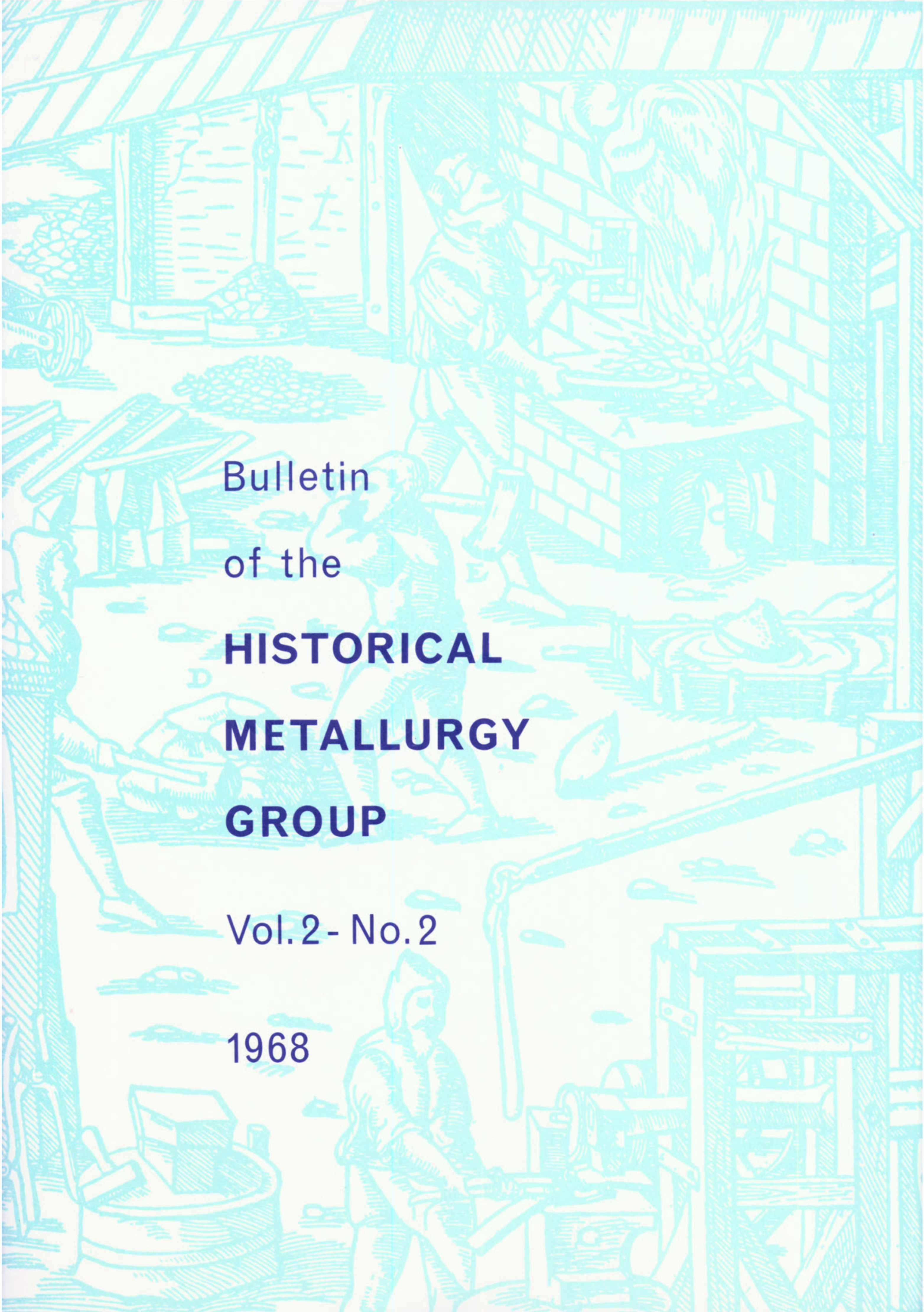

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Contents

A treatise on iron ore as found in the bogs and swamps of Norway and the process of turning it into iron and steel

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(Sheriff and yeoman of Aamods parish in Osterdalan, Norway)

A prize dissertation which won the 2nd Gold Medal of the Royal Danish Agricultural Society in 1782

Preface

I am not going to describe Norway as a country of immense stretches of mountains filled with wretched and desolate bogs, in contrast to the rich cornfields and vineyards of the warmer countries. I would rather wish that competent persons would examine Norway which indeed has forests and bogs that are natural resources equivalent to those of other fertile countries. But the capacity of my knowledge loses itself in ignorance. The disadvantages on one side and the advantages on the other make it difficult to produce a balanced picture. I will not therefore go beyond my primary purpose of showing that the cultivation of certain natural resources is neglected in Norway.

There are many different metals and ores – iron ore is the poorest but there are rich deposits. What an advantage when wrought into usable iron! Owners of ironworks for their part can ship iron from the country in exchange for goods.

Ore is found in the mountains, bogs, and lakes. Its quality differs and it must be treated in different ways. That in the mountains needs large ironworks, the latter (bog ore) only a bloomery furnace, a smithy furnace, and tools. Bog iron ore is what the countryman should take advantage of. Also, I myself have made many experiments with it, and the Agricultural Society exists to disseminate such knowledge.

1. Concerning some characteristics that usually show that bogs have iron ore in them

When the bogs have a supply of water which either filters through the earth or an efficient brook and overgrown hillocks like mounds, they contain ore and one would expect the following test to be rarely used in vain to find it.

2. Searching for ore and the tools required

Use an iron rod of "Ore-spit" which is a forged piece of iron $\frac{1}{2}$ ell long* and 3-4 lines† diameter and octagonal with a pointed end. The top end should have a loop for the hand. (Plate I, Fig. VI).

The ore spit is used by pushing it into the bog, at the edges where there are trees, and in swamps. If the spit goes down easily there is no ore, but if it is difficult ore is present. Then the spit should be pushed down and turned before being pulled up. The granular ore will stick to the spit and will increase its weight. From the way in which the ore clings, one can judge whether it is satisfactory. There is usually peat and iron pan above the ore, but this is rarely more than 5-6 in thick. All this should first be removed with a fork or a pick and spade. The ore is different in colour from the earth. That which is coarse like sand, or gravel mixed with concretions like hens' eggs (round or flat), is good. That with sharp edges is bad. Both have some reservations.

3. Quality of bog ores – colour, shape etc.

Looking for the ore and by various experiments determining its quality. Judging by colour one can divide them into:

(1) That ore which is of an even black colour right through the layer and mixed with lumps which shine like silver when broken. This is rich in iron and has too little gangue in it and must be mixed with fluxes.

(2) That which is black, coarse, and fine with brown streaks and sharp edges, with splinters, needles, and spirals. This produces brittle iron when cold, i.e. cold-short iron.

(3) Red and yellow ore. Flat pieces of ore in thick and thin layers. A mixture of round and flat, but no sharp-edged concretions. After weathering, this material shows itself to be good and not in need of fluxing. It often contains particles of a grey gangue. This is sand that must be separated before weathering or else it will consume iron and make it brittle and bad.

(4) Dark and light brown mixed produces good iron. By itself (light brown ore) it produces hot-short iron.

(5) Grey and coarse rich ore. By itself it gives a fluid [slag?].

(6) Blue iron ore. Rare, but by itself is good when there is good material above.

(7) Verdigris – Useless. This has too big a copper and pyrite content. It is both cold and hot-short. Usually found by itself, but also often present a little below the red ores. When this happens it occurs in layers and streaks and must be separated or it will ruin the iron.

(8) Bog ore of no particular colour and having sharp-edged granules of copper or pyrite is rare. When broken it shows splinters and is useless.

There are two other general characteristics: (a) all good ores have a base of stone or clay – a soft base is no good; (b) the taste of good ore is sweet and sticky to the teeth. If it has no taste it is good but not rich; if acid it is useless. Also if it has shining granules of silver or lead colour and no sharp edges it is equal to good quality. Coppery and pyritic components must be separated and discarded. If the best ore be found mixed with sand it is very harmful and it must be left to purify itself by being put in a dry flat place after roasting. (Wooden boards 12 ells long by 6 ells wide will do). The ore must be thrown like corn after grinding. The ore will fly furthest and the sand nearest to the thrower. Sand from the moor is not harmful. Bog ore grows in the ground, no doubt due to the water. A constant supply increases it. It is best in exposed bogs facing the sun.

If the ore is flooded, first test it by placing it on a lattice of large stick 3 to $3\frac{1}{2}$ hands apart on which is placed chopped dry wood and more lattices. Place the pieces of ore in a circle so that there is an opening in the centre for air. Make it red-hot, and when it is cold it should be like the rest. Figure V, Plate I describes this hearth for roasting.

If in doubt, put it in a smithing furnace, in the embers at the bottom, and make it shallower under the tuyere. Make the hollow firm and place a flagstone under the tuyere in such a

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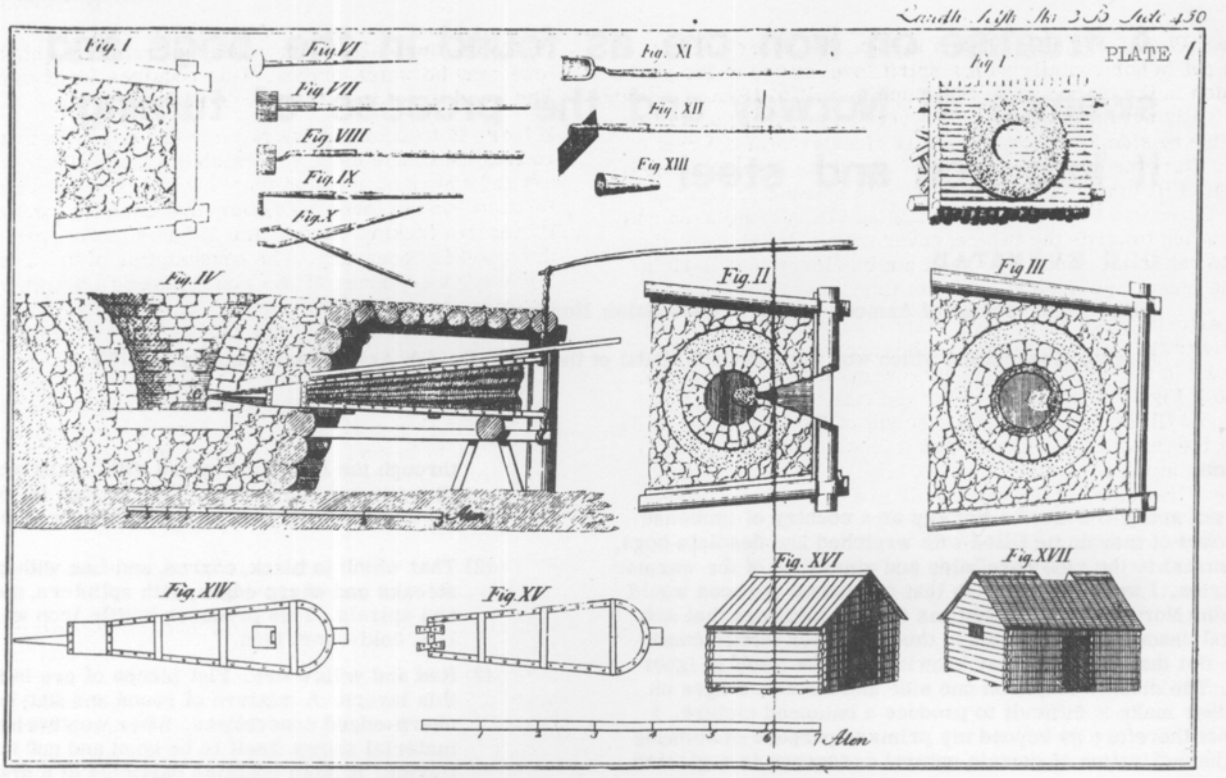
A slightly abridged version of a translation from the Danish kindly made by Niels L. Jensen of the University of East Anglia.

* An ell is about 24 in. (Ed.)

† A line would appear to be about 2 mm, $\frac{1}{12}$ in. (Ed.)



way that it has a forward slope. Place around it a wall of small flat stones without clay and widening at the top. The smithy furnace is then filled with coals and lit. When well kindled it is then blown up with bellows. About half of the previously roasted ore is sprinkled fairly evenly on to the charcoal fire around the walls and not in the middle in order to leave a space for the rest of the ore. Keep it at a red heat by blowing gently. Afterwards press the coal gently together. The coal and the crust which has formed from the ore are pushed into the central hole and the ore slowly disappears into the coals. Then more ore is sprinkled on and the process is repeated. When the coals are almost burnt, the crust of the mould is pushed off with a flat bar and blowing is continued until all the coal is used up. The iron bloom lies close to the tuyere and the slag lies all around the sides like molten lead. The iron is taken out with the tongs and cleaned by hammering. This test is definite.

4. Roasting

Remove the ore from the bog and place in heaps. It may lie as long as you like but roasting must be done when it is not freezing. Clean the ore and free it from earth, or you will get slag on smelting. The ore is deposited in the bogs in different ways. The ore layer may be 2-3 in to 2 ells in thickness or more. The layers may be large in circumference. It is not possible to calculate the quantity until excavated. The ore should be roasted as soon as it is ready as one cannot keep interrupting the work of the bloomery furnace. Roasting reduces the water content and the impurities. Look for a place on dry ground, a sandy moor or a mound. First remove the heather and then place trees 10 ells long and 10-13 in thick alongside each other with 8 ells between. Across them place another layer of the same size to form a lattice. Half of these two layers should be dry wood. On the top layer place 10-12 loads of ore $^3/_4$ ell thick, making sure that air gets to the fire. Under the second layer place chopped dry twigs to fill the space. It is easiest to fill with chopped wood before the top layer is put on. When burnt, rake a little with an axe so that the ore falls through the embers (Fig. XII, Plate I). When cold, separate the charcoal from the ore and keep the latter. Plate II, Fig. I, illustrates the technique of roasting.

This method of roasting is the best that I have tried. The ore is now far more easily reduced than the unroasted ore and does not demand such a strong fire. It is difficult to crush the fine ore if it is overburnt. If too little burnt, it is bad and produces steam and more slag. It is certain that unevenly roasted ore gives a lower yield and much care is therefore required.

Further observations.

(1) The sticks can be made smaller or larger according to the amount of ore roasted.

(2) When bog ore is too soft or if it is difficult to roast, wait until it freezes.

(3) If the wood is damp, chop it early so that it has a chance to dry. Two men can roast and dig enough ore in two weeks for 4-5 weeks smelting.

How to preserve the ore. After roasting keep it dry. Build a hut near the furnace, 5-6 ells square. The walls, roof, and floor must be moisture-tight, and 1-1½ ell from the ground. Under these conditions the ore will keep for years. Alternatively, cover with boards in the open. Do not roast too much at any one time. Plate I, Fig. XVI shows the hut.

5. The Furnace

In the choice of place one must,

(1) Keep the forest near.

(2) Be near the bogs.

(3) Keep far from a farm on small slope south or west, on dry sandy gravel or even ground.

It should be built 6-7 ells into the hill and 2½ ells deep. In this way you will avoid the timber on one side as the uppermost edge of the furnace becomes level with the surface of the hill and the work is eased. It is even better if we can use a stream for the bellows. In this way you will save one man's labour. Use raw logs 9-10 in thick for the three walls. The inside of the bottom of the three walls measure 2 ells long. The earthern wall is 2½ ells so you must make the two side walls come together slightly (Plate I, Fig. I).

The walls must slant outwards. The height should be 2½ ells and the inside length 3¼ ells on each side. It will be somewhat wider adjoining the earth wall. The total length of the sides will be 8-9 ells long since both ends overlap. At each end fix a pole into the ground and put a platform on both sides with one end on the earth surface (Plate II, Fig. II (A)). Dig a hole 1 ell from the earth (front) end, 1¼ ell wide, and 12-14 in high. Fill the inside with stone ¾ ell deep. Place a flat stone ¼ ell thick and 1½ ell diameter on top; place it level and in the middle close to the back (wood) wall. This is the bottom stone of the furnace. Around it tightly pack stone and sand. Then erect a circular wall of flat stones and clay around the bottom stone, 10-12 in thick and 22-23 in inside diameter. At the back of the furnace, the wall comes in 2 in from the circle, thereby producing a small protruding curve (Plate I, Fig. III). When 4 in high, the tuyere arch is then put in horizontally with a spirit level on top of the protrusion in the tuyere wall. Build up the wall to 18 in and slope it slightly outwards. During the erection see that the wall on the tuyere side 3 in from the top is circular with the rest of wall. Start the next (outer) wall of dry stone leaving space between. Fill this with sand and leave an opening coinciding with the tuyere arch the same width as the internal arch and narrowing towards the tuyere; cover with a flat stone at the top to retain the sand. One must not be closer than 8-10 in to the inner wall above the bottom flagstone.

The exterior edge of the tuyere arch stone must be bonded tightly to the outer walls and to the innermost edge of the opening in the outer wall and narrow inwards to the tuyere. Plate I, Fig. IV shows this. When the outer stone wall and the sand filling has reached the height of the innermost wall, start the inner wall again so that it has an internal width of 2½ ells at the top where it is 1½ ell high from the bottom stone. Gradually, as the inner wall is erected, build up the outer wall and fill in the sand as well. The outer wall must be a little lower so that, when the sand filling has been covered with flat stones, these stones slope outwards. The platform must also be slanting away on all sides. Then cover it with earth and turf after filling the space between the wall and the hillside. Line the inside of the furnace with good clay so that it stands neat and stays firm. Make a loose furnace bottom from clay 10 in x 11 in or 12 in, and 1 in thick, and lay it on the bottom stone against the tuyere side of the wall (Plate II, Fig. II (C)). On this the iron is collected and the slag flows downwards around the side. When the loose bottom breaks, replace it.

Tools: (1, 2) Two identical bellows. Bottom wood – 2 in thick; boards 3¼ ell x 9-10 in wide at neck where the hinges are, and 22-23 in wide at the back and there rounded. The bottom is divided into three by pieces of wood. In the middle of the end space is the 8 in square hole for the valve. The neck is 1½ ells long. The pipe is ¾ ell long x 3 in wide, made of iron welded to form a taper. Both pipes should be parallel, since it is harmful if the air is blown crosswise into the tuyere of the furnace. Therefore, both pipes must have a twist, right to right and left to left, so that the ends of both pipes are parallel to each other and blow the air straight away from them. The hole must be narrow at the front and wider at the back. Each pipe reaches 6 in into the neck and is fastened by driving wedges at both sides. The remaining 12 in will project (Fig. XIV, Plate I). The upper wooden board is made from the same wood and is like the bottom except that it will be ½ ell shorter (Fig. XV, Plate I). It should be made of well tanned horse leather, oiled. The height when filled should be 12-13 in for ease of treading. A trestle is made for the bellows and fired at a suitable height. The bellows should be clear of the tuyere by 2-3 in and firmly fixed. Spruce or fir rods 15 ells long by 3 in thick are used as springs. A bench is placed loosely on the ground about the middle of the rods. The bellows are foot-operated with rods for returning them. They are adjusted by moving the bench upon which they rest, back and forward (Plate II, Fig. II, F. G. H. I. K.). There should be a roof over the bellows (E, Fig. II, Plate II).

(3) Rake spade. Flat iron with short square shaft of iron with wooden shaft 4-5 ells long inserted (Plate I, Fig. VIII). The blast spade is 1½ in thick with a heavy iron shaft and a bigger socket than the rake spade (Plate I, Fig. VIII).

(4) A square iron hook, pointed and bent near the end with iron shaft and socket (Plate I, Fig. IX).

(5) Tongs of iron as used in smithies but longer. Wooden shafts (Fig. X).

(6) Shovel, 10 in x 8 in of bent iron plate. Iron shaft and socket ¾ ell and shaft bent at right-angles near blade with wooden shaft (Plate I, Fig. XI).

