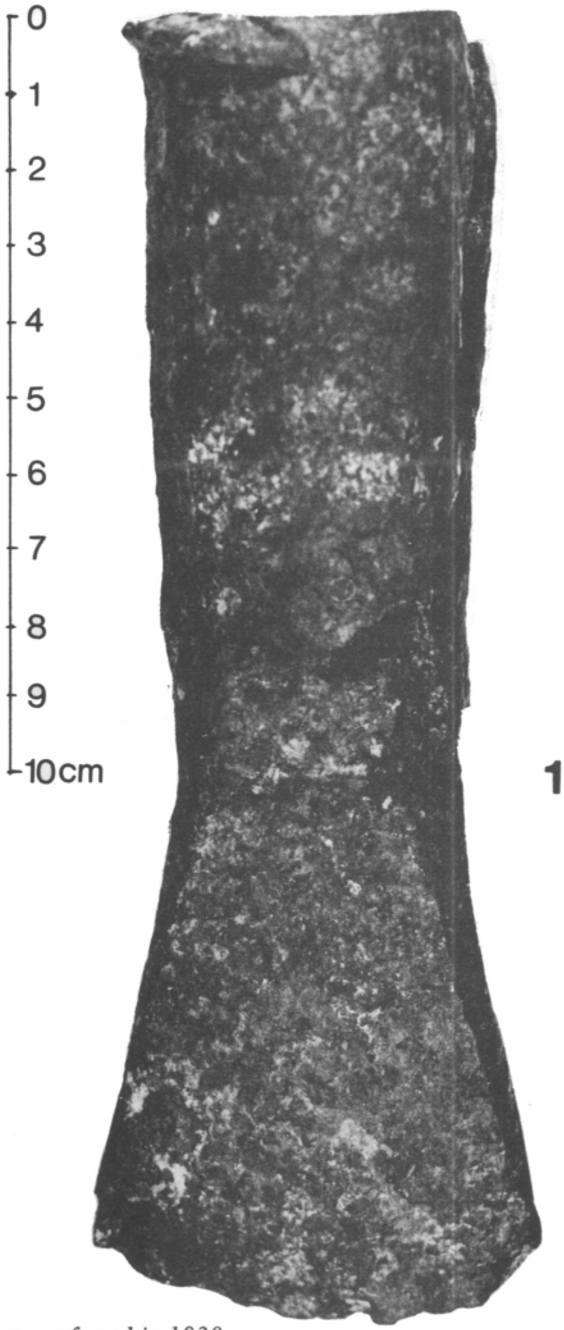
C	Si	Mn	P	S	Ni	Co
0.11	0.05	0.03	0.020	0.004	0.58	0.23%

Cr, W V and Mo were found not to be present.

For the above analysis the axe blade was reduced by milling from the etched side to less than half the original thickness (Fig 4). As is shown further on, the local variations in chemical composition have been shown to be large, so the figures in the table only represent average values of the composition of the elements in the blade. In the early days considerable efforts were made to try to find out a possible origin for the unusual alloy composition of this axe. No result in the form of a simple probable explanation was obtained but the following three alternative raw materials were considered on the basis of the nickel and cobalt contents:

1. rock ore
2. bog ore
3. meteoric iron

Further investigations were clearly necessary. As time went on the methods of examining metallic materials have been



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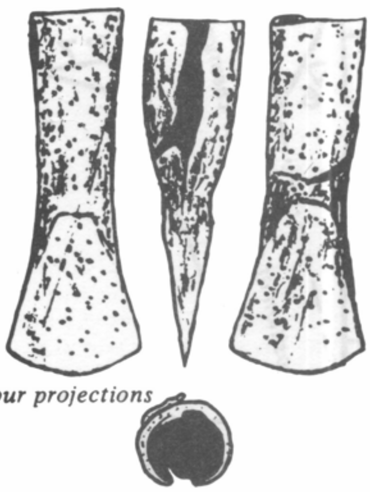
The Kjula axe as found in 1930.



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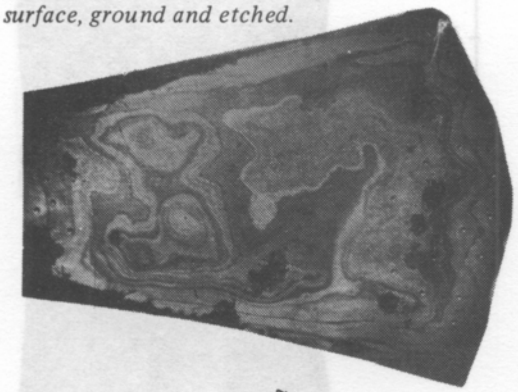
Sketch of the axe in four projections

developed and gradually a clearer picture of the build-up of this particular axe has been established. In 1936, one of the authors (EH) made the first microscopical examination of the axe.[1] A section through the area of the edge, perpendicular to the edge, (section 3 in Fig 4) showed a structure of many converging layers having alternating high and low carbon content. The soft layers thus are stiffened by harder layers of about 0.4% C lying between. From the type of slag inclusions one could state that the soft iron must have been extracted directly from the ore and not from pig iron.

In the following three decades not very much could be done by further investigation, but in 1966 Mrs Lena Thålin in the Statens Historiska Museum in Stockholm initiated a more extensive metallographic investigation to be made by Mr Sten Modin in the Institutet for Metallforskning in Stockholm.

Blade surface, ground and etched.



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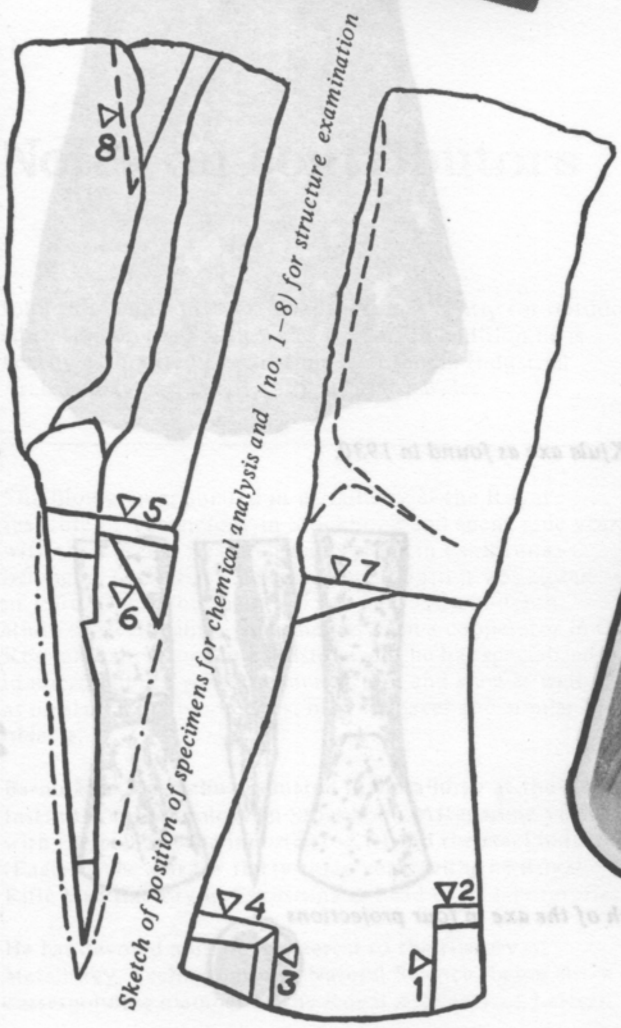

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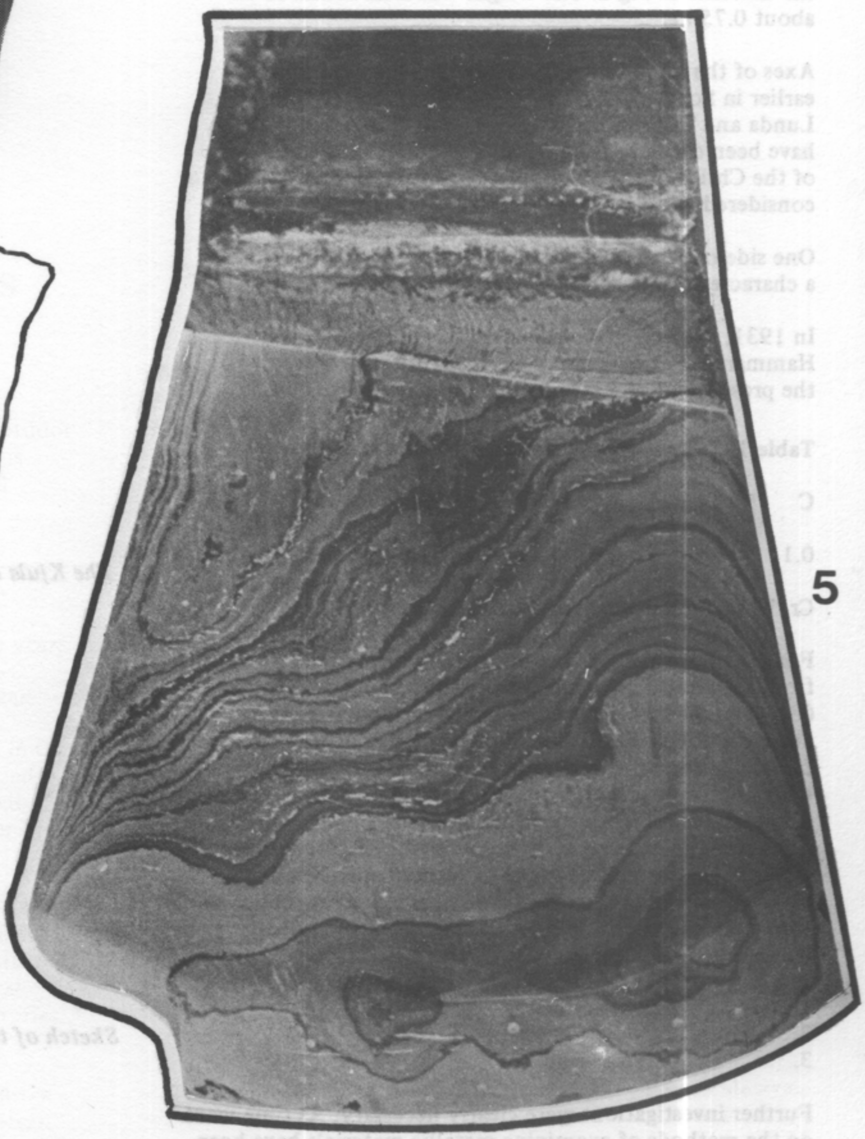
Sketch of position of specimens for chemical analysis and (no. 1–8) for structure examination

A section from the edge (section1 in Fig 4) and a section from the transition between socket and blade perpendicular to the longitudinal direction of the axe (section 5 in Fig 4) were examined. Modin[2] could in 1967 report that the microstructure of the edge mainly consists of martensite which means that the axe has been hardened. However, some free ferrite and pearlite are precipitated in former austenite grain boundaries. Further away from the edge the amount of ferrite and pearlite increases as the martensite decreases. Still further away, about 5 mm from the edge, the structure starts getting stripy from streaks of martensite and pearlite, which appear alternating with low carbon areas. The stripiness is caused by an uneven distribution of alloying elements. It seems probable that the structure has been formed by welding several blanks together or that one blank has been folded. In the section from the transition between socket and blade the structure is laminated too but less pronouncedly compared to that of the blade.

The report was illustrated by photographs of macro- and microstructures, of which the most expressive surface view after macroetching is reproduced in Fig 5 (this surface is the one left after milling away material for the chemical analysis).

Macrostructure of the section through the middle of the blade. Photograph Sten Modin.



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In 1973 Modin, together with Torsten Hansson,[3] published his results on this axe and two other iron artefacts found in Sweden containing nickel and cobalt. In addition to the above conclusions, the following results were obtained on the axe with an electron microprobe analyser:

Martensite streaks	5% Ni and 0.7% Co
Surrounding matrix	0.6% Ni and 0.3% Co

V F Buchwald in Denmark, who has studied many iron meteorites, examined the axe in 1972 and stated that two quite different materials have been forged together.[4] He found that the nickel content varied between 0.2 and 4.2%, and that the cobalt content between 0.1 and 0.5%, with the highest values in both cases being in the martensitic areas. The nickel rich material which occupies about 10% of the blade section does not exist as a raw material in Scandinavia and therefore meteoric iron, eg hexahedrites, can be the only possible origin if Swedish. The hexahedrites which are ferritic nickel iron have the average composition 5.6% Ni, 0.5% Co, 0.25% P and 0.01% C and phosphides appear in their structure. However, there are no phosphides in the structure of the axe.

The hitherto published knowledge about the Kjula axe does not, however, give answers to the following two questions:

1. Which manufacturing technique has been used to give the characteristic laminated structure in the axe?
2. What is the origin of the nickel rich material in the axe?

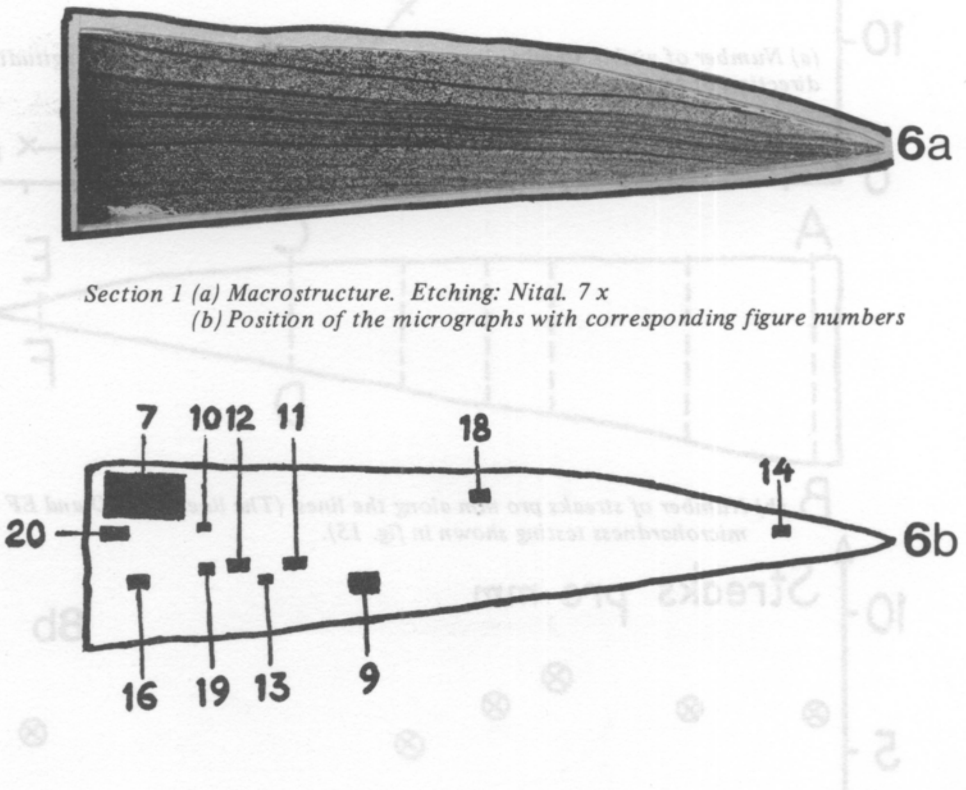
In order to bring about a better understanding of the above aspects of this axe and thus extend our knowledge of that part of the history of European technology which effects early forging techniques and the heat treatment of iron and steel implements, a fresh and detailed investigation has been carried out in Eskilstuna and will now be reported here.

Besides the three sections examined earlier five more specimens were cut for examination. The positions of these sections are shown in the sketch in Fig 4. (The three sections earlier examined are the numbers 1, 3 and 5). The eight sections thus combine four from the blade, three from the transition part between blade and socket and one from the back end of the socket.

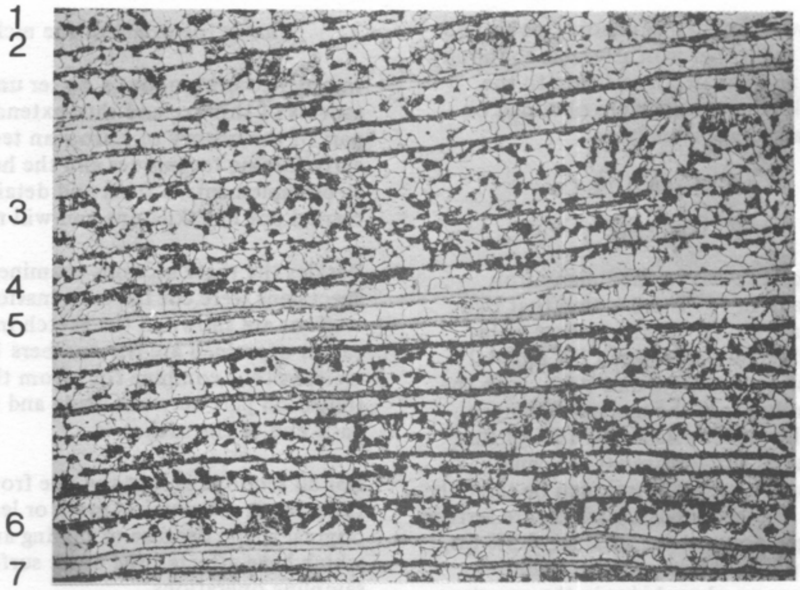
For all sections except the one from the socket-end (No 8) the present geometry is more or less different from the original shape because of milling and grinding operations which have affected the outer surfaces in previous sampling operations.

Microscopical examination

The preparation of sample sections was made in the usual way including grinding, mechanical polishing and etching. Nital (2%) and in most cases also Picral solutions were used for the etching. Numbers and positions of the sections are shown in Fig 4.



Section 1 (a) Macrostructure. Etching: Nital. 7 x
(b) Position of the micrographs with corresponding figure numbers



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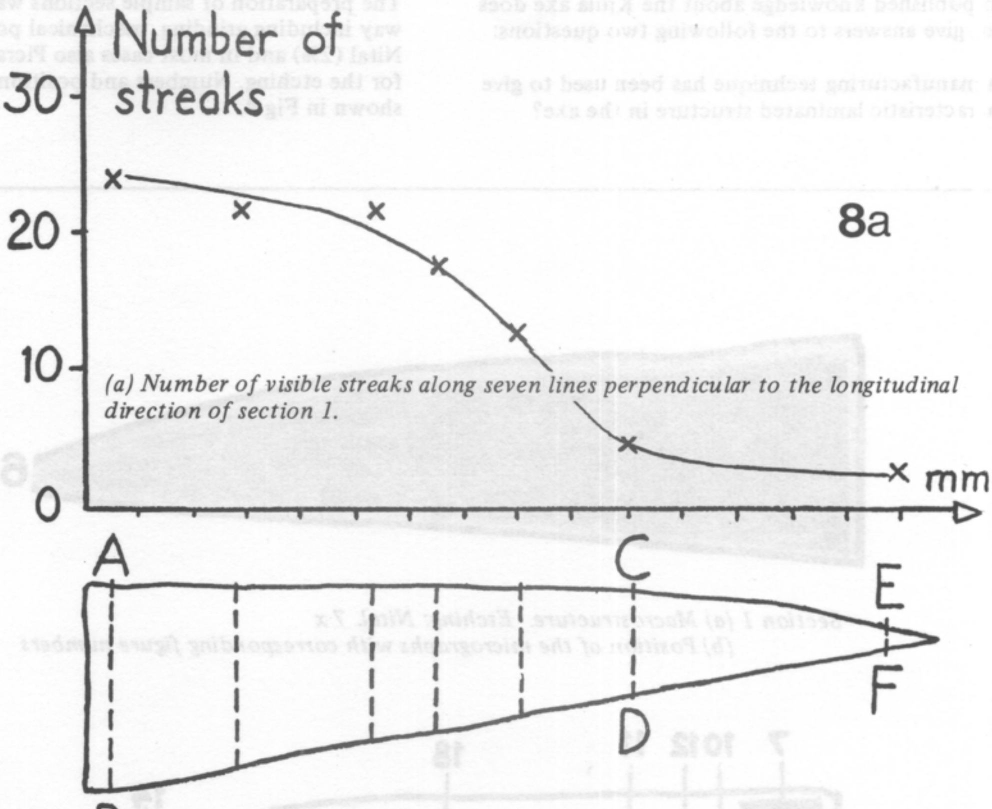
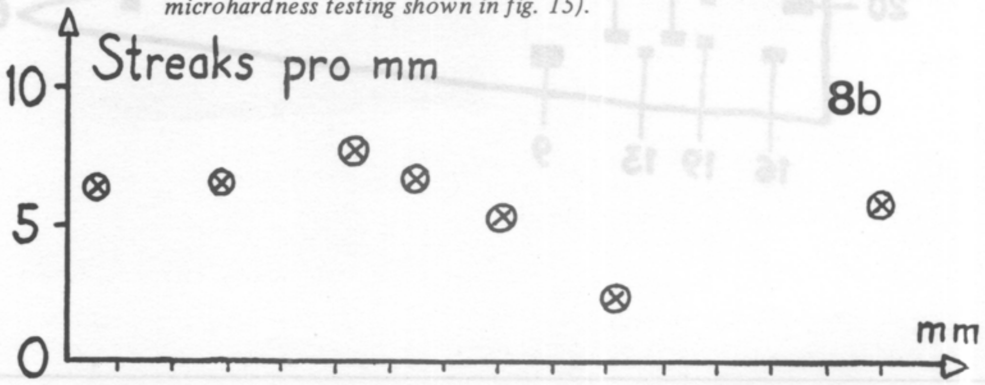
Section 1 Typical structure of streaks and matrix. (The figures refer to the diagram in fig. 17). Etching: Nital. 55 x.



(a) Number of visible streaks along seven lines perpendicular to the longitudinal direction of section 1.

(b) Number of streaks pro mm along the lines. (The lines AB, CD and EF refer to microhardness testing shown in fig. 15).



Section 1

This section is a longitudinal one perpendicular to the edge near a blade corner. In etched condition the surface looks stripy as is shown microscopically in Fig 6a, and microscopically in Fig 7. The last figure shows the existence of several thin streaks slightly converging to the right and causing the stripiness.

The number of observable streaks decreases towards the edge as shown in Fig 8. Of 24 streaks to the left of the section only 3 remain near the point. In the distance 9 to 5 mm from the edge the decrease in streak number is remarkable.

Several streaks disappear near the long side boundaries of the section due to the grinding away of blade material in earlier sampling operations. This, however, only partly explains the decreasing number of streaks towards the edge. A consequence of the converging of the streaks in this direction ought to be that the distance between two neighbouring streaks decreases in the same direction. This should result in an increasing number of streaks per length unit towards the point along lines perpendicular to the longitudinal axis of the section. This, however, is not the case as shown in Fig 8. The reason is that in the neighbourhood of the axe edge the borders between the streaks and the matrix are so diffuse that the streaks there seem to have been dissolved in the matrix.

The thickness of streaks varies to some extent up to a maximum of about 40 microns. Sometimes streaks are interrupted by gaps filled by the matrix, see Fig. 9.

The structure of the streaks consists mainly of martensite, indistinctly acicular[3] (Fig 10). Besides, fine-lamellar pearlite often occurs in the streaks (Fig 11). In general, it can be stated that thick streaks are mostly quite martensitic, while pearlite occurs in greater amounts as the streaks get thinner. The pearlite especially occurs at the borders but a thin streak can be partly pearlitic.

About three quarters of the matrix section consists of ferrite. The rest is fine-lamellar pearlite, usually with some martensite (Fig 12 and 13). However, in the upper, left, part of the section most of the non-ferritic structure is quite pearlitic. The ferrite throughout the whole section is rather fine-grained corresponding to ISO G6.

As stated by Hansen and Modin[3] the structure changes its appearance towards the edge as the number of streaks strongly decreases in the zone 9 to 5 mm from the edge. From there on to the cutting edge the structure mainly consists of martensite (Fig 14). But some pearlite and ferrite occurs in the prior austenite grain-boundaries.

A series of microhardness impressions (15g, 10s) were made along three lines perpendicular to the longitudinal direction of the section and situated as shown in Fig 8. The results are presented in the diagrams, fig 15.

Impressions were made partly in every streak, and partly in the ferrite matrix, see Fig. 16. The values show that the streaks have a considerable hardness; the mainly martensitic ones, HV 500-600, some values reaching HV 700, and the streaks containing both martensite and pearlite, HV 300-500. The ferrite of the matrix has a hardness of HV 170-230.

Also, the pearlite-martensite grains of the matrix were tested by about twenty impressions evenly distributed over the surface. The values are in general, HV 350-450. The

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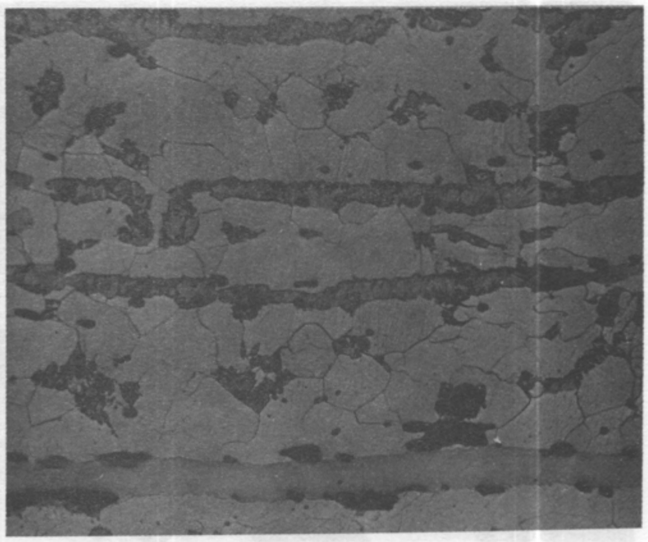

Section 1. Streaks of different thickness. The two streaks at the the top are 'broken'. Etching: Nital. 220 x.

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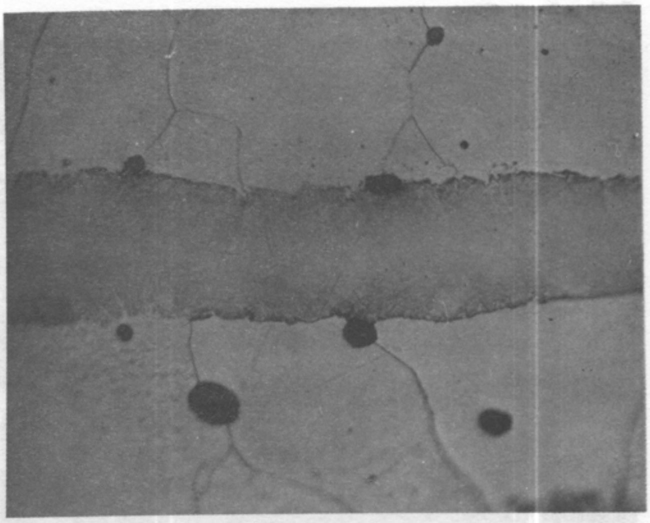

Section 1. Streak of martensite surrounded by ferrite. Etching: Nital. 950 x.

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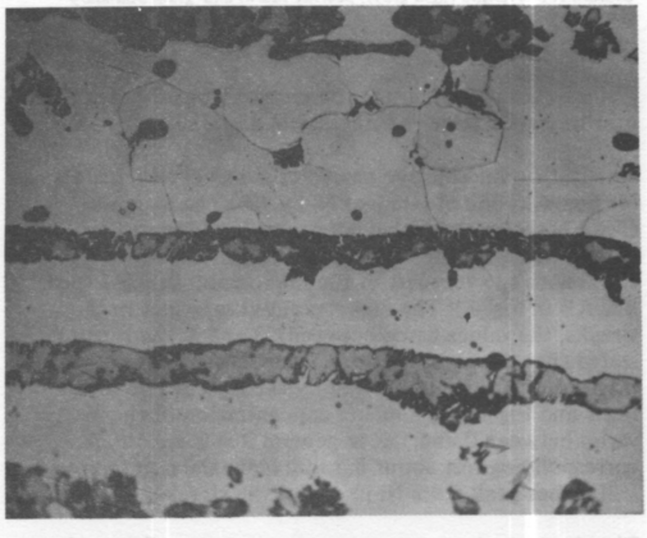

Section 1. Streaks of martensite (light grey) and pearlite (dark). The streaks are surrounded by ferrite. The streak in the middle is partly quite pearlitic. Etching: Picral. 400 x.

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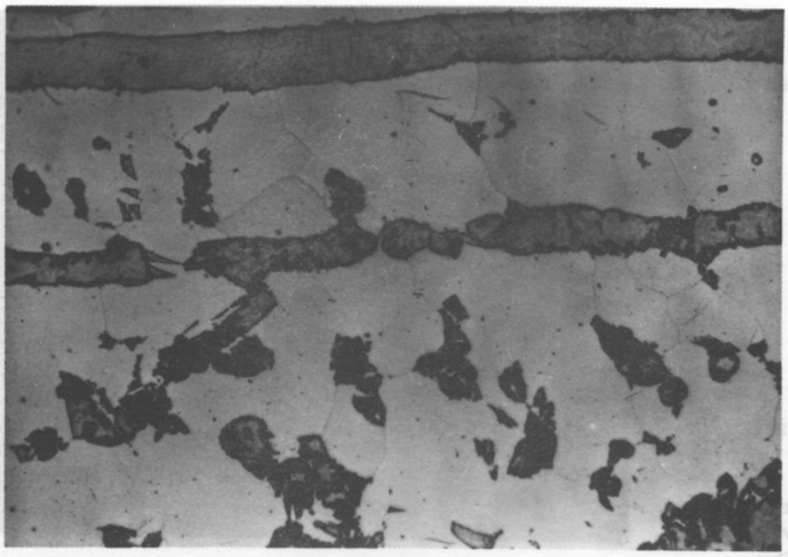
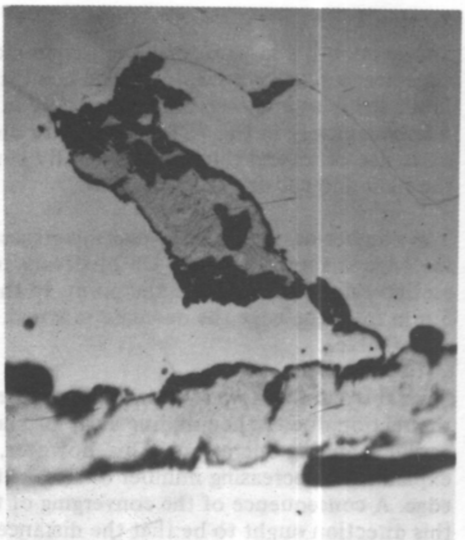


Section 1. Matrix which besides ferrite also contains grains of both martensite (light grey) and pearlite (dark), the latter phase dominating. At the top a streak is seen with almost only martensite and in the middle a streak with both martensite and pearlite. Etching: Picral. 400 x.

13



Section 1. Grain in the matrix containing both martensite (light grey) and pearlite of troostite type (dark). At the bottom a streak of martensite with some pearlite is seen. Etching: Picral. 950 x.