(7) The tuyere is made from iron 1 in thick x 3 in flattened out and thinned to give a width of 15-16 in at one end and 8 in long. The ends are bent together and welded so that it is 1 in diameter internally at the narrow end and elliptical at the wide end (Plate I, Fig. XIII).

(8) Ore iron rake. Blade, iron, 4-5 x 15 in. Very thin at one end of edge; iron socket and wood shaft. Slight bend near blade (Plate I, Fig. XII).

(9) To the tools also belongs the apparatus by which the bellows may be water-driven. This requires local knowledge. The wood is not important; it is all local at no cost.

If there is found about the furnace dry tails (fir trees not rotted), these are most serviceable for smelting. When the dry tails have been felled they may be carted uncut to the furnace and the three men doing the smelting can chop it. If men are lacking, chop it into fathoms in the spring since dry wood is necessary. The consumption of wood depends on the ore. One quarter of the wood must be 1¾ ells long, the rest 1¼ long. Chopped so small as to be 2 in thick either way. If not too far away take trees uncut and chop at furnace, as chips are very useful. The use of charcoal should ease the work considerably, but since a lot of prepared charcoal is needed and since burning costs a lot and the furnace will not bear such a heat, would turn iron to steel and would have to stand idle to cool. So there is no advantage unless bellows are driven by water power as one man could then do the smelting or make the charcoal.

6. The mixing of various sorts of bog ore and the method of smelting roasted ore to raw iron

In Section 3 the types that need blending are described. Rules for blending – This should take place on the smelting site. In order to be brief I will refer to the numbers given to the ores in Section 3. The coarse ores are rich and dry but the fine ores are lean and wet (fluid). The coarse ores are easier to smelt.

Coarse rich dry ores (1) need to be mixed with fine and fluid ore (3). Red and yellow are the most suitable for this; hard iron needs only one-third. If ductile irons are wanted, a different proportion has to be used.

The ore is mixed at the furnace and the "wet" ore used as a flux. No. 2 gives cold-short iron and No. 4 gives hot-short iron; if these are mixed 50/50 they produce good iron. For cold-short iron first add half of the cold-short ore, then the hot-short, and finally the rest of the cold-short ore. No. 4 may also be blended with No. 3. The mixing is done as described for No. 2. No. 5 is similar to No. 1 and is mixed with red or yellow ore. No. 6 alone is too coarse and dry, therefore add it to No. 3; this also fluxes other coarser ores. Fluid ores are more or less fine.

Rich ore by itself is difficult to smelt and it is impossible to resmelt raw iron in order to mix the iron from two different types of ore together. Rich ores need very strong heat and tend to give steel, and strong heat gives lower yields. Therefore, mix fine and fluid ore to dissolve coarse and dry ore. To obtain a mixed hard and soft iron by resmelting would be harmful; the hard would melt and burn before the soft has been dissolved. One notices that converting a hard raw iron to steel gives a high loss; use instead a softer raw iron. Mixing ores before smelting is the only way that is any good; they cannot be mixed in the furnace.

When ore has been roasted and before it is smelted, crush it to a sand grade. Take one fathom of chopped wood; one quarter of this wood is placed in the furnace diagonally. In the middle make a large opening for air. The wood is kindled at once and the rest of the wood is placed in the furnace until it is full. Make it more open at the middle than at the sides. The long logs will reach above the furnace and will be longer than the short logs, so some of the latter are placed around the sides of the long logs. Keep open so as to maintain the fire which must burn the wood to charcoal. Fill up with wood 1½ ells above the furnace and sloping outwards. After the fire is lit, while putting in the long logs you need two men to put the rest of the wood into the furnace quickly before it is too late. When holes appear between the logs, fill them. There must be no ashes – all must go only to charcoal. One can use the coarse chips to fill the holes. When the wood is all coaled, press it together and then place a firebrand on top of coals here and there. Sprinkle 12 parts of granulated ore gently on top of the charcoal fire, leaving an opening in the middle for ore. When the iron ore is red-hot, rake the coal and iron ore towards the middle so that it forms a mound, after which add another 8 parts of fine ore round the periphery. When the ore has turned red, one man starts the bellows gently, the coals start to be consumed, and a hole is produced. Press coal and ore gently into this hole so that it is full. The man now steps on the bellows and blows strongly. When another hole has been made, one man takes the rake-spade and puts it into the coal near the furnace wall, first at the tuyere side, and by this means coal and ore will be pushed into the hole. As soon as it clears and drops into the middle, more coal and ore are pushed into it from the other side of the furnace. One proceeds thus every time until one has pushed the material from all four sides into the middle, making a mound. When it is half burnt, sprinkle ore (four parts) for the third and last time.

Now blow gently until the fire clears in the middle, and with the back of the spade coal and ore are pushed in from all four sides. Now blow strongly and when the hole clears in the middle shovel in more ore. Keep doing this. Blow gently and remove the coals from the tuyere and then push off the sleeve of ore from the tuyere and put it on top of the bloom. The coal from the other side of the furnace and the ore from the walls should also be put on to the bloom after the coal has been taken from the top of the sides. The bloom is now turned with the aid of the furnace hook so that it can be handled and taken up from the furnace with tongs. With a big stone place the bloom on edge and cut it almost into two parts. After the furnace is cleaned out of slag and the remaining coal with the tools, more wood is placed in it and a new smelt starts as soon as possible. Three men can do 5-6 smelts a day, and when wood is ready two men can do 5 smelts. Do not use too much ore at one time, for a good deal of ore will be wasted by falling into the slag and thus producing bad iron from good ore. Judge the quality from the shape of the bloom. When the iron is ductile, the bloom is thin and flake-like; when hard, it is thick and porous. Hardness is due to a mistake in the mixture. Holes are due to a mistake in the smelting. Iron will become more ductile by being remelted.

The first day will be difficult but keep the furnace going. Using charcoal instead of wood use 3 to 3½ barrels of coal. On the bottom of the furnace place small dry wooden logs to make the coal burn quicker. Put half the coal into the furnace and place small dry sticks with it. Otherwise the heat becomes too strong and steel will be made. About half the ore is sprinkled on as previously, then blow gently, and then faster until a hole appears in the middle, when coal and ore must be pushed into it. When the fire has cleared a hole a second time, add half a barrel of coal and then more ore (see previous description). Continue until all the coal and ore have been used. After this the treatment of the ore sleeve and the bloom is as before. When charcoal and water-powered bellows are used, use slow and even blowing or else steel will be produced.

7. How roasted ore is smelted to make steel

First, it is necessary for the furnace to have been in use for four to five days making iron. Try making steel towards evening after having made iron during the day. Get a hot furnace, then as fast as possible clear the furnace of all slag. Throw dry sand under the tuyere, otherwise during steel smelting the strong heat will dissolve the loose bottom. Place and kindle the dry wood as with iron, but use more charcoal. Move the firebrands as close as possible to the wall. After, when the charcoal is packed hard, eight parts of ore are sprinkled on to it. Then four to five parts when the charcoal is red. Take a piece of iron like a spit but quite round in section and pointed; place the pointed end in the tuyere so that the thick end protrudes into the furnace. Blow hard until the charcoal and iron ore are evenly heated and then remove the iron from the tuyere and blow hard and fast. The fire cuts a hole in the charcoal and ore in the middle of the furnace, so then press the charge as before into the hole. Do not shovel charcoal and ore into the hole from both sides. This goes on until half the charcoal is consumed. Then the coal and ore are pushed to the middle from all sides so that it will be the same height all round, and then put two parts of ore around the sides. A strong blast is needed now. The rest follows as with iron. Throw in a handful of dry sand every time the charcoal and ore are put in, to make the slag fluid. Ore and slag must be pushed off the tuyere into the middle. Take care that smelted ore is not deposited above the tuyere so that it blocks the flow of air. If it does, try to push it up from below and flux with sand. All smelted iron from the vicinity of the tuyere must be chopped off the steel bloom when it is removed from the furnace. Continue to shovel the charge to the middle as long as any charcoal is left. When all the charcoal has been burned, one removes the bloom afloat in molten slag carefully so as not to break it. Sprinkle dry sand on it, then hammer and cut it with an axe into narrow pieces or bars. It must be forged in a clean forge with a strong charcoal fire and, when hot enough for welding, taken out and turned and cooled off a little and then put into the fire until whitish-hot. One blows constantly, then stops for 6-8 minutes so that the heat will purify the steel, leaving little holes in it. Repeat this operation and then take the bloom out, sand it, and hammer and compact it. The steel will not stand too long at this heat, so that the whole product cannot be heated and purified at one and the same time. Take it bar by bar as individually cut. If it is wanted all in one piece, weld it together at the end of the process. Such a smelt in which fifteen parts ore give eighteen pounds of steel is suitable for axes. If more steel is to be smelted, as soon as the steel

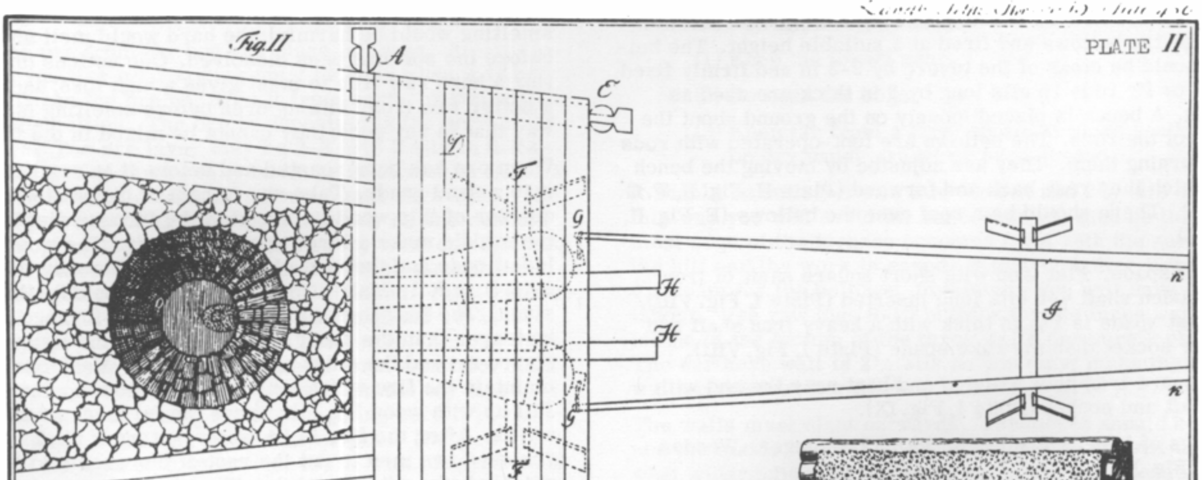


PLATE II

bloom is removed, clean out the slag and start at once. If iron is required, make a new loose bottom, in which case the furnace may stand idle and get cold.

8. Working up the iron

To remove slag to make it weldable etc. Experts find it difficult to judge whether the best iron has been made or not. Use the smithing furnace, but the hole must not be so deep. Air is supplied from the tuyere as before. The fire is now 11-12 in high and 12 in wide. The charcoal is compacted, flat, and level at the bottom. The bellows and tuyere are placed so that air has a straight passage. The forge is filled with coal and, when well aglow, the bloom or the total quantity of iron is placed upon it. When sparkling, grip with tongs and keep near the air hole until melted. Add dry sand and granulated (smithy) slag to it. The slag that falls from the iron when it is cut is most suitable. When the bloom is finished and the slag has melted and fallen into the bottom, the iron becomes a flat lump. It is removed with tongs and placed on a stone and cut into pieces. Then it is finished. Part is lost in this process but the addition of the slag minimises this loss. It is advantageous to make as many forgings as possible at one time. Build a hut with a hammer and bellows driven by water.

9. Converting iron into steel

To convert iron into steel, use a smithy forge. It will take a full day and must be hot. Clean out and remove any previously smithed iron. Make a space 2 in deep under the tuyere so that the air does not touch the steel when it has fallen into the forge during melting. Fill high with charcoal over the edges. Take forged iron, cut it into two pieces, heat and weld them, and then hammer them into a square iron bar. Place it on the charcoal and, when hot, keep charcoal close to the hole of the tuyere so that air does not touch the iron. Make a strong fire and blow. The iron will fall into the forge and become steel. During melting, throw sand on to the fire two or three times until the steel has formed. Remove and weld with the hammer and then cut it into small bars, which should be hammered out and welded where they are porous. The yield will be half the weight of iron from which it came. The furnace bellows are best for re-melting.

Conclusion

Profit and labour costs. Smelting 24 parts of ore gives 36 lb of raw iron (500 gr = 1 lb.), but mediocre iron ore gives only 30 lb. Output should be 150 lb per day. The cutting of timber almost stopped smelting 60 years ago, but I have now revived it. There are many advantages; even if costs rise by one-third, there are still great advantages to be had. The work can be done in winter when the people can do nothing else. Three men can do 5 smelts per day. [Probably in 12 hours; Ed].

Acknowledgment

The translation was prepared from a microfilm copy of the original in the Danish National Library, Copenhagen, which was provided through the kindness of Olfert Voss.

Romano-British ironworks at Bedford Purlieus

G. F. DAKIN

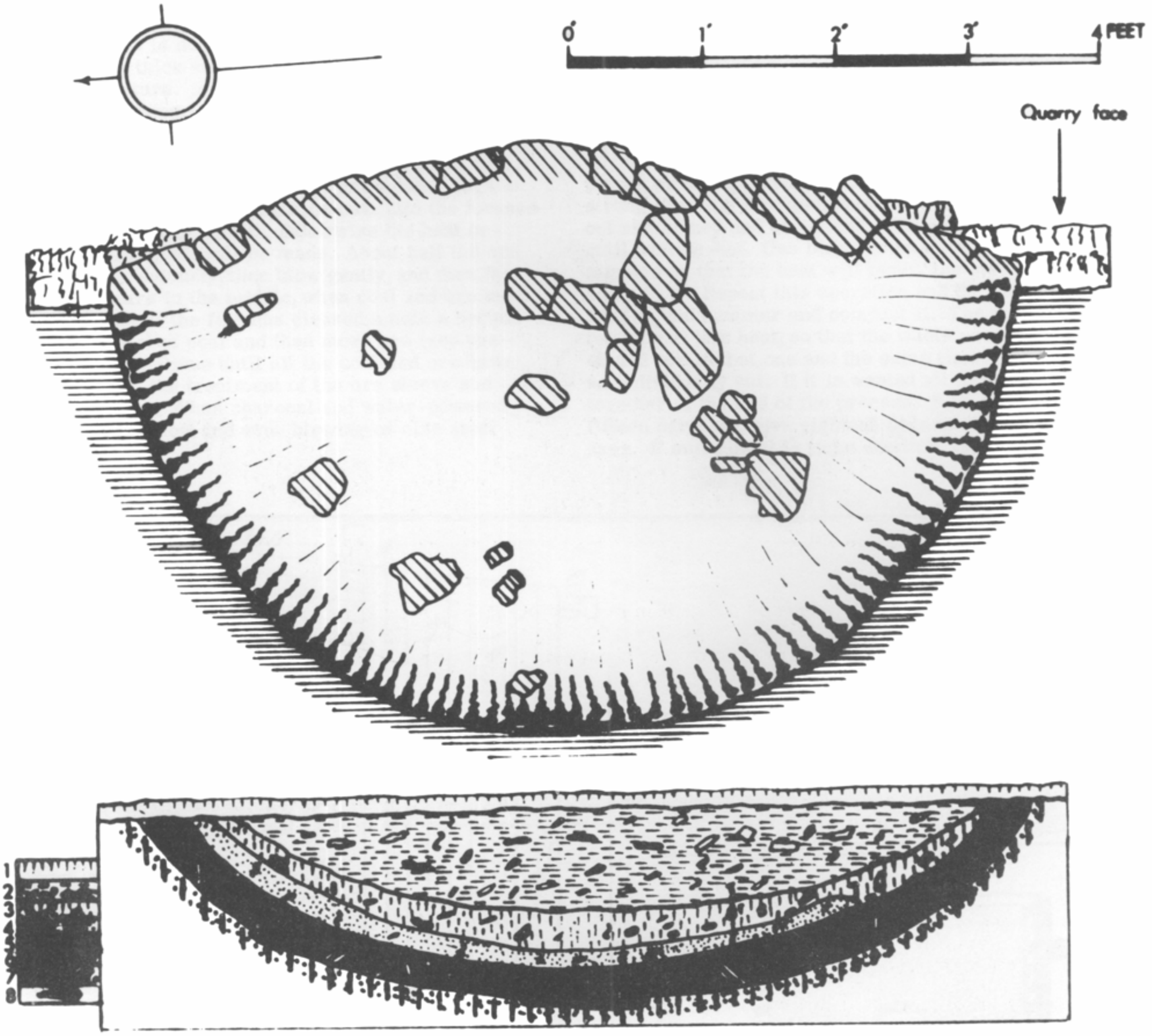
During July and August 1965, the Peterborough Museum Society Archaeological Field Section, at the invitation of the Ministry of Public Building and Works, excavated part of a scheduled area which Richard Thomas & Baldwins Ltd were quarrying for iron ore. The area concerned was at Bedford Purlieus in the parish of Thornhaugh in the County of Huntingdon and Peterborough (National Grid ref. TF 048997).

E. T. Artis, in his book, "The Durobrivae of Antoninus" (1828) showed in the frontispiece map, "iron works" sites among the very many and varied sites he had "explored and examined", including a number at Bedford Purlieus. More recently in September 1932, "The Peterborough Standard", reported, "Tons of iron ore and slag lying about" in four fields purchased by a local contractor for quarrying limestone. These fields were among those in which Artis recorded some of his "iron works" sites.

With this knowledge in mind, the Archaeological Field Section was on the lookout for evidence of iron-working. Eventually two features, and a possible third, were found and judged to have been in use by the Romano-British in the second century.