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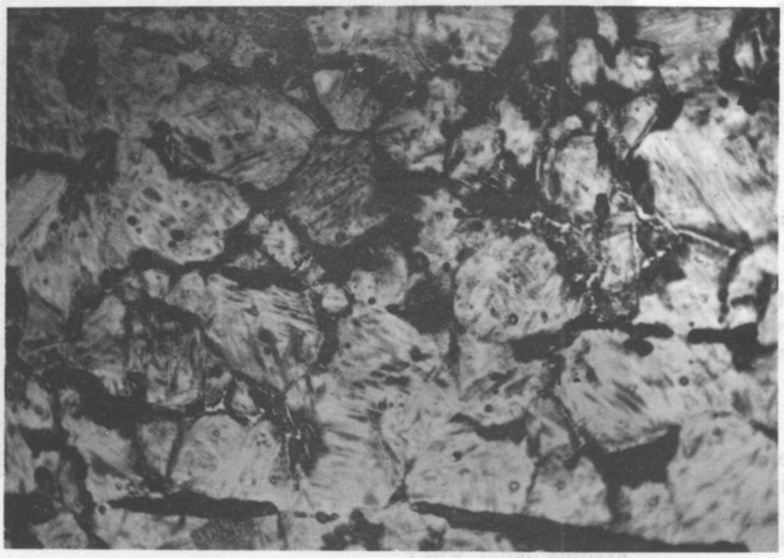

Section 1. Martensite (light grey), pearlite (dark) and grain-boundary ferrite (white). Etching: Picral 400 x.

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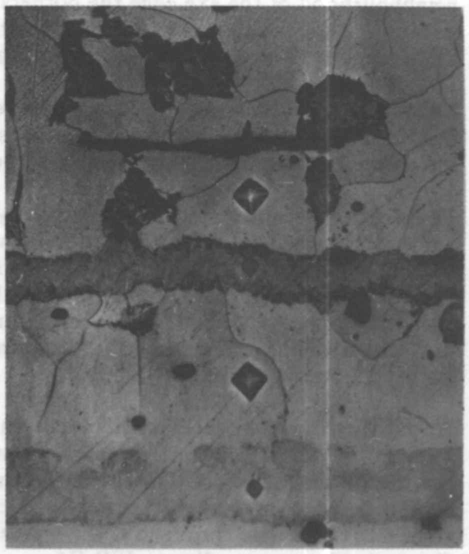


Section 1. Microhardness impressions in streak and matrix ferrite. Etching: Nital. 400 x.

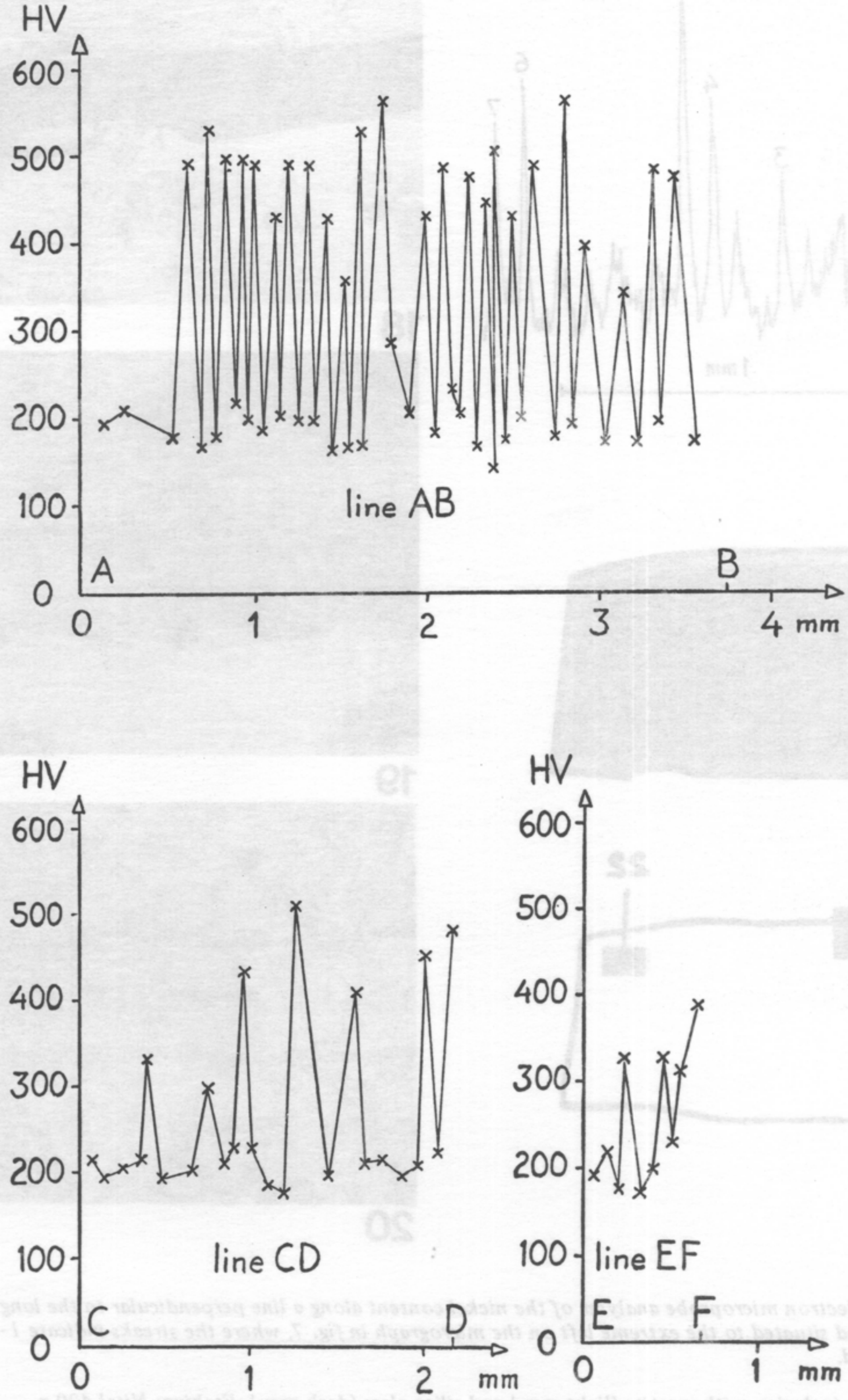
grains in the upper part of the section which only contain pearlite have a lower hardness, HV 250-350.

An electron microprobe analysis for nickel was made by Mr Bengt Lundh at Granges Nyby AB. The diagram (Fig 17) shows the nickel concentration along a line perpendicular to the longitudinal axis of the section in the area to the very left of the micrograph in Fig 7 (near line AB in Fig. 8). The nickel content is largest in the streaks, the values being between1.3 and 4.7%. It can be stated that the highest values occur in the thickest, mainly martensitic streaks, indicated by the figures 1 to 7 in Fig 7 and Fig 17. The nickel concentration of the matrix varies between 0 and 1%, in general it is 0.3-0.5%. A corresponding test about 3.5 mm from the point gave a still higher peak 6.9% Ni in one of the streaks.

The slag inclusions are numerous, occurring all over the surface, usually elongated in the longitudinal direction of the section. Wüstite is the dominating slag constituent (Fig 18), the matrix being a silicate glass and in large inclusions also some crystals of fayalite. The slag inclusions often form the border between the hard streaks and the soft matrix (see Fig. 19). Sometimes slag can also be seen in the middle of the matrix between two streaks (Fig 20).

Section 2

This section is a cross section from the same corner of the axe as section 1. Also here the structure looks stripy because of streaks like those in section 1, which are seen in Fig 21 and Fig 22. The streaks bend against the two corners to the left of Fig 21a. Fig 23 shows in high magnification the upper one of these corners. The number of visible streaks in this section is 24 to the far right but decreases to the left, so that in the middle there are 19 streaks and further to the left 12 streaks. In the very streaky part of the section the average thickness of the streaks along lines perpendicular to the long-side of the section was determined as being 18 microns.



Microhardness D P N (Vickers units) along the lines AB, CD and EF in fig. 8.

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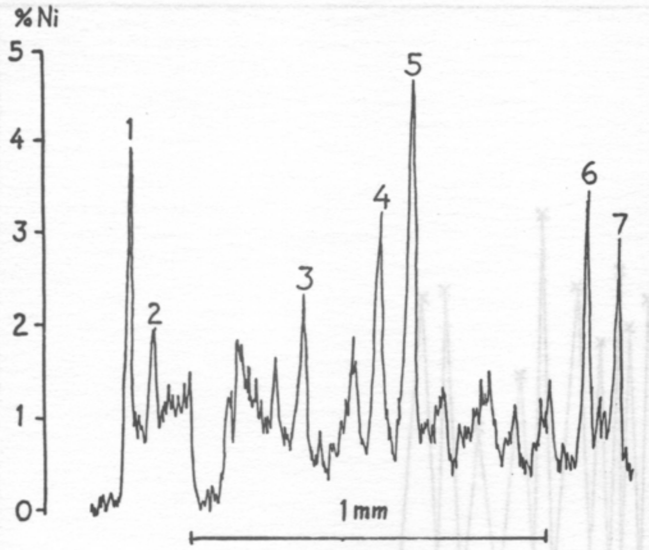

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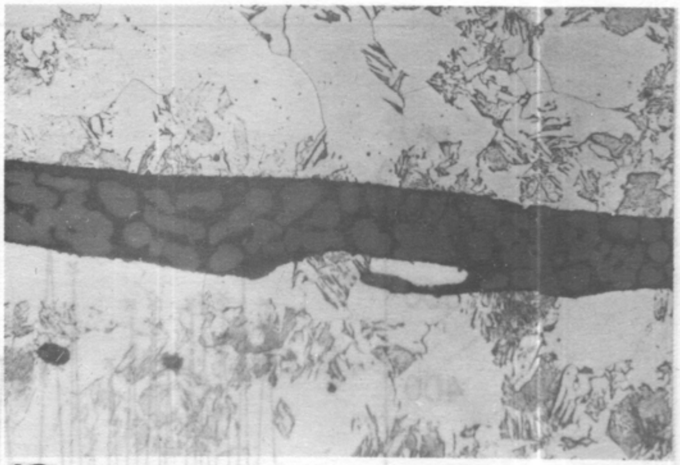

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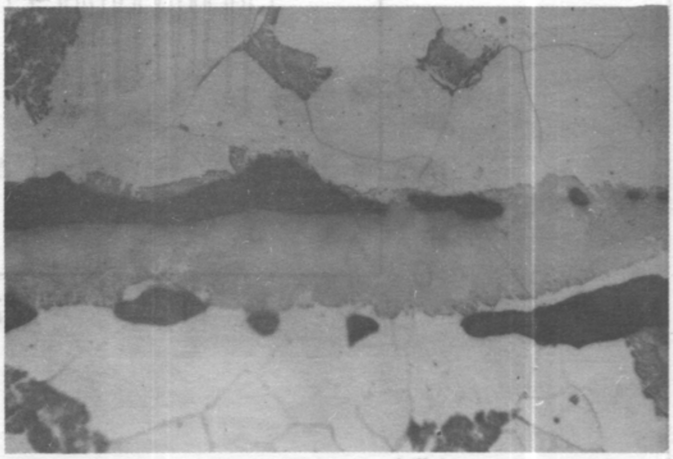

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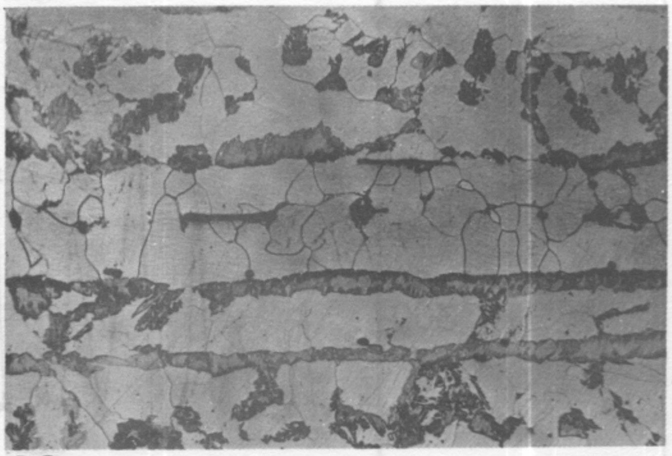

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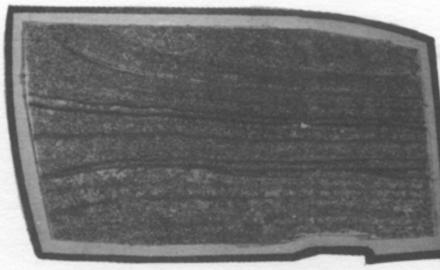

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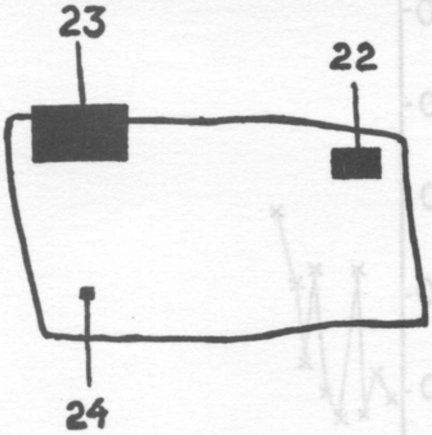

21b

17 Test with an electron microprobe analyser of the nickel content along a line perpendicular to the longitudinal direction of section 1 and situated to the extreme left on the micrograph in fig. 7, where the streaks indicate 1–7 in the diagram are to be found.

18 Section 1. Slag inclusion with wustite (light grey) and silica glass (dark grey). Etching: Nital 400 x.

19 Section 1. Slag inclusions as border between streak and matrix. Etching: Nital: 600 x.

20 Section 1. Stretched slag inclusions in the middle of the matrix between two streaks (in the middle of the picture). Etching: Nital. 220 x.

21 Section 2. (a) Macrostructure. Etching: Nital. 7 x.
(b)Position of the micrographs with corresponding figure numbers

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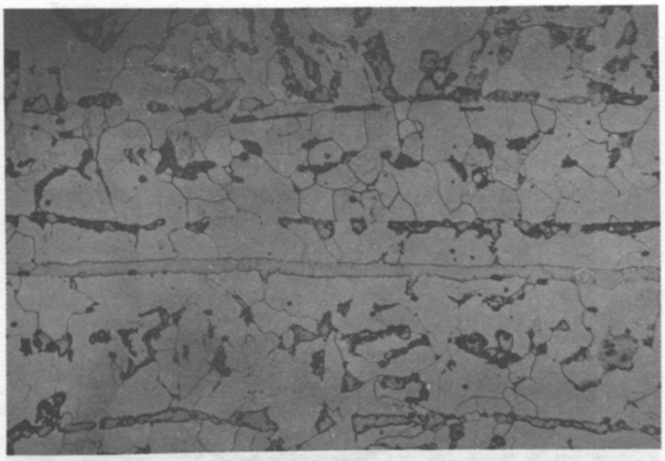

Section 2. Typical structure with streaks and matrix. Etching: Nital. 120 x.

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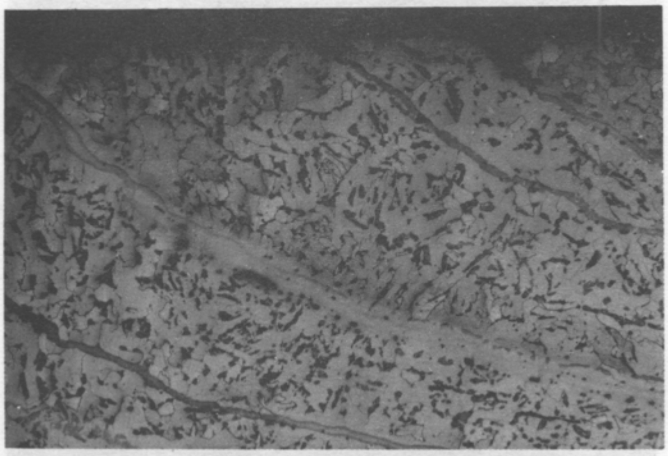


Section 2 'Bent' streaks. Etching: Nital. 60 x.

24

Section 2. Matrix with ferrite and grains of both martensite and pearlite, Etching: Nital: 950 x.

Besides ferrite the matrix contains, as in section 1 scattered grains consisting of pearlite and martensite which are seen in Fig 24. The slag has the same appearance and structure as in section 1, but however, there are also inclusions where only silicate glass can be seen.

Section 3

This is a longitudinal section from the other corner of the area of the edge of the axe (see Fig 25). The structure has the same general appearance as in section 1 containing streaks, the number of which decreases towards the point (see Fig 26). There is a large amount of martensite near the edge (see Fig 27).

Section 4

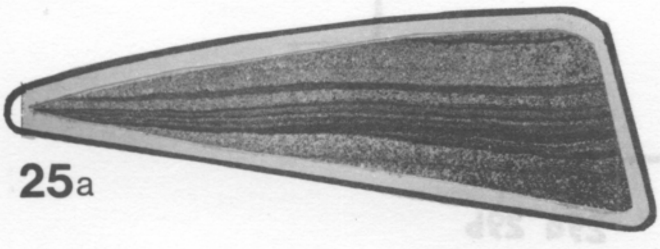
This cross section is from the same corner of the axe as Section 3. The characteristic appearance with streaks all over the surface also occurs here (see Fig 28a). The streaks bend against the corners of the right side, most strongly in the lower one. At the long-side of this corner a spot of rust is seen also containing two-phase slag of the same type as in the rest of the section (see Fig 29). This spot can be interpreted as a kind of centre about which the bending of the streak has taken place. This will be discussed later.

Section 5

This section is from the area of transition between socket and blade and can be considered as two halves, which according to Fig 30 are called 'the lower' and 'the upper' respectively.

The lower half has a stripy structure of streaks like those in the sections from the edge. The streaks bend down strongly towards the ends of the section and form in the left part a 'centre of bending' filled by rust and slag in the corresponding way as in Section 4 but here more distinctly formed. The streaks are often less distinct than in the edge area and have also a somewhat different structure. Martensite occurs but the streaks are dominated by a pearlite-ferrite structure, see Fig 31. As well as in the edge area the same streak can show different types of structure, see Fig 32. The matrix consists mainly of ferrite and pearlite, see Fig 33, but can locally be quite ferritic. No martensite can be seen in the matrix. Where both the streaks and the surrounding matrix consist of pearlite and ferrite it can sometimes be difficult to discern the streaks, making their number hard to determine. The ferrite grain size corresponds to ISO G 5-6. The microhardness of the martensite, HV 400-450, is somewhat lower than that in the edge area. The corresponding values for the ferrite is HV 150-180 and for the pearlite, HV 240-280.

The slag has the same appearance as in the edge area but large inclusions are only slightly elongated see Fig 31.



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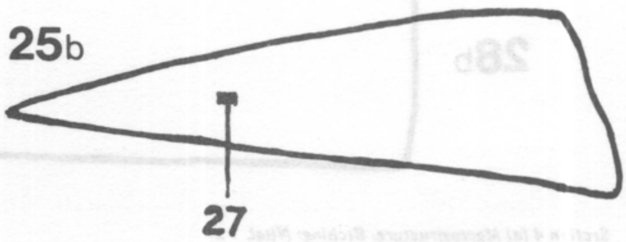
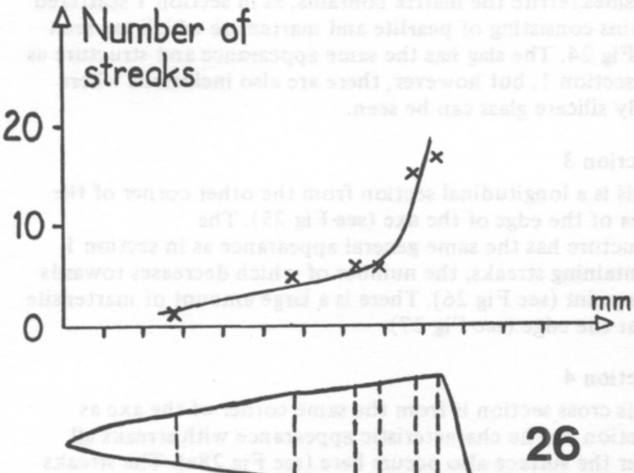


Section 3. (a) Macrostructure. Etching: Nital. 7 x.
(b) Position of the micrograph with corresponding figure number.



26

Number of visible streaks along six lines perpendicular to the longitudinal direction of section 3.

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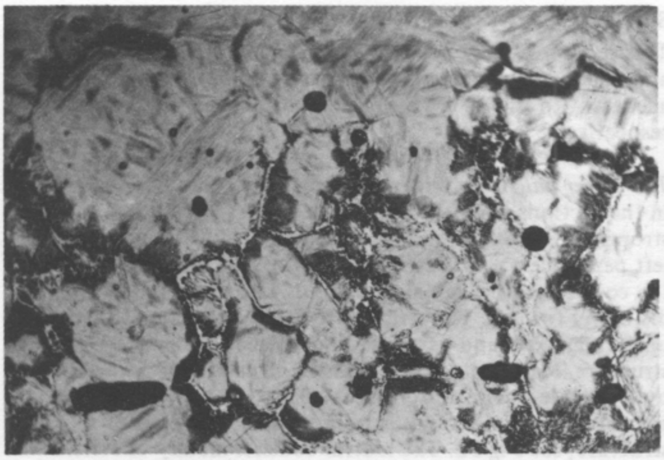
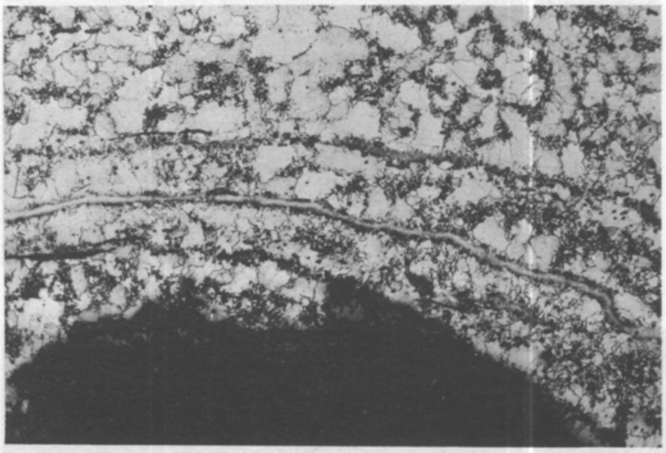


Section 3. Martensite, pearlite and grain-boundary ferrite. Etching: Picral. 400 x.

Section 4. (a) 'Bent' streaks. The dark spot at the bottom contains slag and rust forming a 'centre of bending'. Etching: Nital. 60 x.

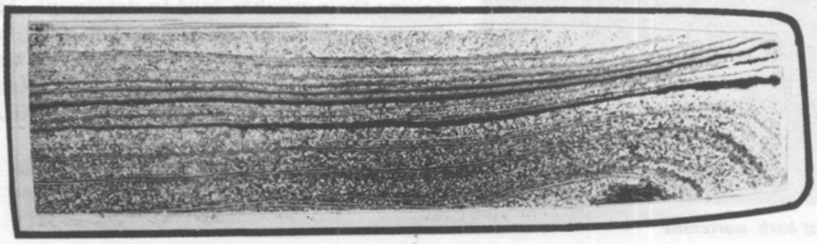
(b) The dark spot in fig. 29a in larger magnification. In the middle there is slag with wustite (light grey) and fayalite (dark grey) surrounded by rust. At the top metallic areas (white) are seen. 220 x.



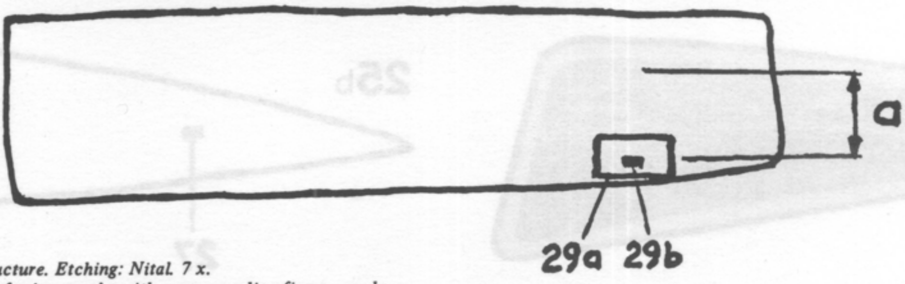
29 a

29 b

28a

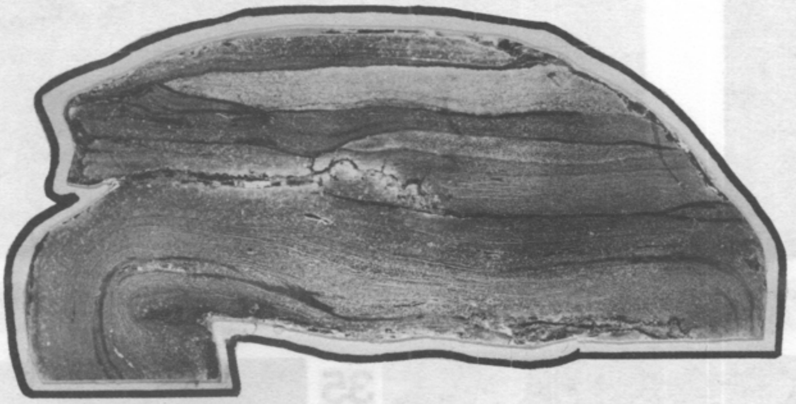


28b

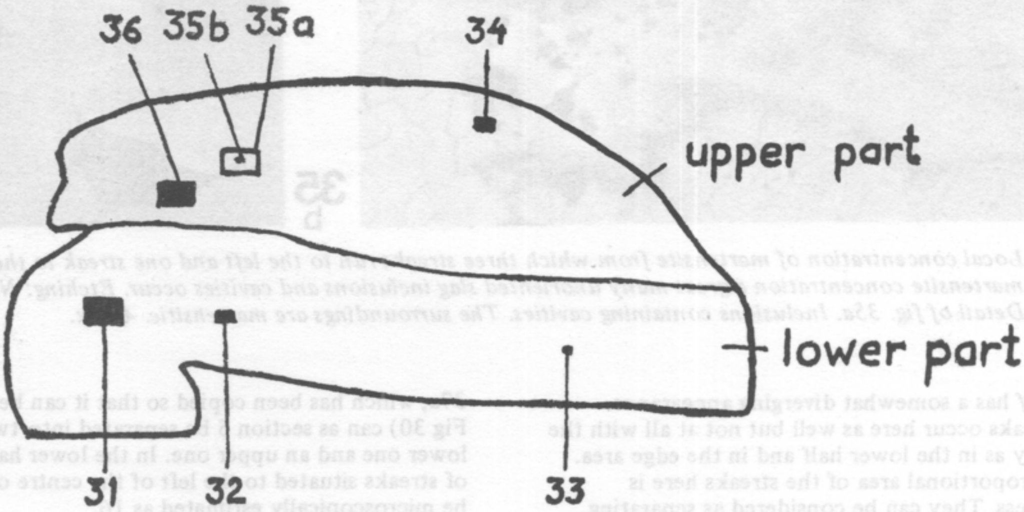


Section 4 (a) Macrostructure. Etching: Nital. 7 x.
(b) Position of micrographs with corresponding figure numbers. (The distance a corresponds to a' in fig. 51:4).

Section 5 (a) Macrostructure. Etching: Nital. 3 x.
(b) The section parted in one upper and one lower half. Position of the micrographs with corresponding numbers.



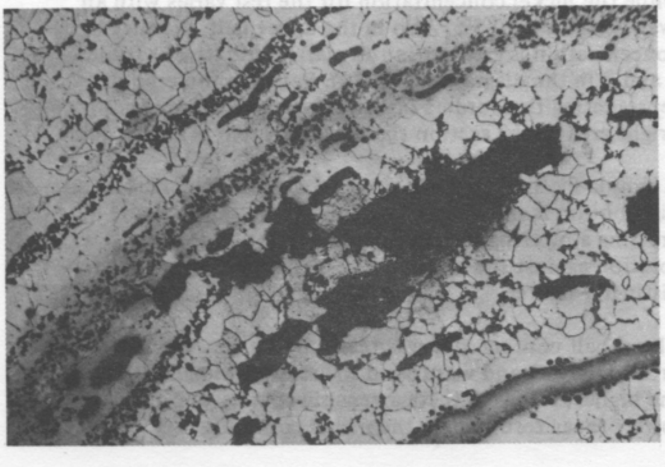
30a



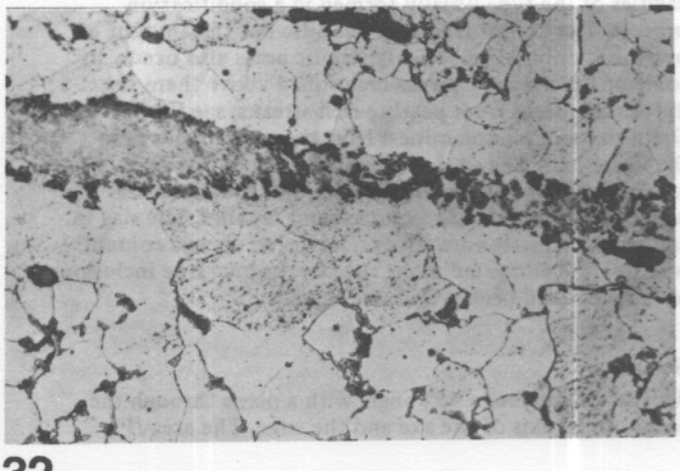
30b

Section 5. 'Bent' streaks with pearlite and ferrite, in three of them there is martensite as well. Large slag inclusions without stretched orientation occur. Etching: Nital. 80 x.

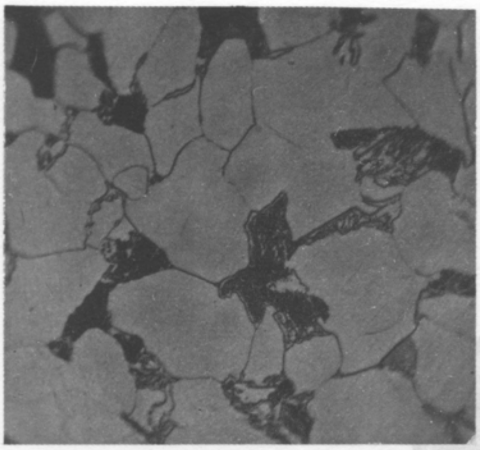
31



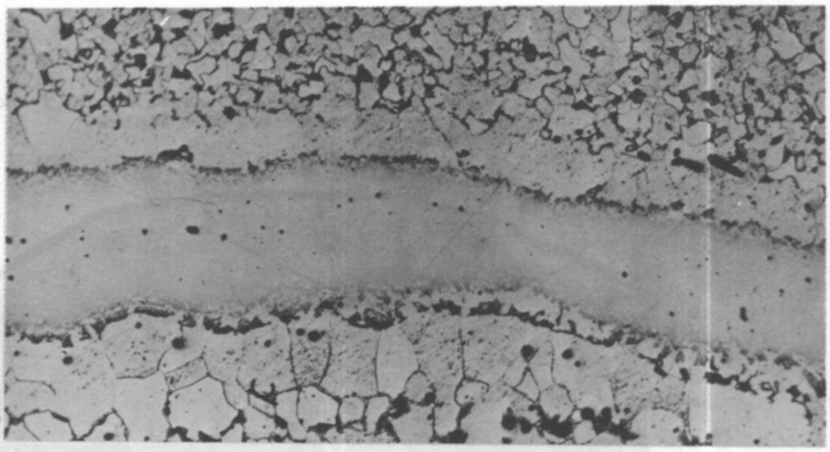
Section 5. Streak with martensite to the left, ferrite and pearlite to the right. Etching: Nital. 220 x.



32



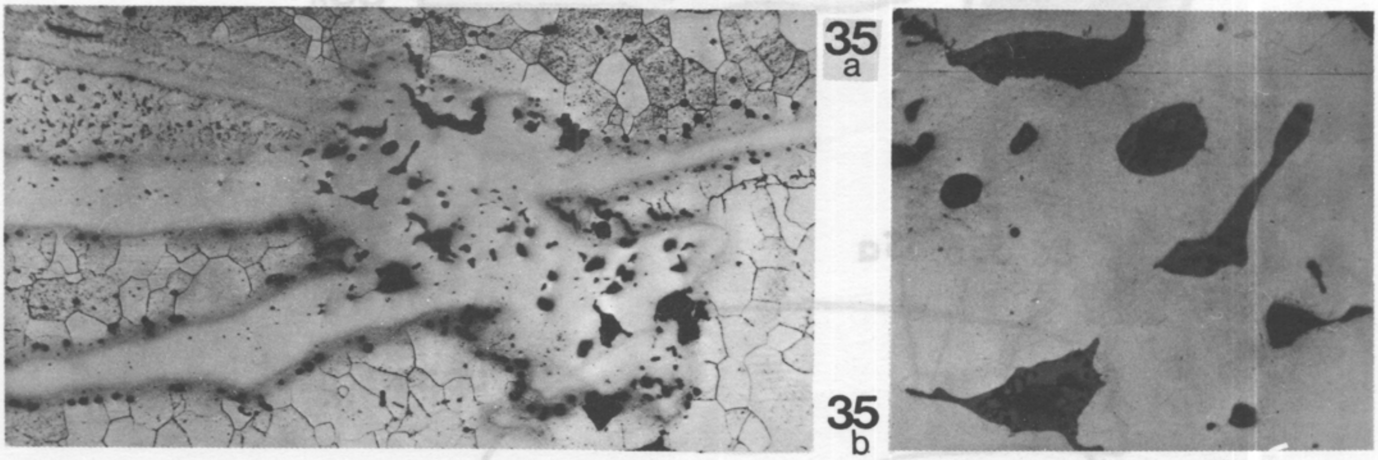
33



34

Section 5. Matrix structure of ferrite and fine lamellar pearlite. Etching: Nital. 950 x.

Section 5. Martensite streak of 0,12 mm thickness. Matrix of ferrite and pearlite. Etching: Nital. 160 x.



35 a

35 b

Section 5. (a) Local concentration of martensite from which three streaks run to the left and one streak to the right. In the martensite concentration a great many unoriented slag inclusions and cavities occur. Etching: Nital. 80 x.
(b) Detail of fig. 35a. Inclusions containing cavities. The surroundings are martensitic. 400 x.

The upper half has a somewhat diverging appearance. Certainly, streaks occur here as well but not at all with the same regularity as in the lower half and in the edge area. Besides, the proportional area of the streaks here is considerably less. They can be considered as separating this half into 6 or 7 irregularly formed pieces.

The streaks consist of martensite (Fig 34) but also of pearlite and ferrite. In some places concentrations of martensite occur from which streaks run in different directions, see Fig 35. In the martensite, slag occurs with cavities of the type usually formed in a solidification process. The matrix is ferritic-pearlitic but the amount of pearlite is only 2-10%. Highly ferritic areas also occur. In some of the irregular pieces mentioned above there is a diffuse stripiness from pearlite-rich streaks, see Fig 36. Grain size and microhardness have the same values as in the lower half. The slag of the matrix is elongated in the longitudinal direction of the section but usually misses the wüstite and consists of silica glass and fayalite. The slag in and near the martensite streaks, however, always contain wüstite. It is elongated along the streaks but large inclusions have no defined orientation, see Fig 35.

Section 6
This section makes a 45° angle with a plane through the longitudinal axis of the axe and the edge. The area (Fig 37a, which has been copied so that it can be compared to Fig 30) can as section 5 be separated into two halves, a lower one and an upper one. In the lower half the number of streaks situated to the left of the centre of bending can be microscopically estimated as 16.

An examination by an electron microprobe analyser was made along two lines perpendicular to each other, see Fig 37b. In the lower half of the section the nickel content reaches maximally 5.5% in the martensitic streaks. The diffuse streaks of ferrite and pearlite have about 1.6% Ni, while the nickel concentration for the rest varies with an average value of 0.5%. Also in the upper half, the nickel concentration is greatest in the martensitic streaks (points 1 and 2 in the diagram in Fig 38). Between these points representing the borders of the almost triangle-shaped, bright area of the section the nickel content is almost nil.

A simple method to qualitatively determine the nickel distribution is shown in Fig 39 which is a 'print' made by pressing a blotting-paper dipped in dimethyl-glyoxim solution against the section. The nickel-poor area appears distinctly lighter.

The cobalt content also was tested by an electron microprobe analyser and was found to reach maximally 0.4% the highest values in the martensitic streaks and the lowest (near zero) where the nickel concentration is low.

Section 7

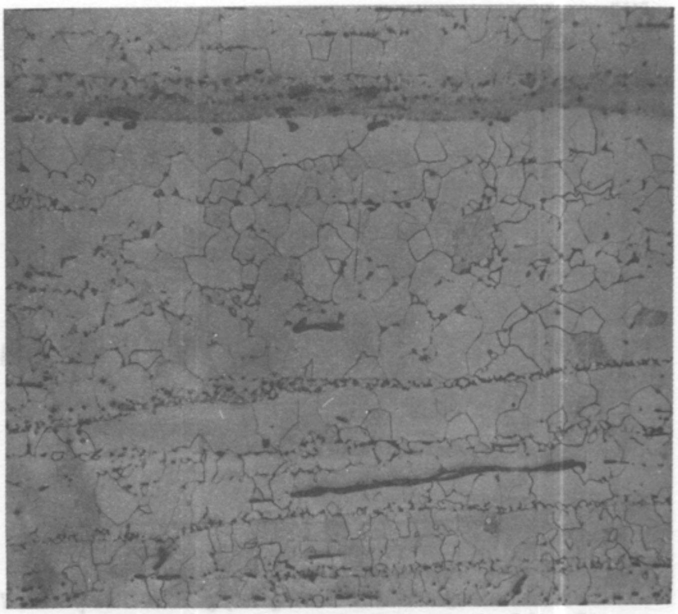
This is in the same plane as Section 5. In the lower part of the section (Fig 40a) there are strongly bent streaks of martensite (Fig 41). The area G (Fig 40b) is almost pure ferrite but there are also diffuse streaks of pearlite and ferrite. In the area H there are distinct streaks of pearlite and ferrite, as in area J where there are also streaks of martensite. Near the upper right corner (area J) the streaks are bent around a concentration of slag and rust but the streaks continue on both sides of it in an unchanged direction (Fig 40a).

The number of streaks in area J is probably 16, while in area G the number is impossible to estimate. In area H the number of streaks is also difficult to determine but a reasonable figure may be 8.

The matrix of the section contains ferrite and pearlite, the latter phase occupying 5-10%.

The slag in Section 7 has mainly the same appearance as in Section 5. An example is shown in Fig 42.

36

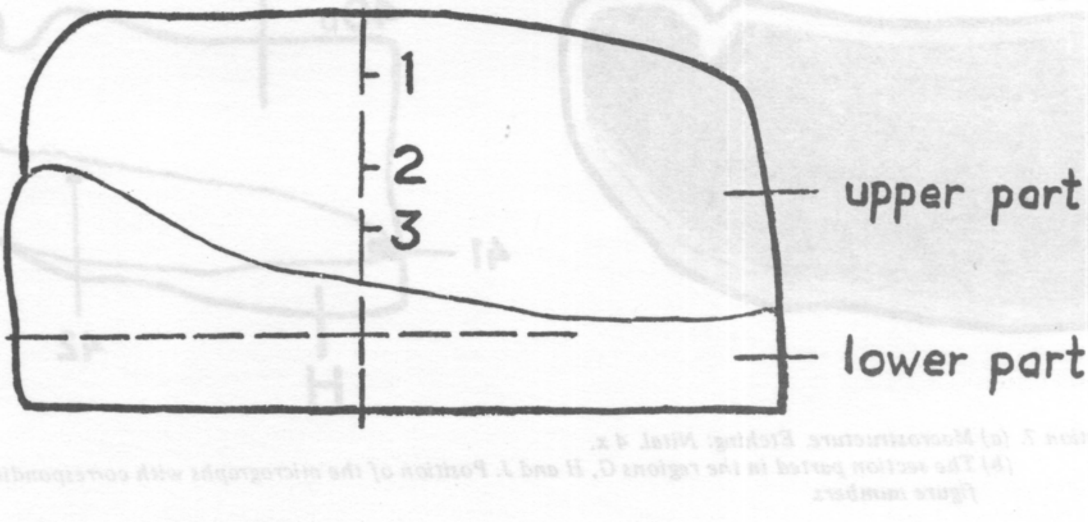


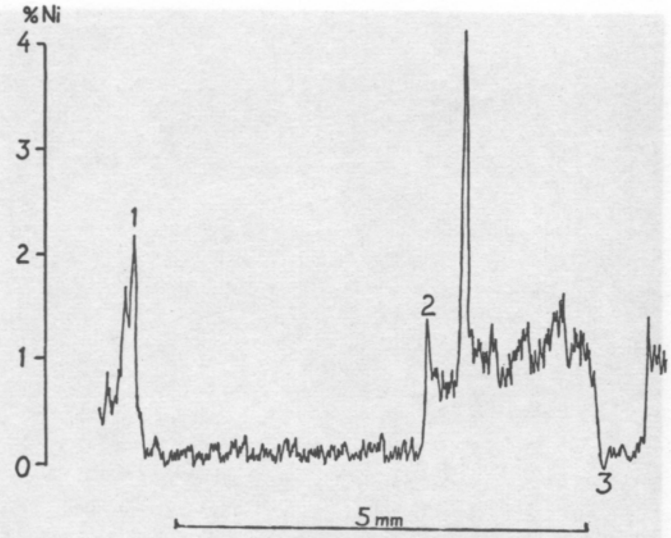
Section 5. Martensitic streak (at the top) and a number of thin diffuse pearlite-ferrite-streaks (at the bottom). Stretched slag inclusions occur. Etching: Nital. 80 x.

37a

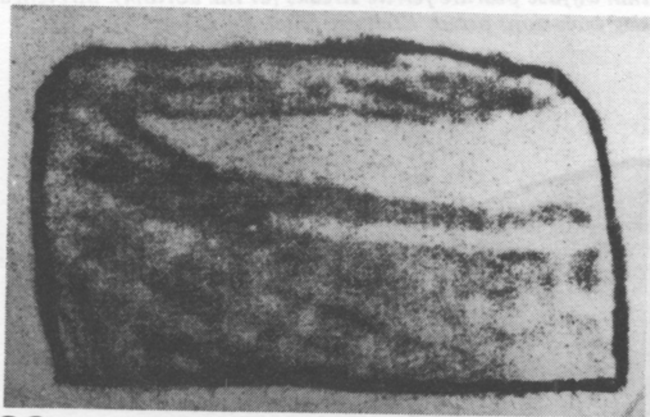
Section 6. (a) Macrostructure. Etching: Nital. 3 x.
(b) Lines for test with electron microprobe analyser. (The figures refer to the diagram in fig. 38).

37b

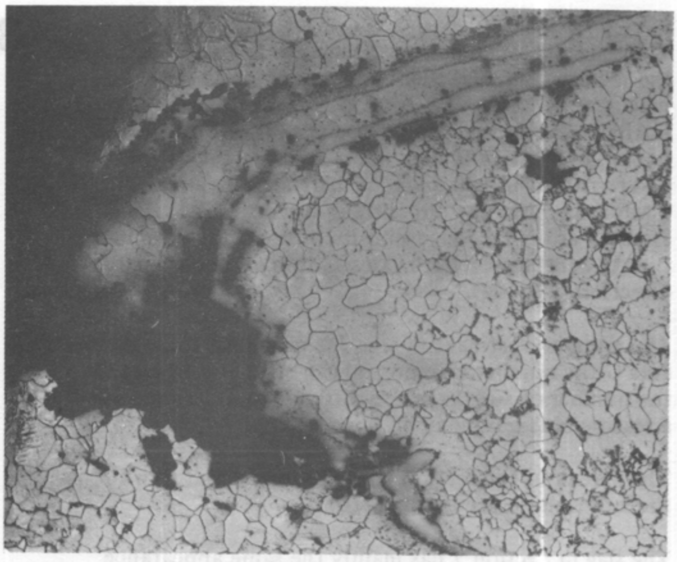




38 *Test with electron microprobe analyser of the nickel content along a line according to fig. 37b. The points 1, 2 and 3 are also to be found in the diagram.*



39 *'Nickel print' with dimethylglyoxim. (Areas containing nickel look dark).*



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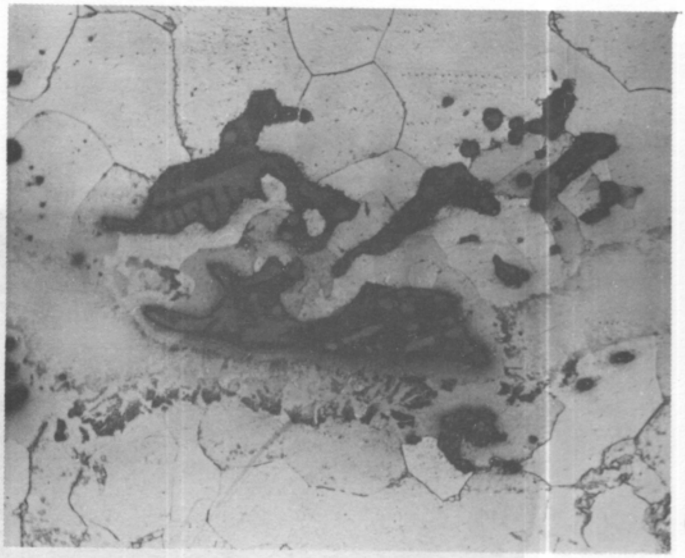
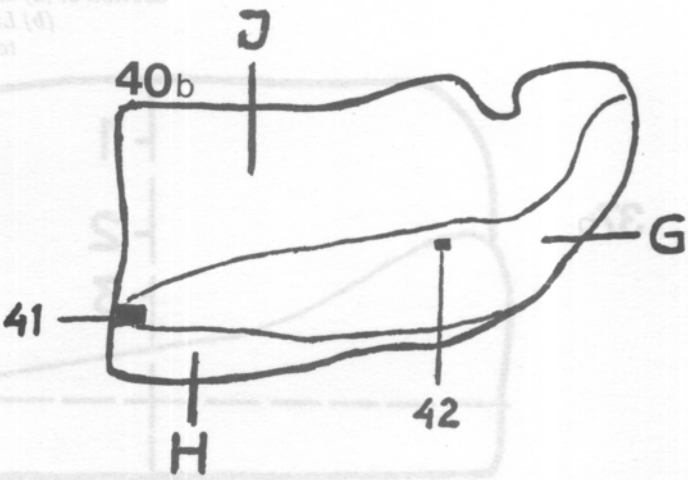


42

40a

40b



Section 7. (a) Macrostructure. Etching: Nital. 4 x.
(b) The section parted in the regions G, H and J. Position of the micrographs with corresponding figure numbers.

Section 8

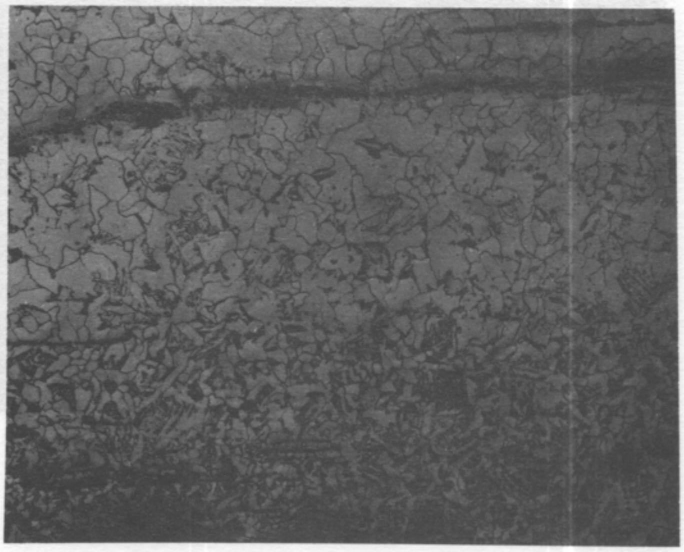
This section is from the end of the socket. It has much the same appearance as the upper halves of the sections 5 and 6, ie. the section consists of a number of pieces, separated by streaks (Fig 43). The structure of the matrix is in the core of the section almost quite ferritic but near the long edges the amount of pearlite increases and so does the carbon content (Fig 44). A distinct tendency to widmannstatten-structure can be seen here. The ferrite in Fig 45 is heavily cold deformed. The macro-appearance (Fig 43a) shows how the streaks are bent through 180^{O} at the left end of the section.

The slag inclusions are in general wüstite-rich and elongated. They occur mainly near to and in the streaks of martensite. In Fig 46 a large inclusion is seen consisting only of silicate glass.

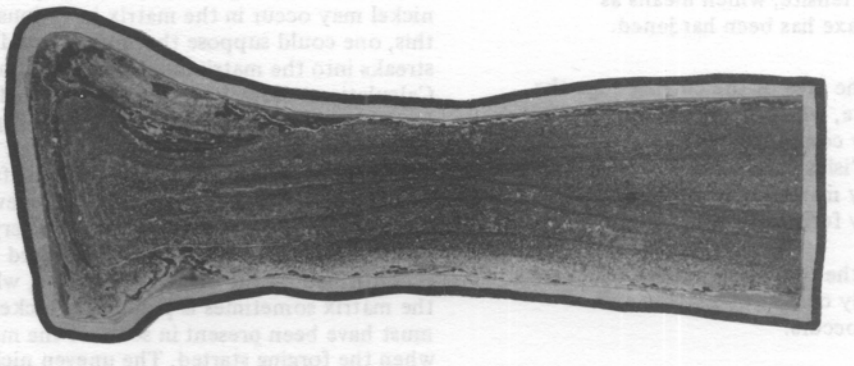
41 *Section 7. Two martensitic streaks one of which being sharply bent. Etching: Nital. 60 x.*

42 *Section 7. Large slag inclusions without defined orientation containing dendrites of wustite in silica glass. In the surroundings martensite and ferrite. Etching: Nital. 220 x.*

44



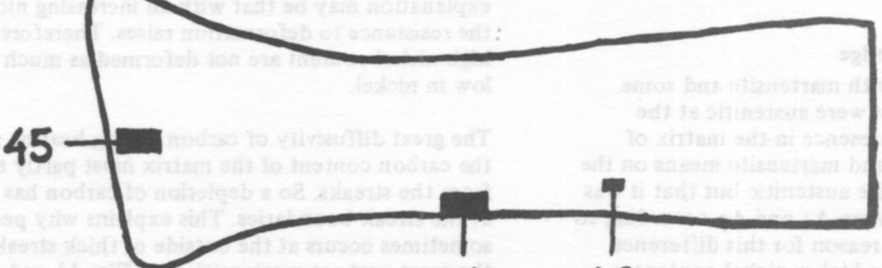
Section 8. Area of ferrite and pearlite. At the top a diffuse, martensitic streak is seen. Etching: Nital. 60 x.



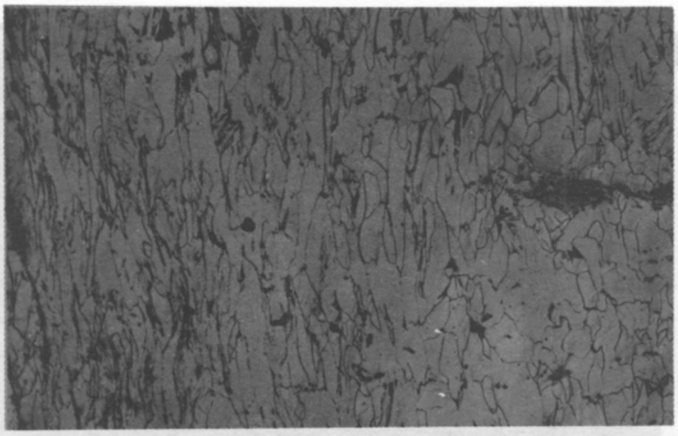
43a

Section 8 (a) Macrostructure. Etching: Nital. 4 x.

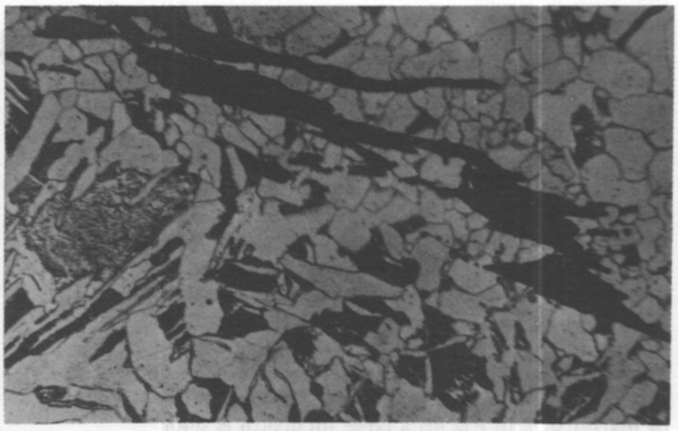
Section 8. (a) Macrostructure. Etching: Nital. 4 x.
(b) Position of the micrographs with corresponding figure numbers.



43b



45 *Section 8. Cold deformed ferrite. Etching: Nital. 60 x.*



46 *Section 8. Slag inclusions consisting of silica glass in a ferrite-pearlite matrix (tendency to Widmannstatten-structure). Etching: Nital. 220 x.*

Discussion of the structural phases

1. Metallic phases

a) General

From the description of the structures in the eight sections it can be seen that in all of them streaks occur in a surrounding matrix. The streak structure and the matrix structure are so different that they must represent two quite different materials, which in one way or another have been welded together.

Every border between these two materials therefore must be a seam. The phases occurring in the examined sections are ferrite, pearlite and martensite, which means as mentioned earlier that the axe has been hardened.

In the four sections from the area of the cutting edge the streaks consist of martensite, which is dominating, and pearlite. The matrix mainly contains ferrite, and the rest grains of pearlite with 'isles' of martensite. Near the edge the structure is mainly martensitic but with some pearlite and grain-boundary ferrite.

In the three sections from the transition between socket and blade the streaks mainly consist of pearlite and ferrite but martensite also occurs.

The matrix is almost entirely ferritic but with some pearlite.

The section from the end of the socket shows, in general, the same structural pattern as in the transition between socket and blade.

b) In the area of the cutting edge

The structure of the streaks with martensite and some pearlite means that the streaks were austenitic at the hardening temperature. The presence in the matrix of ferrite together with pearlite and martensite means on the other hand that it was not quite austenitic but that it was in the temperature range between A_1 and A_3 according to the equilibrium diagram. The reason for this difference must be that the streaks have a higher nickel content (1.3-6.9%) than the matrix (0-1.0%). An increasing nickel content decreases the transformation temperature. The higher carbon content of the streaks, which was estimated at about 0.4%, compared to that of the matrix which from the amount of pearlite was estimated as 0.2%, acts in the same way.

Pearlite appears especially where the streaks are thin (see Fig 11). In such places the nickel content is lower than for the rest of the streaks and this circumstance must favour the pearlitic structure. For the formation of martensite the lower the nickel content the greater the rate of quenching.

In this case the rate of quenching obviously was not sufficient to get martensitic areas in the streaks below a certain nickel content. Instead, the structure there was pearlitic.

We have found that the nickel content varies considerably in the streaks being lowest where they are thin. Also some nickel may occur in the matrix in various amounts. From this, one could suppose that nickel had diffused from the streaks into the matrix during heating for forging. Calculations show, however, that the diffusion constant for Ni in austenite is very low. For example, compared to carbon, the constant for Ni is more than 10,000 times less than that for C. That means that the diffusion distance for Ni will be very short. Therefore, the uneven distribution of nickel in the streaks as well as the very existence of of nickel in the matrix cannot be caused by diffusion. This is confirmed by the diagram in Fig 17, which shows that the matrix sometimes is practically nickel-free. So nickel must have been present in some of the matrix material when the forging started. The uneven nickel distribution in the streak material also must have existed from the beginning.

Why are then the streaks thickest where the nickel content is high and thinnest where it is low? The explanation may be that with an increasing nickel content the resistance to deformation raises. Therefore streaks with high nickel content are not deformed as much as those low in nickel.

The great diffusivity of carbon during heating means that the carbon content of the matrix must partly emanate from the streaks. So a depletion of carbon has taken place at the streak boundaries. This explains why pearlite sometimes occurs at the outside of thick streaks which for the most part are martensitic (see Figs 11 and 12). In nickel steel a greater rate of quenching is required to get a martensitic structure with decreasing carbon content. Where the streaks are thin the depletion of carbon is considerably greater which favours the formation of pearlite.

The area near the edge, with a structure of martensite with some grain boundary ferrite and pearlite (see Figs 14 and 27), was obviously fully austenitic when heated for hardening. The thin edge had then got to a higher temperature that the rest of the blade and therefore the structural difference between streaks and matrix was eliminated. The existence of grain boundary ferrite may mean that there was a certain delay before quenching in the coolant.

Two factors may have favoured an equalization of the differences in carbon content between streaks and matrix near the edge before hardening. Firstly, the distance between the converging streaks decreases in the direction to the edge. Secondly, the edge has been exposed to longer heating time at high temperature during heating and forging that the rest of the blade. This is caused both by the smaller dimensions of the edge and the fact that it probably required some more heating to get it into shape than the rest of the blade.

c) In the transition zone between socket and blade

Here also the streaks are nickel-rich, containing martensite, pearlite and ferrite (Fig 32) which means that the quenching was slower due to the thicker material than that at the cutting edge. The carbon content of the streaks can be estimated from the structure at about 0.4%.

The amount offerrite in the matrix is greaterthan in the area of the edge, probably because the streaks here are so few that the diffusion of carbon from them could influence the carbon content of the matrix only very little. It varies up to about 0.1%.

d) In the socket

In section 8 there are the same phases as in the transition between socket and blade. Also, in some ares differences occur, such as a tendency towards the Widmannstatten-structure, cementite in the ferrite grain boundaries, coarse grains and cold deformed ferrite. This means a somewhat different heating regime at the end of the socket than in the transition between socket and blade, probably because this part of the socket did not reach the hardening temperature. So the coarse 'forging structure' remains locally. The cold deformation effect probably does not originate from the manufacturing process, but may be a later influence, ie. it occurred when changing the handle.

2. Slag Phases

The type of slag dominating in all sections consists of a silicate glass matrix with no precipitation of crystals of wüstite and fayalite (see Figs 18 and 42). The silicate glass was plastic at the forging temperature or even in a molten condition. The fayalite can also form angular, large crystals in the larger inclusions.

This type of slag is common in inclusions occurring in welding seams. In general, during forge welding, two pieces are heated surface to surface. Then scale is formed on the surfaces consisting of solid iron oxides which would prevent welding if sand (SiO_2) were not added. SiO_2 forms a liquid slag with the iron oxides which, during the following forging, is more or less forced out of the joint. Such slag occurs frequently in the axe. Usually it is located in the boundary areas between streaks and matrix (see Figs 9 and 19). The criterion of fusion is the existence of dendrites of wüstite (Fig 42) and crystals of fayalite.

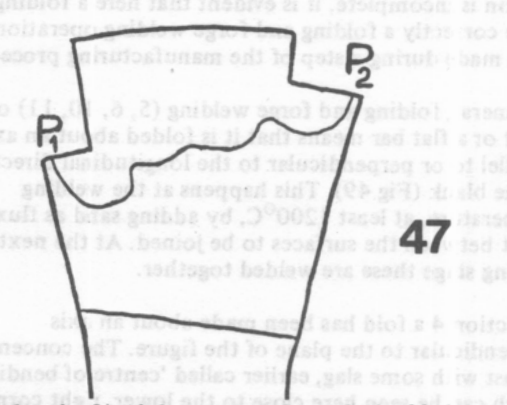
There is, however, also some slag of another appearance not occurring as stringers. Fig 46 from section 8 shows such an inclusion consisting only of silicate glass. This type of slag must be considered as emanating from the ore reduction process.

In general the inclusions due to the forging operations are elongated (see Figs 19 and 20). Exceptions are some large slag inclusions in the transition zone between socket and blade, which are often without orientation, (see for example Fig 42), because the forging reduction here was so small.

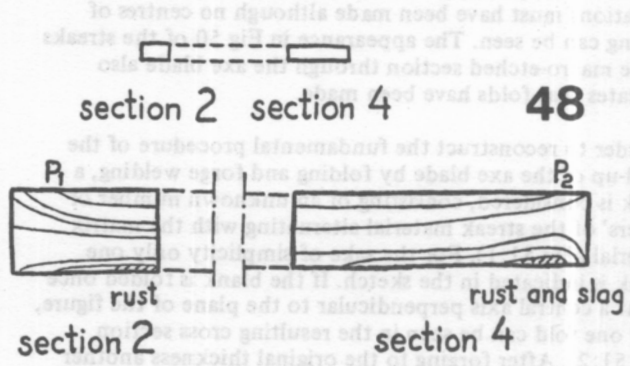
The build-up and manufacturing of the blade

1. Structure and build-up of the edge

It is obvious that the streak material occurs as thin slivers in the whole edge area. In Fig 47 which shows a sketch of the macro-etched section through the blade (compare Figs 4 and 5) it is possible to see how a streak runs from one corner (P_1 in section 2) to the other (P_2 in section 4). In Fig 48 the sketches of the etched sections 2 and 4 (compare Figs 21a and 28a) show the position of the streak P_1 - P_2.



Sketch (after fig 5) of the section through the blade showing that the points P_1 and P_2 belong to the same streak.



(a) Cross sections 2 and 4 indicated in a 'section' of blade.
(b) The main appearance of the streaks in the sections 2 and 4 (comp. fig. 21 and 28). P_1 and P_2 belong to the same streak.

So the cutting edge is built up in layers by two different materials, alternatively welded together, raising the question: Which manufacturing method was used? It is perhaps easiest to think of the blade as being fabricated by piling a number of 'sheets' of the two materials and then forging this 'parcel' to the desired thickness. This, however, would be impossible, because it means an absurdly thick 'parcel' to start with. It must be remembered that the smallest possible thickness of a 'sheet' manufactured by hand-forging could hardly be less than 2 mm. That means that, for example, a 20 microns thick streak would have undergone a hundredfold linear reduction during forging. Thus, the part of the blade section visible in Fig 48 would at the beginning have had a thickness of as much as 400 mm, ie. a totally unrealistic thickness for manual forging.

Another method must have been used. In order to explain this, a reconstruction of the appearance of the whole blade section in the area of the edge will be made. From this starting-point the manufacturing procedure will be discussed.

In Fig 48 sections 2 and 4 have been placed as part of one cross section of the blade. The two parts are certainly not in exactly the same plane and also not in quite parallel planes but that does not influence the following discussion. At first it is observed that in all the four outermost corners the streaks bend against the long-sides. This is most distinct in section 4 at the lower, right corner where the streaks bend 90°. In spite of the fact, that the section is incomplete, it is evident that here a folding, or more correctly a folding and forge welding operation, has been made during a step of the manufacturing procedure.