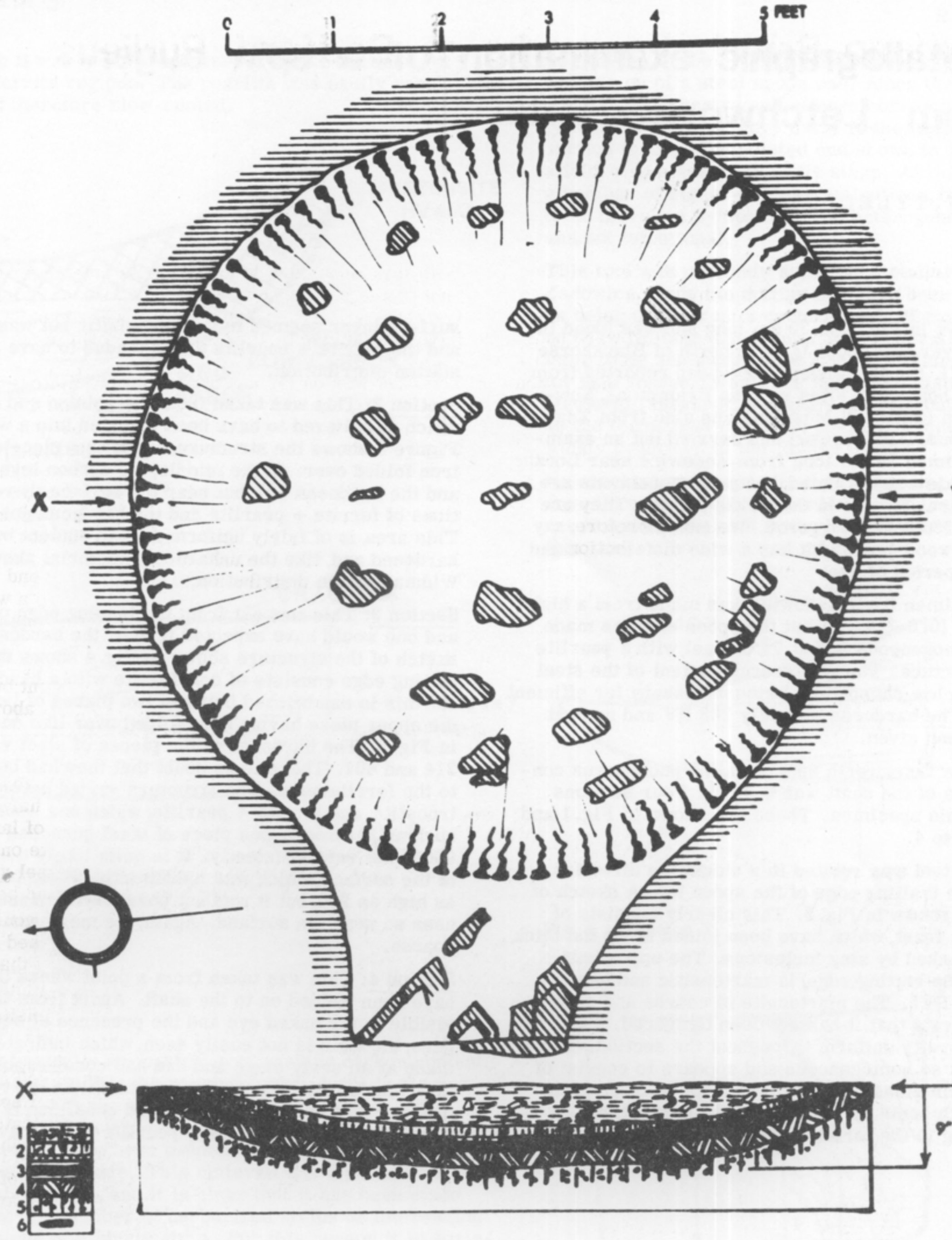
The first was on the newly created precipitous edge of the quarry. Preliminary work by RTB workmen had involved bulldozing the surface. This revealed material, such as burnt stones, red ash, charcoal, and iron slag, which was indicative of some industrial process. On investigation the stratified deposits were removed; they were found to fill what was left of a bowl-like feature which had been cut in the rock. The diameter was 6 ft 10 in and the greatest depth 16 or 17 in. The order and contents of each stratum are illustrated in the appended section (Fig. 1).

The second feature, which was 25 ft west of the first, was



1. Soil smeared over new surface by bulldozer.
2. Mixed deposit of slag, R/B pottery etc.
3. Burnt stones, charcoal, ash, slag, pottery.
4. Light brown and yellow silty layer.
5. Dark red and black silty layer.
6. Red clay.
7. Yellow clay.
8. Limestone-flat rubble.

Fig. 1 – Roasting-furnace 1 at Bedford Purlieus



1. Burnt stones, slag, R/B pottery, tile fragments etc.
2. Light coloured ash with black ash and charcoal above.
3. Red silt.
4. Red clay with a scatter of limestone rubble below.
5. Yellow clay, undisturbed flakes of limestone changing to natural yellow silt.
6. Flat pieces of limestone rubble - probable floor lining.

Fig. 2 – Roasting-furnace 2 at Bedford Purlieus

more complete. It was pear-shaped; the diameter was a few inches less than 7 ft, but the bulldozer had left a depth of only 9 in. The strata remaining were similar in material and succession to those in the first feature (see Fig. 2).

Eighteen feet west of the second feature was what may have been an iron-slag dump. It lay 12-14 in below the surface and covered an area of several square yards. Time for rescue work did not permit an exhaustive investigation. At the base and among the slag and burnt stones were pottery sherds.

Samples of the material from these bowl-like features were examined by Dr R. F. Tylecote (Department of Metallurgy, University of Newcastle upon Tyne). In his opinion the features were iron-ore roasting furnaces and the slag clearly showed that iron smelting had been carried on in the vicinity. Mr B. R. Hartley, M.A., F.S.A. (Leeds University), who examined the pottery, found it to be a consistent group of mid to late second century; it included the base of a Samian cup bearing the stamp of the potter SANTIANUS of Lezoux and much local Nene Valley ware. It seems likely that the roasting furnaces were in use during the first half of the second century and filled after that.

The similarities between the roasting furnaces at Bedford Purlieus and the furnace found at Great Casterton (illustrated and described in R. F. Tylecote, "Metallurgy in Archaeology", Chap. VII, The Roman Iron Age) are striking. Both areas are situated in the iron-ore bearing rocks of the Jurassic series; they are both bowl-like in shape and not very different in depth and diameter; each type has yellow clay at the base and reddened clay immediately above it. They differ in the make up of the fillings. Whereas ore was found pre-packed for roasting in the Great Casterton furnace, those at Bedford Purlieus were filled with late second century Romano-British debris. There is now little doubt that the Great Casterton furnace was a roasting furnace and not a smelting furnace, as previously thought.

Metallographic examination of a spin auger from Letchworth, Herts.

R. F. TYLECOTE

This object, shown in Fig. 1, is 30 cm long and was found in the bed of the River Ivel about $^{7}/_{8}$ mile north of Blackhorse Road (TL 237351). Similar augers have been reported from Romano-British hoards or sites such as Brampton[1], Newstead, and London (Guildhall Museum), and also from Zugmantel and Saalburg. Piaskowski has carried out an examination of a specimen 26 cm long from Zadowice near Lodz in Poland[2, 3]. This was not dated, but many specimens are known from Central Europe in the Celtic period. They are also noted from Medieval Novgorod. We can, therefore, say that this type of wood-boring bit has a wide distribution and an equally wide period of use.

Most of the specimen from Zadowice was made from a high-phosphorus iron (0.6-1.1% P), but the spoon end was made of a piece of homogeneous 0.6-0.7% C steel with a pearlite plus ferrite structure. The phosphorus content of the steel was only 0.045%, low phosphorus being necessary for efficient carburization. The hardness was only 283 HV and no heat treatment had been given.

In the case of the Letchworth specimen, the phosphorus content of the centre of the shaft was 0.091%. Four sections were cut from this specimen. These are shown in Fig. 1 and are numbered 1 to 4.

Section 1: If the tool was rotated in a clockwise direction this would be the trailing edge of the spoon bit. A sketch of the structure is shown in Fig. 2. This clearly consists of two materials at least, which have been joined along the thick line which is marked by slag inclusions. The upper half, which includes the cutting edge, is martensitic and has a hardness of 460 HV5. The martensite is coarse and slow to etch, which suggests that it has not been tempered. The composition is pretty uniform throughout the section. The lower half is not so homogeneous and appears to consist of a number of laminations of very low-carbon wrought iron interspersed with some ferrite + pearlite laminations. A hardness reading in the ferrite gave 221 near the weld. The surface layer seemed to be martensitic but was very thin and the ferrite + pearlite areas tended to have a Widmanstätten distribution.

Section 2: This was taken from the pointed end of the tool, which is believed to have been inserted into a wooden handle. Figure 3 shows the structure, which is a piece of wrought iron folded over. In the middle, the carbon level is very low and the hardness 147, but near the surface there are laminations of ferrite + pearlite and the hardness goes up to 221. This area is of fairly uniform carbon content but has not been hardened and, like the unhardened material above, shows a Widmanstätten distribution.

Section 3: This was cut from the leading edge of the spoon bit, and one would have expected it to be the hardest. However, a sketch of the structure shown in Fig. 4 shows that the actual cutting edge consists of soft ferrite with a hardness of 167, but this is sandwiched between two pieces of laminated steel, the upper piece having been folded over like one of the pieces in Fig. 2. The hardness of the pieces of steel varied between 214 and 407. There is no doubt that they had been welded on to the ferrite core. The structure varied between martensite, troostite, and ferrite + pearlite, which one would expect from such an heterogeneous piece of steel quenched from about 800°C not very efficiently. It is quite likely that a thin layer of the surface, which was martensitic, would have a hardness as high as 500, but it was not possible to measure the hardness so near the surface. Again, the martensite was very coarse.

Section 4: This was taken from a point where the spoon might have been welded on to the shaft. Apart from the notches visible to the naked eye and the presence of some slag stringers, the weld is not easily seen, which indicates that it was made at an early stage and had had considerable heating afterwards which allowed the material on the two sides to diffuse. Side A was laminated and consisted of laminations of fine ferrite and ferrite + pearlite with an average hardness

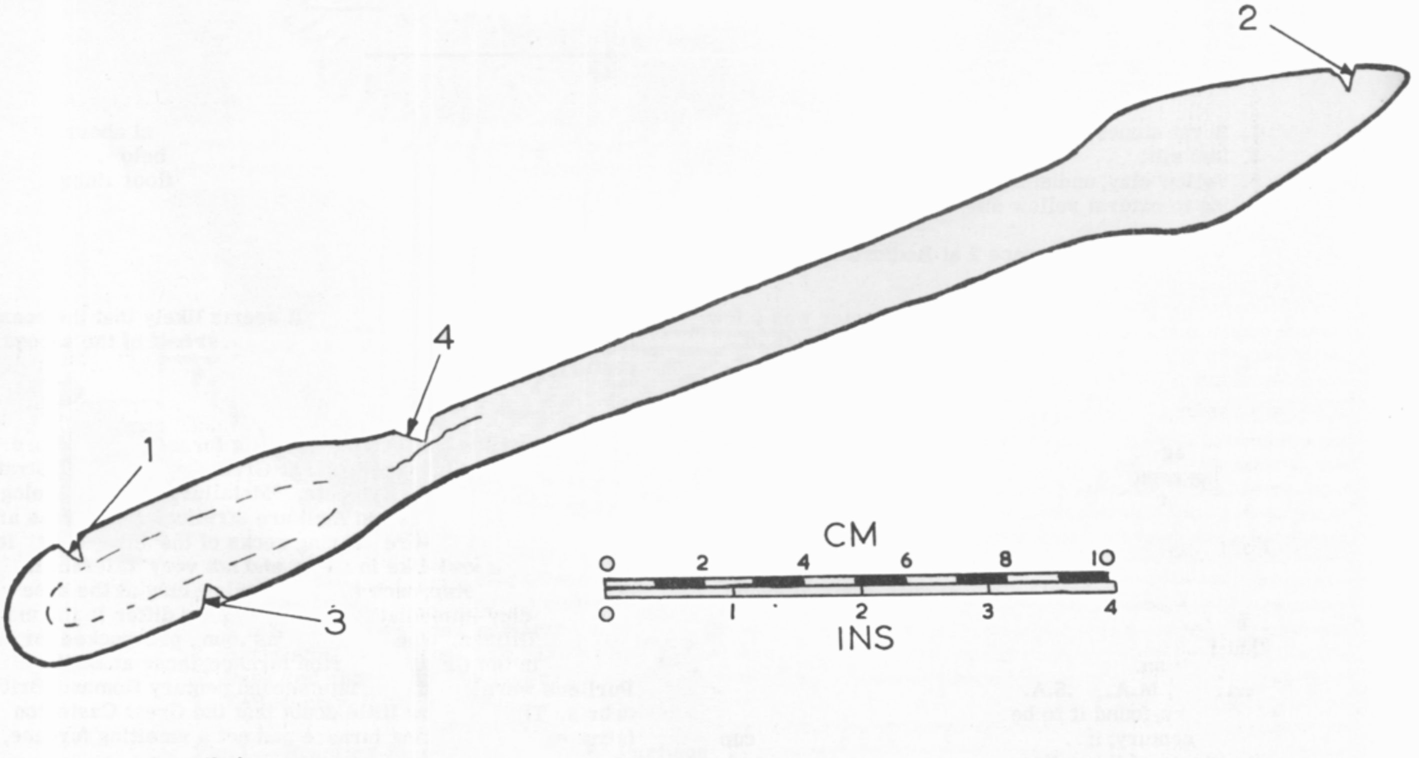


Fig. 1 – Letchworth Auger

of 148. Side B was more homogeneous with a hardness of 126 in the ferrite regions. The pearlite was easily resolvable at X500 and therefore slow-cooled.

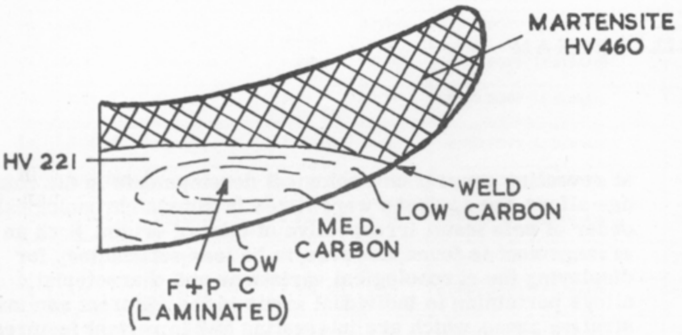


Fig. 2 – Section 1

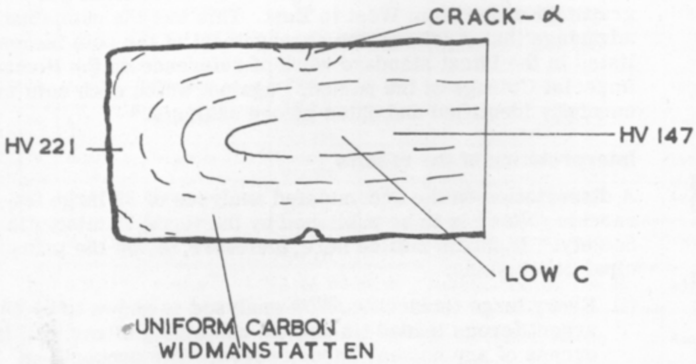


Fig. 3 – Section 2

Conclusions

This tool is basically wrought iron of varying carbon content. It is almost certain that the varying carbon level is the result of smelting, with the exception of the spoon end. Here there is no doubt that a piece or a number of pieces of carburized material have been welded on in order to increase the hardness of the edge. This material has a mean carbon content of about 0.6%, and it is clear that it has been made by the piling of a number of carburized strips or the bending over repeatedly of a single strip. For this reason it is somewhat heterogeneous. It seems that the spoon end was made by hammering out the ½ in square bar to a flat, and welding pieces of steel plate to each side, probably both at once. It is interesting to find that the trailing edge is more efficient than the leading edge, in that the softer ferrite is exposed in the latter. It is possible that this arises as a result of continual sharpening, which has worn away the carburized area at the bottom of Fig. 4. However, it is equally possible that this edge was never quite what the smith intended – unfortunately an all-too-common occurrence in early tools and weapons.

The spoon end has been heat-treated by quenching so as to give the hard structure, martensite; this has resulted in the maximum hardness being about 460 HV, which is comparable with modern wood-working tools. However, owing to the heterogeneity of the steel this hardening is not uniform. The tool has not been tempered, nor would it have benefited from such treatment.

The "weld" shown in Fig. 5 is between two pieces of low-carbon wrought iron; it is most likely a "lap" incidental to the making of the original bar and has nothing to do with the welding on of a steel spoon end. Since the weld is of high quality in the centre and of even composition, it is most likely that it was made very early in the making of the tool. The section through the pointed end shown in Fig. 3 is merely a fold, also made at an early stage. At this end there were a number of higher-carbon laminations, but this is thought to be merely a symptom of the heterogeneity of the material and not intentional.

This tool was certainly superior metallurgically to that from Zadowice, since the cutting edge has been quenched as well as being made from a carbon steel. It may have been designed to cut in both directions. It is generally noticeable that the later tools are made to a higher metallurgical standard, and for this reason I should be inclined to date it as Viking or Medieval. However, this does not rule out an earlier date, as the techniques of carburization and quenching were quite widely practised in the Roman period.

No conclusions can be reached regarding the source of the ore. Up to the medieval period low-phosphorus ores were readily available both in the British Isles and North-West Europe.

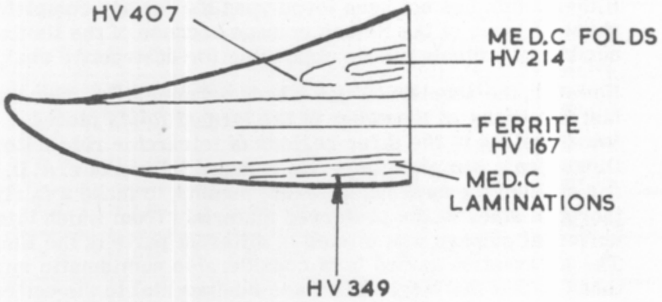


Fig. 4 – Section 3

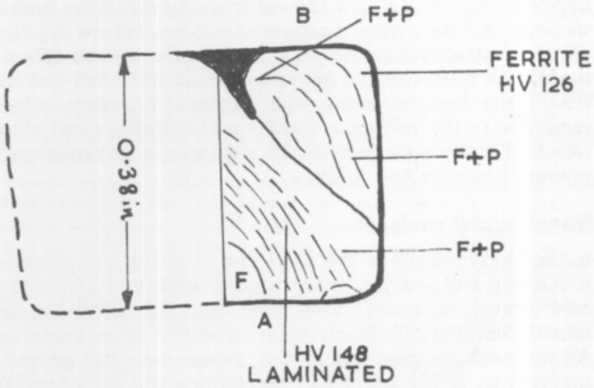


Fig. 5 – Section 4

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1. W. H. Manning: Trans. Cumb. & West. Arch. Soc. 1966, 66, 1-36.

2. J. Piaskowski: Prace Nat. Muzeum Arch. Etnog. Lodz, 1964, (11), 207-231.

3. Ibid., 1967, (14), 249-252.

Acknowledgment

I should like to thank Mr. J. Moss-Eccardt of the Museum and Art Gallery, Letchworth, for kindly allowing me to carry out this examination.

Chemical analyses of 31 large Roman bronze coins minted between A.D.294 and 307

LAWRENCE H. COPE AND HARRY N. BILLINGHAM

In the last two issues of the Bulletin[1, 2] the authors have reported the results of exploratory studies of the compositions and structures of various Roman silver and bronze coins minted in both the third and fourth centuries A. D. The different coins examined were not, however, distributed uniformly over the period, nor could they be regarded as adequate for revealing more than a few of the numerous chronological variations in fineness and base-alloy compositions which are known, or suspected, to have occurred in the turbulent era in which they were minted. It became evident, therefore, that a more systematic and intensive study, covering representative issues of a wider range of the Imperial mints, and in some chronological depth, should be attempted. Hitherto this has not been found possible for any complete phase of issue of the Roman coinage because of the limited number of suitable pieces obtainable for destructive analysis.

However, the acquisition and steady accumulation, over the last two years, of a number of the largest *folles* pieces (which belong to the three periods of tetrarchic rule following Diocletian's complete Imperial coinage reform of c. A. D. 294) has enabled the authors, in recent months, to make a fairly thorough study of the preferred materials from which this universal coinage was minted in different parts of the Empire. The information gained is of considerable numismatic importance in that the large *folles* are fundamental to the entire complex pattern of the late Roman bronze coinage which subsequently developed.

This report records the results of chemical analyses of the alloys of 31 large *folles* issued from mints under both the western and the eastern administrations, before the first steps in substantial coin-weight reductions were effected during the summer and autumn of A. D. 307. For the first time these results enable wide regional differences to be observed in the intrinsic worths and metallurgical characteristics of contemporaneous and supposedly interchangeable pieces of equivalent coinage.

Sampling and analysis

In the early stages of the work the practice was adopted of preparing and analysing duplicate samples of adjacent sectors of core material taken from each coin after the mechanical removal of superficially corroded or silvered layers. As the work progressed, and as experience was gained in the application of the analytical techniques and the correlation of these with metallographic studies, it became increasingly evident that the large *folles* were consistently made in a narrow range of argentiferous leaded tin-bronze alloys of good metallurgical quality. Microstructures were found to be remarkably uniform throughout each coin (corroborated by the similarity of duplicate chemical analyses), except in the case of the most highly leaded alloys. It was first considered to be fortuitous that the *folles* pieces are large enough (circa 10 grams) to provide more than an adequate quantity of clean core material for samples to yield really accurate analyses; however, with the growth of confidence in the reliability of the sampling and analytical procedures adopted, it was eventually considered unnecessary to perform replicate analyses on adjacent samples unless there arose some good reason to suspect any single feature of the first complete analysis, or if the analysis total fell outside the values 99.5-100.5% which were set as the acceptable limits.