In general, folding and forge welding (5, 6, 10, 11) of a sheet or a flat bar means that it is folded about an axis parallel to or perpendicular to the longitudinal direction of the blank (Fig 49). This happens at the welding temperature, at least $1200^{\circ}C$, by adding sand as fluxing agent between the surfaces to be joined. At the next forging stage these are welded together.

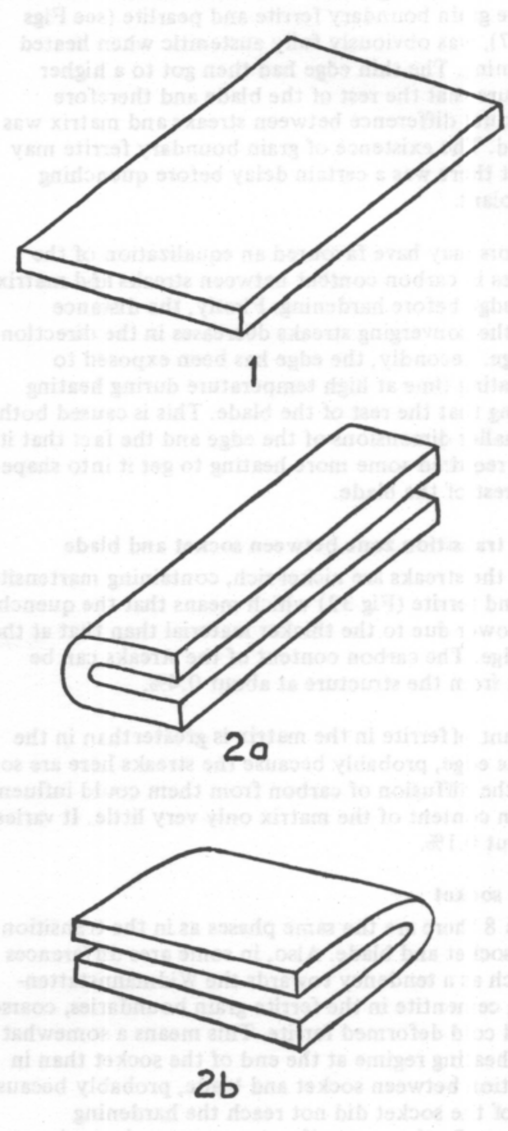
In section 4 a fold has been made about an axis perpendicular to the plane of the figure. The concentration of rust with some slag, earlier called 'centre of bending', which can be seen here close to the lower, right corner (Fig 28 and 29) certainly forms a 'centre of folding'.

Also at the three other corners (Fig 48) the texture shows that the corresponding folding and forge welding operations must have been made although no centres of folding can be seen. The appearance in Fig 50 of the streaks in the macro-etched section through the axe blade also indicates that folds have been made.

In order to reconstruct the fundamental procedure of the build-up of the axe blade by folding and forge welding, a blank is considered, consisting of an unknown number of 'slivers' of the streak material alternating with the matrix material (Fig 51:1). For the sake of simplicity only one streak is indicated in the sketch. If the blank is folded once about a central axis perpendicular to the plane of the figure, only one fold can be seen in the resulting cross section (Fig 51:2). After forging to the original thickness another fold about the longitudinal axis gives the appearance shown in Fig 51:3 with a centre of folding at each of the short-sides. One more fold, but this time perpendicular to the longitudinal direction, gives a cross section as in Fig 51:4. The appearance of the streaks here agrees with Fig 48b, which however, only includes a quarter of the thickness of the whole cross section, see Fig 52. In this figure it is evident that the streaks in both section 2 and section 4 are bent against the longsides of the section.

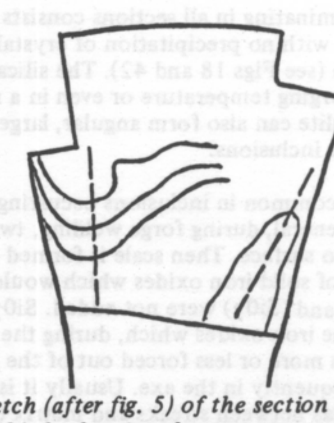
In the axe the thickness of the two sections are 4.0 and 3.6 mm respectively. That means that the thickness of the blade about 20 mm from the edge should be approximately 12-14 mm, a value which reference to Fig 2 shows to be reasonable.

49

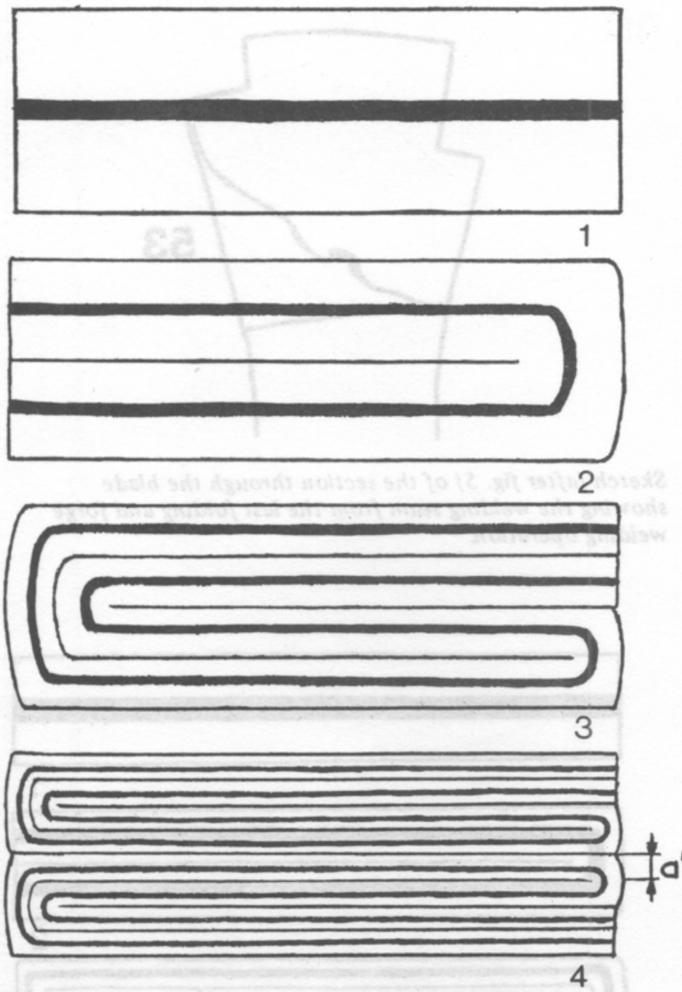


Principal sketch of folding a sheet or flat bar (1) about a central axis partly in longitudinal direction (2a) partly in transverse direction (2b).

50



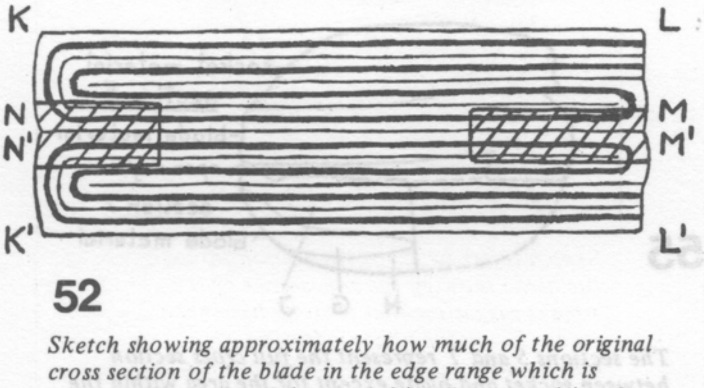
Sketch (after fig. 5) of the section through the blade showing the appearance of the streaks suggesting that foldings have been made. The dashed lines indicate approximate positions of the horizontal projections of two axes of folding.



51

Principal procedure of manufacturing the blade by folding and forge welding.

1. *Cross section of the blade blank with streaks of hard material in soft matrix. For the sake of clearness only one streak is shown.*
2. *The section after folding the blank about a central axis in longitudinal direction followed by welding and forging.*
3. *The section after one more folding about the longitudinal axis (but in the opposite direction according to (2)) followed by welding and forging.*
4. *The section after folding about an axis in the transverse direction of the blank follwed by welding and forging. (Within the distance a' there is the same number of streaks as in the blade blank according to (1) above).*



52

Sketch showing approximately how much of the original cross section of the blade in the edge range which is occupied by section 2 (to the left) and section 4 (to the right) (areas marked with lines).

The fact that no traces of the last folding can be seen in any of the few visible streaks near the point of sections 1 and 3 (Fig 6a and 25a) must be due to a later grinding of the edge.

The whole cross section can be considered as consisting of the two half-sections KLMN and K'L'M'N' (Fig 52). It is also possible to observe the joint between the half-sections running obliquely over this surface (Fig 53).

But how many layers of the material forming the hard streaks was used in the blade blank, from which the above described folding and forge welding procedure started? The structural examination showed that slag mainly occurs in the borders between the hard streaks and the soft matrix, as well as in the matrix itself (Fig 19 and 20). As mentioned earlier it is very probable that such slag lies in welding seams. On the other hand slag of this type does not occur in the streaks. The simplest way to obtain the slag distribution found here would be to use a starting blank consisting of one piece of the hard material surrounded by two pieces of the soft material, see Fig 54:1. By making several folding and forge welding operations with such a blank there will be different numbers of layers of the two materials as is shown in Table 2. The slag stringers will then always occur in the boundaries between the streak and the matrix or in the middle of the latter as in Figs 19 and 20.

Table 2 Numbers of folding and forge welding operations and layers formed by the method shown in Fig 54.

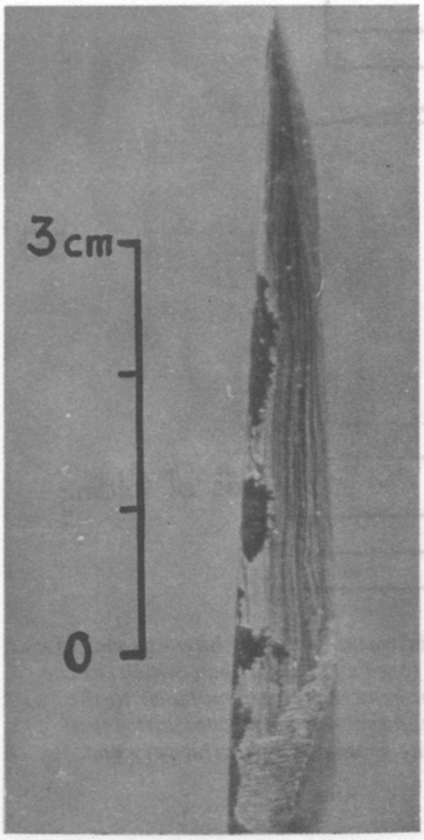
Number of operations	1	2	3	4	5
Number of hard layers	2	4	8	16	32
Number of soft layers	4	8	16	32	64
Total number of layers	6	12	24	48	96

The whole cross section as shown in Fig 51:4 will contain 8 times the number of streaks occurring in the blank of Fig 51:1. This hitherto unknown number of streaks occurs for example within the distance a' in Fig 51:4, which must correspond to the distance a in Fig 28b. With the microscope it is possible within this distance to observe 8 streaks, which according to Table 2 corresponds to 8 layers of the hard material, meaning that the blank must have been fabricated by 3 folding and forge welding operations.

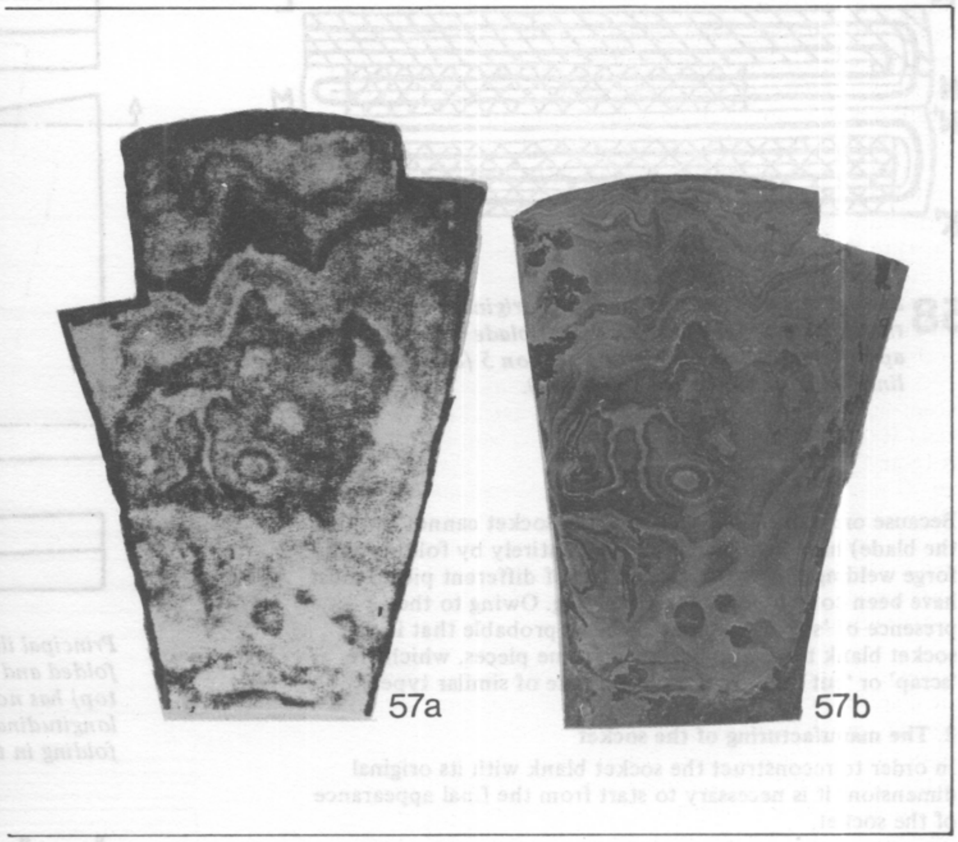
So the blade has been manufactured in two steps, firstly the fabrication of the blank by 3 folding and forge welding operations and then the blade fabrication by 3 more folding and forge welding operations. This means that the axe blade contains 8 x 8 = 64 layers of hard material while the matrix consists of double the number or 128 layers of soft material.

2. Structure and build-up in the transition region between socket and blade

The sections 5 (Fig 30) and 7 (Fig 40) make together an incomplete cross section of the axe in the transition between socket and blade, see Fig 55 (comp. also Fig 4). According to the structural description, the lower half of section 5 as well as section 7 have the same appearance as the sections in the area of the edge ie. with many streaks and the matrix material. So they belong to the blade material, which therefore must run from the edge to the beginning of the socket. So the whole blade throughout consists of 'slivers' of the hard nickel-rich material surrounded by the soft material as is seen in Fig 56.



56 *Part of the blade near to the edge, ground and etched. The stripy appearance comes from the streak structure. (Dark spots indicate areas not affected by grinding). The picture is taken from the report by H & M (2).*



57 *(a) 'Nickel print' of one side of the axe blade (comp. fig. 39).*
(b) The same side after macroetching (before the sections 1 and 2 were cut out. Fig. 3 shows the opposite side (comp. fig. 4). The picture is taken from the report by H & M (2).

absence of the fourth one is due to the loss of material by sampling for chemical analysis.

3. The manufacturing of the blade

Hitherto only the basic build-up of the blade has been discussed. To be able to calculate probable original dimensions of the blade blank it is necessary to take account of the distribution of the two materials in a blade cross section. The average thickness of the streaks in section 2 was found to be 18 microns from which it can be calculated that the streak material occupies about 9% of the section area.

By using nickel-rich material of 2 mm thickness surrounded by two soft pieces of 10 mm thickness, the resulting blank of 22 mm has 9% of the hard material. Such a blank is certainly suitable for manual forging as illustrated by Figs 62 and 54. Assuming a width of 30 mm and a length of 150 mm as suitable blank dimensions, the cross section will be 22 x 30 mm (see Fig 62:1). If, during the forging, the blank was not notched before folding, the thickness could not have exceeded more than about 6 mm. This thickness and an elongation of about 50 mm will result in a forged width of about 80 mm, which was also the final blade dimensions, (see Fig 62:2). After this,folding was made about a central axis perpendicular to the longitudinal direction, followed by welding and a new forging to the same dimensions (6 x 80 x 200 mm), (see Fig 62:3 and 4).

There were now 2 streaks of nickel-rich material in the section and by repeating the folding and forge welding procedure twice,the number of streaks was increased to 8.

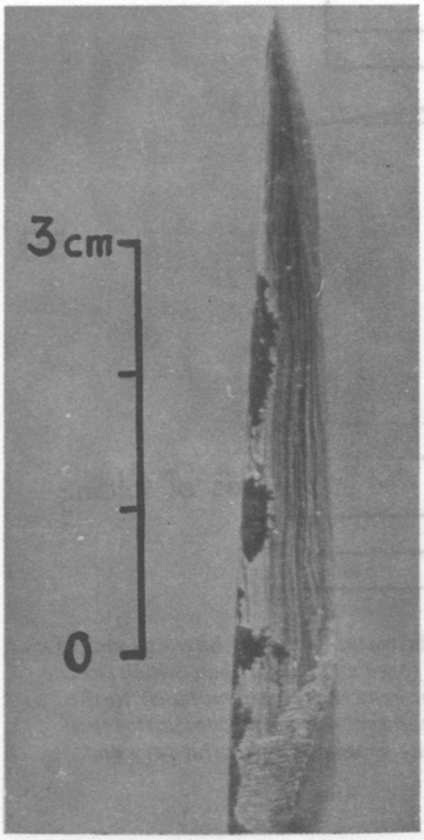
Probably some material was cut off at the two ends of the bar to adjust its size. In this way the traces of the foldings may have been lost so that the final bar texture consisted entirely of parallel layers. The bar manufactured in this way would have been sufficient for making two axes.

It can be considered that the blade blank had the dimensions of 6 x 80 x 100 mm according to Fig 63:1 and its cross section would then correspond to Fig 51:1 in the diagram of the build-up of the blade blank. A fold was made about a longitudinal axis in the middle of the blank (Fig 63:2), followed by forging according to Fig 63:3. The cross section then had 16 streaks and corresponds to Fig 51:2. One more fold about the longitudinal axis was then made but in the opposite direction (Fig 51:3). At one end (the transition to the socket), however, no welding took place, while the rest of the bar was welded and further forged (Fig 63:4). Now the bar had 32 streaks. After that, the middle part was forged down to about 6 mm with some spread and elongation as well (Fig 63:5). The blade got its final shape by folding about an axis perpendicular to the longitudinal direction and forming of the edge (Fig 63:6). The blade now has 64 layers of hard material in a soft matrix (compare Fig 51:4).

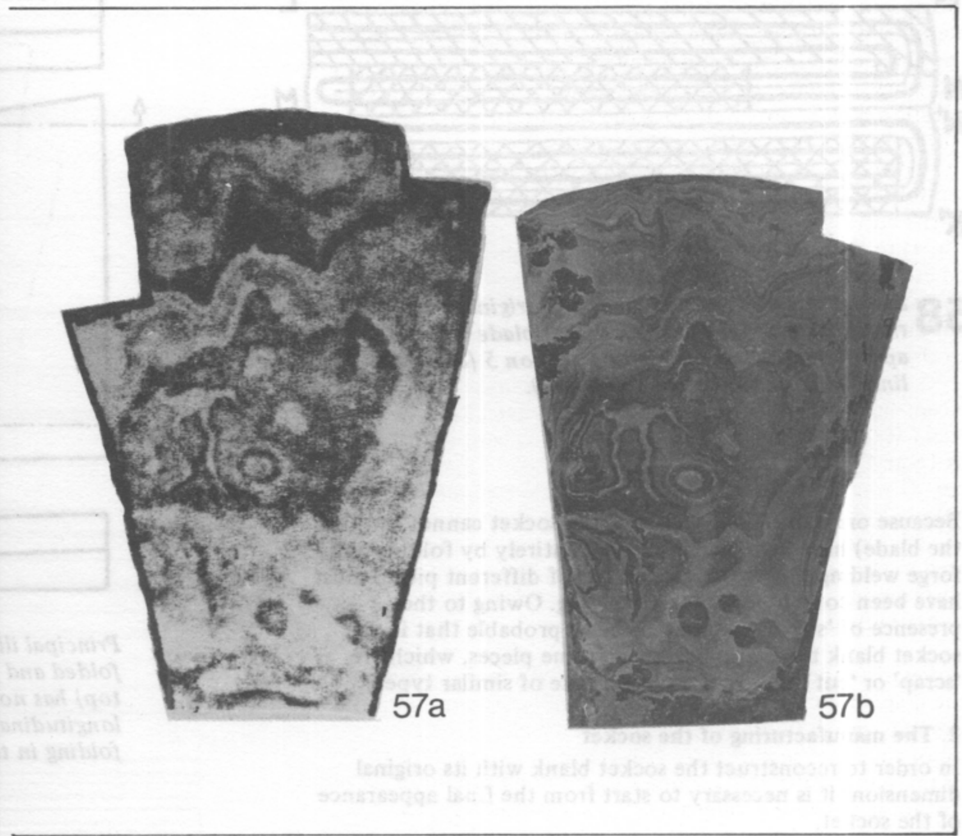
The build-up and manufacturing of the socket

1. Structure and build-up

The texture of the socket occurs in the upper halves of sections 5 and 6 (Fig 30 and 37) for the transition between socket and blade and in section 8 (Fig 43) for the back end of the socket. The socket parts of these sections consist of areas with low carbon content separated by streaks containing martensite and/or ferrite and pearlite.



56 *Part of the blade near to the edge, ground and etched. The stripy appearance comes from the streak structure. (Dark spots indicate areas not affected by grinding). The picture is taken from the report by H & M (2).*



57 *(a) 'Nickel print' of one side of the axe blade (comp. fig. 39).*
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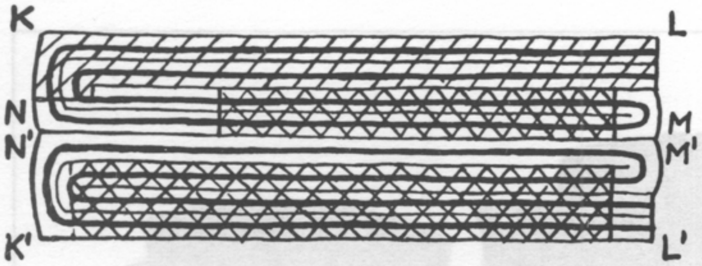
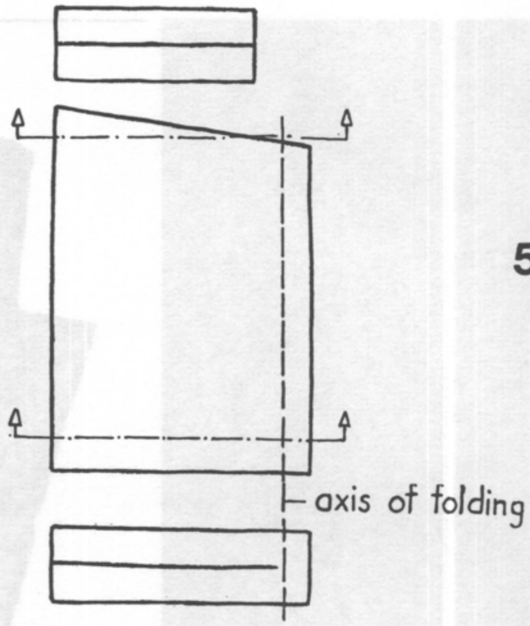
The build-up and manufacturing of the socket

1. Structure and build-up

The texture of the socket occurs in the upper halves of sections 5 and 6 (Fig 30 and 37) for the transition between socket and blade and in section 8 (Fig 43) for the back end of the socket. The socket parts of these sections consist of areas with low carbon content separated by streaks containing martensite and/or ferrite and pearlite.



58 *Sketch showing how much of the original cross section in the transition between socket and blade which approximately is occupied by section 5 (area marked with lines) and section 7 (squared areas).*



59 *Principal illustration showing how one end of a folded and forge welded flat bar, which (at the top) has not been quite perpendicular to the longitudinal direction, may have no traces of folding in the cross section at this very end.*

Because only one fold can be seen the socket cannot (unlike the blade) have been manufactured entirely by folding and forge welding. Before this a number of different pieces must have been combined by forge welding. Owing to the presence of 'streak material' it seems probable that in the socket blank there also have been some pieces, which are 'scrap' or 'cut offs' from an earlier axe of similar type.

2. The manufacturing of the socket

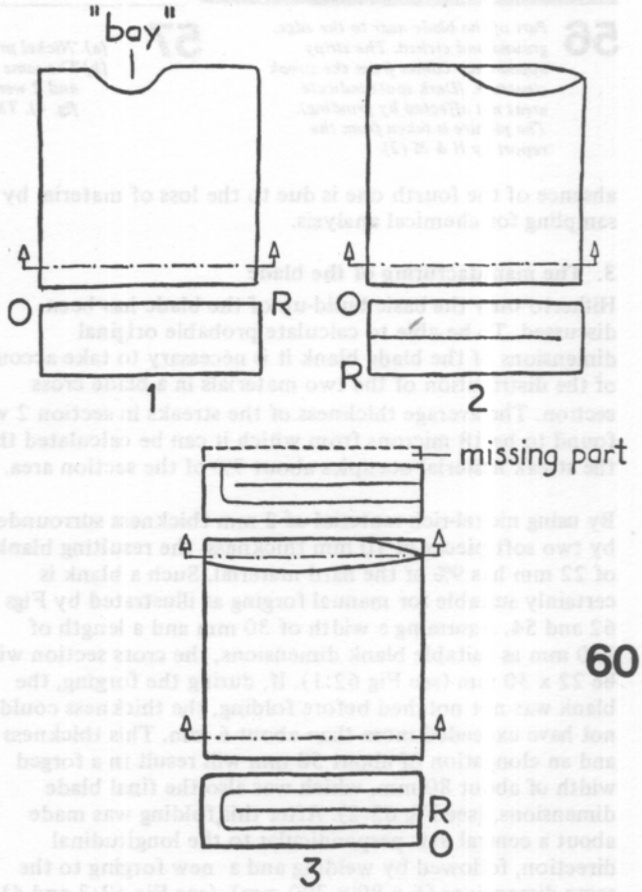
In order to reconstruct the socket blank with its original dimensions it is necessary to start from the final appearance of the socket.

The back end of the socket has a ring-shaped section with an opening (as seen in Fig 2). The greatest thickness, 7 mm, occurs opposite to the opening. From here on the thickness decreases in both directions so as to be almost zero at the opening. The ring shape can be considered as approximately circular (Fig 64) with an average diameter of about 45 mm which means a circumference of about 140 mm. The area of the section will be (140-15). 7/2=440 mm^2, where 15 is the width of the opening.

At the transition between socket and blade the area of the socket material can be estimated as approximately 210 mm^2, ie. less than half the area at the back end of the socket according to section 5 (Fig 30). The outer circumference of the socket near the transition between socket and blade has been estimated as about 110 mm. From section 6 (Fig 37) it is clear that the socket material continues on the upper surface of the blade, see Fig 65.

Assuming that the socket is spread out in a plane it gets the appearance shown in Fig 66, where the thickness values on some spots are estimated. The part of the socket covering the upper surface of the blade forms a 'tongue'. Probably the socket had this appearance before its final forming. From the beginning, the socket blank probably had an even thickness of at least 7 mm. This blank was widened and thinned by forging especially in the back part, while the elongation was small. Probable dimensions of the socket blank are about 7 x 65 x 100 mm, from which a part was cut off from one corner to make the tongue. The welding of the socket tongue to the blade blank (Fig 67) ought to have been made between the steps 3 and 4 in Fig 63.

The manufacture of the socket took comparatively less work than the manufacture of the blade. The smith certainly was conscious of the need for putting more work into the blade than the socket.



60 *Principal illustration showing how a flat bar having a 'bay' at one of the ends after two folding and forge welding operations becomes and incomplete section at this end.*

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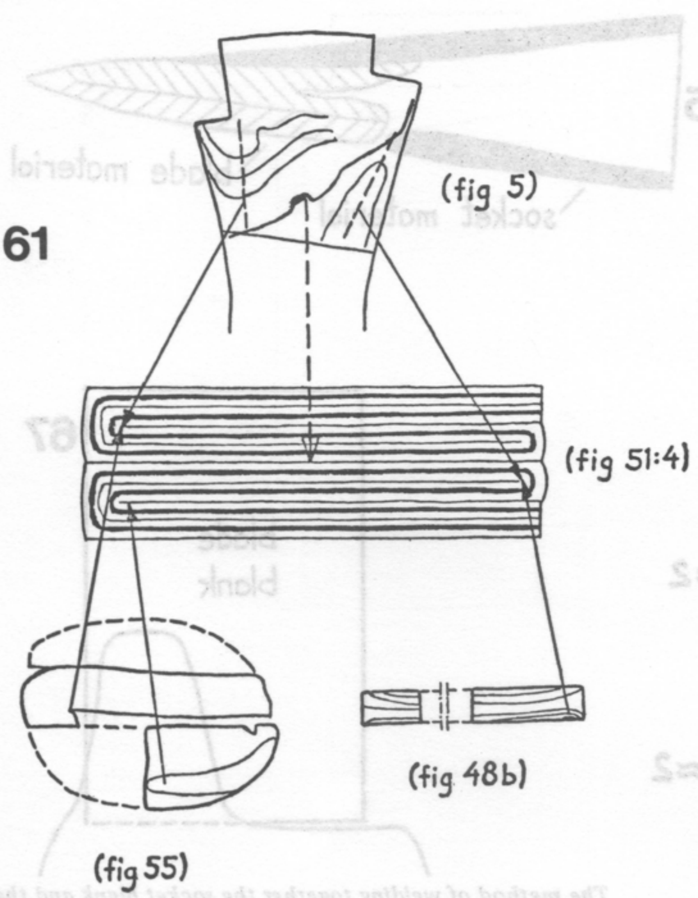
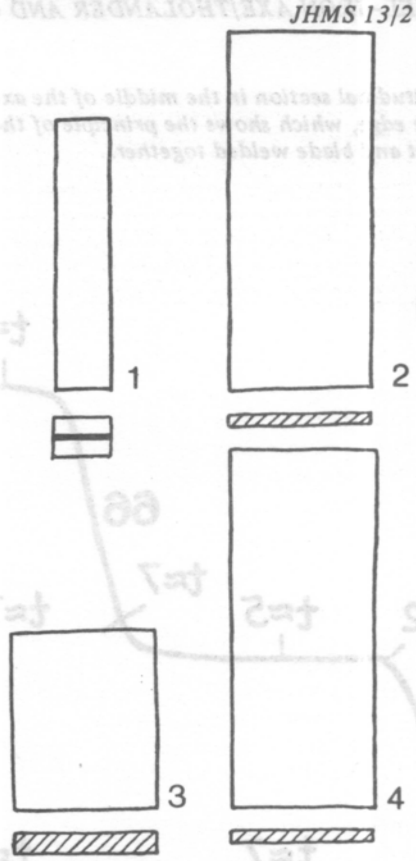


The principal build-up of the blade (in the middle), the section through the blade (at the top), the cross section of the edge range (to the right) and the cross section of the transition between socket and blade (to the left). Foldings are indicated with arrows as well as the seam from the last folding and forge welding (dashed line).

62

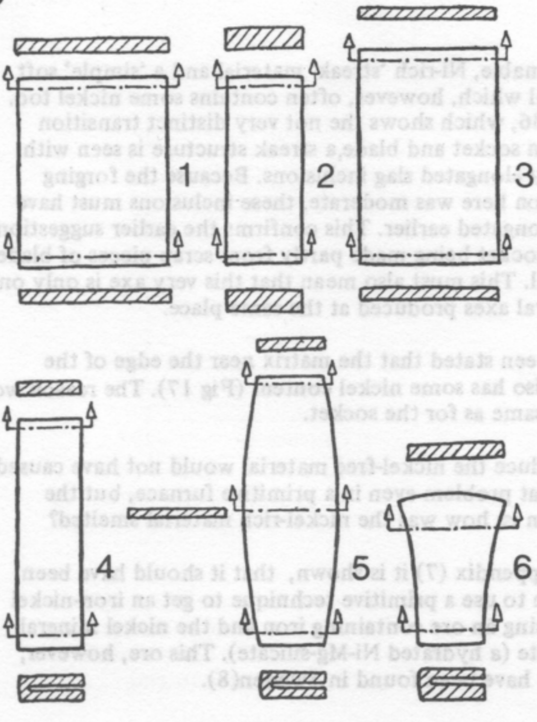


Procedure of the manufacturing of the blade blank.

1. *Piled blank having outer dimensions approximately 22 x 30 x 150 mm. Two bars about 10 mm thick of soft material on both sides of a hard material of about 2 mm thickness.*
2. *After forging to reduce area giving large spread and some elongation. Dimensions about 6 x 80 x 200 mm.*
3. *After folding about a central axis perpendicular to the longitudinal direction. Dimensions about 12 x 80 x 100 mm. The cross section now contains 2 hard layers ('streaks').*
4. *After welding and forging with considerable elongation. Dimensions about 6 x 80 x 200 mm. The cross section still contains 2 hard 'streaks'.*

By repeating the procedure two more times according to (3) and (4) above one gets a flat bar according to (4) but now containing 8 hard streaks in the cross section.

63



Cross section of the back end of the socket, idealized appearance (comp. fig. 2).

Procedure of the manufacturing of the axe blade.

1. *Blank containing 8 parallel layers of hard material surrounded by softer material. Dimensions about 6 x 8 x 100 mm.*
2. *After folding about a central longitudinal axis. Dimensions about 12 x 40 x 100 mm. The cross section now contains 16 hard layers (streaks).*
3. *After welding and forging with considerable spread. Dimensions about 6 x 80 x 100 mm. The number of streaks is unchanged.*
4. *After folding about a central longitudinal axis, partial welding (not at the prospected socket end) and forging with some elongation. The cross section now contains 32 hard streaks.*
5. *After further forging of the middle part with some elongation. The sections of the ends are unchanged. The number of streaks is still 32.*
6. *After folding about a central axis perpendicular to the longitudinal direction, welding and final forging of the axe edge. The cross section of the blade now contains 64 hard streaks.*

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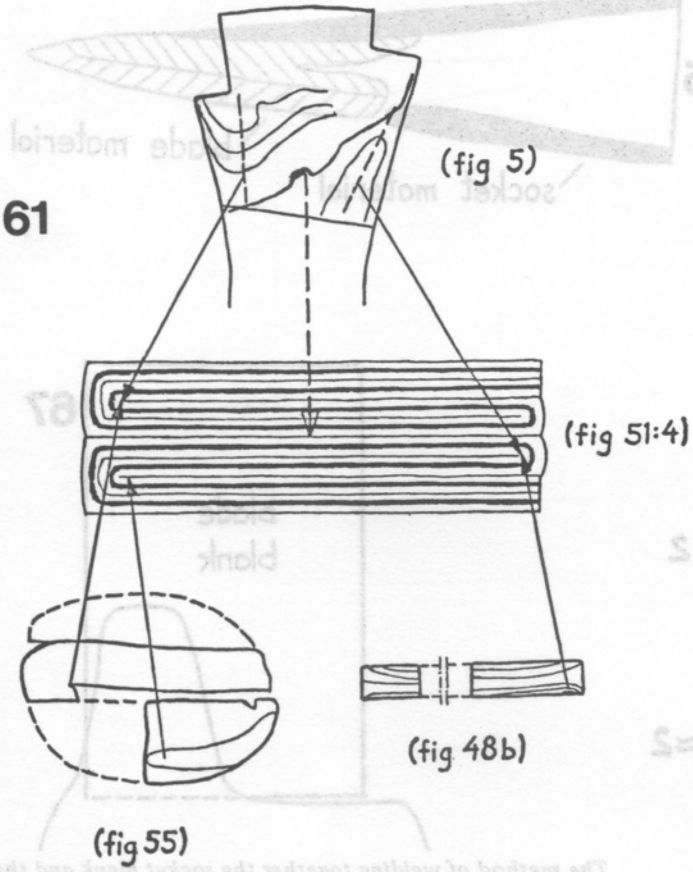

The principal build-up of the blade (in the middle), the section through the blade (at the top), the cross section of the edge range (to the right) and the cross section of the transition between socket and blade (to the left). Foldings are indicated with arrows as well as the seam from the last folding and forge welding (dashed line).

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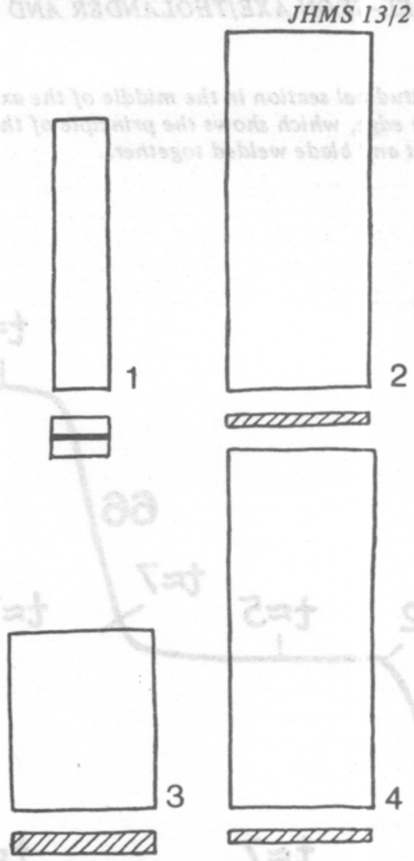

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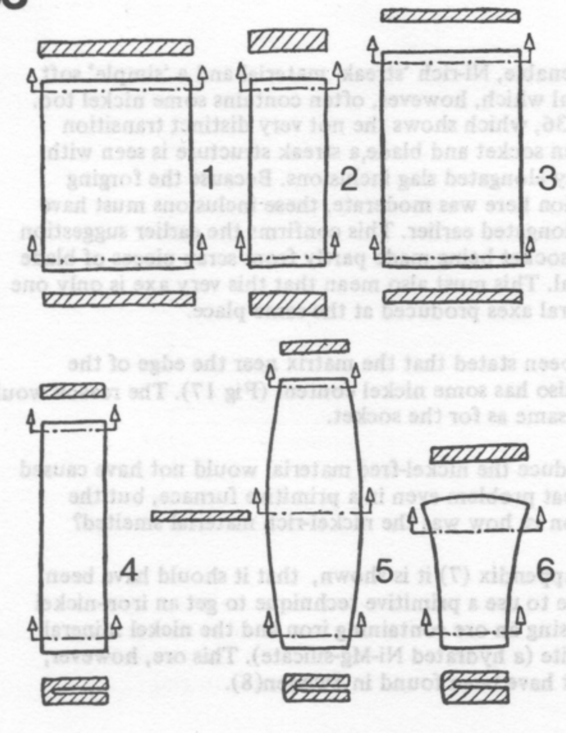
63



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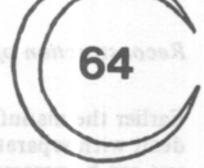

Cross section of the back end of the socket, idealized appearance (comp. fig. 2).

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1. *Blank containing 8 parallel layers of hard material surrounded by softer material. Dimensions about 6 x 8 x 100 mm.*
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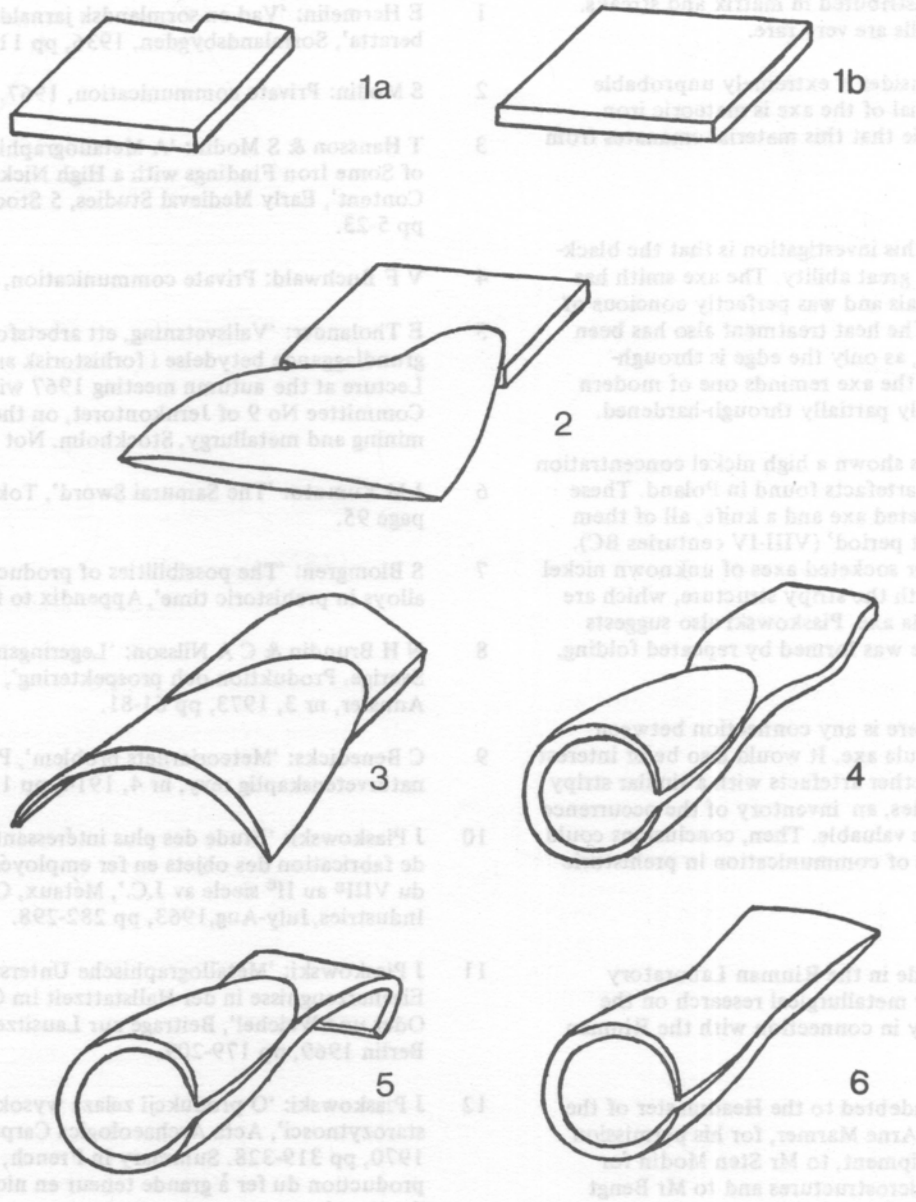
6. *After folding about a central axis perpendicular to the longitudinal direction, welding and final forging of the axe edge. The cross section of the blade now contains 64 hard streaks.*



Principal sketches of the manufacturing procedure for the axe.

1. *Socket blank (to the left) and blade blank (to the right).*
2. *After forging of the socket blank its tongue has been welded together with the blade blank to form the axe blank.*
3. *The axe blank has been bent about its central longitudinal axis.*
4. *The socket has got its shape by forging over a mandrel. The blade portion has been folded, forge welded and further forged down somewhat in the middle.*
5. *The blade part has been folded backwards.*
6. *After welding the blade has got its shape by a final forging through which also the edge was formed.*

68

In the introduction the possibility was mentioned that the iron-nickel material may emanate from meteoric iron (9), which are Fe-Ni-alloys usually with 5-15% Ni, but mostly also with other elements such as cobalt and phosphorus. A high P-content, round 0.25%, can almost always be expected in meteoric iron(4). A test by microprobe analysis (by B Lundh) showed, however, that the P-content in the axe blade is low and evenly distributed in matrix and streaks. Besides, iron meteorite falls are very rare.

Therefore the authors consider it extremely unprobable that the nickel rich material of the axe is meteoric iron. Instead it seems reasonable that this material emanates from ore containing garnierite.

Conclusions

A definite conclusion of this investigation is that the blacksmith of those days had a great ability. The axe smith has used two different materials and was perfectly concious of their different qualities. The heat treatment also has been done with great precision, as only the edge is through-hardened. In that respect the axe reminds one of modern axes which usually are only partially through-hardened.

Piaskowski (10,11,12) has shown a high nickel concentration in some of the numerous artefacts found in Poland. These are: two bracelets, a socketed axe and a knife, all of them belonging to the 'Hallstatt period' (VIII-IV centuries BC). In the knife and two other socketed axes of unknown nickel content streaks appear with the stripy structure, which are very like those in the Kjula axe. Piaskowski also suggests (10,11) that this structure was formed by repeated folding, welding and forging.

The question then is if there is any connection between these artefacts and the Kjula axe. It would also be of interest to know if more axes or other artefacts with a similar stripy structure are found. Besides, an inventory of the occurrence of garnierite ore would be valuable. Then, conclusions could be made about the routes of communication in prehistoric times.

Acknowledgments

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The authors are greatly indebted to the Headmaster of the Rinman High School, Mr Arne Marmer, for his permission to use the laboratory equipment, to Mr Sten Modin for valuable discussions on microstructures and to Mr Bengt for the assistance with microprobe analyses.

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Trengganu White Brass

G Van Praagh

Summary

Trengganu White Brass is an alloy of copper, zinc, nickel and a little lead. It has the appearance of silver and is made into vases, dishes and other vessels. The craft is practised in Malysia, only in the State of Trengganu. It appears to have been introduced by a craftsman from Lingga, Indonesia. Analyses show that the older samples contain about 9% of nickel, three times the nickel content of the alloys made today. The former retain their colour, whereas the latter tarnish to an ordinary brass colour.

Similar alloys have been made in China for about 1500 years and the alloy 'pakfong' was exported to Britain in the 18th century. The Chinese made the alloy directly from the nickel ores without first extracting the nickel. There is no evidence that this method was ever used in Trengganu.

Trengganu white brass is an alloy with a colour resembling silver used to make vases, dishes etc, of a variety of shapes and sizes. The alloy takes a good polish and some fine old samples can be found in private collections and occasionally in antique shops.[1] The craft is still practised but is found only in one state in Malaysia – Trengganu. The alloy is made, and the articles are manufactured as a 'cottage industry' and there are said to be about 200 people involved in it.

How far back the craft can be traced in Malaysia is not certain. The names of four generations of craftsmen who have practiced it in Trengganu are known, so white brass must have been made there for at least 90 years. The craftsmen say the art came from Java. The alloy is made by melting together brass from used cartridge cases, a zinc-nickel alloy and a little lead.

The first reference to Trengganu white brass is in a paper dated 1897.[2] The author refers to the brass as "gracefully and excellently finished. To the manufacture of ordinary brass vessels the local people have added an art said to have been taught them by an artisan brought from Daik by the Baginda. The brass was cast with certain ingredients to produce **tembaga puteh** – white brass. It was sold in Trengganu and other East Coast states for four times the price of ordinary brass For example, 5 chembul (vessels used in connection with betel nut chewing) cost 6-8 dollars as against 2 dollars for ordinary brass. Trengganu, alone of the Malay States seems to have manufactured it in any quantity."

Method of Manufacture

The castings are made by the 'lost wax' process. This process has been used for over 2000 years and is still used for a variety of castings in modern times. It is the best method of producing accurate castings of a hard alloy. The castings need scarcely any machining and are finished by means of a little filing where necessary and by polishing. It is thus very suitable for making objects in hard, easily cast metal. The decoration on the articles is simple and of a kind that can be filed on. It is noteworthy that the modern pieces have additional decoration made by the use of a lathe tool. This is possible because less nickel is used in the alloy and this results in a softer material. Details of the process as carried out in Trengganu are fully described[3,4] and have been reproduced.[5]

Composition of the alloy

The craftsmen say that the alloy is made today by melting together 4 parts of ordinary brass, 2½ parts of 'nickel', 1 part of zinc and a little lead. To investigate this further, a number of analyses have been made on several samples of the white brass.

In order to find out what metals were present, spectrographic analyses were first carried out (Note 1). These showed the presence of nickel in addition to the constituents of ordinary brass.[5] Two samples were used, one from a piece of modern white brass bought in Trengganu, the other from an old piece bought in an antique shop. There is a considerable difference in the appearance of the two pieces: the older sample retains its silvery colour better than the new one which tarnishes and becomes yellow in a few days, but the newer sample takes a higher polish than the old, which is not so smoothly finished.

A further analysis of the two samples was therefore performed on an X-Ray fluorescence spectrometer. This showed up the difference between the two alloys: both contained copper, zinc, nickel and lead, but there is about 3 times as much nickel in the old one. There is also a little tin and cobalt.[2]

A quantitative analysis of the two samples was then made. Two methods were used: gravimetric analysis and analysis by the absorption spectrophotometer.[3] The results showed the presence of 9.6% nickel in the old sample and only 3.2% in the new. (There is an inconsistency between the nickel content as stated by the craftsmen in Trengganu and the percentage found by analysis, but this is due to the fact that the ingot used is not pure nickel but an alloy of nickel with zinc). The use of less nickel nowadays is understandable in view of the high price of the metal. This lower percentage of nickel also explains why the modern pieces tarnish so easily. Muspratt[6] comments that 'if the nickel is less than 14.8% the alloy is little better than pale brass and will tarnish rapidly'. An analysis was also made of the white brass inlay in a **sireh** box from Brunei. This remains untarnished and was found to contain 8% of nickel. These analyses show that Muspratt's statement (made over 100 years ago) is incorrect: 8% nickel appears to be sufficient to produce an allloy that does not tarnish to a yellow colour. Brasses with a high zinc content are white-ish and require less nickel to give them a silvery appearance.

Phase diagrams of the copper-zinc-nickel systems show that alloys with the compositions of white brass consist of several solid solutions. The alloy used to make the older articles, containing about 10% nickel, consist of the alpha solid solution only, whereas the alloy now being used, containing only about 3-4% nickel, consists of a mixture of the alpha and beta solid solutions. The presence of the two components would give rise to galvanic corrosion under suitable conditions. This would explain why the alloys poorer in nickel tarnish when exposed for a time to the atmosphere.

Origin of the Craft

We may ask 'How did the craftsmen in Trengganu first come to make the alloy?' The records and the present local population agree in stating that the art was introduced to them by an artisan from Daik, now Kotadaik in Lingga, an island in the Riau peninsula, east of Singapore. The royal families of Lingga and Trengganu are related and craftsmen were brought to Trengganu to teach the people this craft 'which they had learnt from the Javanese'.[7] "The Javanese are good brass workers. The best of the luxury crafts have, however, now died out."[8]

It therefore seems that white brass could have been made in Java, so the author visited Jakarta and Jogjakarta to look for samples. A search in museums, antique shops and markets failed to find any, although it was said that there were candlesticks and boxes for cosmetics in the Sultan's palace in Jogjakarta whose description seemed to suggest that they were made of white brass. Some of the musical instruments, the gamellan, especially the saron, are made of a metal which polishes to a silvery colour. These are some 200 years old but have not so far been analysed. It is interesting to note that Engestrom[9] refers to Chinese white brass as 'something like silver and having a good ring.'

White brass alloys have been made for many centuries in China and it seems likely that knowledge of their manufacture came to south-east Asia originally from China. In spreading over S E Asia the Chinese could have imported samples of the alloys, which were made in the province of Yunnan and exported through Canton (see below). It is also possible that they came to know of the existence of nickel ores in S E Asia. These are found in the Phillipines and in Sulawesi (Indonesia), and the Chinese may have used these ores to make the alloys. There are at least three routes by which the Chinese craft could have reached Trengganu:

1. It is possible that the knowledge spread down from China through Thailand into Malaysia, but a search in southern Thailand failed to produce any evidence of the manufacture of white brass there today. However, this possibility would seem to be supported by the presence in Trengganu of a community of Chinese Muslims from the Yunnan province of China. Many add 'Yunnani' to their names and there do not appear to be communities like this elsewhere. So these people might be a possible source of the knowledge of how to make white brass. The community, now numbering about 220, all came from the Kwantung district of Yunnan about 90 years ago, but enquiries among them by a local teacher in Trengganu have shown that none of them now know about the craft of making white brass.

2. There are nickel mines in Sulawesi at Towoeti and it is possible that the Chinese could have used the ore from there. The alloy could then have been taken via Java to Lingga and thence to Trengganu.[4] As stated above, no white brass articles were found in Java, but this does not mean that this was not the route by which knowledge of the craft reached Lingga and then Malaysia.

3. Nickel ores also occur in the Phillipines and it may be that the Chinese made white brass there. It could then have reached Lingga via Borneo. The author found an number of examples of white brass in the Brunei Museum, mostly insets in sireh boxes, but it is said that none were more than 50 years old. Bronze and other metal casting is long established in the Southern Phillipines.[10] Probably the knowledge was brought there from China as their links were direct and numerous. Brunei also excelled in these forms of craftsmanship in the 16th to 18th centuries and after.

These three possible routes all presume that the knowledge came originally from China, so it is of interest to look at the history of the manufacture of white brass in China.

History of White Brass

As far back as the first millennium BC an alloy of a bright light colour was made from copper by the Mossynoeci, a people living south of the Black Sea in a region near Trebizond.[12,16,19] The alloy is described as being "of an extraordinary whiteness. They do not add tin but a special kind of earth that is smelted with the copper". There are many records[12] of the manufacture of brass by the addition to copper of calamine (zinc carbonate) or of calcined calamine (zinc oxide) plus charcoal, so the 'special kind of earth' probably refers to an ore of zinc. There appears to be no evidence that the alloy made by the Mossynoeci contained nickel. Brasses containing higher percentages of zinc are also of a whitish colour.

In China brass has been made for many centuries.[12] Chinese alchemists in the 3rd century BC describe the manufacture of brass by adding the mineral calamine to molten copper. The Chinese were far and away the earliest people to make alloys of copper and nickel, using them extensively for coinage by the 1st century AD. The Chinese alloy 'pak tong' is mentioned by Kuang Ya in the 3rd century[12] while the earliest mention of the use of pak tong for coins is 420 AD. Its use became more frequent after the 12th century. Ingots and objects made of pak tong were exported to the west from the 16th century onwards.

The method of making pak tong was to add nickel ore (possibly NiAs or NiFeS) to molten copper. This is described in some detail by Ho Wei about 1095 AD[12]. To molten copper in a crucible is added the reagent in the form of little pills. A slag forms, a little saltpetre is added, the contents of the crucible are stirred and the metal poured. The resulting metal is like brilliant silver. The nickel ore used came from the province of Yunnan.

Chinese white copper is described in du Halde's History of China, vol.1, p.16 (1735) and is referred to by Bishop Richard Watson of Cambridge in his Chemical Essays, vol.4, pp.108 ff (1786): "The most extraordinary copper is called Pe-Long, or white copper: it is white when dug out of the mine and still more white within than without. It appears, by a vast number of experiments made at Peking, that its colour is owing to no mixture: on the contrary all mixtures diminish its beauty; for when rightly managed, it looks exactly like silver, and were there not the necessity of mixing a little tutenag to soften it it would be so much the more extraordinary"

The famous chemist Joseph Black,[13] wrote to James Watt in 1770 about the Chinese white metal: "I am convinced that manganese is the substance with which Chinese copper is whitened." Black was wrong; pak tong is an alloy of copper, zinc and nickel.

Pak tong was first recognised as containing nickel in 1776[14] It is, of course, related to German Silver, which was the term used for alloys resembling that prepared in Vienna from 1824.[6,14,18]. The composition of these alloys varies considerably: the commonest German Silver contains 59% Cu, 26% Zn and 15% Ni; others contain over 20% Ni.[5] The term pak tong has been retained for alloys of inferior quality, poorer in nickel and containing other metals.[15] The term tutenag was used in England in referring to Chinese white brass, but originally it referred to the metal zinc. Muspratt describes tutenag as "very serviceable for casting, being fusible and hard, and used frequently by the Chinese".[6] Its composition is given as 46% Cu, 37% Zn and 17% Ni.

The metal nickel was not isolated in China: nickel was first produced from its ores by Kronstedt in Sweden in 1751. The Chinese alloy of copper and nickel was produced by smelting a mixed ore. Samples of the Chinese alloy were analysed by G von Engelstrom in 1776[9] and found to contain nickel and copper in the ratio of 5 or 6 to 13 or 14. This alloy came from the mines in Yunnan to Canton in the form of triangular rings with a diameter of 8 or 9 inches and a thickness of about 1½ inches. In Canton, zinc was added, making the alloy silvery white. The percentage of zinc was not always the same, rendering the alloy of different degrees of whiteness. Canton was the principal port in China for European trade and objects made of this metal were shipped to England by the East India Company. Unwrought paktong was also shipped to England for the manufacture of utensils. The only record at the Public Records Office in London which might refer to the alloy, is one for the year 1760 under the heading "white copper".[17] These articles and the alloy samples would have come to England via Singapore, and and it could be that samples and the knowledge of how they were made reached Lingga later from Singapore.

The first imitations of paktong were not placed on the market until 1824 by the brothers Henninger of Berlin.[18] By 1830 the manufacture of "German silver" had started in England and is referred to by J A Phillips in his Elements of Metallurgy, published in 1852.[14] The production of nickel metal expanded after about 1870 when nickel plating began to be adopted. However, no great quantity of nickel was produced until after the development of the Mond process in 1890.[18]

For the production of these alloys in the nineteenth century, the metal nickel was used, whereas the Chinese made pakfong directly from the nickel ores. The starting point for the manufacture of the white brass of Trengganu is the metal and there is no evidence that the older Chinese method has ever been used there. This suggests that the craft was introduced as a result of information, perhaps from Singapore, that is less than 100 years old, and that there may be no direct connection between the present day manufacture of white brass in Trengganu and the Chinese manufacture of pakfong.

Conclusion

To sum up, it seems likely that the craft of making white brass was brought to Trengganu by an artisan from Lingga, now part of Indonesia, via Singapore. The alloy is made from ordinary brass (70% Cu, 30% Zn) with the addition of nickel in the form of an alloy with zinc, and a little lead. Apart from the question of where the skills originated, and where the materials came from, there is the question of motivation. For what purpose was the manufacture of the alloy begun in Trengganu? Perhaps the silver-like appearance of the alloy, and the fact that it is considerably cheaper than silver, provide sufficient reason.

Notes

1 Thanks are due to the Chief Scientist of Dato Kramat Smelting Company for this analysis.

2 This analysis was kindly carried out by the School of Physics, Universiti Sains Malaysia.

3 I am grateful to the School of Chemistry, Universiti Sains Malaysia, for providing facilities for these analyses.

4 The mines at Towoeti, Sulawesi, are being worked today and for the past 4 or 5 years ore has been exported via Singapore to Canada for the production of nickel.[20] The ore is found in lateritic deposits, and crystals of the nickel mineral are said to be clearly visible to the naked eye. The lateritic deposits in the Phillipines contain between 1.2 and 1.5% Ni. The ore is not refined in Signapore but ingots of metal are made there, probably by melting nickel pellets imported from Canada. The nickel used for making white brass in Trengganu today is bought from Singapore in the form of ingots of an alloy with zinc.

5 The following figures illustrate the wide variety in composition (%) of samples of white brass from the past:[12]

	Cu	Zn	Ni	Fe	Pb
Chinese pak tong (1929) (representative)	62	22	6.1	0.6	–
Chinese pak tong ingot (Engelstrom, 1776)	41	44	15	–	–
Candlestick, English, made from Chinese metal. Dark. (Analysed by Armstrong College, Newcastle)	58	32	7.7	2.5	trace
Candlestick, 18th Century, English, made from Chinese metal. Light.	41	45	11	2.5	0.2
Candlestick (analysed by Cook & Co) Lightest.	43	34	22		
Typical German Silver	58	26	15	–	–

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OBITUARY

Sir Frederick Scopes, who died on 10 November 1978 at the age of 86, was the first president of the Historical Metallurgy Group, serving from 1963 to 1967. As one of the most distinguished leaders of the iron industry and having a keen interest in history, he was a natural choice for the presidency.

After education at King Edward's Schools, Birmingham, he took his degree in modern history at Corpus Christi College, Oxford. Abandoning thoughts of an academic career, he joined Stewarts and Lloyds Ltd of which company he eventually became a managing director, as well as chairman and managing director of the Stanton Ironworks Co Ltd, one of the largest iron foundry complexes in Europe. Subsequently he became chairman of Chamberlin & Hill Ltd.

His interests in these fields led him into parallel activities in iron ore and coal, particularly coking. In the first he became chairman of the Oxfordshire Ironstone Co and during the early part of the war Director of Home Ore. In the second he served for many years as chairman of the Solid Smokeless Fuels Federation and also held office in the Coke Oven Managers Association. In his main field of iron founding he held many offices, serving as president of the Joint Iron Council, both as treasurer and president of the British Cast Iron Research Association and as chairman of the National Foundry College. He was knighted in 1954, was also a knight of the Order of St John, a liveryman of the Worshipful Company of Founders and a freeman of the City of London.

His character was marked by special concern for the well being of his employees. He combined a massive intellect, enabling him to exercise the most sound judgement, with an outstanding memory for details. Backed by wide reading, it is not surprising that he was a formidable solver of cross word puzzles.

The Society will remember him as a competent and genial chairman, able to recall many facets of industrial history. His own history published in 1968 'The Development of Corby Works' is a model of authoritative statement and meticulous accuracy.

Twice married, he leaves a widow and two sons.

MMH

Analyses of Bronze Age artifacts from Irish Museums

H H Coghlan,

These 114 analyses were made on behalf of the Ancient Mining and Metallurgy Committee of the Royal Anthropological Institute by the late Dr Maurice Cook of ICI Metals Ltd, Birmingham in 1959. All those without a prefix come from the National Museum of Ireland in Dublin. Those with the prefix CPM come from the Cork Public Museum.

The analyses follow logically those published by H H Coghlan and H Case in a paper entitled 'Early Metallurgy of Copper in Ireland and Britain' which appeared in the Proceedings of the Prehistoric Society for 1957, Vol. 23, pp. 91-123. A further series of Irish analyses appeared in the monograph 'Ores and Metals' published by the RAI in 1963, Occasional Paper No 17. Some of these are repeated here and are recognisable by the serial number.

In the earliest paper of the series, three groups of compositions were recognised: – Group I with high As, Sb, and low Ag, but low Ni and Bi, smelted from sulphide ores and Irish in origin. Group II, a mixed group differing only in detail from I. Some of these possibly originate from oxide ores. It has a greater proportion of non-Irish finds. Group III has a high Ni content and other anomalies. Most of the specimens are non-Irish and possibly of central European origin. Only two specimens in the present series have a high Ni content (Nos 120 and 203) and it would appear that the majority fall into Groups I and II of the previous series.

All of the samples consisted of drillings of varying degrees of fineness, some containing visible amounts of copper oxides and corrosion products which as far as possible were removed before analysis.