In those cases where duplicate analyses were made, however, these are recorded in detail in the Table, where the average of the duplicate results, for each element, is taken as the accepted proportion in the coin as a whole.

Presentation of the results

In the two earlier reports,[1, 2] which were aimed principally at revealing general chronological developments in the coinage alloys, the analyses were listed in simple chronological order of coin issue, irrespective of mint of origin. Such an arrangement is found, however, to be less satisfactory for displaying the chronological variations and characteristic alloys pertaining to individual mints in the different administrative areas, which are interesting and important features revealed by the present results.

In the accompanying Table, therefore, the analyses are listed in a chronological order of coin issue, but under individual mint headings, which are arranged in a conventional geographical order from West to East. This has the numismatic advantage that it follows the arrangement of the coin issues listed in the latest standard work of reference on the Roman Imperial Coinage of the period,[3] against which each coin was carefully identified and dated before analysis.[4]

Interpretation of the results

A dissertation on the accumulated analyses of 39 large tetrarchic *folles*[5] is to be published by the Royal Numismatic Society.[6] It should suffice here, therefore, to list the principal conclusions:

(i) Every large tetrarchic *follis* analysed is shown to be an argentiferous leaded tin-bronze containing silver well in excess of any normal impurity level. The proportions observed leave no doubt that the silver contents of the *folles* were controlled to various (but nevertheless definite) standards,[7] most of which can be positively identified. (This work clearly refutes earlier works[8, 9] which declared the large *folles* to be void of alloyed silver).

(ii) In view of the deliberate silver additions to the alloys, which markedly increased their intrinsic values compared with the plain bronzes used for two lower denominations[10] it is now evident that the large *folles* should henceforth be regarded as the baser of two contemporaneous silver denominations, and not as belonging in any way to the Imperial *aes* coinage series in which they are often classified. On the basis of their silver contents, the large *folles* of eastern mintage, c. A. D. 300, can now be calculated as having possessed an intrinsic value fitting them to have been exchanged at the rate of 5 *folles* to the small silver piece.[11] Assuming the accuracy of a long-established deduction (that the *follis* itself was a 5 – *denarius communis* piece), it is possible to conclude, therefore, that the XCVI – marked silver *denarius-argenteus* was, almost certainly, a 25 – *denarius communis* piece.

(iii) The seemingly universal and common large *follis* coinage is seen to have possessed by no means a universal intrinsic value throughout its short history. The sharp divergence now revealed between Western and Eastern silver standards furnishes positive evidence for a suspected coinage reform.[6] From c. A. D. 299 the Western and Eastern *folles* clearly separate into two distinct groups of argentiferous bronzes. The Eastern mints, and Siscia, then began to produce not only alloys of superior fineness (20 obols of silver per *libra*), but also a coinage of greater alloy homogeneity in tough alloys having more optimized proportions of lead and tin than are to be found in the coinage alloys of any of the Western or Central mints. The metallurgical inferiority of the Western *folles* is manifest by their greater propensity to edge-cracking in coining, and by their subsequent corrosion. In general the Western coin alloys are seen to have been made not only with less silver but with much higher proportions of both lead and tin.

(iv) There is some evidence that, at every mint, the lead and

TABLE I ANALYSES OF SOME LARGE ROMAN IMPERIAL BRONZE COINS MINTED BETWEEN A.D. 294 AND 307

No.	Code No.	Emperor	Date of issue (A.D.)	Weight (grams)	Reverse Type	Mint	CHEMICAL ANALYSIS – weight per cent									Sample	Coin Reference
							Copper	Tin	Silver	Lead	Iron	Nickel	Cobalt	Zinc	TOTAL		
1	A. 2	Galerius	c. 300 onward	10. 74	GENIO POPV/LI ROMANI	London	92. 86	2. 58	2. 23	2. 19	0. 01	0. 02	0. 01	Nil	99. 90	1	RIC, VI London 15
2	A. 1	Maximian	c. 300 onward	9. 53	GENIO POPV/LI ROMANI	London	86. 30	5. 02	1. 70	6. 43	0. 02	0. 03	0. 02	0. 01	99. 53	1	RIC, VI London 18
3	B. M. 51	Severus	306-early 307	10. 57	GENIO POPV/LI ROMANI	London	90. 49	3. 56	2. 07	3. 50	0. 04	0. 05	0. 02	0. 02	99. 75	1	RIC, VI London 59a
4	B. M. 73	Diocletian	c. 296-297	10. 21	GENIO POPV/LI ROMANI	Trier	90. 09	4. 25	2. 56	3. 48	0. 02	0. 02	0. 01	Nil	100. 43	1	RIC, VI Trier 170a
5	N. M. W. 9	Constantius	c. 296-297	10. 90	GENIO POPV/LI ROMANI	Trier	91. 33	3. 44	2. 25	2. 72	0. 07	0. 06	0. 02	0. 01	99. 90	1	RIC, VI Trier 213a
6	N. M. W. 2	Diocletian	c. 298-299	8. 04	GENIO POPV/LI ROMANI	Trier	89. 74	3. 55	1. 73	4. 60	0. 02	0. 05	0. 04	0. 02	99. 75	1.	RIC, VI Trier 277a
7	Br. 17	Maximian	c. 302-303	9. 15	GENIO POPV/LI ROMANI	Trier	92. 95	3. 39	2. 28	0. 77	0. 12	0. 09	0. 07	0. 03	99. 70	1	RIC, VI Trier 520b
8	A. 4	Galerius	c. 302-303	8. 87	GENIO POPV/LI ROMANI	Trier	91. 01	3. 80	1. 52	3. 74	0. 05	0. 04	0. 04	Nil	100. 20	1	RIC, VI Trier 532
9	A. 3	Diocletian	c. 303-May 305	9. 29	GENIO POPV/LI ROMANI	Trier	86. 66	5. 93	1. 37	5. 62	Nil	0. 02	0. 04	0. 02	99. 66	1	RIC, VI Trier 582a
10	A. 5	Maximinus Daza	May 305-early 307	10. 20	GENIO POPV/LI ROMANI	Trier	86. 32	6. 62	1. 38	4. 94	0. 03	0. 04	0. 04	0. 01	99. 38	1	RIC, VI Trier 667b
11	B. M. 47	Constantius	c. 295	9. 51	GENIO POPVLI ROMANI	Lyons	93. 93 93. 86 93. 90	1. 27 1. 12 1. 20	2. 61 2. 70 2. 66	1. 82 1. 80 1. 81	0. 04 0. 05 0. 05	0. 02 0. 03 0. 03	0. 08 0. 07 0. 08	0. 01 0. 01 0. 01	99. 78 99. 64 99. 74	1 2 Av.	RIC, VI Lyons 6
12	N. M. W. 8	Constantius	c. 298	8. 47	GENIO POPV/LI ROMANI	Lyons	84. 89	6. 94	2. 07	5. 56	Trace	0. 04	0. 01	0. 03	99. 54	1	RIC, VI Lyons 53a
13	N. M. W. 6	Maximian	c. 303-May 305	8. 30	GENIO POPV/LI ROMANI	Lyons	85. 63	6. 18	1. 41	6. 07	0. 12	0. 14	0. 02	0. 01	99. 58	1	RIC, VI Lyons 176b
14	A. 6	Diocletian	c. 303-May 305	10. 95	GENIO POP/VLI ROMANI	Lyons	85. 62	6. 39	1. 40	5. 43	0. 39	0. 08	0. 27	0. 04	99. 62	1	RIC, VI Lyons 177a
15	A. 7	Maximian	c. 303-May 305	10. 37	GENIO POP/VLI ROMANI	Lyons	85. 88	5. 58	1. 42	6. 53	Nil	0. 14	0. 02	Nil	99. 57	1	RIC, VI Lyons 177b
16	N. M. W. 4	Maximian	c. 303-May 305	6. 00	GENIO POP/VLI ROMANI	Lyons	88. 33	5. 15	1. 34	4. 56	0. 10	0. 06	0. 04	0. 02	99. 60	1	RIC, VI Lyons 177b
17	Ca. 4	Constantine I	c. Spring 307	7. 56	GENIO POP/VLI ROMANI	Lyons	85. 53	6. 19	1. 65	6. 52	0. 08	0. 03	0. 07	0. 01	100. 08	1	RIC, VI Lyons 213b
18	B. M. 77	Maximian	c. 304-May 305	8. 76	SACRA MONET AVGG ET CAESS NOSTR	Ticinum	89. 32	3. 74	2. 09	4. 60	Trace	0. 01	0. 06	0. 01	99. 83	1	RIC, VI Ticinum 47b
19	B. M. 50	Severus	c. May 305-July 306	10. 72	VIRTVS AVGG ET CAESS NN	Aquileia	88. 30	3. 96	1. 35	5. 98	0. 04	0. 04	0. 01	Nil	99. 68	1	RIC, VI Aquileia 67a
20	Br. 15	Galerius	c. 299	11. 18	GENIO POPV/LI ROMANI	Rome	88. 83 88. 78 88. 81	2. 79 2. 71 2. 75	2. 90 2. 92 2. 91	5. 36 5. 28 5. 32	0. 02 0. 03 0. 03	0. 04 0. 03 0. 04	0. 03 0. 04 0. 04	0. 02 0. 03 0. 03	99. 99 99. 82 99. 93	1 2 Av.	RIC, VI Rome 95b
21	Ca. 3	Galerius	c. 299	8. 09	GENIO POPV/LI ROMANI	Rome	92. 75	2. 40	2. 40	2. 25	0. 03	0. 03	0. 01	0. 02	99. 89	1	RIC, VI Rome 95b
22	B. M. 78	Severus	c. 305 (after May)	8. 98	SAC MON VRB AVGG ET CAESS NN	Rome	85. 83	8. 31	1. 94	3. 47	0. 06	0. 07	0. 02	0. 02	99. 72	1	RIC, VI Rome 123a
23	N. M. W. 10	Galerius	c. 297	7. 97	GENIO POP/VLI ROMANI	Siscia	91. 54	2. 20	3. 62	2. 22	0. 04	0. 02	0. 04	0. 01	99. 69	1	RIC, VI Siscia 102b
24	N. M. W. 7	Maximian	c. 300-301	9. 43	GENIO POPV/L/I ROMANI	Thessalonica	91. 89	1. 84	3. 55	2. 30	0. 03	0. 04	0. 03	0. 03	99. 71	1	RIC, VI Thessalonica 21b
25	A. 8	Galerius	c. 302-303	10. 87	GENIO POPV/LI ROMANI	Thessalonica	92. 57	1. 56	3. 74	1. 81	Nil	0. 24	0. 10	0. 03	99. 96	1	RIC, VI Thessalonica 24b
26	B. M. 74	Galerius	c. 297-298	8. 99	GENIO POPV/L/I ROMANI	Heraclea	91. 49	2. 26	3. 05	2. 70	0. 06	0. 07	0. 02	Nil	99. 65	1	RIC, VI Heraclea 20b
27	B. M. 75	Galerius	c. 297-299	7. 28	GENIO AVGG ET/CAESARVM NN	Cyzicus	87. 54	5. 11	2. 32	4. 82	0. 02	0. 02	0. 03	0. 01	99. 87	1	RIC, VI Cyzicus 11b
28	B. M. 76	Galerius	c. 300-301	8. 89	GENIO POPV/LI ROMANI	Antioch	92. 75	1. 86	3. 13	1. 86	0. 04	0. 04	0. 01	Trace	99. 69	1	RIC, VI Antioch 55b
29	B. M. 48	Diocletian	c. 304-May 305	9. 54	GENIO POPV/LI ROMANI	Antioch	91. 12 91. 07 91. 10	2. 19 2. 09 2. 14	3. 82 3. 86 3. 84	2. 68 2. 61 2. 65	0. 01 0. 01 0. 01	0. 06 0. 05 0. 06	0. 05 0. 04 0. 05	Nil Nil Nil	99. 93 99. 73 99. 85	1 2 Av.	RIC, VI Antioch 58a
30	B. M. 79	Constantius	c. 306 (to July)	10. 10	GENIO POPV/LI ROMANI	Antioch	90. 86	2. 38	3. 73	2. 66	0. 02	0. 05	0. 02	0. 01	99. 73	1	RIC, VI Antioch 74a
31	N. M. W. 5	Maximian	c. 295	8. 87	GENIO POPVL/I ROMANI	Alexandria	92. 92	3. 49	2. 30	0. 81	0. 03	0. 02	0. 05	Nil	99. 62	1	RIC, VI Alexandria 16b

tin alloying additions were made to the copper base in equal proportions, probably as a 50/50 master alloy. This would have been good metallurgical practice, minimising (by densification and dilution) the oxidation losses of the tin component and facilitating a more efficient and rapid alloying by virtue of ensuring the complete immersion of a denser and more readily soluble master-alloy addition.

(v) Major political events in the period (such as the joint abdication of the two Senior Emperors in May 305) appear to have had no direct influence on the choice of coinage alloys or on the silver standards adopted at the time. However, a continuous and persistently unrealistic monetary policy, in which official Roman economic policies completely disregarded the logical outworking of economic laws, forced both the eventual degradation of the alloys of what was an impressive and worthy coinage and a precipitate decline in both coin weight and fineness, in the period which immediately followed that associated with the coins listed here.[12]

Some points of metallurgical as well as of numismatic interest emerge from the analyses when correlated with the coin fractures and metallographic structures. The Eastern coins, although much tougher than the others by virtue of their lower lead and tin contents, tend to exhibit a higher incidence of flattened central shrinkage cavities originating from either imperfect internal 'feeding' during the solidification of the cast coin blanks, or from the release of dissolved gases. The alloys of the more highly leaded coins of Western mintage, although comparatively brittle, are found to be much more effectively degassed and internally 'fed'. They have been, however, much more susceptible to corrosion than the Eastern coins in the course of the centuries. This is attributed to the presence, at the surface, of exposed microscopic lead particles which have created electrolytic corrosion cells with their bronze matrices. In the case of some of the more highly leaded Lugdenese coins, where the lead phase has been sufficiently interconnected to have acted as the medium for continued corrosion, the penetration is deep into the coin interior. The Eastern coins (with isolated lead particles, and more optimized tin contents) are observed to have been far less susceptible to interdendritic corrosion penetration; the effect is usually found to be one of a fairly uniform surface corrosion.

Every *follis* which has been microscopically examined shows signs of having been hot-struck. The hardness measurements also indicate hot-striking to have been the minting process, for the hardness is not found to be appreciably greater than that of the material in an annealed condition.

Impurities in the alloys

There is an interesting incidence of both high and low cobalt levels, associated, respectively, with low and high nickel levels in some Lugdenese coins. These are not only of the poorest metallurgical quality encountered, but the unusual impurity levels and their variations suggest that the mint of Lyons had its own peculiar sources of copper. In contrast the mint at Treveri (also in the Province of Gaul) shows a different and much more regular pattern for these impurities which indicate that supplies of copper from different sources were generally used by these mints.

In the light of these results it is now apparent that the similarities of only two coin analyses reported by Lewis[8] do not really substantiate his suggestion that the mints of Lyons and Trier were supplied with alloy blanks from a common source – certainly not on a regular basis.

Acknowledgments

We express again our gratitude to the Governors, the Principal (Mr H. A. MacColl), and the Head of the Department of Metallurgy (Dr G. J. T. Hume) of the Wednesbury College of Technology, for continued encouragement and for the facilities made available for performing the analyses.

We are also deeply indebted to the following for their generous provision of disposable coins for analysis: Mr G. C. Boon, National Museum of Wales, Cardiff (Coins coded N. M. W.); Mr R. A. G. Carson, The British Museum (Coins coded B. M.); Mr L. V. Grinsell, The City Museum, Bristol (Coins coded Br.); Mr Robert Hogg, The City Museum and Art Gallery, Carlisle (Coins coded Ca.); and Dr C. H. V. Sutherland, The Ashmolean Museum, Oxford (Coins coded A).

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(3) C. H. V. Sutherland: "The Roman Imperial Coinage", Vol. VI: Diocletian to Maximinus, A. D. 294-313 (1967)

(4) We are deeply indebted to Mr R. A. G. Carson, Deputy Keeper, Department of Coins and Medals, The British Museum, for identifying and dating each coin before it was sectioned for analysis and metallography.

(5) The 31 coins whose analyses are reported here, together with 8 which are contained in previous works. (Ref. 1 and 2 above).

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(8) N. Lewis: "A hoard of folles from Seltz (Alsace), with a supplement in 'The Chemical composition of the follis' by D. Lewis, NNM 79

(9) H. L. Adelson: Museum Notes, 1954, 6

(10) The two smaller post-A. D. 294 bronze pieces identified by radiate and small laureate bust imperial images on their obverses.

(11) The *denarius argentius*, a silver piece weighing one-ninetysixth of the Roman *libra* of approx. 325 grams.

(12) Analyses of the reduced *folles* of A. D. 307-312, which we are now beginning to accumulate in our study of the next period of development of the Roman Imperial coinage.

Corrigenda and Addenda

A. Paper in Vol. 1 – No. 9 (Reference 1)

(i) p. 2, line 29; for "studies" read "studied"

(ii) p. 2, line 37; for "liquidation" read "liquation"

(iii) p. 4, Coin No. 6; read "GENIO/POP ROM" for the Reverse type.

(iv) Coin No. 8; can be more closely dated as A. D. 321. The Reverse type is DN CONSTANTINI MAX AVG with VOT XX in wreath. Coin reference is also R. I. C. VII Rome 237.

(v) Coin No. 10; the date is now ascertained as A. D. 325-326. The reference is R. I. C. VII Cyzicus 34.

(vi) Coin No. 11; the date is A. D. 330-331, and the reference is R. I. C. VII Trier 522.

(vii) Coin No. 14; the average copper content is 80.94%, not 80.96%. The average total thus becomes 99.98%.

B. Paper in Vol. 2 – No. 1 (Reference 2)

(i) P. 51, line 34; for Reference "2" read "1".

(ii) P. 53, Coin No. 14 in Table I: the nickel content of the second sample is 0.05%, not 0.04%.

(iii) P. 53, Footnotes to Table I; for Reference "1" read "2".

(iv) P. 53, Coin No. 1 in Table II; the Reverse legend is broken . . V/L. .

(v) P. 53, Coin No. 2 in Table II; The Reverse legend is broken . . P/V. .

(vi) P. 53, Coin No. 4 in Table II; The Reverse legend is clearly shorter than the one recorded for R. I. C. VII Rome 163. The coin, which at first appeared to be genuine, is now considered to be of dubious regularity in view of the analytical evidence and the unusual combination of inscriptions and mint-work.

(vii) P. 53, Coin No. 12 in Table II; The Reverse legend is broken . . I/P. .

A note on prehistoric casting moulds

H. H. COGHLAN

Tylecote[1] has given a very comprehensive survey of the whole question of the moulds used for casting of non-ferrous metal during prehistoric times. Hodges[2] has surveyed in detail the moulds of the British Isles, and Coghlan and Raftery[3] have examined Irish casting moulds in the collections of the National Museum of Ireland. The present note is intended to draw attention to one or two specific points.

Concerning the so-called open moulds of stone used for casting such things as flat axes Tylecote[4] mentions that such moulds may have been used with a weighted cover, which would avoid unnecessarily wasteful loss of metal by oxidation. There would appear to be little doubt that this technique was known to some prehistoric founders, since the following examples are known of moulds upon which a cover was used. Déchelette[5] figures one of the sandstone moulds found by Siret in the 'fondries' of the El Argar region of Spain with its capstone or cover in place. The author has examined two stone moulds in Como Museum, Italy. One is arranged for casting three flat knife-like objects and one comb-shaped object; a flat capstone covers the mould and bears heat markings from the molten metal cast. The other Como mould is for casting a sickle, and the way in which a pouring channel is arranged shows that the mould was completed by a flat cover. Another stone mould with a flat cover has been recorded from Kultepe. Anatolia.[6] In Sweden, Oldeberg[7] mentions stone moulds for casting knives and sickles which have a top cover. No doubt more examples could be quoted by those familiar with the vast archaeological literature, but the few examples mentioned show that the term 'open mould' is not always truly applicable. There are, of course, moulds of which the upper surface is so irregular and badly finished that it would be useless to endeavour to apply a cover. To these the term 'open mould' is appropriate.

While not nearly so numerous as the moulds made of stone, there is a small but very interesting class of moulds made of bronze for palstaves and socketed axes, and a firm conclusion does not appear to have been reached as to the precise purpose of these moulds. One school of thought would see the purpose of these bronze moulds as for the production of wax models or patterns. Tylecote,[8] while pointing out that it was unquestionably possible to cast bronze directly into such moulds, says that the important question is how many castings could be made in them, and would it not be cheaper to use the mould for making wax or lead patterns, when it would have an indefinite life? Perhaps no firm conclusion will ever be reached in this matter, but it would seem unnecessary to make an elaborate bronze mould merely to produce patterns when a finished implement, or indeed a wooden pattern, would serve the purpose quite well. Again, if wax patterns are in question which would be invested in the normal manner of waste-wax casting one would not expect to find casting flashes on the implement but, in fact, these are very commonly found. For instance, of nearly two hundred socketed axes examined, about half retained evidence of casting flashes, and many others may have had flashes which had been cleaned off in the finishing of the implement.

Concerning the bronze moulds, Drescher's experimental work[9] has given some important data. He made a series of experimental moulds of bronze based upon originals, and found upon casting into these moulds there was no difficulty with fusion between the poured metal and the mould, even when the same alloy used for the mould was also used for the metal cast. Various dressings were applied to the moulds, but these were not absolutely necessary, and contraction of the castings freed them from the mould upon cooling. It was not always easy to fill the mould so that a clean casting, corresponding in all respects with the mould, was obtained. Gas and ventilation problems gave more trouble than in the case of clay moulds, and also to some extent than stone moulds; these difficulties gave rise to bad castings in some of the experiments. By inclining the mould during pouring, such defective castings were largely avoided since with inclined pouring the air and evolved gases escape more readily.

Examination of original moulds confirmed the experimental results, since it was found that in nearly all bronze moulds one valve was up to 15 mm longer than the other in order to facilitate inclined pouring. A heavy winged axe from Falkensee is figured in which the casting riser is still in place, and the upper surface of this riser shows that the axe was cast at an inclination of 23°. Palstaves from Hippersdorf in Lower Austria were cast with even greater inclination, and Drescher says that the examination of a large number of casting risers confirms the practice of inclined casting. Such factors indicate, at least in certain instances, the direct casting of bronze in bronze moulds, since inclined casting would not be necessary merely to cast patterns in wax or lead.

In Drescher's view, even more important than inclined casting was the correct heating of the mould before casting and a correct pouring temperature for the metal. A cast made in an unheated mould was a failure, the casting being porous and unusable. When the mould was heated to 50-100°C good castings were produced, and this was repeated twelve times without damage to the mould. In another bronze mould, which had unusually thin walls, fifteen casts were made without apparent damage. Although the experimental moulds remained undamaged by the tests applied, and only when too quickly cooled did they suffer from cracking, it should be noted that after a given number of casts the moulds did become unusable, because from the frequent heatings and coolings the previously fine-grained structure became coarse and porous. This was clearly shown by a broken experimental mould. This postulates a limit to the life of the mould, and Tylecote's suggestion of replacement every fifty or so castings may not be far out. Drescher[10] has found evidence to prove that some of the original bronze moulds which he examined had been used for direct casting of metal. Hence, it may be stated that these bronze moulds were suitable for direct casting and that they were, in fact, sometimes so used. To what extent they were used for the direct production of castings must remain an open question for the present.

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(4) R. F. Tylecote: op. cit., Fig. 24, p. 111.

(5) J. Déchelette: Manuel d'Archéologie, 1910, II, 181, Fig. 51.

(6) S. Przeworski: "Metallindustrie Anatoliens", Leiden, 1939, pp. 111-112.

(7) A. Oldeberg: "Metallteknik under Forhistorisk Tid", Lund, 1943, vol. II, p. 146.

(8) R. F. Tylecote: op. cit., 125.

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Technical terms used in the brass mills in the Saltford and Keynsham area

JOAN DAY

A brass mill was started by Abraham Darby at Baptist Mills, Bristol, in 1702. When he left the area for Coalbrookdale a few years later, the company continued under the leadership of its remaining Quaker partners, and developed rapidly over the next 50 years. Several new mills were established along the River Avon and its tributaries between Bath and Bristol; Keynsham, the most suitable site, became the headquarters of the company. Other new firms were also established in this area, which was at this time regarded as the technical centre of the industry, but by the end of the century the initiative had passed to other regions with the coming of steam power and other developments. During the 19th century the local brass industry declined rapidly and most of the mills were closed, until by 1900 only Saltford and Keynsham remained, still using water as their main source of power. Saltford battery mill closed in 1908, the last brass battery in the country, but the rolling mills there remained, as did the wire and rolling mills at Keynsham, to be revived a little by the 1914-18 war effort. Saltford finally closed in 1924, to be followed just three years later by the old headquarters of the firm at Keynsham.

These local terms have been taken from tape-recorded interviews with three of the last very elderly and rather infirm old men, who remember their work in these mills. The author would be glad to hear of any similarities or differences of such terms used in comparable industries from other parts of the country.

The Annealing Process

Nealing	Annealing (in general use)
A fire	A furnace load
Buckle or buck hole	Ash pit of annealing oven
Bosh	Trough or large bowl for water, kept in front of ovens
Killott	Three-legged stand to take trays carrying wire

Rolling Process

Slabs	Rectangular brass mould used for rolling sheet
Slips	Elongated moulds for rolling strip
Shab	Dross or impurities in sheet brass; had to be removed before final process
Stranded or studded	The jamming of rolls when incorrectly adjusted for thickness of metal (invariably accompanied by unmentionable language)
Pritchel	Punch or pointed tool for marking sheet to pattern
Curls	Strip metal curled round into circles after going through slitting mill

Battery Work

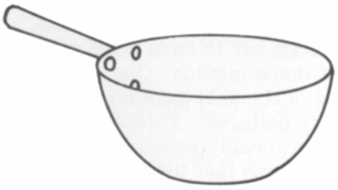
Helve	Arm or shaft of tilt hammer (made of wood)
Stulch or stulsh	Sprag or length of wood used to prop under helve disengaging it from cogs, thus stopping hammer
Husk or Hursk	Metal ring enclosing helve, on which it pivoted
Naps	Round shapes of brass cut on shears in preparation for hammering into shapes of pans
Ferrier	Outer pan of three, placed one inside the other, whilst being shaped up by battery hammers

Wire Drawing

Strings	Narrow brass strip prepared for wire drawing
Rumpling	First stage in wire drawing
Wortle plate	Die or plate through which wire was drawn
Jacobite	Pincers which drew wire through wortle plate
Rumple pritchel	Tool for reaming out holes in wortle plate to correct size

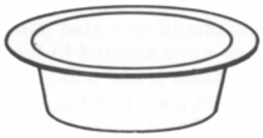
Other Processes

Pickling	Immersion of brass in 'vitriol and water', to give hard bright finish
Stamps	Crushing process for furnace ashes and other waste to extract usable metal for remelting
Lemmel (?) or lemmey (?)	Iron pot into which waste wire was hammered for remelting



A Compass Bowl

A Guinea Kettle



A Lisbon Pan

Shuff (men's version today)	Waste brass, filings, off-cuts etc., used for remelting
Shruff	Same as above. This version taken from 1862 sales catalogue of Keynsham and Saltford premises. Hamilton's 'English Brass & Copper Industries to 1800', p. 340, quotes Houghton's method of making brass in 1697, in which '1/7 shruff or old plate brass', is used.
Water Wheels	These provided the main source of power for mills; they were undershot, and from 15 to 18 ft diameter. Eight were in use at Keynsham until 1927, and five at Saltford, although only three were used latterly.
Floats	Paddles
Starts	Wooden slats which paddles were fitted on
Stays	Metal rods between each float
Rings	The two circular frames of each wheel without floats, starts or stays

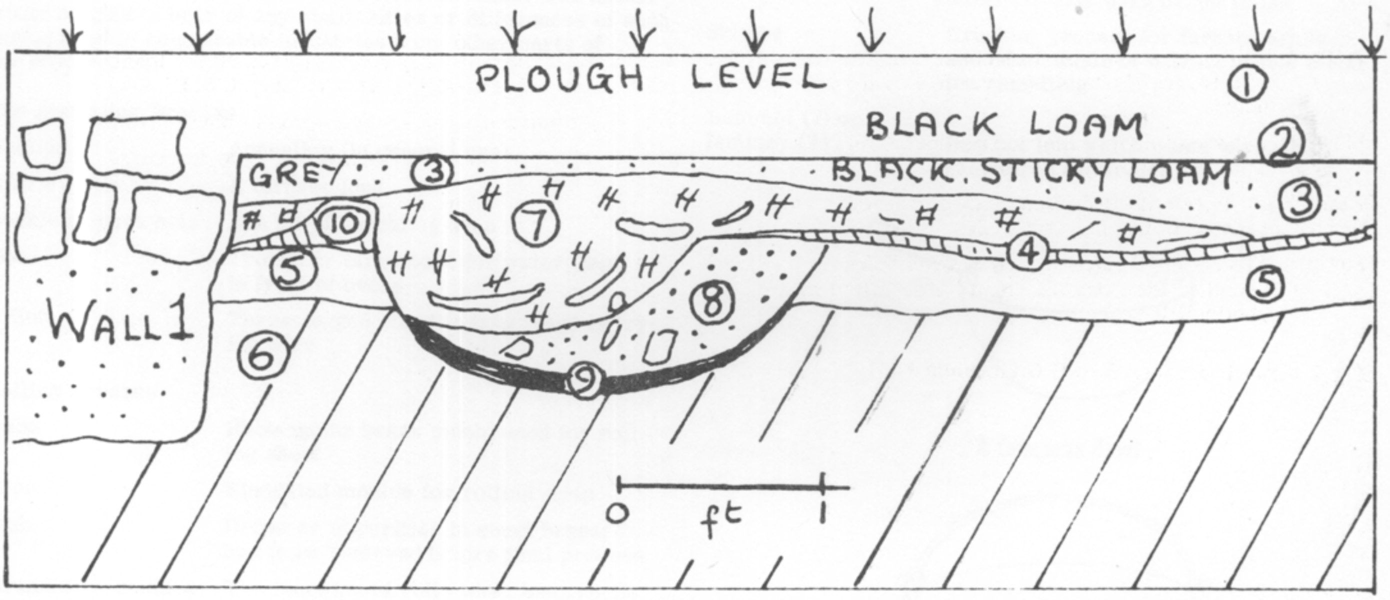
Further excavations at Ariconium

A. P. GARROD AND N. P. BRIDGEWATER

In October 1967 further excavations were made on this iron-working site of the Roman period. A trench was cut in an endeavour to locate a mosaic floor which had been observed on several occasions during ploughing. Unfortunately the floor was missed, but the remains of furnaces similar to those reported by N. P. Bridgewater in Trans. Woolhope Soc., 1965, 38, 124-135 were discovered. Two bowl furnaces (A and C) with a depression between them (perhaps a quenching pit or smithing hearth) were found (see Figs. 1 and 2). These were about 500 yards to the south of the previous excavation.

There was much clay about and some had been thrown back into the furnace hollow. The furnaces contained charcoal in the bottom, then cinder and slag, and finally clay on top.

A penannular fibula of the 1st century A.D. was found in the layer above the working surface in Area III; hence the furnaces may be either Belgic or early Roman. The features were cut through by a later wall (1) but most of the pottery has come from the robber trench (2) and seems to be late third century.



Typical of furnaces A to G

1 & 2 Black loam accumulation.

3 Contemporary level of dry stone wall. Greyish/black sticky garden loam.

4 Industrial occupation contemporary with furnaces.

5 Packed brown sand (Floor?).

6 Natural red sand.

7 Red clay and furnace lining.

8 Purple ash with heavy iron slag.

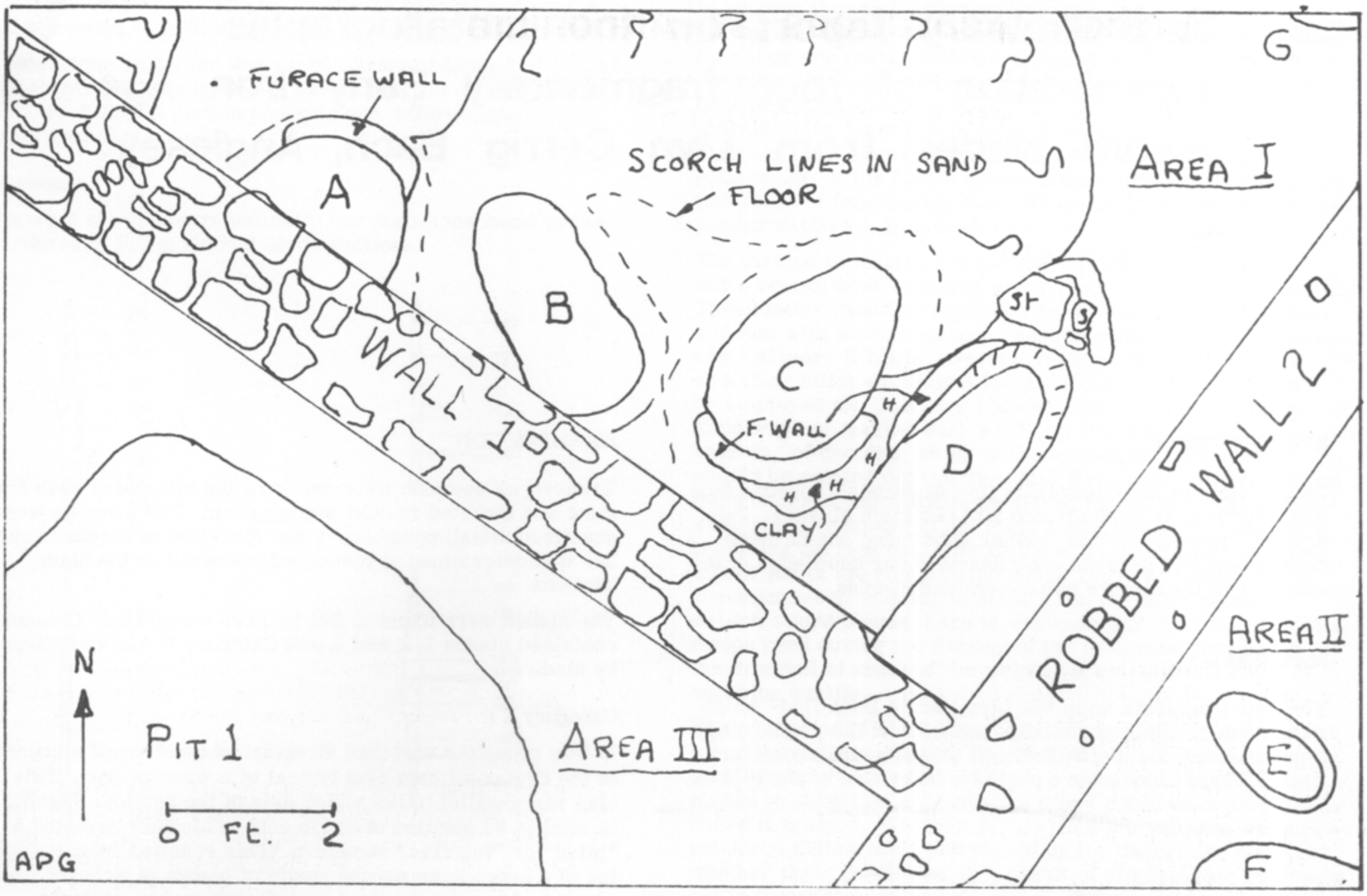
9 Thick layer of charcoal on the bottom of hearth.

10 Part of furnace wall remaining in situ.

Note Numbering shown here may not be used in final report.

A. P. Garrod (Glos.)

Fig. 1 – Section through furnace C (Ariconium 1967)



Phase 1 Laying of sand. Floor level and construction of furnace. No building structure evidence noted.

Phase 2 Industrial activity. Accumulation of occupation on floor, area I, II, III.

Phase 3 Furnaces disused. Demolished clay walls and furnace lining, filling hearths.

Phase 4 Foundation trenches. Dug through filled-in hearths. Pit 1 dug for clean sand. Filled with roofing tile rejects.

Phase 5 Accumulation of a greyish/black sticky loam of garden or grass all over area I, II, III.

Phase 6 Abandoned site. Accumulation of black loam.

Phase 7 17 or 18 century levelling and robber trench.

Fig. 2 – Bowl furnaces A to G (Ariconium 1967)

A preliminary report on the metallographic examination of four fragmentary Early Iron Age sword blades from Llyn Cerrig Bach, Anglesey

J.N.McGRATH

INTRODUCTION

On the basis of metallographic investigations[1, 2] Celtic Iron Age swords have been divided into two main classes. The present investigation has further subdivided one of these classes and has perhaps contributed to our knowledge of the ancestry of the famous pattern-welded swords.

MATERIAL

The four fragments from the Llyn Cerrig Bach find[3] which were made available by kind permission of the Archaeology Department of the Welsh National Museum, are shown in Fig. 1. These blades were part of a large find of Early Iron Age objects discovered during the building of the Valley air base on Anglesey in 1944. Archaeological evidence suggests that the deposit, which consisted of weapons, harness, chariots, and animal bones, was deliberately placed in the lake as a votive deposit. The intentional damage done to some of the objects in antiquity, a practice well documented in similar finds on the Continent, confirms this. The absence of articles showing any Roman influences places the latest possible date of deposition as A.D. 61, when Suetonius Paulinus raided the island, or perhaps A.D. 77-78, when Agricola completed the conquest of North Wales. The earliest objects are a sword and a spear which are dated as second century B.C. This gives a period of about 250 years during which the swords examined could have been deposited. Unfortunately the circumstances of the find destroyed all the stratigraphical evidence which could have been useful in determining the order of deposition of the artefacts.

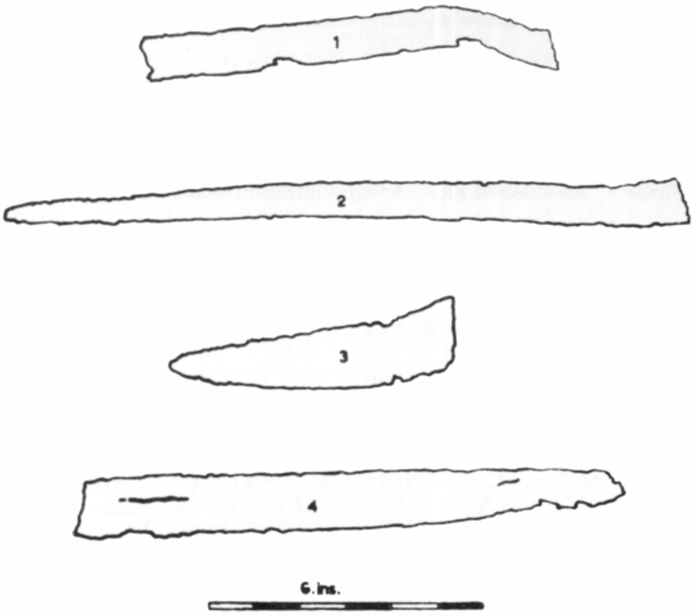


Fig. 1 – The fragments of blades

EXAMINATION

Transverse sections were cut from the hilt end of each fragment and mounted in cold-setting resin. The samples were examined metallographically and the Vickers hardness number was determined at measured intervals on the blade sections.