All samples were subjected to a preliminary magnetising treatment to remove extraneous magnetic particles and alpha iron inclusions. The following elements additional to those mentioned in the tables were not detected: Be, Ge, P, Zr, Ta, Nb, W, Te, Mo, Pt, Cd, Hg, V, Ti and Cr.

The limits of detection for the spectrographic analyses were as follows: –

Pb 0.01	Sb 0.01	Fe 0.01	Ni 0.01	Mn 0.005
Ag 0.01	Sn 0.01	Bi 0.005	As 0.01	Zn 0.005
Au 0.005	Co 0.005%			

It was felt that it would be useful to make these results available without further delay to research workers for statistical analysis. The archaeological implications are being considered by Humphrey Case FSA of the Ashmolean Museum, Oxford.

ANALYTICAL RESULTS OF DRILLINGS FROM ANCIENT ARTIFACTS FROM ROYAL ANTHROPOLOGICAL INSTITUTE, ANCIENT MINING AND METALLURGY COMMITTEE

	AXES								Halberd	Halberd	AXES						
SAMPLE NUMBER	9	10	11	12	16	17	19	20	85	86	114	115	116	117	119	120	121
SAMPLE WEIGHT (g)	0.17	0.97	1.06	1.08	0.87	0.75	0.74	0.67	0.83	1.16	1.31	1.29	1.84	1.71	1.35	1.33	0.78
Chemical Results %																	
Copper	86.2	88.6	89.3	86.1	87.5	87.6	86.3	86.4	95.1	95.6	97.3	97.2	97.6	97.1	96.5	98.7	98.3
Silver	.01		.06	.27	.34		.19		.21	.19	.11	.12	.13	.19	.30	.01	.21
Tin	10.21	11.02	9.83	12.13	10.62	11.11	12.60	12.22									
Arsenic			.46	.82	.49		.11		4.02	3.30	2.03	1.92	1.73	1.61	1.93	.36	.62
Antimony				.38	.56		.22		.52	.69	.30	.47	.37	.71	.62	.01	.37
Lead															.48		
Nickel								.18									
Iron	.3																
Zinc			.03		<.01												
Spectrographic Results %																	
Lead	.01	nd<.01	.03-.05	.1	.08	.02	.3	.05	.03	.05	.03	.03	.01	.2		.3	.01
Tin									---nd	<.01---	.03	.05-.07	---tr	<.01---	.01	.02	tr<.01
Iron		.01	.04	.01	.02	.02		.01	------	------	tr<.01	------	.02	.015	----tr	<.01---	.03
Nickel	.02	.01	.05	----tr	<.01---	.01	.05		.01	.01	.01-.02	.03	.02	.02	.01	.2	.06
Manganese	nd<.005	tr<.01	-----nd	<.005--	tr<.01	------	------nd	<.005---	------	tr<.01	------	nd<.005	------	tr<.01	------	nd<.005	------
Silver		tr<.01				.03		.01									
Antimony	<.01	tr<.01	.02			.02		.01								.01	
Bismuth	---nd	<.005---	tr<.01	nd<.01	---nd	<.005--	tr<.01	nd<.005	---tr	<.01---	nd<.01	----tr	<.01---	---nd	<.005---	.03	nd<.005
Arsenic	nd<.01	nd<.01				.02	.07	.04									
Zinc	------	------nd	<.005---	------		------	------	------	nd<.005	------	------	------	------	tr<.01--	------	------nd	<.005 ---
Gold	------	------	------	------	------	------	------	------	nd<.005	------	------	------	------	------	------	------	------
Cobalt	---nd	<.005--	.01	tr<.01	------	nd<.005	------	tr<.01	------	------	nd<.005	------	tr<.01	----nd	<.005---	.03	nd<.005
	Patarch Aberdeen	Ireland	Caerphilly Glamorgan	Dumfries	Clough Mills Antrim	Falkland Fife	N. Ireland	Swansea Glamorgan	Allen Kildare	Croft Longford	Cordal Kerry	Cordal Kerry	Cordal Kerry	Tallagh Dublin	Tallagh Dublin	Tallagh Dublin	Tallagh Dublin

	AXES					Halberd	Knife	AXES									
SAMPLE NUMBER	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138
SAMPLE WEIGHT (g)	1.11	.76	1.63	1.07	1.09	.42	.1	1.65	1.1	1.18	1.0	.91	1.22	1.14	1.14	1.31	1.52
Chemical Results %																	
Copper	98.5	96.2	96.8	98.1	97.2	93.7	97.5	98.1	98.3	98.8	97.3	97.6	98.2	97.6	98.1	99.5	99.2
Silver	.12	.26	.15	.27	.29	.16	.11	.22	.16	.02	.21	.26	.26	.38	.22	.05	.12
Tin																	
Arsenic	.41	2.51	1.83	.60	1.79	4.30	1.98	.82	.68	.80	1.70	1.65	.70	1.45	.98	.14	.13
Antimony	.50	.75	.96	.62	.46	1.22	.22	.48	.53	.19	.56	.21	.60	.16	.27		.14
Lead																	
Nickel																	
Iron						<0.01											
Zinc																<0.01	
Spectrographic Results %																	
Lead	.08	.07	.03	—tr	<.01—	.05	.01	.05	.01	.01	.05	.01	.05	.06	.03	.03	.02
Tin	<01	.01	tr <01	nd <01	.03	tr <01	.01	—	—	—	—	tr <01	—			.01	.01
Iron	nd <01	—	—	—	tr <01	—	—	.02	.07	—	—	tr <.01	—	.01	—tr <.01	—	.01
Nickel	.02	tr <.01	.01	tr <.01	.01	.15	nd <.01	.01	.01	.01	.01	—	tr <01—	.03	.02	tr <.01	.02
Manganese	—	—	nd <005	—	—	tr <.01	nd <.005	tr <.01	tr <01	—	—	—	nd <005	—	—	—	tr <.01
Silver																	
Antimony																.04	
Bismuth	.005	nd <.005	nd <.01	.01	—	—	nd <005	—	tr <.005	nd <.005	—	—	tr <005	—	nd <.005	tr <.005	nd <.005
Arsenic																	
Zinc	—nd <005	—	tr <.01	tr <.01	nd <005	.06	tr <.01	—	—	—	—	tr <.005	—	—	—		tr <.01
Gold	—nd <.005	—	tr <01	—	—	—	—	—	—	—	nd <005	—	—	—	—	—	—
Cobalt	nd <005	—	tr <.01	—nd <005	—	tr <.01	—	—	—	—	nd <005	—	—	tr <01	—	nd <005	—
	Dalkey Dublin	Glenmere Wicklow	Monastery Wicklow	Monastery Wicklow	Whitespots Down	Whitespots Down	Whitespots Down	Cappeen Cork	Cappeen Cork	Cappeen Cork	Cappeen Cork	Cappeen Cork	Cappeen Cork	Clontoo Kerry	Clontoo Kerry	Nash Wexford	Nash Wexford

	AXE	AXE	Smelted Copper	AXES			KNIFE	AXES				Haberd	AXES			Dagger	AXE
SAMPLE NUMBER	139	140	141	142	143	144	145	158	159	160	161	162	163	164	165	166	167
SAMPLE WEIGHT (g)	1.36	1.75	.35	.87	1.23	.34	.08	1.58	.56	1.22	.73	.57	.92	.91	.91	.23	1.23
Chemical Results %																	
Copper	98.8	99.3	97.8	98.3	94.8	98.6	97.9	91.3	87.5	97.3	89.0	88.5	94.9	87.0	99.2	95.5	87.9
Silver	.21		.23	.21	.31	.21	.24		.21		.20	.32	.20		.15		
Tin								5.40	11.11	.61	9.35	10.47	2.87	9.55			10.44
Arsenic	.38		.81	.69	3.40	.33	.90		.39		.44	.33	1.25			4.02	
Antimony	.18		.47	.46	1.11	.40	.57		.41		.27	.07	.24		.26		
Lead								2.78		1.14	.30			2.76			.74
Nickel										.11				.11			.57
Iron																	
Zinc			.23		<.001								.05				.04
Spectrographic Results %																	
Lead	.01	tr<.01	.09	.06	.015	.03	.05		.15			.01	.30		nd<.01	.015	
Tin	tr<.01		.02	.03	.01	tr<.01	nd<.01								tr<.01	.02	
Iron	tr<.01	.01	.08	tr<.01		.07	.20	.07	tr<.01	.02	.04	.01	.04	.04	nd<.01	.02	.01
Nickel	.01	tr<.01	.01	.02	.01	.02	.01	.02	tr<.01		.03	tr<.01	.01		nd<.01	.05	
Manganese						nd<.005							tr<.01		nd<.005		
Silver		.07						.02		.07				.10		.015	.01
Antimony		.07						.07		.15				.10		.01	.01
Bismuth	.005	.005			nd<.005			.03	nd<.005	.04	.02	nd<.005		.007		nd<.005	
Arsenic		.20						.08		.20				.01	.03		.05
Zinc	nd<.005			nd<.005				nd<.005							nd<.005		
Gold								nd<.005									
Cobalt	tr<.01	nd<.005	tr<.01	nd<.005	tr<.01		nd<.005	tr<.01	nd<.005	.01	tr<.01	nd<.005	tr<.01		nd<.005		.035
	Nash Wexford	Nash Wexford	Nash Wexford	Kilbarron Galway	Kilbarron Galway	Kilbarron Galway	Kilbarron Galway	Killala Kerry	Killala Kerry	Killala Kerry	Killala Kerry	Killala Kerry	Killala Kerry	Killala Kerry	Killala Kerry	Killala Kerry	Kilcrea Cork

ALL AXES

SAMPLE NUMBER	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184
SAMPLE WEIGHT (g)	1.65	1.22	.61	.59	1.22	.80	.77	.84	.29	1.05	.78	.88	.42	.66	.81	.27	1.13
Chemical Results %																	
Copper	98.1	97.4	89.9	89.1	87.3	97.1	87.9	88.9	88.2	98.9	96.7	87.3	86.6	89.0	97.2	86.5	88.7
Silver	.15	.18	.17	.28		.25	.22	.20		.14	.39	.11	.34	.09	.36		
Tin			9.04	8.63	10.25		10.64	9.81	11.52			11.96	11.91	9.87		13.03	10.88
Arsenic	1.13	1.53	.35	1.17		1.82	.40	.34		.50	1.63	.17	.37	.54	.59		
Antimony	.44	.47	.16	.41		.44	.26	.37		.20	.75	.13	.23	.01	1.36		
Lead					1.95						.15						
Nickel																	
Iron																	
Zinc															.02		
Spectrographic Results %																	
Lead	.02	.01	.20	.02		.015	.07	.01	nd <.01	.10		.08	.10	.09	.07	tr <.01	nd <.01
Tin	tr <.01	—				.01				tr <.01	—				tr <.01		
Iron	tr <.01	—	.02	nd <.01	.01	.01	tr <.01	.02	.02	tr <.01	—	.02	.08	.01	tr <.01	.10	.02
Nickel	tr <.01	.01	.01	.02	.04	.02	.15	.02	.01	.01	.01	<.01	.01	.05	.04	tr <.01	nd <.01
Manganese	nd <.005	—	tr <.01	nd <.005	—	—	—	—	tr <.01	nd <.005	—	tr <.01	nd <.005	tr <.01	nd <.005	tr <.01	—
Silver					.10				tr <.01							.10	.02
Antimony					.10				tr <.01							.10	.01
Bismuth	nd <.005	—	—	—	.05	nd <.005	—	—	—	—	—	—	—	—	.01	nd <.005	—
Arsenic					nd <.01				nd <.01							.01	nd <.01
Zinc	nd <.005	—	—	tr <.01	nd <.005	—	—	—	—	tr <.01	—	nd <.005	tr <.01	nd <.005		nd <.005	—
Gold	nd <.005	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cobalt	nd <.005	—	tr <.01	—	nd <.005	—	tr <.01	nd <.005	—	—	—	tr <.01	nd <.005	tr <.01	—	nd <.005	—
	Cullybally Antrim	Skibereen Cork	R. Shannon Cornacarrow	Dramgoodland Down	Newry Down	Dundrone Tipperary	Kilglas Longford	Killala Mayo	Ginness Down	Lixnaw Kerry	Leterkenny Donegal	Clonallan Down	Ennistymon Clare	Glencullen Dublin	Dramore Down	Nowington Kildare	R. Bann at Portnashoal

ALL AXES

SAMPLE NUMBER	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201
SAMPLE WEIGHT (g)	.52	.63	.74	.49	.27	.48	.91	1.10	.87	.93	.67	.99	.63	.89	.63	.49	.36
Chemical Results %																	
Copper	97.7	95.3	87.5	86.6	86.7	86.3	90.1	88.1	97.5	98.3	99.0	97.0	86.3	87.6	89.8	89.1	88.4
Silver	.23	.24			.11	.24	.24	.28	.28	.23	.38	.27		.14	.19	.27	.16
Tin			11.71	13.02	12.41	12.63	8.51	10.12					13.44	9.56	8.64	9.55	9.75
Arsenic	1.12	.90			.33	.34	.68	.91	1.01	.42	.37	2.06		.98	.84	.53	.98
Antimony	.61	1.85			.11	.24	.19	.25	.69	.45		.42		.32	.24	.27	.30
Lead		1.49															
Nickel																	
Iron																	
Zinc						<.01			<.01								
Spectrographic Results %																	
Lead	.05		.25	.025	.07	.08	.03-.05	.06	.25	.25	.03	.015	nd<.01	.30	.01	.05	.02
Tin	tr<.01	—							tr<.01	nd<.01	.01	nd<.01					
Iron	.01	tr<.01	.30	.01	.01	.02	.02	.01	.01	tr<.01	nd<.01	tr<.01	.01	tr<.01	—	.02	.02
Nickel	.02	.015	.02	.01	.01	.01	.01	.015	.01	tr<.01	.05	tr<.01	.01	.025	.02	.01	.01
Manganese	—	nd<.005	—	tr<.01	nd<.005	tr<.01	—	—	—	—	nd<.005	—	—	—	tr<.01	nd<.005	nd<.005
Silver			.02	.01									.01				
Antimony			tr<.01	nd<.01							.03		.01				
Bismuth	nd<.005	.005	nd<.005	.005	tr<.005	nd<.005	tr<.01	—	—	tr<.005	—	—	—	—	nd<.005	—	—
Arsenic			.05	nd<.01									.02				
Zinc	—	nd<.005	—	—	—		tr<.01	nd<.005	tr<.01	—	—	—	nd<.005	—	—	—	tr<.01
Gold	—	—	—	—	—	nd<.005	—	—	—	—	—	tr<.01	—	—	nd<.005	—	—
Cobalt	—	—	nd<.005	—	—	—	—	tr<.01	—	nd<.005	.02	—	nd<.005	—	—	tr<.01	—
	Craigbilly Antrim	Ireland	Clonallan Down	Dromballyroney Down	Clonallan Down	Clonallan Down	Coleraine Derry	Iveragh Kerry	Hospital Limerick	Templeport Cavan	Cullybackey Antrim	Youghal Cork	Whitechurch Waterford	Iveragh Kerry	Whitechurch Waterford	Manorhamilton Leitrim	Ireland

	ALL AXES												KNIVES				
SAMPLE NUMBER	202	203	204	205	206	207	208	209	210	211	212	213	215	216	217	218	219
SAMPLE WEIGHT (g)	.69	.42	.49	.72	.80	.50	.47	.53	.53	.83	1.06	.55	.28	.08	.14	.17	.12
Chemical Results %																	
Copper	90.8	87.8	86.8	88.2	89.6	88.9	88.4	87.2	88.1	86.6	86.8	88.3	88.1	97.1	97.7	97.4	99.0
Silver	.05		.28	.16	.18			.09	.17			.29		.18	.12	.45	.23
Tin	8.47	10.60	12.17	10.56	8.73	10.78	11.18	11.31	10.73	12.80	12.95	10.45	11.40				
Arsenic	.32	.59	.32	.49	1.04			.60	.32			.43		1.77	1.18	.90	
Antimony		.17	.17	.28	.17			.09	.45			.23		.45	.66	.81	.37
Lead																	
Nickel		.36															
Iron																	
Zinc		<.01															
Spectrographic Results %																	
Lead	.03	.07	.01-.02	.05	.02	.02	.01	.15	.02	.30	tr<.01	.01	.01	.03	.05	.02	.01
Tin														.01	.01	—tr<.01	—
Iron	.05	.01	.01	tr<.01	.01	.01	.01	.30	tr<.01	.01	tr<.01	.03	.04	.20	nd<.01	.07	tr<.01
Nickel	.01-.02		.01	.01	tr<.01	nd<.01	.04	.015	.01	.02	tr<.01	.01	.10	.01	.02	<.01	.02
Manganese	tr<.01	tr<.005	tr<.01	—	—	—	nd<.005	—	—	.01	—nd<.005	—	tr<.01	tr<.01	—	nd<.005	—
Silver		.03				.02	.01			tr<.01	.02		.01				
Antimony	.07					nd<.01	.01			.01-.02	nd<.01		nd<.01				
Bismuth	tr<.01	nd<.005	tr<.01	nd<.01	nd<.01	.01	—	nd<.005	—	nd<.01	—nd<.005	—	.007	—	nd<.005	—	—
Arsenic						nd<.01	.01			.05	nd<.01		nd<.01				.01
Zinc	nd<.005		—	tr<.01	—	—	—	—	—	nd<.005	—	—	—	—	tr<.01	—	nd<.005
Gold	tr<.01	nd<.005	tr<.01	—	—	—	—	—	—	—	nd<.005	—	—	—	—	—	—
Cobalt	nd<.005	.065	tr<.01	—	—	—	—	nd<.005	—	—	—	—	.015	—	nd<.005	—	—
	Letterkenny Donegal	Sligo	Letterkenny Donegal	Letterkenny Donegal	Hospital Limerick	Dysart Kildare	Cloghan Donegal	Clonaslee Laois	Abbey of Fore Westmeath	Draperstown Derry	R. Clare at Dunmore	Dromshambo Leitrim	Ireland	R Shannon at Jamestown	Kilnagamah Offaly	Ireland	Cantymore Fermanagh

	KNIFE	KNIFE	ALL AXES									
SAMPLE NUMBER	220	221	CPM1	CPM3	CPM4	CPM11	CPM15	CPM18	CPM19	CPM20	CPM80	CPM276
SAMPLE WEIGHT (g)	.10	.14	.52	.41	.43	.15	.69	.49	.54	.21	.42	.49
Chemical Results %												
Copper	94.5	98.1	88.9	89.5	98.5	90.6	98.0	96.5	98.0	87.1	86.6	97.9
Silver	.39	.17		.19	.28	.10	.20	.26	.15		.18	.30
Tin			9.24	9.10		7.00				12.40	12.09	
Arsenic	3.18	1.06		.35	.26	1.01	.93	1.79	.90		.43	.93
Antimony	1.55	.39		.26	.34	.44	.43	.69	.42		.27	.55
Lead			.34					.39				
Nickel			.27									
Iron												
Zinc				.03	.01	.03		<.01				
Spectrographic Results %												
Lead	tr<.01	.03		.09	.25	.085	.01		.03	tr<.01	.04	.08
Tin	.03	tr<.01			.02		.02	.01	.03			.01
Iron	tr<.01	—	.07	.15	.05	.10	.10	.02	.02	.10	.03	nd<.01
Nickel	.02	.02		.03	.01	.015	.01	.01	.01	.06	.015	.02
Manganese	nd<.005	—	tr<.01		tr<.01	nd<.005	—	tr<.01	nd<.005	tr<.01	nd<.005	—
Silver			.01							.02		
Antimony			nd<.01							nd<.01		
Bismuth	—	—	—	—	—	nd<.005	—	—	—	—	—	—
Arsenic			nd<.01							nd<.01		
Zinc	tr<.01	—					nd<.005		—	nd<.005	—	—
Gold	—	—	—	—	—	—	nd<.005	—	—	—	—	—
Cobalt	tr<.01	nd<.005	.01	nd<.005	tr<.01	—	—	—	—	nd<.005	—	—
	Listack Donegal	Drumshaughlin Meath	Vicarstown Cork	Ireland	Ballycullane Limerick	N of Ireland	N of Ireland	N of Ireland	N of Ireland	N of Ireland	Ballyard Kerry	Newtownsands Kerry

Research Centre

Centralne Laboratorium Instytutu Historii Kultury Materialnej Pan, Warszawa. The research and conservation laboratory of the Institute of Material Culture (within the Polish Academy of Sciences) was established in 1963, however, its main tasks were directed to non-ferrous metallurgy. A research programme relating to the early metallurgy of iron has been developed since 1973. Both mentioned branches fall under the Section of Metallurgy, while there is also another Section, that of Glass. At the head of the laboratory is Prof Dr *T Dziekonski* with 9 members of staff. The laboratory is very well equipped with large and medium dispersion spectrographs, a flame photometer, DTA, TG and DTG analysers, a high temperature microscope, polarising and metallographic microscopes, an X-ray diffraction apparatus and an X-ray defectoscope.

Investigations of copper and its alloys have taken recently about 60% of capacity, technology of iron objects about 10%, examinations of slags and waste products about 20%. Analyses of silver, gold and lead have been also carried out but on a smaller scale.

As to the bronze technology there is a catalogue under compilation which is based on finds from the recent Polish territory giving their composition, structures, hardness etc.

Of great interest is a detailed study of slag blocks from slag pit furnaces from the area of Warsaw (La Tene and Roman periods). In order to complete the samples, slag finds from the Holy Cross Mountains and from primitive African bloomery furnaces have been added. The analyses are complex: chemical, petrographical, X-ray diffraction and thermal, all of them pointing to the knowledge of building individual slag blocks which show that so far unknown physico-chemical processes have occurred during the bloomery smelt.

After *Z Hensel,* Warsaw

Note

Pattern-Welded Gun-Barrels from Soviet Museums. Despite the late occurrence of pattern-welded gun-barrels (18th-19th centuries) we need to mention their metallographic examination because of the well-known tradition of the pattern-welding technique. 240 pattern-welded gun-barrels (pistols, revolvers, rifles) are kept in the State Historical Museum at Moscow, and 70 similar objects in the museums of the Soviet Baltic area. Their places of origin are Belgium, Germany, Russia, etc, but also Dagestan, India and Turkey. 31 barrels were submitted to microscopic examination to show that the European gun-barrels were usually made of iron and mild steel strips (0.1 – 0.2% C), while some Turkish specimens, handforged, consisted of harder steel strips with approximately 0.5 – 0.6% C-content. A Russian weapon manufactured at Tula consisted of welded elements made of an alloy steel producing sorbite-troostite structures instead of the usual ferritic-pearlitic ones. Reports on this investigation have been read by the author at the occasion of the 11th Baltic Conference on the History of Science and Technology (Tartu 1977, Baltic specimens), and also at the conference on the History of Science held at Baku, in the same year. Both papers will be published.

After *A K Anteins,* Riga

Work in progress

Bloomery Furnaces at Eg, Norway. Seven features described as slag pits had been excavated in 1977 by *Mrs E Schaller* and *Mr T B Nakkerund* on the bank of the Otra river near Kristiansand, South Norway. The hearths measured ca. 50 cms in diameter, some of them were stone-lined and explained as bowl furnaces, others were considered to be low shaft furnaces. It may be of interest that according to the analyses made in Møsstrond, the first type contained slag of a low silica content (5-18%), whereas shaft furnaces yielded normal bloomery slag with ca. 25% SiO_2. The site is situated on the southern coast in an area abouding in Roman Iron Age finds their frequency there being higher than in other regions. A circular area demarcated by 15 postholes was to one side of the furnace remains. Two C14 dates point to 290 and 360 AD.

After *E Schaller (Mrs), T B Nakkerund* and *I Martens,* Oslo

Lodenice, Bohemia. A Settlement with Bloomery Furnaces Rediscovered. During building operations at Janska-Lodenice, Central Bohemia, a slag-pit furnace appeared in the profile of a ditch as a part of a sunken-floored bloomery. Its preserved height was 88 cms, the inner diameter of the slag-pit (with the slag block removed after the last smelt) measured 24 cms. It was somewhat wider at the bottom apparently to make the extracting of the bloom easier. It seems most likely that this was simultaneously the position of the air-inlet from the bellows. According to local information further similar furnaces had been destroyed at the same site in previous times. Considering several pottery fragments the furnace in question may be of the early Romano-Barbarian period in Bohemia. It should be mentioned that in the distance of about 300 m there is the finding place of a known fully preserved free standing shaft furnace (1923) which serves as a model of a smelting device in the category of clay low shaft furnaces (type of Lodenice – late Roman period). The ancient metallurgy of iron exploited there involved gossans from local deposits of the iron ore of the Nucice type, which is a sort of chamosite. Rescue operations with the aid of geophysical prospection are organized by the Archaeological Institute, Prague.

Traces of Medieval Blacksmith's Activity at Tisova, East Bohemia. The excavations carried out by the Museum of Hradec Kralove in cooperation with the Archaeological Institute, Prague, were focused in 1974-1977 on the medieval site of Stare Myto, in the area of Tisova. The complex of buildings represents an abandoned part of a medieval town. All over the excavated area iron slag was dispersed. A certain concentration could be seen in and around the vicinity of a smithy (not yet excavated). Typical plano-convex shapes together with their macroscopic structure (some of them are quite large, 20 x 17 cms) allow us to interpret this waste as a smithing slag (ie sintered and melted scales, clay and sand from the Smith's hearth). Its volume reflects the intensity of production which possibly included also the refining of blooms or bars which came as imports from distant centres.

The site is dated into the 13th and to the beginning of the 14th centuries; this is clearly the predecessor of the town of Vysoke Myto which was founded by the king Premysl Otakar II in the sixties of the 13th century.

J Sigl, Hradec Kralove

Romano-Barbarian iron smelting at Kyjice, distr. Chomutov, NW Bohemia. A large scale rescue dig (Most branch of the Archaeological Institute) revealed a complete settlement area from about the 2nd century AD, having spread over the surface of 30 hectares. There are two micro-areas of importance. The first of them, occupying an area of about 5 ha was characterized by common dwelling huts, at the northern end of which 4 shaft furnaces and a pit for charcoal burning could be identified. The other district of about 25 ha served for production activities. Besides 73 storage pits there came to light 11 baking ovens and pottery kilns but attention was paid to the remains of 50 shaft bloomery furnaces scattered in groups of 3-5 units in the central and eastern part of the area. In the western and central part there occurred, moreover, sunken-floored bloomeries with slag pit furnaces placed in the walls of working-pits. Two had a single furnace, 2 workshops had twin furnaces, 3 had two furnaces in different ends of the pit. Surprisingly well preserved was a sunken-floored bloomery with 7 and 8 furnaces resp. both in the wall and in the floor of the hut. Over the whole area there were dispersed 30 reheating hearths and traces of 4 charcoal piles. About 20-40 further furnaces must have been destroyed due to gravel quarrying on the site. Detailed chronological, typological and technological studies are foreseen.

After *Z Smrž,* Most

Romano-barbarian settlement with bloomeries at Orech, near Prague. A similar rescue dig to the above, organized by the Archaeological Institute, Prague, took place during road building in the close vicinity of Prague, in a flat valley near the village of Orech. Sunken-floored bloomery workshops of the early Roman period were unearthed. Traces of a preceding La Tène settlement have been found as well. Two of the workshops measuring about 1 x 1 m contained single slag pit furnaces in the walls, one had a twin with units in the northern wall (ca 2 x 2 m). Another larger pit (no.14) was equipped with 3 slag pit furnaces situated side by side in its eastern wall; one of them was fully preserved up to the throat. As in the case of Kyjice, the most important feature was the semi-sunken bloomery (no.5) with 11 slag pit furnaces: some of them were situated in the floor – they represent the remains of an earlier phase of the workshop existence. After an enlargement, new furnaces were built-in in the southern wall. In the front of them two iron ore roasting places were situated in the floor. Two features (nos. 14 and 5) were documented three-dimensionally in the field by making scale models.

K Motykova – R Pleiner, Prague.

Sudice: Four Seasons of Excavations on Romano-Barbarian Bloomery Sites: The bloomeries of the late Roman period at Sudice, West Moravia, represent up to now the only evidence of slag pit furnace remains organized in more or less indentifiable rows and fields which are similar to those known from the Polish Holy-Cross-Mountains. This feature may be explained by building a new furnace after each smelt but on a limited – possibly roofed – area. There have been excavated until now three furnace agglomerations which could be discovered thanks to the proton-magnetometer prospection: the first agglomeration with 72 furnace hearths covering the surface of 39 m^2 came to light in 1975, the second one amounting to 17 furnaces in 1976 on the surface of 15 m^2 (in addition to which a prolonged reheating hearth was excavated); finally, the third place consisted of 47 furnace furnace remains on 25 m^2 – which is obviously the rest of the bloomery area which remained after ploughing away the north-eastern part. The characteristic grey pottery enables us to date the bloomery activity into the 3rd-4th centuries AD. Local conditions such as ore resources, suitable refractory clay deposits and fuel supply (only oak wood used to be charred) led to the foundation of many iron smelting sites in the area; systematic prospecting possibly will ascertain further sites in the future. The reconstructed shape of the slag pit furnace by means of partially preserved elements showed that the hearth was 30 cms deep, measuring 50-60 cms in diameter; above the hearth there used to be erected a shaft approximately 100 cms high. The reconstruction was tested in June 1978: the trial smelt having consumed 50-60 kgs of ore in 3½ hours yielded 10% of sponge iron. The specimens are being studied. The results have been discussed at the conference entitled 'Recent tasks of the Czechoslovak archaeology' at Valtice, in October 1978.

After *K Ludikovsky,* Brno

Roman Period Smelting Furnaces at Spisske Tomasovce, *distr. Spisska Nove Ves, N Slovakia.* At the place called Cingov there came to light a battery of four furnaces with the inner diameter of 15-20 cms; only hearths remained. The smelting furnaces were situated on the border of a settled area dated to the mid-first century AD.

K Pieta, Nitra

Excavations of Slav Bloomeries at Olomucany, Moravia. The season of 1978 was extremely successful. On the terrace of an unnamed brook there were excavated further well preserved dug-in Furnaces, definitely dated owing to pottery finds to the late 8th century AD, ie. to the period of formation of the Great Moravian Empire. There occurred two variants of the same type: one of them was equipped with a gate-shaped hearth opening, covered with a special clay tuyere panel; on the other hand, two recently discovered furnaces possessed long tunnels in their fronts and resembled the well known Zelechovice furnaces (N Moravia). Only the position of the rear tuyere has not yet been identified because the detailed search was interrupted by the coming winter. Of special importance are two semi-split iron blooms weighing about 2 kgs, grindstones, and two types of tube-shaped clay tuyeres. A detailed research project in terms of metallurgical evaluation of finds has been proposed. The above area evidently played a most important role in the economic life of the Slav settlement in central Moravia.

V Sonchopova, Blansko, *R Pleiner,* Prague

A Hoard of Iron Ware at Lozna, Roumania. In the north-west part of Roumania, at the village of Lozna near Dersca, Botosani district, a large hoard of iron objects has been found during the peat exploitation in the depth of 2 m. It consisted of 56 well preserved iron objects with traces of wooden handles. From the rich assortment we mention two anvils, two tongs, one hammer, one file, three axe heads, 15 sickles, 3 scythes, a trident, further knives, a lance head, rings, fragments of wheel tires, etc. Originally the objects were wrapped in linen cloth and kept in a wooden box. The assemblage is dated to the La Tene C–D period. The find is being kept in the Historical Museum of Botosani.