The blades were found to fall into two categories. Category I contained blades 1, 2, and 3, and Category II was represented by blade 4.

Category I

In this group the unetched structure showed small amounts of the duplex silicate slag typical of a wrought iron. This slag ran parallel to the major axis of the section. Etching in nital (a 2% solution of nitric acid in alcohol) revealed a "piled" or "fagotted" structure. This resulted from the forging of a heterogeneous composite of pieces of wrought iron which had been carburized to differing carbon contents. These laminations ran parallel to the major axis of the section. There was no evidence of cold working, the structure being that to be expected from forging an iron-carbon alloy in the correct hot-working range. Macroexamination of the etched structure (Fig. 2) suggested that originally all three blades had consisted of a core of relatively low-carbon steel (0.15-0.25%C by metallographic estimation) between two outer layers of higher-carbon material (0.3-0.7%C). In blades 1 and 2 small longitudinal cracks were observed (Fig. 2). The decarburization around these and the considerably quantity of entrapped slag suggests that they result from poor welding during manufacture.

Category II

The slag pattern in blade 4 is completely different from that in the Category I blades. The slag crosses the blade section approximately at right-angles to the major axis. Etching with nital revealed that the layers of steel, the carbon contents of which were similar to the Category I blades, were orientated in the same way as the slag. The macrostructure (Fig. 2) shows this quite clearly. This same illustration also shows that no attempt was made to encase soft material in

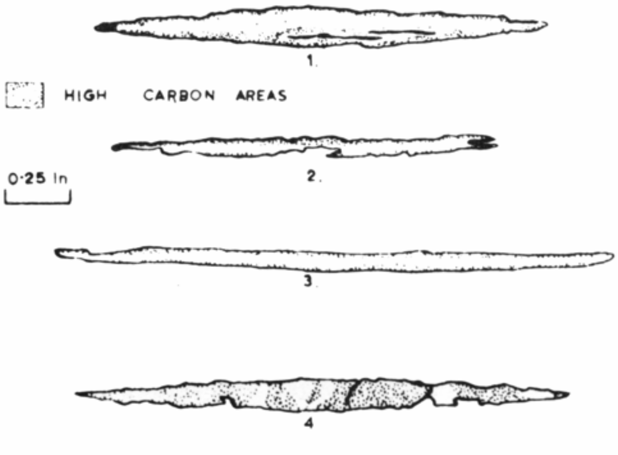


Fig. 2 – Etched cross-sections of the blades

a harder outer skin. The large cracks running across the blade section (Fig. 2) are typical of severe welding faults.

The various high- and low-carbon areas indicated in Fig. 2 are themselves composed of several layers of steels with slightly different carbon contents and different amounts of entrapped slag.

Hardness

Figure 3 shows diagramatically the variations found in the hardness of the individual blade sections.

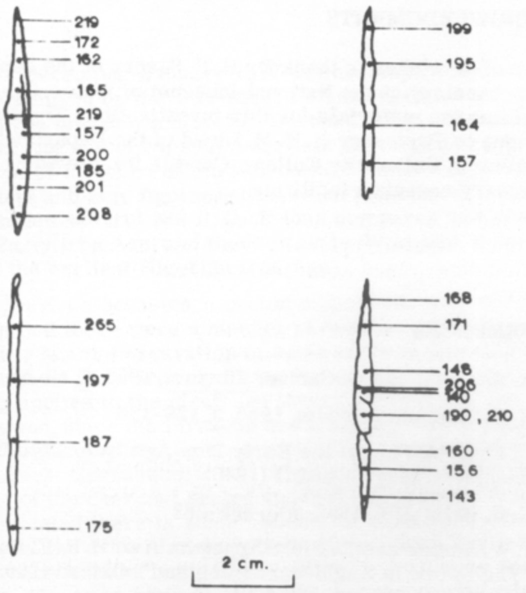


Fig. 3 – Variations of Vickers Hardness

DISCUSSION

On the basis of the work by Reggioni and Garino[1] and Coghlan[2] it is possible to divide Celtic swords into two classes:

A. Swords showing a ferritic structure which has not been carburized.

B. Swords with a piled structure which have in part been brought into the class of steel by means of carburization.

Of these two clases, Class B swords represent a considerable technical advance over the Class A swords. The present work indicates, that, whilst this broad division holds good, the second class requires further subdivision. Figure 4 shows the scheme suggested to include all the metallurgical types so far reported.

This subdivision makes possible the recognition of six types on metallurgical grounds alone. Types 3 and 4 would seem to provide the most effective weapons, but at present it is not known whether these were produced deliberately or whether they are really accidentally good examples of type 5 swords. The examination of more swords is necessary before this point can be settled. The similarity of type 4 swords to the Nippon – to swords of Japan which also consisted of hard cases surrounding a tough core[4] should be pointed out. If the Celtic sword cutlers deliberatly employed this mode of fabrication some 900 years prior to the Japanese master cutlers it is indeed a tribute to their skill.

The method of forging the Category II blades is obviously more complicated than that needed for the Category I blades. These latter would be produced quite easily by forging down a bloom with a heterogeneous carbon content. The production of a Category II blade, however, requires the manufacture of a stout billet as distinct from the thin billet which could be employed for Category I blades. Figure 5 shows two possible ways of making such a billet. There is no metallographic way of deciding which of these methods was used. It should be pointed out that the final structure would depend on the number of laminations employed for the original composite, on the tightness of the folds made, and on the amount of trimming carried out. The smith who forged blade 4 made a poor job of the complicated welds required and produced a weapon much inferior to blade 1. In the later pattern-welded sword blades there is evidence that the twisting of the strips used during the forging of the patterned part led to the removal of much of the welding scale, giving a blade of superior quality.

The corrosion of blade 4 during its long immersion indicated a sinuous pattern running longitudinally down the blade. A small sample of the face of blade 4 was ground, polished, and etched to show that a decorative effect could have been produced if desired. Whether at this time the patterns were produced deliberately and etched up for decorative effect, or whether their revelation as a result of atmospheric corrosion led to their later deliberate use in pattern-welded blades, is not known, but it would seem that the Type 6 blade is a direct fore-runner of pattern welded weapons.

The hardness results are comparable with those reported in an earlier investigation.[2] The upper limit of 219 V. H. N. in one of the high-carbon areas suggests in agreement with metallographic observations that no attempt was made to improve the hardness of the cutting edges by cold working.

Examination of further Celtic sword blades to establish the relative frequencies of the various recognisable types is now a matter of some urgency. It would be of outstanding value if the weapons examined came from finds which are accurately dateable.

The statement by Oakeshott[6] that the swords of the Llyn Cerrig Bach find are weapons of inferior quality must be somewhat modified. Two of the blades examined were stout and practical, capable of giving good service, but blades 2 and 3 were too thin. It is, of course, impossible to be certain that this is not due to the loss of metal during their immersion. Another fragmentary blade from the same find now in the Welsh National Museum has on its shoulder a bladesmith's

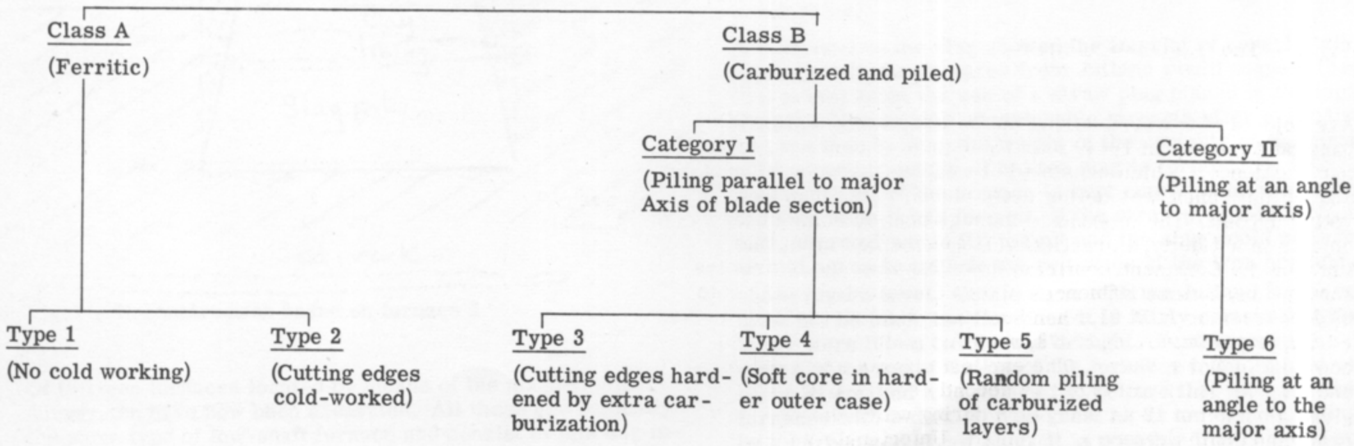


Fig. 4 – Classification of Celtic swords

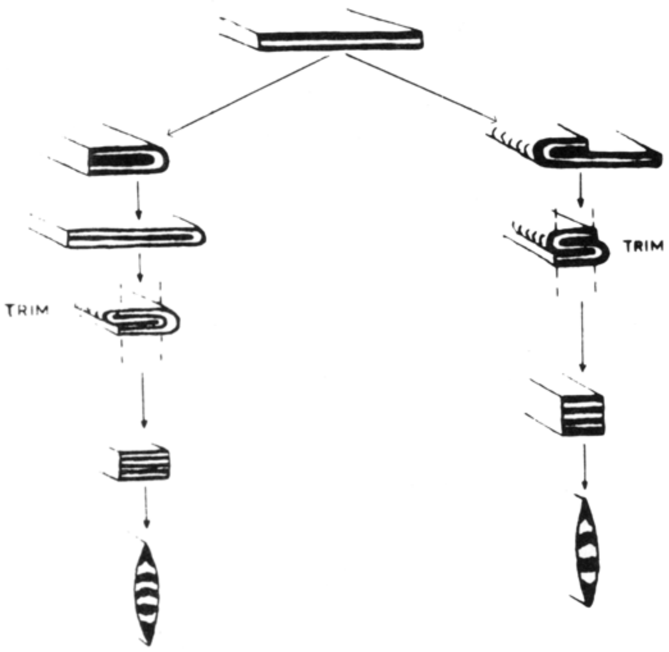


Fig. 5 – Two methods of forging a Type 6 blade

mark. Wyss[7] believes that such stamped swords were above average in quality. As far as the present author knows no such blade has been examined metallurgically, although Coghlan[2] suggested this in 1956.

CONCLUSIONS

1. It has been shown that at least six types of Celtic sword can be distinguished on metallurgical considerations.
2. On the basis of the present classification, Type 6 swords would appear to be direct forerunners of later pattern-welded weapons.
3. It is important that the chronology of the major metallurgical types be established if a fuller understanding of the history of early metal-working techniques is to be achieved.

ACKNOWLEDGMENTS

The author wishes to thank Dr H. N. Savory of the department of Archaeology at the National Museum of Wales, Cardiff, for providing the materials for this investigation. Thanks are also due to Professor H. K. M. Lloyd of the Department of Metallurgy, University College, Cardiff, for providing the necessary research facilities.

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Iron smelting on the Nigerian Early Iron Age site at Taruga, Abuja Emirate

R. F. TYLECOTE

During December-January 1967-8, I accompanied the expedition organized by the Pitt-Rivers Museum, Oxford, and directed by the museum's director, Bernard Fagg. The object was to excavate one of Nigeria's earliest Iron Age sites. This was one of the sites of the Nok culture which had yielded iron artifacts and clay figurines and which had been dated by C^{14} to between 440 and 280 B.C. It thus compares with the British Early Iron Age, and there is little doubt that it represents the earliest Nigerian Iron Age.

On a previous occasion, a proton magnetometer survey had shown that there were a number of hearths or furnaces on this site and the excavation of some of these anomalies had shown them to be iron-smelting furnaces. However, the C^{14} dating applies to the stratified layers surrounding the furnaces and, since the furnaces had been dug directly into the subsoil (decomposed igneous rock) they could be later than the layers surrounding them. Thus, until the radiocarbon dating of the charcoal sealed under the slag in the furnaces is completed there is some element of doubt regarding the dating of the actual furnaces themselves. Such early types of furnace went on being used in Nigeria until very recent times. There is, however, no doubt that the stratification relates to an Iron Age culture and that this can be dated to the last few centuries of the 1st millennium B.C.

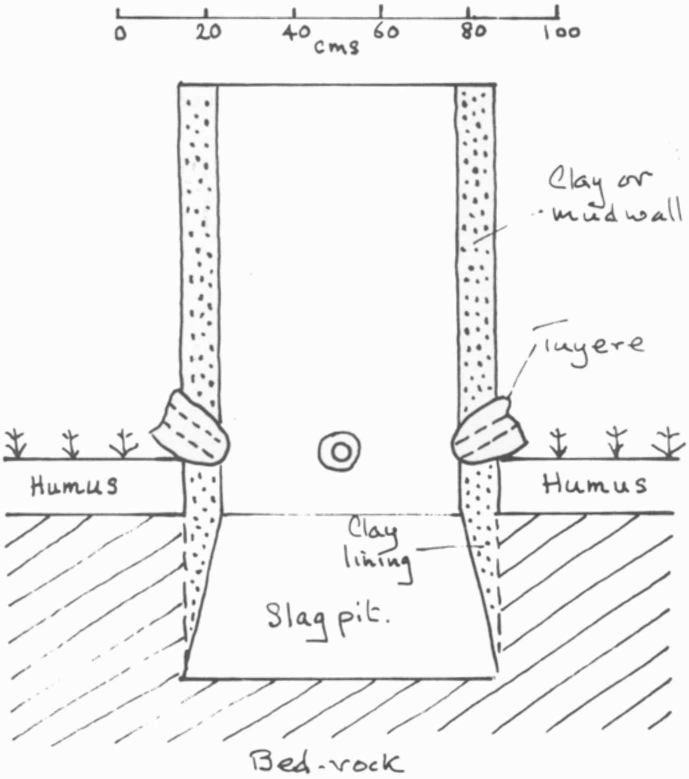

Fig. 1 – Reconstruction based on furnace 2

Of thirteen furnaces located by means of the magnetometer survey, ten have now been excavated. All these are basically the same type of low-shaft furnace and consist of pits dug into the ground or decomposed bedrock to a depth of about 30 cm, with walls standing from a few cm to as much as 20 cm high. All but two of the furnaces excavated had the pits lined with clay, and an important feature of these pits was the way in which their diameter increased with depth, resembling furnaces found in Jutland dated to the 4th century A.D. [1, 2].

The furnaces varied in internal diameter from 34 to 91 cm at the top of the pit. The walls varied in thickness from about 3 cm to as much as 18 cm and appeared to be made from the same sort of material as the local round huts. The clay lining of the pits was fired black, as would be expected from the reducing conditions maintained in the pits. The walls themselves were mostly red-burnt. Not all the furnaces were circular; three had some degree of ovality, one varying from 41 cm on one axis to 58 cm on the other.

Some of the furnaces were filled with little more than collapsed furnace wall and it would seem that these had been cleared of slag ready for eventual re-use. Others (particularly the smaller ones) were full of slag which appeared to be in some cases the product of a single smelt. Some merely had slag sticking to the pit lining in some places, as though no slag had formed in the centre or else had been cleared out. Others contained a complex fill of isolated pieces of slag, furnace wall, and pieces of fallen-in tuyere. In no case were tuyeres found in place, and it would seem that in all cases the tuyeres had been fixed in the part of the furnace wall that had collapsed.

The tuyeres were all of the same pattern, with walls about 3 cm thick and internal diameters varying from about 3 to about 10 cm. In length most of them were little more than 12 cm long, but one was as long as 25 cm; however, none is complete. All appear to be of a type normally associated with forced-draught furnaces; it is very unlikely that these tuyeres would have been used for induced draught. Induced draught tuyeres all seem to be more than 60 cm long with very thin walls.

The slag was of the fayalite type always found associated with the bloomery or direct process. No unworked blooms were found, although a considerable number of small artifacts turned up. It therefore seems very likely that the product of smelting was not a single compact bloom but a complex mixture of reduced iron fragments, charcoal, and slag. This is the sort of product made by most of the traditional Nigerian smelters during the last 50 years; it has to be worked into a solid piece of metal by breaking it up and welding the individual pieces of iron together. Some old discarded saddle querns were found on the site with deep and narrow holes made in them which had probably been used for separating the malleable iron from the brittle slag and charcoal by hammering.

A good deal of the slag showed the imprint of cereal stalks. Analogy with the furnaces from Jutland would suggest that this arises from the use of a straw plug placed in the top of the pit, which attains considerable strength after carbonizing and can then hold up the weight of the contents of the furnace until a certain weight of molten slag is formed. By this means the pit of the furnace is kept empty so as to receive the slag when it has formed. If the straw plug were not present, charcoal would fill the pit and the slag would be formed so high up as to impede the reduction of the iron ore just above tuyere level. Comparison with the Jutland furnaces must not be taken too far since it is fairly certain that the latter were blown by induced draught. Furthermore, the diameter of the top of the pit of the furnaces from Jutland was about 24 cm, and it is difficult to believe that the contents of furnaces with a diameter as great as 91 cm can be held up by a carbonized straw plug. It is possible that only the smaller furnaces were worked in this way.

Very little in the way of obvious specimens of iron ore were found. A few pieces of what appear to be siderite, both roasted and unroasted, were found, but an attempt to discover the source of this material failed. Ore of high iron content has been mined at some time in the laterites some 40 miles away but none of this was found on the site and it is very unlikely that early iron smelters would go as far as this for their ore. A magnetic search of one of the spoil heaps from the excavation of one of the furnaces yielded a small amount of fine magnetic material. Much of this was slag and furnace lining, but some at least was found to be roasted crystals of magnetite. There are substantial deposits of magnetite in the local stream bed and a sample has been taken. If the use of magnetite is confirmed, it would support the forced-draught hypothesis, since fine ore cannot be used in induced-draught furnaces.

One of the medium-sized furnaces was partly built over the remains of a smaller furnace, which suggests that there was a tendency for the furnaces to increase in size. The wide range of sizes is one of the more unusual features of the site.

Conclusions

The remains excavated support a bellows-blown low-shaft furnace with a pit dug in the ground for the receipt of the slag. The pit was usually clay-lined and increased in size with depth. The furnace wall consisted of clay and probably rose to a height of at least 1 metre. The fact that the furnaces were mostly found at present ground level makes it very difficult to determine the exact height, since a good deal of the wall will have weathered and been dispersed.

There were probably at least four tuyeres in the larger furnaces, although two would be sufficient for the small ones. In the larger furnaces, they were probably inclined (see Fig. 1). The most probable source of ore was magnetite from the local stream beds. So far no furnaces of this type have been reported from Nigeria, although induced draught pit-type furnaces have been reported from Gombe. [3]

References

1. Olfert Voss: Kuml, 1962, 10.

2. R. Thomsen: Kuml, 1963, 61

3. Jos Museum: File on iron smelting, TF 92, 1961-67.

The phosphorus content of iron from the bloomery site at West Runton, Norfolk

R. F. TYLECOTE

This site was excavated in 1964 and was found to be of Saxo-Norman date[1]. No obvious pieces of unworked iron were found, but in going through the slags and debris from iron-working a number of small magnetic pieces were found. These came from a number of widely spaced areas of the site: D. 20; E. 8a (pit); F. 22; D. 15.

These all appeared to be debris from smelting and appeared at first sight to be rust. However, on cracking them open, a number of cleaved iron crystals could be seen; these were particularly well revealed in two of the specimens, from E. 8a and F. 22, and these were examined metallographically.

The specimen from F. 22 consisted entirely of coarse ferrite with evidence of phosphorus coring on one half and thin carbide-filled grain boundaries on the other. The phosphorus-cored side also contained well developed nitride needles, showing that it had cooled slowly through the range 400-200° C. In view of the flat nature of this piece it may have had some forging, but it showed no obvious signs of work. The hardness varied from 218 in the P-containing ferrite regions to 183 HV5 in the nitride regions. Since the carbon content is so low there is no doubt that this high hardness is due to phosphorus, probably about 1-1.5%.

The second piece (from E. 8a) had merely been smelted and showed the cavities associated with the adhesion of roughly spherical reduced-iron particles. Some slag was present but no nitride. The ferrite grain-size was very large and the grain boundaries weak. The hardness varied from 210 to 223 HV, again showing the presence of high phosphorus.

Pieces of this material were taken from each of the areas of the site where they were found, mixed together, and then ground down to obtain an average sample. Part of this sample was separated with a magnet and chemically analysed for iron and phosphorus. The result gave 1.34% P and 64.0% Fe. If it is assumed that the remainder is oxygen and that all the phosphorus is dissolved in the iron, the phosphorus content of the iron would be 2.1%. However, some of the phosphorus will be present as slag. There is no doubt that a high-phosphorus iron was being produced.

The nodular ores found on this site had contents of 1.32% P_2O_5 and the iron pan, 2.79% P_2O_5. Some local ores contained as much as 3.5% P_2O_5. If one assumes an average in the charge of 2.0% P_2O_5 one would expect the value for the metal to be about 0.5% P. Since the hardness of the metal is about 200 HV, one would expect the phosphorus in the metal to be nearer 1% and the bulk of the ore to have contained 4.0% P_2O_5.

There is no doubt that this material had been struck off ferritic blooms and that it represents the type of metal being made at West Runton in the Saxo-Norman period. It would be cold-short (brittle) and excellent for nails.

Reference

1. R. F. Tylecote: Norfolk Arch, 1967, 34 (II), 187-214.

Iron and steelmaking in the Sheffield area in the early 19th century

K.C.BARRACLOUGH

"The Northern Star" was a monthly magazine publication put out in Sheffield, the first issue appearing in July, 1817. In each of the first eight issues under the heading of "History of Trades and Manufactures" is a series of articles on iron and steel. The first two articles are mainly historical and, as we would now feel, rather naive and conjectural, although there is quoted Mr John Ray, F.R.S. in his 1674 account of ironmaking at Cuckfield in Sussex and also the preamble to the act incorporating "The Company of Cutlers in Hallamshire" in 1623.

"The Natural History of Iron" describes the ores and in particular the mining of ironstone in bell-pits. The production of copperas from pyrites is also noted.

A further article describes the preparation of coke, quoting Parkes's "Chemical Chatechism", as to "ovens which are circular, 10 ft. diameter within the floor laid with common brick set edgewise. The wall of the oven rises 19 inches perpendicular from the floor, the whole covered with a brick arch rising 3 feet 5 inches more, forming nearly a cone, whose base is 10 feet and whose apex is 2 feet measured within. The opening of 2 feet is for the supplying of coal and to serve as a chimney. The wall is 18 inches in thickness, is built of good brick and closely laid that no air may get in through any part of the work. The floor is 3 feet above the ground, for the convenience of placing a carriage under the doorway to receive the coke as it is raked from the oven. When the oven is thus finished, a strong perpendicular wall of common unhewn stone is thrown round it, of about 20 inches in thickness and carried up to the whole height of the oven, forming a complete square. The four corners between the circular building and these outward walls are then filled with soil or rubbish and well rammed to give greater firmness to the work and the more effectually to exclude atmospheric air. When these ovens are once heated the work goes on day and night without interruption and without any further expense of fuel it is concluded thus: small refuse coal is thrown in at the circular opening on top, sufficient to fill the oven up to the springing of the arch, it is then levelled with an iron rake and the doorway built up with loose bricks. The heat which the oven acquires in the former operation is always sufficient to light up the new charge. The combustion is accelerated by the atmospheric air that rushes in through the joints in the loose bricks in the doorway. In 2 or 3 hours the combustion is to such a height that they find it necessary to check the influx of atmospheric air; the doorway is therefore now plastered up with a mixture of wet soil and sand, except the top row of bricks which is left all night. Next morning (when the charge has been in 24 hours) this is completely closed also: but the chimney remains open until the flame is quite gone, which is generally in 12 hours more;a few loose stones are then laid on top of the chimney and closely covered up with a thick bed of sand and earth. All connection with the atmosphere is now cut off and in this situation the whole remains for 12 hours, to complete the operation. The door is then opened, and the cokes raked out into wheel barrows to be carted away.

The whole takes up 48 hours; and as soon as the cokes are removed the ovens are again filled with coal for another burning. About 2 tons of coals are put in for each charge. The cokes are ponderous, extremely hard, of a light grey colour and shine with metallic lustre."

And again: "When coke is required to be more of the nature of charcoal the process is conducted in a different manner. The small coal is thrown into a large receptacle similar to a baker's oven, previously brought to a red heat. Here the door is constantly open and the heat is sufficient to dissipate all the bitumen of the coals, the disengagement of which is promoted by stirring with a long iron rake. The coke from these ovens, though made with the same kind of coal, is very different from that produced by the former operation; this is intensely black, very porous and as light as pumice stone".

In addition, at an extensive ironworks in the neighbourhood of Chesterfield (?Staveley) "A substantial brick chimney is built on an open space of ground and the coal piled round it. When the pile is constructed, instead of lighting it in different places on the outside of the heap, a quantity of ignited coal is thrown down this brick chimney, which, being built on open arches, the fire readily communicates through them to those parts of the pile which are immediately contiguous to the chimney, so that the fire commences at the middle instead of at the outside of the heap and soon spreads through the whole mass. When sufficiently burnt, and partially cooled, the heap is broken into and the whole quenched with water. The coke thus prepared is so much better than that which is produced in the common way that a much less quantity is sufficient for making any specific quantity of iron."

The following article, naturally, is on the "Smelting of Iron" which gives the following description of one furnace. "To give a general idea of the internal shape of a blast furnace, we should place a wine-decanter on a funnel, whose greatest diameter is equal to the bottom of the decanter. The dimensions are nearly as follows: the total height of the furnace is 50 feet, the width at the top 4 feet in diameter, the middle 13 feet, the bottom 2 feet square, which is placed at the end of a trough 6 feet long, 2 ft. deep and 2 ft. wide, the Hearth. The blast is introduced immediately above the hearth by a pipe of 2 inches diameter on each side". [This is essentially the design of the early Carron Furnace: see Sexton & Primrose-K.C.B.]

Later, in describing the working of the furnace: "About every half hour the furnace requires what is termed a half charge: viz. 24 stones of cokes, nearly the same of iron ore and six or seven stones of limestone. These proportions will vary according to the state of the furnace, which is affected by that of the atmosphere, the quality of the materials used and also the quantity of metal wanted. It would certainly be a matter of astonishment to our forefathers, could they perceive the magnitude of our present furnaces and the ponderous machinery employed to excite the blast. Instead of two or three men as formerly, it is now common to employ steam engines of 20 or 30 horses' power, being near a 100 fold greater and the furnaces are 40 or 50 times the contents. The quantity of metal made in one furnace, where materials are good, will amount to 40 tons per week and will require near 200 tons of coal and from 30-40 tons of limestone. Iron ore in general produces from 25-30 per cent; Cumberland ore upwards of 50 per cent. The best fuel is undoubtedly charcoal; this is well known to consist almost entirely of carbon; but as the supply was found so totally inadequate to the consumption, pit-coal has long been substituted; therefore such of it as contains the most portion of carbon and the least of sulphur is the best adapted for the purpose. There are at present a few furnaces in the nation still working with charcoal, the metal for which is generally used for iron wire, which requires iron of a superior quality to that for any other purpose. The blowing apparatus for these furnaces are propelled by water wheels and as they can only obtain charcoal sufficient to work the furnaces for a few months in the year, they fix on the winter season when water is most plentiful. Coke furnaces are universally driven by steam engines and, except stopping the blast half an hour during the time of letting out of the metal, and unavoidable repairs to the engine, they continue blowing or working of the furnace without intermission while the hearth or lining will endure, which is generally three years and where the fire-brick and hearthstones are good, a longer time."

Descriptions of the blowing mechanisms mention "fly-pistons", "the water regulator" and "the most approved mode, what is termed a dry regulator; this is only a large metal box about three yards square, and ten or fifteen long perfectly air tight; in this case, there is nothing but the elasticity of the air, which answers every purpose and keeps up a perfectly regular blast; this mode is considered the best, from its regularity and the air being more free from moisture, which is an essential matter. In some of the recently erected blowing engines, they have added a fly wheel to the engine, which has a great tendency to regulate the motion of the engine and blast. The quantity of air thrown into a furnace per minute is upwards of seventeen thousand gallons, and at a pressure of two and a half or three pounds per square inch. We are told by chemists that six inches of vital air is absorbed by each individual in one minute, then, by calculation the quantity destroyed by a blast furnace is equal to that destroyed by two hundred thousand persons; however, we need not fear a deficiency as the Creator in his wisdom has appointed means for its restoration as quickly as the support of animal life and combustion shall destroy it."

Thereafter follows a contribution on "The Conversion of Metal into Malleable Iron". This describes the conversion of Russian and Swedish iron with charcoal in a finery, with the comment that the use of coal in this country gave an inferior product, followed by forging into bar from the chafery.

The writer then goes on to describe the improvements which took place "around 20 years ago" referring to Cort's puddling process [introduced 1784, thus 33 years earlier – K. C. B.] He refers to the necessity of remelting the pig iron and running it into a metal trough to give a long plate, 18 in broad and 2 in thick, this then being broken into pieces about a hundredweight each, ready for puddling, which he then describes.

His final chapter is "On the Conversion of Malleable Iron into Steel". The description of the production of blister steel by cementation shows the process to have been fully developed in 1818, but that the troughs or pots were 2 ft square internally, as against 3 ft 6 in to 4 ft 0 in square in 1865.

Shear steel is referred to as "German Steel". "The origin of this term must doubtless be traced to the fact of that article having been imported from Germany; so late as forty years ago much of this kind of steel was brought over for the more valuable purposes. The first manufactory of it in England was established at Newcastle and having been found very suitable for making sheers it thus obtained the other title thus mentioned. It is about 30 years since several forges for this purpose were erected in the neighbourhood of Sheffield, and as each met with much success, more were established so that for a number of years all the steel used in the manufactures has been made in the vicinity of that town. The process consists in simply laying six or eight bars (of about a foot long) together, and welding them into one piece; it is then drawn down under a forge hammer to 2″ square, cut in the middle, doubled and welded again and then reduced to the size wanted [N.B. This is what was considered to be "double shear steel" – K.C.B.] From this operation, an improvement of the steel is effected by increasing its malleability, and from having obtained a greater uniformity of quality, it is rendered more ductile and stronger than iron, and will bear suspended nearly half as much more; it has moreover the capability of being hardened to sustain the finest edge. Of this article are manufactured the best kind of table blades and such articles as require great strength but little substance. Although Sheffield has not the merit of invention of sheer steel yet it has justly to boast that of cast steel and to this production of its ingenuity is owing its inparalleled excellence in hardware manufacture and not a little of its prosperity."

The writer goes on to say it is around 50 years since Huntsman was successful in his attempts to melt steel. Here again the chronology seems a little wrong, since Huntsman's first experiments are to be dated around 1740 and his full commercial exploitation somewhere in the period 1761-1767, the latter date being some 50 years earlier than this article. He goes on:

"The process appears simple but requires good management. The tops of the furnaces are level with the floor; they are 12-15″ square and from 2-3 feet deep: at the bottom are the grates; the outlets for the fire are on one side near the top and immediately enter the chimney. Frequently there are six or eight of these furnaces in a row. The crucibles are six inches wide and twelve inches or more deep. The bar steel is broken in pieces about 2″ sq. 28-30 lb are put in each time; the crucible is then covered and placed in the furnace when sufficiently hot; fuel is frequently added until the steel is completely melted. Afterwards the pot is taken out with the tongs and the fluid steel poured into cast iron moulds the shape wanted; if for rolling to sheet the ingots are six inches broad, one inch thick and from 12-18 inches long; but if for tilting (viz drawing into rods for the Cutlers) it is cast 2″ sq. and three feet long. The heat required to melt steel is very intense; and when it is running into the mould it is studded with sparks as brilliant as burning wire in oxygen gas; the strongest and hardest kind of coke is used as fuel being capable of producing the greatest degree of heat. The cause of the improvement in steel by melting has long been a subject of enquiry and speculation; the chemical change is very unimportant, a trifling loss of carbon being all that takes place; it is generally attributed to a complete mechanical change in the size and construction of the particles of the metal which in some measure appears confirmed by its extraordinary density when hardened and the much higher polish it will sustain than common steel."

There are one or two discrepancies here. The larger pots used fifty years later held around 60 lb and were around 9-10 in dia. and 18-20 in deep, so that the crucible size is somewhat small for a 28-lb charge. An ingot 6 in × 1 in × 16 in long would be possible or a 2 in sq. × 2 ft, not 3 ft as stated. Huntsman in 1761 is reputed to be melting charges of 13 lb; in 1818 we have this report of 28 lb, and in 1865 a charge of 56-60 lb is usual.

The three final paragraphs of the whole series appear worth quoting verbatim: "Perhaps no other country on the surface of the globe produces, in the same compass, such a variety and abundance of minerals as our own; nevertheless we are still indebted to Sweden and Russia for our best steel iron and it seems probably this will continue to be the case. Patents have been taken out and much money expended in manufacturing English iron into steel, but without any prospect of ultimately succeeding. In the first place we are deficient in wood for charcoal to pursue the foreign method of working and, providing this difficulty did not exist, there is in our ores a want of manganese. Attempts have been made, and a patent obtained, to mix manganese with the iron ore, but neither this nor presenting it to the metal in any subsequent part of the process has found to be the answer. They were enabled to make some of the steel good but the quality was too irregular to be depended upon; it appears that nature alone can properly blend the ingredients together. The ore obtained from Cumberland is superior to any other produced in this country and approaches nearer to the Swedish, but even from this good steel has not yet been manufactured; the quality will suit for many purposes but not for the best and it is probable that a scarcity of wood will prevent a much further pursuit of the scheme.

"As the town of Sheffield has long stood pre-eminent for its hardware manufactory, it is much to be regretted that any part of its good name should be sacrificed to the interest or mistaken notions of a few; this, we conceive, must be the case till the legislative shall interfere to prevent the circulation of cast metal [cast iron – K.C.B.] knives and scissors as steel ones. A legible mark on the metal ones seems all that is required. For a number of years back it has been customary to make forks of metal; and probably, except the polish, they may not have been much inferior to steel; but wherever a good edge and strength are wanted, as in the case of knives and scissors, steel is universally acknowledged to be much preferable. In the present relaxed state of things, the unwary customer is imposed upon and frequently without reduction in the price."

"We have now described the various processes through which this invaluable mineral passes, from its natural state to that in which it is fitted for the hands of the manufacturers of the finest articles of cutlery and for every other useful and ornamental purpose to which it has hitherto been applied; and as, in a work of this multifarious nature, we have in consequence a variety of tastes to gratify, we hope, to those who feel an interest in this development of the arts, we shall be found to have afforded a pleasing and intelligible outline."

Reports on work in progress

A metallurgical investigation of material from early copper working sites in the Arabah

R. F. Tylecote

The majority of the material examined came from Dr Rothenberg's Timna site No. 2, dated to the 12th century B. C., and therefore belongs to the earliest Iron Age in this area.

Metallurgical examination is capable of determining methods of working, i. e. whether the metal has been cast or forged, the hardness of the metal, and whether it contains lead, oxide, and certain other non-metallic inclusions. For a full knowledge of the composition of an artifact it must be supplemented by chemical or spectrographic analysis. As far as slags and crucible residues are concerned the method is capable of giving nearly as much information as a petrographic examination by thin-section transmitted light techniques.

Some of the non-metallic material has been analysed by X-ray fluorescence techniques; for this I am much indebted to Dr M. H. Battey of the Department of Geology of the University of Newcastle. I am also indebted to Dr W. R. Dearman and Dr J. H. Jones of the same department, for their determination of the minerals present in the nodules.

Copper Nodules

Four cupriferous nodules, typical of those that can be extracted by hammering the "Middle White" sandstones, have been examined. These contained varying amounts of silica in the form of fractured sand grains. The best contained 20-30% SiO$_2$, whilst one specimen contained over 80% and seemed to consist of sand cemented with a very thin cupriferous deposit. In the best cases the sand grains were surrounded by a layer of malachite and this in turn was cemented together with a layer of cuprite. There was very little sulphide or iron compounds present and it is clear that such nodules would reduce very easily to fairly pure copper if sufficient iron was added to flux the silica.

Metallic Artifacts

SF1: Piece drilled from spear butt. In the unetched state it contained many small particles of lead or slag. These varied in shape, some being angular and others rounded. Some were clearly intergranular. Most were two-phase, bluish, and not lead but probably cuprous oxide or sulphide. The surface was covered with a green single-phase patina. Slag particles near the surface had been elongated by working. On etching, the structure was found to be very fine-grained, equiaxed in the centre, and elongated by working near the surface. There was no trace of coring; some of the grains were twinned and some of these twins were bent. There were no slip bands. The hardness was 107 HV.

This specimen consists of a piece of impure copper which has been hot-worked, or cold-worked and annealed. This has been followed by a limited degree of cold work which has not penetrated to the centre of the object.

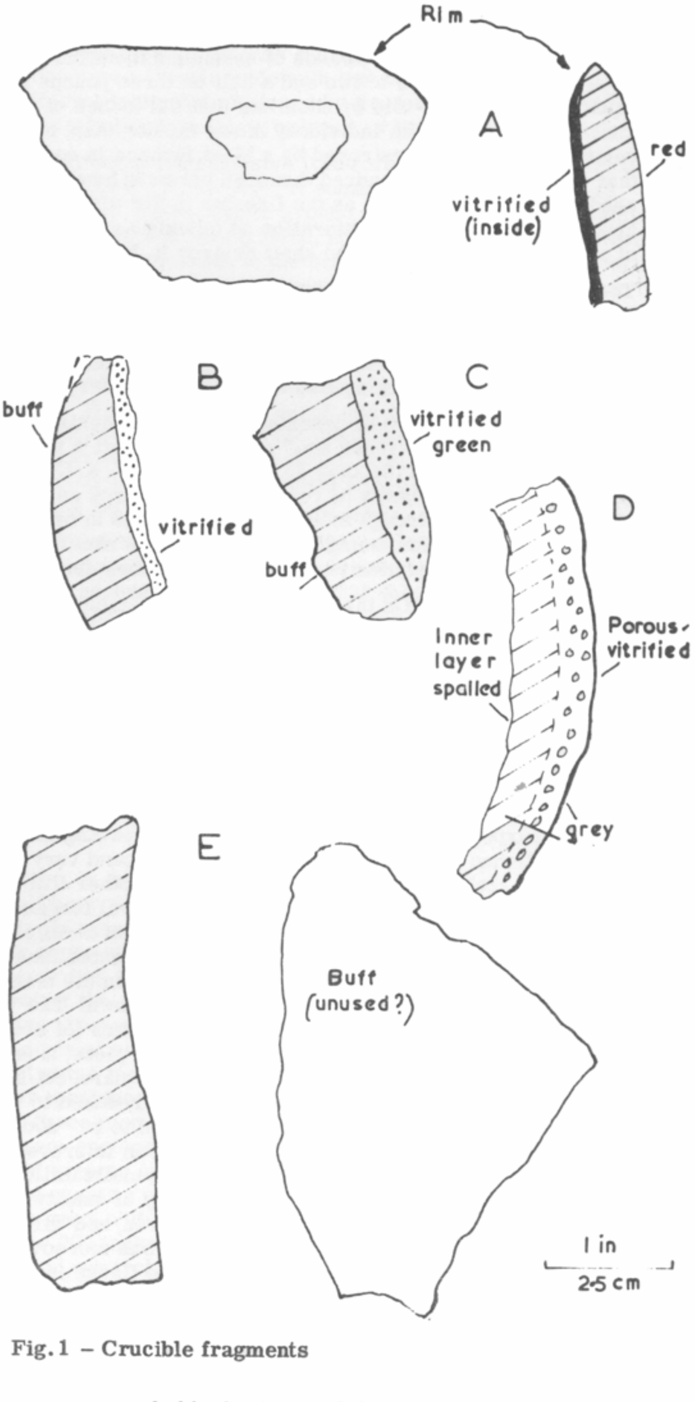

Fig. 1 – Crucible fragments

SF2: Tip of implement (possibly an awl). Not pure copper, as it is brassy in colour. In the unetched state it contains slatey-grey particles surrounded by dark grey lines which look like a corrosion product, and also groups of black globular particles. Upon etching it was clear that the material had been very heavily worked, resulting in very fine equiaxed twinned crystals. There was also signs of a fine precipitate as in the axe-head from Abu Matar. The hardness varied from 151 HV5 at the surface to 204 at the centre. Normally, of course, it varies the other way round, with the highest hardness at the surface due to superficial working. It seems that the surface has been partly annealed by heating and that the heat has not spread to the centre. Even so, the hardness is extraordinarily high and suggestive of a very highly alloyed copper. Since it is a solid solution it is not likely to be a bronze but more likely an arsenical copper. Key[1] found Chalcolithic material in the Kfar Monash hoard with As contents in the range 1.15 to 4.07%. Maréchal[2] gives the hardness of a 4% As copper cold-worked to 50% as 192HV, and that of an 8% As copper as 215. The hardness of such coppers would be reduced to 150 by annealing at 300°C.