S Teodor (Mrs) Iassy

Books reviewed

EXCAVATIONS AT NICHORIA IN SOUTHWEST GREECE George Rapp Jr and S E Aschenbrenner (Eds). Vol.I, Site, Environs, and Techniques. University of Minnesota Press, Minneapolis, 1978, $ 29.75. 21 x 28 cm, 268 pp,.index, 60 plates with 4 folding plans in pocket.

This is the first volume describing the results of 5 years work on the site, and includes the results of most of the studies made under the supervision of the first editor. Volumes II and III will present the results of the excavation by separate chronological periods. Volume IV will give an overview of the history of the habitation of the site.

The two editors are respectively geologist and social anthropologist; they have been responsible for a number of chapters of this volume and have been joined by a number of their colleagues amongst whom is the metallurgist S R B Cooke. The first ten chapters deal with the usual aspects of excavation and the historical background of the site. The techniques, which include dry screening and gravity concentration, are now standard on well-excavated sites. Froth flotation was tried, but due to the dearth of water in the area, was replaced by other techniques which were adapted to recover charcoal, seeds, micro and macro fauna. The use of a captive balloon for photography would seem to be original.

From the archaeometallurgical point of view the two chapters of greatest interest are 11 and 12 which are entitled 'Analyses of the metal artifacts' and 'Slags and other metallurgical products' respectively. To see such subjects dealt with at such length is really breaking new ground in excavation reports and this is a model of the degree of information that can be obtained on material that previously got sent to a museum store and left unexamined, since most of it is not photogenic nor of obvious interest to the layman. These two chapters amount to 70 pages and justify the purchase of the volume from the archaeometallurgist's point of view. The techniques used include optical emission spectroscopy (11 elements), XRF, and neutron activation. The objects were mainly copper-base or residues originating from the processing of copper-base alloys. As is usual nowadays a large proportion were prills, blobs and dross dating from Middle Helladic (MH) to Byzantine. Half were bronzes of variable tin content; zinc was low or absent in all but a few cases; lead also. Arsenic was low in most cases.

XRF was used for non-destructive analysis and, as it determines the surface concentration, it was not surprising to find that a higher proportion of the artifacts analysed by this technique had high arsenic contents.

Generally, production techniques were not consistent nor sophisticated. Tin contents varied widely and no metallic tin was found. It was clearly based on the availability of scrap metal. No furnaces were found but there were numerous crucible sherds and simple hearths.

Chapter 12 deals with slags and other residues. Slags are divided into smelting and melting (casting) slags, and we also have vitrified fuel ash. Analyses of some tin-bearing phases in crucible slags gave some interesting results such as crystals of cassiterite with a microhardness in the range 1400-1700 HV. It is not thought that this has any connection with the use of cassiterite as an alloying component but is merely an oxidation product. The problems of gain and loss of arsenic are also discussed. Melting a Cu-As alloy was found in one case to give a speiss (FeAs) with Co and Ni.

Other compounds found in the slags were magnetite, sulphides, and delafossite ($CuFeO_2$). The basic constituent, the silicate matrix, comes from the crucible fabric and the cover fluxes. Here we are given full details of the crucible fabric and its origins. While most crucible slags were high in SiO_2 and Al_2O_3 (>75% in all) there were exceptions. This section contains a detailed discussion on metal corrosion and corrosion products.

Thin-section mineralogical examinations were also made on five of the slags. The magnetite varied from 50-66% and appeared to be 'zoned' with copper oxide in solution. The included metal prills were almost pure copper. It was concluded that these five slags were smelting slags although the presence of magnetite rather than wüstite presented a problem. This leads to suggestions as to the possible use of very minor occurrences of copper ores in Greece, not in the area close to the dig but in the east Peleponnese.

Imported iron was known but was scarce in Late Mycenaean levels in Greece. At Nichoria, iron was also scarce but confined to Dark Age (975-850 BC) and Byzantine levels, where it was accompanied by smelting slags. It is estimated that a total of 250 kg of iron was made on the site mainly in the Byzantine period. Local ores were available.

Further chapters deal with lithological studies, archaeological geology and conservation of finds. In the latter section we find some useful details about the soils surrounding copper and bronze finds.

This is a most detailed treatment of some rather insignificant finds to the archaeologist or art historian. Considering the relative absence of iron the discussion on this metal is rather superfluous. But to the unitiated, however, is no doubt very useful. If the rest of the volumes treat their subjects in such detail, this is going to be a very lengthy comparative work which will form a much sort-after reference work on modern excavation and examination techniques.

Errors seem to be non-existent. Printers, publishers and editors should be thanked for a very satisfying presentation.

R F Tylecote

DAMASCENE STEEL: J Piaskowski, (in Polish). Wroclaw – Warszawa – Krakow – Gdansk 1974, 366 pp, 170 Figs

The book presents a general survey of data relating to the properties, technology and history of investigation of the so-called Damascene steel. Contents: Part One, General information: I) On 'Damascene' blades or scimitars, II) How the pattern on the surface of steel blades is produced, III) On other ornamental blades: Part Two, The development of the Damascene steel: IV) The beginning of examinations of Indian steel, V) The first examinations of sword blades from the Near East and defining of the chemical composition of Damascene steel, VI) The adoption of modern methods of physical metallurgy to research on Damascene steel; Part Three, Attempts to produce Damascene swords in Europe: VII) Experiments in the production of Damascene swords in Western Europe; VIII) The work of Major-General Paul Piotrovitch Anossoff, IX) P.P. Anossoff's accessors; Part Four, Damascene Steel in Historical written sources and accounts of travellers in India and the Near East: X) Damascene steel in the works of authors from ancient times and medieval sources, XI) Information on Damascene steel in accounts (sic) by French travellers of the XVI-XVIIIth centuries, XII) The production of Damascene swords in India and the Near East, according to accounts of the XIth and XXth century; Conclusion, Bibliography, Summary. The headings of individual chapters have been taken from the summary by B Przybylska. The author presents his own definition of Damascene steel which – in his view – is an iron-carbon alloy comprising two structural components of differing resistance in relation to diluted acids where the grains, as the result of a special heat treatment, become visible to the naked eye. If one of the components be ferrite then we have to deal with soft Damascene steel (cooled slowly within 910^{o} – 723^{o}C); if it be cementite then hard Damascene steel is involved where the pattern is due to slow cooling from 1145^{o} to 723^{o}C; forging and hardening temperatures could not exceed these limits. The manufacture of Damascene steel is one of the most interesting episodes in the general history of the metallurgy of iron which has fallen into oblivion and – in spite of later experimental work – it still lacks its place in modern technology.

CPSA

SECOND INTERNATIONAL CONGRESS ON THE CONSERVATION OF INDUSTRIAL MONUMENTS (SICCIM), Transactions, ed. Werner Kroker (in German, English, French). Deutsches Bergbau-Museum Bochum 1978; Publication No. 13, 452 pp, 109 photographs. Price DM 35 (about £9.00).

The 'Second International Congress on the Conservation of Industrial Monuments' took place at Bochum/West Germany from September 3 to 9 1975. Though it took three years for the transactions to appear, it was – in the reviewer's opinion well-worth waiting for.

The congress covered eight working sessions: I) regional reports on industrial archaeology, II/III) theoretical aspects of industrial archaeology, IV/V) documentation of industrial monuments, VI/VII) conservation of industrial monuments and VIII) social aspects of industrial archaeology. Participants came from the following countries (number of attendants in brackets): Austria (2), Belgium (1), Denmark (3), East Germany (2), France (1), Great Britain (11), Hungary (1), Italy (1), Japan (3), Yugoslavia (1), Netherlands (3), Norway (2), Poland (5), Soviet Union (2), Sweden (4), Czechoslovakia (1), USA (3) and West Germany (16); thus exemplifying the international scope of this enterprise.

Of the wide range of papers, published in the language they were presented in, the majority is dedicated to mining and metallurgy. The international character of the conference is not only documented by the regional reports, but also by the world-wide similarity of problems in the field of industrial archaeology. Questions of documentation, conservation and protection of monuments are not specific to individual countries; they seem to be common. A growing conscience that time is running out and that fast actions are being called for, was voiced unanimously by all the attendants invited.

Apart from regional diversification, the papers ranged chronologically from early Egyptian mining relics to workers' settlements in the industrial centres of Europe, dating back to the end of the last century. The normal shortcomings of conference proceedings, the seemingly incoherent array of papers dealing with different topics, was overcome by placing related contributions under common headings, ie. working sessions. This principle of classification enables the reader to get a quick and fairly thorough review of present international activities in the conservation of industrial monuments. The high standard of the thought-provoking introductory address by Kenneth Hudson at the beginning of the book is maintained throughout this publication, until right to the end with a set of fine photographs augmenting the texts of the articles. For those anxious to learn about current activities in industrial archaeology on the international scene, the transactions are likely to present them with a well-balanced summary.

H G Bachmann

Abstracts

GENERAL

E G West: Textbooks and Teachers – Thoughts on Education of Metallurgists. ***The Metallurgist and Materials Technologist, Aug 1978* 10, *427-431.***

Based on a talk given at the Royal Institution – part of a series on Education in the Nineteenth Century. The article lists the books which the author regards as landmarks in metallurgical education from Pliny's 'Historis Naturalis' of AD 100 to T Turner's 'Practical Metallurgy' and 'Lectures on Iron-Founding' of AD 1908. 'The Little Book on Ores' of 1500, V Biringuccio's De La Pirotechnia, and Agricola's De Re Metallica are discussed in more detail. The teaching of metallurgy in Britain is traced from the appointment of Dr John Percy as the first Professor of Metallurgy at the Royal School of Mines, Jermyn Street, London in 1851. Particular emphasis is given to the work of Professor Roberts-Austen, appointed successor to Percy in 1880. A brief indication is given of developments in the first half of the twentieth century.

APG

G C Boon: Gold-in-glass beads from the ancient world. ***Britannia, 1977, 8, 193-207.***

These beads were covered in gold (or silver) foil, then dipped into molten glass. During the Roman period they are found in Egypt and S Russia in some quantity, but are unknown in Italy, Spain, Gaul and Germany before the 4th century; in Britain, examples dating from the later 2nd-4th centuries probably came from the Euxine via Sarmatian soldiers. During the 4th century similar beads appear along the Rhine and Upper Danube; and in the Migration Period they were manufactured in NW continental Europe while production continued in the East. In Britain poor quality examples are common in late 5th and 6th century cemeteries, with a few examples in a Viking context. Quantitative spectral analysis of three gold beads was undertaken. AT

M Norris: Monumental brasses: the craft: *London, Faber and Faber, 1978, 148pp Price £25.*

Renewed interest in brasses since 1950s has revitalized what had been a stagnant subject, and produced a new climate more conducive to research. Brasses are now seen in their proper context as a reflexion of society and an index of craft achievement, and the depictions on them are studied with the help of information from many different sources. This survey covers the period c 1180 to 1800, dealing with the origins of monumental brasses, their manufacture, geographical distribution, social distribution, interpretation, their engravers, and the sources of designs. (BAA)

B M Allen: Discovering soft-soldering history. *Metallurgist — Materials Technologist 1978,* **10**, *537-540.*

Soft-soldering is used to mean the process of allowing molten tin, lead, or their alloys, to solidify in the gap between metal parts to form a joint. The earliest undoubted reference to the technique appears in Lucretius and soft-soldering appears to have been fairly common practice in the Roman Empire. Surprisingly, there is no reliable evidence for the use of soldering irons before the early Middle Ages — Biringuccio is the first to mention the use of sal-ammoniac as a flux, instead of resin, or axle grease (tallow?), and also the use of a copper soldering bit. APG

Susan Cackett: The Percy Collection — a unique view of metallurgical evolution. *Metallurgist & Materials Technologist, 1979* **11**, *(2) 79-81.*

The Percy collection of over 4,000 specimens collected from many parts of the world was purchased by the Science Museum in 1889. Some of the more interesting specimens are now exhibited at the Science Museum, London. The rest are stored nearby, but these can be examined by appointment. In the article, some specimens relating to copper and lead production and refining are briefly described and illustrated. A large number of samples trace the evolution of the iron and steel industry from earlier times to the development of the Basic Bessemer, and a few illustrate early steel alloys. One piece of a cast-iron grave slab from Burwash in Sussex is attributed to the 14th century, but S C provided the abstractor with copies of letters to Dr Percy which make it clear that the evidence for this date is very weak, being based on the style of the lettering and of the cross. Metallic chromium, selenium, and aluminium represent 'new' metals. The article ends with an appeal for information and offers of specimens so that the collection of exhibits may continue. APG

R F Tylecote, H A Ghaznavi and P J Boydell: Partitioning of trace elements between the ores, fluxes, slags and metals during the smelting of copper. *J Arch Sci, 1977, 4 (4), 305-33.*

Seven copper ores from ancient mining areas were smelted in a furnace modelled on the type found at Timna, Israel, and dating to about 3000 BC. The behaviour of up to 49 trace elements introduced from the ore, the fuel and the fluxes was detd. by analysis of metal and slags. Most ores were capable of giving Cu of high purity; loss of trace elements increases with smelting temp., but Cu high in As and Ni could be obtained from artifical ores. Results show that Chalcolithic technology was able to smelt a wide variety of Cu ores to produce Cu of high purity except for Fe, which can be removed by further refining. The remaining elements are present at the parts/10^3 level. Wood fuels contribute little to the trace element pattern. Comparison is made between the trace element pattern resulting from these expts. and material from archaeol. sites in the vicinity of the mining areas. CWB

Cyril S Smith: The interpretation of microstructure of metallic artifacts. *Appl. of Sci. in Exam. of Works of Art, BMFA, 1967, pp 20-52.*

The importance of metallographic studies of the internal structure of metal art objects is surveyed and illustrated. The author discusses the various metals used by ancient artisans, and illustrates how metalworking techniques may be more clearly understood with the help of metallography. Techniques described include wire work, filigree and granulation. Creative use of internal structure is illustrated in the etching used in Japanese swords. RDZ

A R Williams: The gilding of armour. *Gold Bull 1977,* **10** *(4), 115-117.*

Brief discussion of the gilding of armour in the 17th century based on the metallurgical investigation of a sample from the armour of Sir John Smythe in the Tower of London and also of a discussion of the relevant items of medieval technological literature. WAO

L O K Condon: Steel in antiquity: a problem in terminology. *In book, Studies presented to George M A Hanfman. Mitten Pedley and Scott, Eds;Fogg Art Museum, Harvard Univ, Cambridge, Mass 1971, pp 17-27.*

The author states her purpose in writing this paper as providing 'a more precise terminology for ancient iron-based objects through basic definitions, a survey of steel-making techniques and the summarized history of early steel and carbon-iron production". The steel-making techniques are summarized in a diagram. The author concludes that 'unless the speaker is absolutely certain that an object he is talking of (particularly if it is early or pre-Roman) is true steel, he should avoid the use of the term 'steel', for the sake of accuracy . . . It is far more accurate to term the products dating from about 1000-200 BC as being carburized iron or, if one is certain of his ground, as being case-hardened or semi-steel. As for iron products before 1000 BC or better still, 1400 BC, unless the sample has been analyzed, it is safest to refer to it as iron or wrought iron.' CWF

J N Barrandon, J P Callu and C Brenot: The analysis of Constantinian coins (AD 313-40) by non-destructive californium 252 activation analysis. *Archaeometry, 1977,* **19** *(2), 173-186.*

We show that a californium 252 neutron source permits a quick and non-destructive determination of three important elements of a coin's composition, viz. gold, silver and copper. Using this technique of activation analysis, we studied more than two hundred Constantinian coins. For the period AD 313-40, we followed the evolution of the silver concentration in these coins coming from different mints of the Roman Empire. A numismatic interpretation is also given. AA & JSO

G W Healy: Six thousand years of copper smelting. In: *E F Korzinski, ed.Instrumentation in the Mining and Metallurgy Industries, proc. 6th Ann Mining and Metallurgy Div Symp Salt Lake City, Nov 1977, p45-49.*

The development of copper smelting is reviewed from its inception to the general acceptance of the process in which flotation concentrates are smelted in reverberatories followed by conversion in Pierce-Smith type converters, about 1920. Illustrated. 17 Ref. HG

N A North and C Pearson: Thermal decomposition of FeOCl and marine cast iron corrosion deposits. *Stud in Conservation, 1977, 22 (3), 146-157.*

The thermal decomposition reactions of prepared FeOCl and natural marine cast iron corrosion products in inert, oxidizing and reducing atmosphers were determined for temperatures up to 1000^{o}C. The results were used to discuss thermal stabilization treatment of marine iron. Pure dry hydrogen was shown to be the best atmosphere to use in thermal stabilization treatments but even in this case, to achieve complete chloride removal would require treatment temperatures above the limit of metallurgical stability. AA

K F Skidmore and H Schwartbart: Corrosion and dezincification of brasses in water. *J Test Eval 1976,* **4** *(6), 426-433.*

Specimens of various commercial brasses, leaded brasses and Al bronze were corrosion tested for 17d in $FeCl_3$ + $CuSO_4$ + HCl at rt and for 1 year in synthetic drinking water at rt and 82C. The occurrence of dezincification is discussed. ICIB

Tom Ryder: Carriage axles. *The Carriage J 1977,* **15** *(3), 327-330.*

Describes and illustrates structural details of iron axles,arms and wheelboxes for carriages as they developed, particularly during the 1800's in the United States. Methods of lubrication and other procedures for maintenance in use are noted. RHL

Pyne Press (Ed). Victorian silverplated holloware. *Book. Pyne Press, Princeton, 1972, pp 156.*

This volume reproduces portions of catalogues from three companies which were amongst those which merged in 1898 to form International Silver. Catalogues from which the sections on silverplated holloware are taken are the 1857 Rogers Bros. Mfg. Co, the 1867 Meriden Britannia Co and the 1883 Derby Silver Co. The introduction includes a brief review of the silverplate industry and the different silverplating processes used, from 1752 to the present. RDZ

H H Coghlan: Some aspects of the study of prehistoric non-ferrous metallurgy. In *Festschrift für Richard Pittioni, 1976, Wien.*

A short guide through the literature of archaeo-metallurgical problems with a detailed report on a bronze socketed axe from Vienna discovered in the Newbury Museum. The cutting edge of this one-looped axe had been locally worked increasing the hardness from 96.5 HV to 156 HV close to the cutting edge. ECJT

Irmelin Martens: Some reflections on the classification of prehistoric and medieval iron-smelting furnaces. *Norwegian Arch Rev 1978,* **11** *(1), 27-47.*

A detailed study of bloomery furnaces – three basic types – bowl, shaft and domed furnaces divided into subgroups. Natural and artificial draught is discussed. ECJT

H K Cameron: Technical aspects of medieval monumental brasses. *The Archaeological Journal, 1975, pp 215-238*

A complete study of the technical aspects of brasses dealing with the composition of the metal, metallography, and the decoration, coloring and firing of brasses together with a long discussion on the historical evidence for their manufacture and the organization of the men and workshops who produced them. There is an appendix on the restoration of brasses. PTC

P H Stanier: The Copper Ore Trade of South West England in the Nineteenth Century. *J Transport History, 1979, 5 (1) 18-35*

A well-researched account of the shipping of the ore from Devon and Cornwall, with incidental references to the back-carriage of coal. The difficulty of shipping during winter months is emphasised. APG

J A Owen: The history of Dowlais iron works, 1759-1970. *Book. Starling Press, Newport, Gwent, 1977, pp 161. 21 cm; £3.50.*

A factual and interesting account of 200 years of growth and development from the modest Myrthy furnace of 1759 down to the modern foundry of 1971. RFT

K Branigan: Gatcombe: the excavation and study of a Romano-British villa estate, 1967-76. *Brit Arch Rep, 1978,* **44**, *257 pp. £5*

ST 526698. Settlement on the site began c AD 50-80 and continued on a small scale until mid or late 3rd century, when construction of a 4m-thick wall enclosing 7–8ha began. Most of the excavated buildings belong to this period and were zoned into a group of workshops and ancillaries, some cultivated open space, and a further group of buildings including a presumed villa (under the railway). The workshops included smithies, a slaughter house, cold store and bakeries; the economy was based on grain and cattle with some sheep and pigs. Produce was traded for manufactured goods in the local towns, and population of the settlement is estimated at 300-400. Abandonment appears due to the troubles of 367-9; more limited occupation is evidenced thereafter. Attempts are made to assess the size of the entire villa estate and the origins (?Gallic) of its owner. Many specialist contributions include those on pottery, copper and bronzes, coins, ecological remains, and metallurgy (mostly coal-fired). (BAA)

M O'Connell and S Needham: A Late Bronze Age hoard from a settlement at Petters Sports field, Egham, Surrey. *London Arch, 1977, 3, 123-30*

In the terminal of a large half-silted ditch of an LBA enclosure was a 78-piece hoard containing Carp's Tongue and Ewart Park elements and including a faulty casting of a truncated-socket sickle, the centre of the base-plate of a Kurd bucket, and a mould fragment for a South Welsh type socketed axe. The hoard was stratigraphically related to structures and pottery of LBA which, like the Runnymede material, may predate the Scarborough-Staple Howe settlements. (BAA)

J Musty and S Butcher: A reassessment of Roman 'bronzes' from Richborough Roman fort, Kent. *Antiq. J 1976,* **106** *(2), 241-242*

A brief report of work on the re-examination of metal finds from Richborough. Atomic absorption analysis on drilled samples has shown that more than half the first century AD brooches are made of brass, the rest being bronze or leaded bronze. Actual analytical results are not given. WAO

J L Ferns: The Walker Company of Rotherham: Practical Proof of its Greatness. *Industrial Archaeology, 1977 12 (3) 206-220*

This firm made all the cannons on HMS Victory (except two carronades), and a number of notable cast iron bridges, of which one survives – that carrying the A50 at Newport Pagnell, built in 1810. Estimates are made of the number of cannons cast at Rotherham, and a few other facts about the Walker family and their works at Rotherham are included in this article. APG

R L Hunter: Falkirk — Cradle of the Scottish Light-Castings Industry. *Foundry Trade Journal 1978* **144** *(3138) 1101-1110 (also published as a pamphlet by the Carron Company).*

Traces the story of the Carron Company from its foundation in Falkirk in 1759 by the scientist John Roebuck, the Birmingham businessman Samuel Garbett, and the Scottish merchant and shipowner William Cadell. At the start, skilled labour for the foundry and associated coalmines was brought in from England. Financial difficulties were encountered until the demand created by the Napoleonic wars finally put the company on its feet. In the latter half of the 19th century, the great bulk of the output was devoted to the housing trade, but a large number of new foundries was established, and competition was fierce. Some of the characters of the time are briefly described. Since 1900 business has declined, and the reasons are briefly outlined. APG

Dud Dudley: iron-smelter, 1599-1684: *Industrial Archaeology 1977* 12 *(3) 252-264.* Reprinted from the 1879 edition of Samuel Smiles' "Life of Dudley" with a short added commentary. APG

Harry Green and Lawrence Ince: Venallt Ironworks, Cwmgwrach. *Industrial Archaeology, 1977 12 (3) 375-376.*

An exchange of correspondence arising out of the article on the Neath Abbey Ironworks by L Ince (IA 1977 12 (1), 21-37). It is agreed that Venallt Ironworks did not exist in 1842. The date 1826 for the establishment of the works quoted by D Rhys Phillips in History of the Vale of Neath (1925) is mistaken, and probably arises out of confusion between Venallt and Abernant ironworks. The Neath Abbey partners had an interest in the latter works. APG

W K V Gale: Sal Ammoniac in Iron Aqueducts. *J Rly and Canal Hist. Soc. July 1978* 24 *(2) 73. Letter.*

Arising out of D W Halley's article on the Role of Iron in Reconstructing the Oxford Canal 1829-35 (J Rly & Canal Hist. Soc 1978 24 (1), 9-15, the author points out that sal ammoniac was an important constituent of iron cement (or 'rust cement') used for making water-tight joints and (mixed with iron filings) for concealing blowholes and other flaws in iron castings. Two receipes for such mixtures are quoted from an 1888 'Pocket Book'. APG

Susan M Pearce: The Middle and Late Bronze Age metalwork of the south-west, and its relationship to settlement. *Proc. Devon Arch Soc. 1976,* **34**, *17-40.*

More finds may have been associated with occupation debris or structures than has sometimes been assumed; 37 such associations are listed and their place in the chronological sequence and the character of their contents and of their find sites have been analysed. Two chief groups emerge: finds from BA activity sites, and finds from the sites of present hillforts. The difference between these two groups in the later Bronze Age may not have been clear cut. Nine or ten sites showed evidence of bronze working (moulds, waste metal, slag, crucible fragments etc). *Author (adapted)* (BAA)

R Lister: Decorative wrought ironwork in Great Britain. *Book. Bell and Sons, London, 1957, 265 pp.*

Decorative ironwork, both architectural and domestic, is surveyed. The author includes a chapter on ironworking techniques (pp 10-66) in which the basic smithy techniques are described (drawing out, joining, decoration, repousée, engraving, etching), as well as the fabrication of various scrolls. The remainder of the book is taken up with the description of various architectural wrought iron pieces in Great Britain (gates, etc), and with domestic iron objects (pots, fire dogs, etc). The author also includes a short history of the blacksmith and his position in society. RDZ

C King: The alloy content of folles and imitations from the Woodeaton Hoard. *Pact, 1977, 1, 86-100.*

The 350 remaining coins of the Woodeaton Hoard have been analyzed by x-ray fluorescence to determine the variation in alloy content of fourth century Roman copper base coins between mints, the variation through the fourth century, and the composition of the contemporary forgeries included in the Woodeaton hoard. Analysis showed that the silver content was reasonably constant at just over 1%, as was the tin content at around 1½ to 3 percent. The lead content was much more variable, quantity over 10% being common. There was little variation from mint to mint, but quite a lot with time. The forgeries only contained traces of silver and tin but often large quantities of lead. PTC

Ian Blanchard: Labour productivity and work psychology in the English mining industry, 1400-1600. *Econ. Hist. Rev. 1978,* **31**, *1-24.*

The working pattern of farmer-miners in the 15th century Mendip lead fields is related to weather, harvests, holding size, and demand for ore. Per capita output and wages indicate that miners in Mendip, and also in Derbyshire and Co Durham, had generally uniform expectations of cash income, which can be related to the levels of rent on their agricultural holdings. The specialized miner became dominant in Mendip between 1520 and 1600, but he also aimed at a recognizable level of real income. There are parallels with the emergent coal-mining districts, with their full-time miners, and contrasts with the western tin districts and the Derbyshire lead deposits, where the 'cottar-miner' remained active. DWC(BAA)

C E Challis: The Tudor coinage. *Book, Manchester Univ. Press, 1978, 348 pp. Price £12.*

The five main phases of Tudor minting have the common themes of intrigue and incompetent mint-management, together with government manipulation of the coinage for fiscal purposes. Throughout the period the English economy was set firmly within Europe, though it moved from a gold-dominated to a mainly silver economy rather earlier than other countries, ie by 1525. The influence of New World bullion is clear. The five chapters of the book are: mints and minting, the organization and chronology of production, the supply of bullion, the circulating medium, and the role of government. Appendices give mint outputs and mint contracts. (BAA)

A K Knowles: The Roman settlement at Brampton, Norfolk: interim report. *Britannia, 1977, 8, 209-221.*

TG 223237. The pattern of roads, river (with wharf) and defensive ditch is discussed for this 30ha settlement. Within the defences (6ha) are workshops for bronze- and iron-working, and a (thoroughly robbed) bath house. Along the road are over 130 pottery kilns of varying types, of which 14 have been excavated, and pottery from them runs c100 to 300 +. Mortaria stamped by Aesuminus indicate a tentative date of 160-200. Herring-bone stamps from Scotland and Lincs are from the same die as one at Brampton. Mass-produced pottery for the army might have been shipped hence to Caister-by-Yarmouth for distribution along the E coast. AT (BAA)

Colin Martin: La Trinidad Valencera: a Spanish Armada wreck. *Archaeology, 1978,* 31 *(1), 38-47.*

Illustrated general account of the underwater excavation of the wreck in Kinnagoe Bay, off Co Donegal. Hull fragments and historical sources show that the boat was originally a large Venetian merchantman seized and converted by the Spanish authorities. The anchors and cable, six bronze cannons and their fittings, personal equipment, wooden artefacts including bellows and a tackle block, ceramics and pewter are briefly discussed. (BAA)

R Avent and D Leigh: A study of cross-hatched gold foils in Anglo-Saxon jewellery. *Med Arch 1977,* 21, *1-46.*

Over 500 pieces of gold foil on 181 objects of jewellery were studied to discover the method of manufacture and the possibility of understanding workshop practice and links. Photographs and photomacrographs show that the foils were stamped, possibly using a fine-grained wooden or bone stamp, and subsequently cut to cell-shape. Various pattern types were distinguished and an apparently choronological progression from fine to coarser line spacing is seen. There may have been a fixed unit of measurement in use, and different foils were chosen for the separate parts of a single object. (BAA)

A Burton: Industrial archaeological sites of Britain. *Book. Weidenfeld, London, 1977, 160 pp, 23 cm, £5.50.*

Covers the period 1700-1900 and the whole of England, Wales and Scotland. Contains an appendix on transport systems. Grid references are given. Illustrated. RFT

Colin A J Jacobs: Archaeology at Bersham nr Wrexham Clwyd. *County Planning Department, Clwyd. (nd).*

From documentary evidence, old maps and drawings we know that, during the eighteenth century, there was at Bersham a large ironworks run by the industrialist, John Wilkinson. Later a paper mill was erected on the site. Excavation carried out in 1976 has revealed part of the layout of these buildings on the site of the Bersham East Iron Works. ECJT

J H Money: The Iron Age Hill-fort and Romano-British Iron-working settlement at Garden Hill, Sussex. *Interim Report on Excavations, 1968-76. Britannia, 1977,* 8, *339-350.*

Romano-British occupation included a rectangular timber building, roasting and smelting furnaces and a forging hearth of the 1st century. It is suggested that Garden Hill was the base from which local iron smelting sites were operated in the 1st and 2nd centuries. Finds included local and imported pottery and products of iron working, ie. ore, natural and roasted and various types of slag and iron nails. ECJT

A C Jones and C J Harrison: The Cannock Chase ironworks 1590. *Engl. Hist. Rev., 1978,* 93, *791-810.*

The discovery of a remarkable report from the Coke Manuscripts at Melbourne Hall (Derbyshire) gives the most detailed information about the whole gamut of blast furnace and forge operations. This report is unusual in that it was not primarily intended to establish the potential or actual profits of an ironworks, but to recommend the best way of running such a works. It is stated to be the earliest first-hand account in English, as there is no doubt that the writer was an ironmaster and he prefaced all his recommendations by complete descriptions of the processes, not forgetting the importance of the supply and preparation of all raw materials. Beyond this the report contains a rare account of law to guard against any sharp practices and to maintain industrial discipline in the 16th century. BMH

C F Tebbutt: An abandoned Medieval industrial site at Parrock, Hartfield. *Sussex Arch. Soc, Lewes, 1976,* 113, *146-151.*

Evidence of a medieval iron industry in Parrock as seen from a scatter of bloomery slags and possible bloomery sites shown on map. Pottery evidence points to a beginning in the 12th century, perhaps earlier and expansion from the 13-15th centuries. Water-powered blast furnace nearby at Newbridge set up in ca. 1496 and in Parrock a few years later. ECJT

P A Rahtz and E Greenfield: Excavations at Chew Valley Lake, Somerset. *Dept of the Environment Arch. Reports No.8, 1977.*

Excavations carried out in 1953-55 included settlements dating from the Neolithic to recent times. The finds include a wide range of pottery, ironwork, bronze, jet, glass and coins. Nearly all the principal scientific data were obtained on Roman material, much of it from the well. The environment and economy of the villa are outlined, trade links are indicated, and local industries are described in detail. authors.

N Q Bogdan & J W Wordsworth: The medieval excavations at the High Street Perth, 1975-76. *Publ. by the Perth High Street Arch. Excavation committee, 1978, Price £0.50.*

The excavation yielded a variety of metal objects, including iron, bronze, lead, pewter gold and silver. Everyday objects such as knives, nails, pins, barrel locks and tools like spades are all represented. Weapons were also found including a well-preserved axe and a number of iron arrowheads. Three stone moulds indicate metal working. The finds can be dated from the 12th to the 15th century. ECJT

P Weaver: Iron Boats on the Canals (of England). *J Rly. Canal Hist Co. Nov 1978,* 24 *(3) 97-99.*

A further discussion on the early use of iron for boatbuilding mainly concerned with design. There is also further correspondence on pp 110-112. APG

J R Hume: Cast iron and Bridge-Building in Scotland. *Ind. Arch. Review – Summer 1978,* 2 *(3), 290-299.*

This illustrated note analyses cast-iron bridge building in Scotland from about 1810 until the end of this era in bridge building in 1905. One appendix lists the surviving bridges, and a second lists significant cast-iron bridges now demolished. APG

Anon: Early Cast-Iron Grave Slabs in Herefordshire – some correspondence. *Foundry Trade Journal 1978* 145 *(3149) 1078.*

The writers give some brief notes on the site of the Bringewood furnace, and on the site of a blast furnace on Titterstone Clee Hill, Shropshire. Another grave slab at Burrington is illustrated. APG

H Van Suchtelen: Castings in Nineteenth Century lighthouse construction. *Foundry Trade Journal 1978,* 1 *(1) 46, 47, 50, 57. (bound with Foundry Trade Journal, 1978,* 145 *(3152).*

Alexander Gordon designed components in cast iron for a 90 ft high lighthouse, which was erected at Mount Point, Jamaica. The flanged components were cast and pre-assembled within 3 months from the date of contract, dismantled, and shipped, requiring only bolting on the inside flanges during assembly. The resistance to wind and salt-spray has been so good that the structure is still in service. It is thought that about 140 cast iron lighthouses have been built world-wide, many of which are still in service. Two are illustrated – Den Helder, Holland, and Slangkop, South Africa. APG

EUROPE

R Thomsen: Iron, a remarkable metal. *Varde Steelworks, Varde, Denmark, 1975. (in Danish)*

A short history of early iron including metallographic investigation of ancient iron artifacts. Pattern-welded swords (Roman period) from Illerup Moor are discussed. ECJT

R Hachulska-Ledwos: An early medieval village at Nowa Huta-Mogila. *Materialy Archeologiczne Nowej Hut III, Krakow, 1971 (in Polish)*

An axe-shaped iron bar found in a pit; mild steel with a carbon content of 0.2-0.3% C. (CPSA)

J Piaskowski: Metallographic investigation of iron objects and slag samples from an early medieval settlement at Nowa Nuta-Mogila. *Mat. Arch. Nowej Huty V, 1976, 181-199 (in Polish)*

Twenty iron objects (mainly knives, an axe head and axe-shaped bar) dating from the 6th-10th century AD have been investigated. The analysis of bloomery slag indicates the smelting of bog iron ores (P-contents given). (CPSA)

J Emmerling: Investigation of late La Tène sword hilts and scabbards from Munsingen, Switzerland. *Alt-Thuringen, 1977,* **14**, *186-193. (in German)*

Observations on the construction of sword hilts (rivetting, wood inlay) and sheet scabbards (overlapped rims) made during conservation carried out on completely corroded specimens. (CPSA)

D A Khakhutaisvili: Recent discoveries concerning the metallurgy of iron in ancient Kolchis. *Kratkiye Soobsceniya, 1977, (151), 29-33 (in Russian)*

An account of excavations of bloomery sites in Kolchis, western Georgia. Stone lined smelting hearths – date 9th century BC. (CPSA)

A Mazur and E M Nosek: Report on the metallography of objects from Opola-Ostrowka. *Archeologia Polski, 1977,* 22 *(2), 454-459 (in Polish)*

Four iron needles with rings, 11th-12th century AD were examined. They were made of mild steel with elevated P content; one piece was covered with copper. (CPSA)

G Alessandrini, R Perruzi and E Broglia: A study of some bronze objects from the Necropolis of Colle del Forno (Rome). *Conservazione dei Monumenti, 1976, pp 143-154 (in Italian)*

Chemical, metallographic and sclerometric analysis have been carried out on two bronze artifacts taken from a necropolis. It has been possible to establish the manufacturing techniques and the alterations undergone by the artifacts. MCU

U Schaaf: Celtic helmets of the pre-Roman Period. *Jahrb. Rom-Germ. Zentralmus. 1974,* **21**, *149-204. (in German)*

The study divides the helmets into four main types: 1) with attached neck-protector; 2) with a reinforced cap at the top of the helmet; 3) with applied bronze decorative mounts; 4) with an attached hemispherical cap. A final complete check-list under countries of provenance shows concentration in Austria and N Italy. The illustrations and text throw light on the origin of the Roman helmet. GW

Stuart Piggott: A glance at Cornish tin. In: *Ancient Europe and the Mediterranean, Ed. V.Markotic, 1977, 141-5.*

Reconsideration, in the light of recent work by Muhly, Laing and Villard, of the tin trade. The advantages and disadvantages of land and water transport are set out; the time specified by Diodorus for the tin-trade route from the Cassiterides would fit the land-route from the mouth of the Gironde to Marseille by pack-animals. However, the route problem may remain unsolved. (BAA)

K Wilhelmi: A further 'new' find of pre-Roman Iron Age bars from north of the Rhine. *Germania, 1977,* **55**, *184-190 (in German)*

Discussion and map of N German finds of sword-shaped iron bars, occasionally found in association with blacksmith's tools (tongs 'pokers' etc); but there is no hint on the Continent of their use as 'currency' as in England. (BAA)

C and H Domergue: Study of ancient alluvial mines; the Roman gold mines of the Valduerna. *G Mélanges. Casa Velazquez, 1977,* **13**, *9-30 (in French)*

Explanation of field observation of successive water-channels and other evidence of Roman gold workings. Full publication of results will appear elsewhere. A J P (BAA)

J F Healy: Mining and metallurgy in the Greek and Roman world. *Book. London, Thames and Hudson, 1978, 316pp. £11.*

British material is included in this survey, which treats the sources of ore minerals, mining and its administration, processing and refining of ores, manufacture of alloys and quality control, characteristics of minerals, metals and alloys, the properties of metals and the effect of treatment, and the use of metals, their compounds and alloys. Covers the Greek Bronze Age to the end of Roman Britain, and uses literary, epigraphic, archaeological and mine-site evidence. (BAA)

Carol C Mattusch: Bronze and ironworking in the area of the Athenian Agora. *Hesperia, 1977,* **46** *(4), 340-379*

This article includes a descriptive catalogue of bronze and iron foundries and smithies, both workshops and dumps (c.25) found in the region of the Athenian Agora. They date from 6th century BC to the 6th century AD and were located in excavations conducted by the American School of Classical Studies in Athens. No foundries or smithies have been excavated in the Agora that date between 2nd century BC and 3rd century AD, however. The remains from one iron smithy found are insufficient to reconstruct the nature of the work done there. But, the lost-wax technique of bronze casting is well attested. RDZ

M Sonnecken: Research on iron smelting in the late Middle Ages and early modern times at Kierspe, Maerkischer Kreis. *Book. V D Eisenhuttenleute, Dusseldorf, 72pp, 1977, 18 DM (in German)*

In the region of Kierspe/Westfalia, 22 iron works dating from the 13th to the 17th century were localized from slag heaps and historic records. Three sites could be excavated. The size of the furnace was 1.10 m in diameter and 3.5-4 m high. Different types of slags were found and analysed. It is obvious that different types of iron were produced. JR

J–P Mohen: The Bronze Age in the Paris region: synthesizing catalogue of the collections of the National Museum of Antiquities. *Editions des Musées Nationaux, 1977, 263 pp. Price, 250 FF (in French)*

The opening of the new exhibition galleries at Saint-Germain-en-Laye in 1973 prompted this catalogue, illustrated with many drawings and photographs and backed up with graphs and distribution maps. The catalogue proper is prefaced by a chapter on the origin and history of the collections, and followed by a summary account of the Bronze Age in the Paris region. Results of spectrographic analyses are included where available, and for completeness material from other collections, public and private, relating to the Paris region is included. (BAA)

J Francaix and J Liszak-Hours: Analysis of weapons and tools of the Bronze Age from the Paris region. *J Annales Lab Recherches Mus France, 1976, pp 46-57. (in French)*

Reports results of quantitative spectrographic analysis for eight elements in a sample of axes, swords, spearheads, daggers, knives and a halberd; particular attention was paid to lead, tin and arsenic constituents. (BAA)

H J Köstler: History of steelmaking in Carinthia from the end of the 18th century. *Radex-Rundschau, 1978, (2), 519-545 (in German)*

Steel producing methods in Carinthia-Cast steel production in Lippitzbach around 1795. Cast steel foundry in Maierhofl (1818) – disc roasting and smelting of pig iron. Refining processes: fining in a charcoal bed to 'iron' and working raw steel (Brescian steel). Production figures of some puddling processes: first Austrian puddling furnace in Frantschach, 1830, using brown coal in Pravali. Wood carbonisation in Lippitzbach. Peat carbonisation in Buchscheiden and Freudenberg. Puddling, using exhaust gasses from other furnaces. Inventing steel puddling in Frantschach (1836). The Carinthian puddling foundries – Bessemer process: Bessemer foundry in Heft (1864) and Pravali. Production figures and works results. Open hearth furnaces in Streiteben (1889) and Ferlach (1911). Electric steel production with furnaces of the Héroult type (1901) and Fiat type (1925) in Ferlach. 1940 – the end of steel production in Carinthia – the steel works of Carinthia since the middle of the 19th century. (Author)

N H Gale: Lead isotopes and archaic Greek coins. *Proc. Int. Symp. Archaeometry, Bonn, 1978. p 194-208.*

New lead isotope analyses are presented for archaic Greek silver coins from the Asyut Hoard (ca. 475 BC) and for silver and lead ores from mines around the Aegean. Aeginetan coins were of central interest in this study, which has also included work on Athenian, Corinthian, Thasian coins and Persian sigloi. The isotopic results are discussed in parallel with chemical analyses made at Heidelberg; together the data allow suggestions to be made about the sources of the silver used by the Athenians, Aeginetans and Corinthians in the archaic period. Author.

S C Belyayeva, D P Nedopako and I P Moskalenko: On medieval cast iron production. *Archeolohiya (Kiev), 1977 23, 78-87. (in Ukranian)*

Cast iron products found at Ozaryci contain 3.24-4.6% C and are low in Mn, Si and S but high in P. Thus, their properties differ only a little from the Volga Bolgar specimens; However, the difference is striking compared with Mongolian cast irons. All specimens are fragments of cauldrons dated to the 12th-14th century AD. (CPSA)

U Zwicker and F Goudarzloo: Investigation on the distribution of metallic elements in copper slag, copper matte and copper and comparison with samples from prehistoric smelting places. *Int. Symp. Archaeometry, Bonn, 1978. p.360-375 (in English)*

Investigation of slags from Jochberg near Kitzbuhel and the possibilities of prehistoric copper smelting from sulfide ores are discussed. ECJT

E N Chernik: Aibunar – a Balkan copper mine of the fourth millennium BC. *Proc. Prehist. Soc. 1978,* **44**, *203-217*

This is a translation of a paper published in Sov Ark 1975 (4), 132-153 and abstracted in JHMS 10/1, 1976.

D Denecke: Mining and extraction metallurgy in the Harzvorland and Oberharz in the Middle Ages. *Arch. Korrespondenzblatt, 1978, 8 (2), 67-75 (in German)*

A commentary to a map of the Harz area which covers all the early traces of mining and extractive metallurgy. Exploitation of iron ore took place in the Osterode-Altenau, Elbingrode and Langelsheim districts. Traces of 13-14th century bloomeries. (CPSA)

Excavations at Helgo V-1, Workshop, Part II. *Stockholm 1978. (in English)*

The volume is entirely devoted to iron working technology. Chapter I. Locks and keys (by **J–E Tomtlund**), 3–13. Cylindrical padlocks appear after the 6th century AD, box locks not until the Viking period. Chapter II. Tools (by **J–E Tomtlund**), 15-39. Chapter III, Iron currency bars in Sweden (by **P Hallinder** and **H Haglund**), 30-58. Spade-shaped currency bars (by **P Hallinder**), 30-37. Distribution: mainly in the southern Norrland province. Rod- and scythe-shaped currency bars (by **K Haglund**), 38-45. V-shaped thin rods in bundles. Currency bars of Mastermyr type (by **P Hallinder**) 45-46. Chapter IV. Rod-shaped blanks from Helgo (by **P Hallinder** and **J–E Tomtlund**), 58-80. 242 iron bars were found. The large ones were used as semi-finished products for making massive tools; the group of small rods (90%) for the manufacture of minute artifacts. The metallographic examination of the rod-shaped iron blanks from Helgo (by **J–E Tomtlund**), 77-80. Comments on results of analyses made by S Modin and M Lagerquist. Chapter V. The metallographic examinations of locks, keys and tools (by **S Modin** and **R Pleiner**), 81-109. The introduction and conclusions from the report on metallographical examination of tools, knives and arrow-heads (by **R Pleiner**), 81. Lock springs were made of ferritic iron, copper soldering was found in one case. 70% of chisels were made with sophisticated methods of iron-and-steel welding, the same relates to knives; arrow heads reflect more simple techniques and softer material. Chapter VI. The metallographic examinations of rod-shaped blanks (by **S Modin** and **M Lagerquist**), 110-150. The so-called rod-shaped blanks consist partly of wrought iron, partly of unhomogeneously carburized steel; hard steel is rare. Martensite structures indicate in one case the presence of an unidentified alloy element. (CPSA)

H Hamann: The induced draught bloomery: *Jahrbuch fur die Schleswigsche Geest 1975, 24-28 (in German)*

Teutonic bloomeries of the Roman period in the region of Flensburg, N Germany, took advantage of the acceleration of winds blowing regularly about 110 days per year (10 kms/h) on the profiles of sand dunes. The article forms the second part of a contribution published in the same journal in 1974 (CPSA)

H Hamann: The induced draught bloomery. *Jahrbuch fur die Schleswigsche Geest, 1976, 22-24 (in German)*

Experimental measuring of flow conditions in a low shaft furnace. More tuyeres do effect favourably a suitable centralization of the air/gas stream. (CPSA)

M Kowalczyk (Mrs): The medieval smith's workshop in Raciaz stronghold, Tuchola district. *Acta Universitatis Lodziensis – Folia Archaeologica ser. A, no. 11, 1976, 59-74. (in Polish)*

While excavating the castle of Raciaz there came to light a house, one part of which was a smithy with hearth, charcoal, slag, and tools: tongs, anvil. A lot of scrap and fragments of iron. Late 13th century AD. (CPSA)

V Hasek and St Mayer: On the application of geophysical methods in discovering early bloomery-furnaces in the region of Blansko. *Sbornik Okresniho vlastivedneho muzea v Blansku 6/7 1974-75 (1977), 57-65. (in Czech)*

Proton magnetometer prospection in the Blansko region, W Moravia pointing to the remains of local iron smelting. Early medieval sites with slags and tuyeres discovered. (CPSA)

A Wallander: Medieval Iron. *Fornvannen 1977, 72 32-36 (in Norwegian)*

A report on the project of a broadly conceived research on medieval iron artifacts. Split blooms (called here osmunds) from Waldstena and Riseberga monasteries. (CPSA)

H Walling: The earliest mining in the Pfalz. *Mitteilungen des Historischen Vereins der Pfalz 1977* **75** *15-46 (in German)*

A list of 24 bloomery sites mainly dating to the Roman period. Three iron ore mines. (CPSA)

W Werth: Pre-medieval mining in Markgraeflerland. *Das Markgraeflerland NF 1977, 8 (39), Nos 3-4, 211-218 (in German)*

Indirect evidence of a very early iron-making in the form of a compact slag circle in the late Hallstatt period tumulus of Schlatt-Bad Korzingen, SW Germany (6th century BC). (CPSA)

B N Grakov: The Early Iron Age Cultures of Western and South-Eastern Europe. *Moskva, 1977 (in Russian)*

Professor Grakov (1899-1971) was one of the leading Soviet archaeologists renowned in Scythian archaeology. The present volume, in fact, represents a compendium of his lectures and it has been edited as a university text book. It covers the Hallstatt and La Tène culture complexes; in further detail the pre-Scythian situation in the eastern part of the Continent. The introductory chapters are devoted to iron as a cultural phenomenon. The terms Iron Age is discussed, interesting historical and ethnological data on iron workers are added. Technical problems, however, are treated according to the state of knowledge of about 1939. (CPSA)

Jernkontorets Berghistoriska Utskot. 1977. (in Swedish)

Contains two articles of interest. G Magusson, Ironmaking in Jamtland and Harjedelen, p. 9-46. Lake shore bloomeries dating from ∓ 500/900 until 1700 equipped with stone-lined smelting hearths.

The second paper is by K Calissendorf, the use of bog iron in Jamtland as shown by place names, p.47-55. (CPSA)

V D Gopak and O V Suchobokov: Ironworking amongst the Saltova culture tribes. *Archeolohiya, 1978,* 25, *60-70 (in Ukranian)*

Steppe tribes of the 8-9th century AD in the Ukraine. 42 iron objects consisting of knives, scythes, battle-axes, lance heads, hoes and other minor objects have been investigated. Many pieces have been made by iron-to-steel welding and other advanced techniques but rarely quench- hardened. Contain a large amount of slag. (CPSA)

P–L Pelet: Iron, Carbon and Steel in the Vaud region (II), The slow triumph of the blast furnace. *Lausanne, 1978, 354 pp, 51 figs and map (in French)*

One of the most instructive books describing the steady development of medieval smelting technique. Describes the transition from the simple bloomery to the first blast furnace plants of the 16-17th century from written sources. Deals with ore mining, and the distribution of blacksmiths between the towns and the country between 500 and 1399 AD. Concludes that **molendina ferraria** referred to grinding wheels up to the 12th century. The earliest hammer-mill is that of 1185 at Pisa, and water-driven bellows came in a century later. This conclusion will influence the interpretation of the spread of innovations relating to iron technology all over Europe. (CPSA)

ASIA

Gerd Weisgerber: Observations on the ancient copper mines in the Sultanate of Oman. *Der Anschnitt, 1977, 29 (5/6), 190-211 (in German).*

In Oman a great number of ancient places for copper mining could be localized from slag heaps, shafts, tools for grinding and pottery. The slags were analyzed and dated by inclusions of charcoal. By that it was found that copper was mined in this region from the 3rd millennium BC until the 18th century AD. Traces of nickel in copper from slags of Oman indicate that Sumerian copper objects, which have similar amounts of nickel were made from copper of this region, which could be the region of Makon, mentioned in early texts on cuneiform tablets. JR

Noel Barnard: Ancient Chinese bronzes and southeast Asian metal and other archaeological artifacts. *Book. National Gallery of Victoria, Melbourne, 1976, 467 pp. £13.56.*

This volume is a collection of papers given at the Symposium of Scientific Methods of Research in the Study of Ancient Chinese bronzes and Southeast Asia Metal and other Archaeological Artifacts.

The papers are principally on the metallurgy of the bronzes. There is a paper on the radiography of relics from Cook's *Endeavour* and papers on the T L dating of casting cores, and on the general uses of radiocarbon dating.

Work on the provenancing of obsidian in the Pacific is reported. PTC

T Motomura: Bronzes of strange shape from Omi province (present Shiga prefecture). *J Arch Soc Nippon 1977,* **63**, *283-290 (in Japanese)*

The Tokyo National Museum has two strange-shaped bronze objects of the Yayoi period. One is composed of four arrowheads connected in series, and the other of six connected arrowhead-like objects. The length and the weight of the former are ca 16.5 cm, and 20.5 g, and those of the latter are 23 cm and 25 g, respectively. Fluorescence x-ray analysis showed the chemical composition of the former to be Sn 6-10, Pb 20-50, and Cu 40-70%, and that of the latter Sn 6-10, Pb 40-60%, Cu 35-50%. The locality of these objects excavated is only known to be the Omi Province. The author concluded these objects to be arrowheads cast in the connected state. KY

R J Gettens: Joining methods in the fabrication of ancient Chinese bronze ceremonial vessels. *Appl. Sci. in Exam of Works of Art (1965) BMFA, 1967, 205-217.*

Highly sophisticated metal technology is illustrated in the skillful piecing together of cast bronze sections by ancient Chinese metalworkers. Techniques include the use of hard (tin) solders, and interlocking techniques whereby two pieces are locked together by casting one piece on to the other (pre-cast) piece. RDZ

T Kendall: Urartian art in Boston; Two bronze belts and a mirror. *Boston Museum Bull 1977,* **75**, *26-55.*

This article on a fragment of an Urartian (ancient Armenian) bronze belt dating from the mid 8th century BC, and a second complete belt from the mid-7th century BC, includes mention of the manufacturing of such belts. HMP

D K Chakrabarti: Distribution of iron ores and the archaeological significance of early iron in India. *J Econ Soc Hist Orient 1977,* **20** *(2), 166-184.*

An examination of geological and archaeological evidence for ironworking throughout India indicates wide-spread availability of suitable iron for pre-industrial smelting. Five centres of early iron in India are examined and dated, with the aid of radiocarbon dating. Author favours local development of iron-working and is opposed to the diffusionist theory which places the origin of iron-working in Anatolia. RDZ

M V Krishnan: Cire Perdue Casting in India. *Book. Books India, Kanak Publ. New Delhi, 1976, 100pp. Paper-back Rs 30.*

The author is a practising sculptor and teacher at Banaras Hindu University in Varanesi. Though he writes from a practical viewpoint, he is interested in the diversity that occurs under different regional and cultural influences. He compares the modern practice of cire perdue casting in various parts of India today with that given in three ancient Sanscrit sources (here given in translation) and with that followed in countries adjacent to India, in the Far East, in South America, and in the modern West. Full of practical detail on modelling, molding, casting and finishing, the book presents a mixture of technical and historical information. Its emphasis on diversity of techniques will deter any student from assuming that any given piece of sculpture 'must have been' made in every detail by the way he happens to know best. There is a short bibliography and a 7-page glossary of terms in Hindi, Tamil, Sanscrit and other languages. CSS

M J S Beltran: Catalogue of Luristan bronzes in the National Archaeological Museum (Madrid). *Trabajos de prehistorica, 1977,* **34**, *111-154 (in Spanish).*

Among numerous objects there occur daggers, many pieces are equipped with forged blades. There is one iron hilt of the well-known type of Luristan dagger with bearded head on its pommel. CPSA

D C Epler: A Brief History of Chinese Metallurgy. *The Metallurgist and Materials Technologist. June 1978* **10** *303-307.*

Three achievements of early Chinese metallurgists are discussed. The principal technique used in the great age of bronze casting, from 13th to 6th centuries BC, was casting into piece moulds built-up section by section, relief units of decor being moulded separately and fitted into grooves on the mould surface. Appendages were sometimes added to the main body of the vessel by a casting-on process. Crucibles with capacities up to 1650 Kg have been unearthed, and a vessel dating from 1200 BC weighing over 875 Kg is in existence, indicating the high standard of organised effort which was achieved during this period.

In the Imperial age (post 3rd century BC) the manufacture of copper-base coinage became important. In AD 1085, 35 mints employing more than 35,000 workers produced over 6,000,000,000 coins – almost entirely by casting. Metallic zinc, 97-99% purity, produced from smithsonite that had been sealed in earthenware jars which were then piled in layers with coal and charcoal and fired, was produced from the Ming Dynasty onwards.

Iron did not appear in China until the 7th or 6th century BC, but from the beginning it was produced as liquid cast iron. This difference from the West is attributed to the Chinese metallurgists following the tradition of ceramic technologists, taking over highly effective furnace designs and firing techniques, so that casting, not forging was always predominant, as exemplified by the bronze casting tradition. The development of double acting piston bellows and the use of good refractory clays contributed to the successful casting of iron and from the 1st century AD the use of power for working the bellows. As a consequence, techniques of steelmaking also differed from those used in the west. By AD 1078 production reached a figure between 75,000 and 100,000 tons per year.

By this period, a ferrous industry unmatched anywhere had built up and China appeared to be heading for a true industrial revolution. But for reasons which are still uncertain, progress was not sustained and much of the original potential for development was lost. Two factors which must have been of considerable importance are the wars with the Jurchen and the Mongols, and the relationship between government and industry. The significance of these factors is briefly discussed. APG

K R Maxwell-Hyslop: A silver earring from Tell-El Farah (South). IN: *Archaeology in the Levant. Essays for Kathleen Kenyon Edit. PRS Moorey and PJ Parr p. 180-182 Warminster (nd)*

A close study of the manufacture of the silver earring; other examples are discussed. Date 6th-5th century BC. ECJT

K R Maxwell-Hyslop et al. An Iron Dagger from tomb 240 at Tell Farah South. *Levant, 1978,* **10**, *112-115.*

Examination of the surviving metal core of the dagger has an estimated carbon content of 0.4%. Various theories expounded on whether the blade was carburized intentionally Date c 1000-950 BC. ECJT

C W Brewer: Metallographic examination of metal artifacts. *Atiqot, (Eng. Ser.), 1977,* **12**, *75-80.*

From LBA II tombs north of Akko in Israel; the objects include 2 daggers, a spearhead, a mirror, some arrowheads and other unidentified objects. The compositions were lead-free bronzes with tin contents in the range of 6.3 – 15%. ECJT

AMERICA

H V Michel and F Asaro: Chemical study of the plate of brass. *Laboratory Reports (L Berkeley Lab, Univ Calif) No. LBL.6338, 1977, pp 1-46.*

An inscribed Plate of Brass found in 1937 in the San Francisco Bay Area has been alleged to be identical with that posted by Sir Francis Drake in 1579 to claim the territory for Queen Elizabeth. A chemical analysis published in 1938 seemed to indicate that the Plate was authentic. Analyses carried out by the Lawrence Berkeley Laboratory of the University of California, and by the Oxford Research Laboratory indicate a late 19th c to 20th c date. The LBL report describes the work done largely by neutron activation and x-ray fluorescence analysis. FHS

Associacao Brasilerira de Metals. Charcoal-based iron and steel production in Brazil. *Book; Associacao Brasilerira de Metals, San Paulo, 236pp, 1977 (in Portuguese).*

An illustrated account of the use of charcoal as fuel in present day iron smelting and steel making. MG

AFRICA

H M Friede and R H Steel: An experimental study of iron-smelting techniques used in the South African iron age. *J S African Inst Min Met 1977, 77 (11), 233-242.*

An experimental furnace was constructed to the pattern of an Iron Age furnace and the major variables evaluated. In particular the action and efficiency of skin bellows were investigated to gain a better understanding of the air-supply system. Iron ore, slag and metallic iron, both excavated material and the iron produced in the experimental furnace, were analysed and the results are reported and discussed. 26 ref. MG

H M Friede: Iron Age metal working in the Magaliesberg area. *J S African Inst Min Met 1977, 77 (11), 224-232*

Iron implements and copper ornaments found at the Magaliesberg sites in South Africa are described and the analyses of some of these objects are reported and discussed. Ametallographic examination of two iron objects from Broederstroom points to similarities in the smelting and forging techniques that were practiced in the Transvaal and Nigeria during the Early Iron Age. 21 ref. MG

Z Stos-Fertner and N H Gale: Chemical and Lead isotope analysis of ancient Egyptian gold, silver and lead. *Proc Int Symp Avchaeometry, Bonn, 1978. p 299-314.*

In an attempt to characterise Egyptian gold, electrum, silver and lead chemical and lead isotope analysis have been made of artefacts, burial galenas and modern samples of galena from Egypt and elsewhere. The bearing of these analyses on mineralogical and geographic sources, on the debasement of gold and silver with copper and on the date at which the Egyptians achieved the parting of gold from silver is discussed. Authors

INVESTIGATIONAL TECHNIQUES

J Todd and J A Charles: The analysis of non-metallic inclusions in iron. *Pact, 1977, 1, 204-220.*

Energy dispersive x-ray fluorescence was used to characterize the inclusions in bloomery iron from Ethiopia. The process by which the bloomery iron is made is described in detail, as is the metallographic and analytical investigation of the iron. Inclusions of clay and unchanged ore found in the iron could be used to provenance the material. The considerable implications of this method to the study of ancient iron artifacts are discussed. PTC

J Ashley Smith: The scientific examination of small bronzes. *The Conservator, 1977, 1, 5-7.*

Bronze statuettes owned by The Victoria and Albert Museum have been the subject of a program of scientific examination. Many of the bronzes were cast by the lost wax method which is fully described. The stages in the examination of a bronze are set out and the use of optical and metallographic microscopy, x-radiography, ultrasonic wall thickness measurements and ultrasonic hardness testing in these stages are described. The usefulness of bronze analysis is discussed. SMB

H McKerrell: Non-dispersive XRF applied to ancient metal-working in copper and tin bronze. *Pact. 1977, 1, 138-173.*

The use of a portable XRF system of analysis using radio-isotope excitation can provide valuable information in regard to early metallurgy.Accumulation of analytical data, by non-destructive analysis, can rapidly yield the information necessary to provide a detailed study of metallurgical developments within the Near East and Europe. The comparative level of use of different alloys, for a number of areas, shows the extensive and international use of arsenical copper and silver-coloured arsenic-plated artefacts in the 3rd millennium BC. Tin bronze eventually replaces arsenical copper in all areas, but the rate of replacement is very dependent upon access to tin supplies. For Britain, where tin ores were readily available, bronze appears rapidly and completely before 2000 BC. At the other extreme, even by the end of the 2nd millennium BC, southern Mesopotamia was quite clearly extremely poorly supplied in such metal. The possibility exists that the well known Old Assyrian trade in tin in reality involved a silver coloured high content arsenic-copper alloy. Author (BAA)

Z Stos-Fertner and J Kusinski: The presence of mercury in Kufic silver coins. *Pact, 1977, 1, 181-203.*

Kufic silver coins were analyzed by radioisotope non-dispersive x-ray fluorescence on the surface, and by milli-probe analysis of the interior of the coins. This established that the interior of the coin was of fine silver, but the surfaces invariably contained up to 30% of mercury. PTC

M R Cowell: Energy dispersive XRF analysis of ancient gold alloys. *Pact, 1977, 1, 76-85.*

The x-ray fluorescence unit used at the British Museum Research Laboratory is described in detail together with the calculation procedures. The problems of variation in the analytical results caused by sample orientation, layer thickness, and matrix effects are discussed. The effect of surface leaching on gold coins was followed using an SEM and was shown to be confined to the first two microns. PTC

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