SF10: Fragment of a pin or needle. Fully oxidized.

SF21: A piece of heavily corroded cast copper containing two (?) oxide/sulphide phases. It shows coring and so cannot be high-purity copper, but probably contains As or Sb. The hardness was 62HV5. Analysis of some of the corrosion product from the surface gave 69% Cu, 8% Fe, 0.22% Pb, 0.1% Zn; rest H_2O, CO_2, and O_2.

SF26: Another heavily oxidized piece of cast copper, but this was considerably purer than the above and had been heated after casting to give an equiaxed grain structure. It was also porous, and one is therefore not surprised that the hardness should be as low as 37HV5. There were traces of residual coring.

SF30: A large pellet. A cast copper of high purity; no coring and large grain structure. Hardness 83HV5.

SF35: Fragment of a needle or pin. Fully oxidized to a reddish (? cuprite) colour. No metal remaining.

SF36: Slag containing the usual small copper globules. Fayalite with large laths.

SF38: Fully oxidized copper dross. No residual metal.

SF41: A piece of baked clay which could be part of a thick-walled crucible of hemispherical or angular (Tel Quasilah) pattern (more likely the latter). It contains no metal or slag residue and, if a crucible, would appear to be unused. Thickness 22 mm. Colour buff to grey (Fig. 1E).

SF42: Slag, probably from a crucible, containing an acicular (?SiO_2) phase and small copper globules.

SF43: Fully oxidized; no metal.

SF44: Pieces of a magnetic slag, weathered green. The piece examined has some oxidized copper in solution and contains dendrites of magnetite. There is very little metallic copper. This is most probably a crucible slag as it has formed under oxidizing conditions. Analysis gave 43% Cu, 19% Fe, 0.62% Pb, 0.1% Zn; rest SiO_2 etc.

SF46: Fully oxidized pellet. Also red in colour. Traces of a (?) slag structure. No metal.

SF49: Fragment of a needle or pin. Fully oxidized to a green colour. (?) Malachite. Angular particles. No metal.

SF53: Slag or mineral with some partly reduced ore (i.e. copper forming a grain-boundary cement to the ore particles). This metal has very fine grain, probably due to its rapid rate of cooling. Hardness of metal 132 HV5. Analysis confirmed that it was a mixture of metal and slag containing 31% Cu, 13% Fe, 0.53% Pb, Zn, <0.1%; rest SiO_2 etc.

SF62: Oxidized copper showing its cast origin. Parts have a grain-boundary oxide network, with some precipitated copper in the oxide. Heavily cored equiaxed grains. Shows no twins and therefore would appear neither to have been annealed nor worked, but merely heated after casting. Hardness 64 HV5.

SF63: Copper implement fully oxidized to a green colour. No residual metal.

SF66: Pellet of copper with a lot of oxide/sulphide globules, many of which are intergranular. The copper is equiaxed and shows traces of coring, and has therefore been annealed after casting. Perhaps this was accidental as it seems to have been a drip. Hardness 61 HV5.

SF67A: Piece of copper ingot. In the unetched state this shows blue-grey inclusions which are single-phase and rounded. Some form inter-granular networks. Lighter inclusion form intra-granular groupings. There seems to be no lead but there is some porosity. Upon etching coring was visible and the cored grains were equiaxed. The hardness was 83 HV. This is an equiaxed casting with eutectic cuprous oxide. The oxygen content was not above liquid solubility. The darker phase is probably fayalite slag.

SF67B: Slag accompanying the above. A rather oxidized fayalite slag showing laths of fayalite and dendrites of magnetite precipitated within the fayalite. The matrix is glassy and contains a small amount of copper in globular form. There is some porosity. The physical nature suggests a casting slag (crucible) but its phase composition is more like that of a smelting slag.

SF71: Toggle pin. In the unetched state this shows an intergranular network of corrosion product. The very fine grains are equiaxed and show no coring. There are twins and these do not seem to be bent, but this is very difficult to tell with such a small grain size. There are no slip bands. The hardness could not be measured due to the large amount of corrosion product. This is a piece of cast and forged copper.

185A: A piece of thin sheet metal. Unetched, this contains oxide inclusions with adjacent porosity. On etching it was found to have an equiaxed structure of large grain size with a few twins. It etches easily, which suggests that it has impurities in solid solution. There were no traces of coring. Hardness 60 HV5. This seems to be a piece of impure copper sheet which has been worked and finally annealed.

229A: Large globule. Cast copper with two oxide/sulphide/lead phases. One of these is certainly cuprous oxide and the other is lead or sulphide. The surface is oxidized. The grains are equiaxed and there are some twins but no slip bands. Hardness 112 HV5. This globule has been heated after casting and has been squashed or in some way worked to give a high hardness for what can be no more than an impure copper.

506: A number of crucible sherds mostly belonging to fairly thick-walled crucibles (Fig. 1). A represents a rim which is reddened on the outside and vitrified black inside. B and C are body sherds of buff ware with straw or chaff remains. Both vitrified black inside. D is a sherd of grey ware from which the inside has spalled. The outer half is very porous, suggesting that it has been exposed to a very high temperature resulting in some calcination of calcareous material in the ware. All sherds relate to crucibles in the thickness range 13 to 25 mm. The shape is uncertain.

Table I

Composition of Timna Smelting slag

(After P. Fields), wt – %

SiO_2	41.75
CuO	0.98
Fe_2O_3	13.7
FeO	24.94
CaO	10.18
MgO	1.57
MnO	1.59
P_2O_5	0.82
Al_2O_3	2.69
Na_2O	0.49
K_2O	0.77
BaO(SrO)	0.29
H_2O	0.16
CO_2	0.05
	99.98

Conclusions

The hardness of pure copper in the worked and annealed condition is about 50 HV. This can be increased to over 100 by cold working. "As-cast" pure copper usually has a hardness of about 40, but porosity will reduce this. Oxides and sulphides will cause hardening in the cast state, and arsenic, antimony, and other solid-solution elements will cause considerable hardening in the annealed state.

The material from Timna is clearly copper or arsenical copper. There is no doubt that it comes from the local deposits of copper ores. The presence of zinc in most of the corrosion products analysed is said by Key to be proof that they come from ores on the west or east (Feinan) side of the Arabah. The analyses have been carried out by X-ray fluorescence analysis and it is not easy to detect As when lead is present, as it is in this case. The lead is also derived from the ore, and its existence has already been noted by Lupu and

Rothenberg[3]. The iron probably comes mostly from the soil. Corroding artifacts have often been found to absorb considerable iron from this source.

A good deal of the material examined, particularly the pellets, are waste material from smelting and melting. The artifacts themselves have been forged, i. e. hot-worked, or have been cold-worked followed by annealing.

The slags SF36 and SF67B are almost certainly smelting slags. Their appearance could be reconciled with the composition given by Fields in Table I. SF42 is, however, more probably a crucible slag or a piece of slagged furnace lining containing more silica than the smelting slags. SF44 is certainly a crucible slag containing 43% Cu, most of which is in solution as oxide and some as small copper globules. This might be compared with the slag recorded by Sebelien[4] from Serabit in Sinai shown in Table II. From the high lead content of the latter it would seem that a Cu-Pb alloy was being melted.

Table II

Composition of Casting slag from Serabit[4], wt – %

SiO_2 etc	37.9
Cu	21.7
Pb	38.0
Fe	1.9
Ni + Co	Tr.
As	0.5
Sb, Bi and Ag	Nil

There is no doubt that the bulk of this material represents waste from a copper smelting site of the Early Iron Age. The fact that there is no bronze amongst it at such a late period indicates that it is a primary producing site. Judging by the volume of smelting slag, the copper produced must have been considerable and this was exported to urban sites to be alloyed with tin or zinc for bronze or brass making. The crucibles were used for making implements for local use such as the spear-butt or awl, or for melting and casting prills recovered from slag and other waste material. The fact that the two implements examined are impure copper and not bronze shows clearly that they are of local manufacture for local use.

The methods of manufacture of the implements consist of casting sheet or billets from crucibles, and hot or cold forging these into suitable shapes.

References

1. C.A. Key: I.E.J., 1963, 13, 289-290.
2. J.R. Maréchal: Métaux-Corrosion-Industries, 1958, No. 397, 377-383.
3. R. F. Tylecote, A. Lupu and B. Rothenberg: J. Inst. Metals, 1967, 95, 235-243.
4. J. Sebelian: "Ancient Egypt", 1924.

Annual Conference 1968: The Furness Peninsula

Friday, 27 September	(at the Town Hall, Barrow-in-Furness)
7.30 p.m.	Papers presented by Dr J.D. Marshall and Mr G.R. Morton. "The Early Iron Industry of Furness and District" Dr Marshall will consider the economic and historical aspects, and Mr Morton will discuss the technical details involved.
Saturday, 28 September	
9.0 a.m.	Visits to selected sites in the Furness and Millom Districts. The sites will include either Newlands or Backbarrow furnaces, Duddon furnace and Hodbarrow mines. Lunch at Broughton-in-Furness, tea at Millom.
7.30 p.m.	(at the Hotel Imperial, Barrow-in-Furness) Informal discussion led by Mr. J. Cherry. Theme: "The Bloomery Process"
Sunday, 29 September	(at the Hotel Imperial)
9.30 a.m.	Paper presented by Mr M. Davies-Shiel. "The Industrial Archaeology of the Lake District" Paper presented by Mr D.R. Wattleworth. "The West Cumberland Iron Industry"

The conference will terminate with lunch on Sunday, 29 September, but arrangements can be made for those members who wish to visit additional sites on their way home.

Letter to the Editor

14 October 1967

LEAD CHAMBERS IN BIRMINGHAM

Perhaps there may be members of the Historical Metallurgy Group who can throw light on the development of lead fabrication over the period 1740-1840. This is important in getting a better understanding of the growth of the sulphuric acid industry.

Roebuck built the first lead chambers in Steelhouse Lane, Birmingham, in 1746. These apparently had a cast base, rivetted sides, with a knocked-over seam at the top edge. No solder was used. Yet in France, in 1765, Holker was prepared to offer £1500 to reward a good English workman who might know how to unite lead without solder. In 1769 French manufacture of acid began industrially without lead chambers.

It would appear that the Birmingham lead technique was simple but the French thought that something more sophisticated was employed.

But what, indeed, was the state of skill in the joining of lead at the time? The joining of lead by pouring of molten metal, or by the application of a hot iron, must have been somewhere available.

The size of lead chambers did not change greatly for some years. Was this due to limits in the width and length of sheet available? To inability to support more than a given width by lead rivets?

Lead-burning with hydrogen is usually taken as introduced by de Richemont in 1837. But large chambers had been constructed before then. What then was the joining method used?

Yours sincerely,

S.A. Gregory

Quorn House,
Rowley Park,
Stafford.

Notes

ANCIENT METALLURGY TO BE INVESTIGATED

Bronze castings poured in the last centuries before Christ are the subject of a metallographic study aimed at reconstructing an ancient civilisation's art of metallurgy. The results of this research may help archaeologists at the American Smithsonian Institution to determine more precisely how far the South Arabian City of Timna' had advanced before its destruction around 10-25 A.D.

Sponsored by the Smithsonian Institution, the study is being conducted by a team of metallurgists at the Columbus Laboratories of Battelle Memorial Institute headed by Richard D. Buchleit. The metallurgists are working closely with Dr G. W. Van Beek, curator of old-world anthropology for the Smithsonian.

Recovered from diggings of the pre-Islamic capital city of the Kingdom of Qataban, located in what is today the People's Republic of South Yemen, the 24 artifacts include fragments of statues, cauldrons, bowls, and furniture.

Through the study it is hoped to learn about the alloying techniques used by the Timna' people. So far, for the most part, the fragments have been cast tin-bronze, or leaded-tin-bronze. The variations in tin content suggest that they were intentionally alloyed.

The present one-year study follows one recently completed at Battelle which centred on pre-Columbian Indian artifacts found in Ecuador. These represented a culture that existed in the period of 700-1519 A.D.

The investigation requires a number of examinations of the artifacts including chemical analysis, microstructural interpretation, and hardness and density measurements.

The use of metallographic techniques for archaeological studies represents an unusual approach. Conceivably, metallography might make it possible to correlate metalworking techniques of Qataban with the ancient cultures in other parts of the world, thus shedding new light on human migration and the transfer of knowledge from one civilisation to another.

Through the ages corrosion has almost completely permeated most of the 21-century-old metal objects. However, the samples are sufficiently intact to permit polishing and etching to reveal the metal's grain structure.

Smithsonian scientists are interested in knowing if there is a marked difference in alloy content. If there is this might indicate that there was more than one shop in Timna' turning out metal work.

Although it is difficult to identify some of the fragments, others are intricate in their detail. From observations of the finely executed lines of a bull's head, it seems certain that they used the lost-wax process.

With the lost-wax process, the artisan covered a clay core with a layer of wax in which he fashioned features of a statue, for example. Next, he moulded clay over the wax. Putting the three-part mould over heat would cause the wax to drip out, leaving a cavity into which molten metal was poured to reproduce the statue shape. The basic idea has been rediscovered and is used today to produce intricate castings for items ranging from jewellery to jet engine blades.

[Reprinted from "Metals and Materials", May 1968]

CORRIGENDA

The following errors have been pointed out in the last issue of the Bulletin (Vol. 2, No. 1):

p. 4 Bromley Hill (Oakwood) Furnace. For 'Proposed Development Plan' read 'Parliamentary Deposit Plan'. For 'Monmouth Union and Private Railway' read 'Monmouth, Usk and Pontypool Railway'.

p. 5 Line 3: for 'frit' read 'grit'.
Line 20: for 'Landham' read 'Langham'.

p. 6 Ref. 45: for 'S. & S. Min. Bks.' read 'S. & W. Min. Bks.'

p. 13 Line 43: for 'exampled' read 'examples'.

p. 32 Line 5: for 'of' read 'or'.

p. 40 Line 37: for 'this' read 'his'.

Abstracts

By arrangement with the Editor of the Journal of the Iron and Steel Institute, abstracts of papers of historical interest published in the Abstracts section of that journal are reprinted in the Bulletin, together with certain abstracts prepared by members of the Group.

British Isles

Romano-British iron working near Ariconium. N. P. Bridgewater (Trans. Woolhope Naturalists Field Club, 1966, 38, 124-135. The paper describes excavation of part of the Ariconium iron-making area (see Bull. Hist. Met. Group, 1966, 1, No. 6 and this issue). Remains of six furnaces (probably of the shaft type) were found, together with slag pits and working hollows. These were in use from c. 125 to 200 A.D. Fieldwork showed the Ariconium complex to cover c. 250 acres.

Iron currency bars in Britain. Derek Allen. (Proc. Prehistoric Soc., 1967, **33** (NS), 307-335) The paper discusses the 'currency bars' found on Early Iron Age sites in Britain. It recognizes 3 main types: A. sword-shaped bars; B. spit-shaped bars; and C. ploughshare bars. Distribution maps show group A in the Durotrigan region (Dorset), stretching up the Jurassic Way to Lincolnshire and Yorkshire, group B in Worcestershire, Warwickshire, and part of Somerset, and group C in the Thames Valley, Kent, and Essex. The author favours the classical interpretation of these objects as currency (based on a somewhat obscure reference in Caesar) rather than that put forward by Tylecote ('Metallurgy in Archaeology', 1962, 211) that the bars 'represent a convenient way of distributing semi-finished products'. An appendix lists all the iron bars found in Britain.

A hoard of Romano-British ironwork from Brampton, Cumberland. W. H. Manning. (Trans. Cumberland & Westmoreland Ant. & Arch. Soc., 1966, 66 (NS), 1-36). The paper catalogues iron from a tilery connected with an auxiliary fort. The hoard included a ploughshare, tools (hoe, scythes, axe, adze, chisels, augers), chains, hubs and tires, bucket handles, nails, etc.

Europe

Swedish prehistoric iron – a research project. L. Thålin (Jernkon. Ann., 1967, **151**, (5), 305-324) [In Swed.] Prehistoric iron objects found in different parts of Sweden have been analysed, using spectrographic and activation analysis, the main object being to study the appearance of trace elements. Different trace patterns can be distinguished, which might eventually make possible a determination of the sources of the ore used in making the iron.

The Besche brothers in the service of French metallurgy, 1666-1667. P. Harsin (Rev. Hist. Sidér, 1967, **8**, (3), 193-224) [In Fr.] The work of two Swedish brothers in the improvement of French manufacturing processes for military purposes is reviewed and 23 relevant documents are appended.

The development of iron furnaces and the introduction of the Walloon blast furnace in Bohemia. J. Krulis-Randa (Rev. Hist. Sidér, 1967, 8, (4), 245-275) [In Fr.] A study has been carried out to determine from various literary sources the design and dimensions of blast furnaces in 17th century Bohemia. A review of blast furnaces in existence during the 17th century is followed by a summary of furnaces for making iron in existence in Bohemia at various times. An attempt is made to calculate the dimensions of a Walloon furnace known to have been built by Heinrich Kaspar of Sart, at Strasice at the beginning of the 17th century.

The history of the Suhl iron and steel works: From the outset to the middle of the nineteenth century. H. Kühnert (Tradition 1967, **12**, Aug., 457-483) [In Ger.] Ironstone found near Suhl in Thuringia in Germany formed the basis of the iron, and later steel, industry of this district. The large forests of Thuringia supplied the fuel and the mountain streams in the valleys the power for the forges. A musket factory based on six forges was founded. The ironstone deposits became depleted in the nineteenth century and fuel from the forests scarce and expensive. The iron and steel production ceased, but small arms were still produced from steel from other sources. (37 refs.)

A short history of the establishment and early years of the Ozd 1 ironworks. A. Ovari (Koh. Lapok, 1967, **100**, Oct., 437-443) [In Hung.] An historical outline is given of the oldest ironworks in Hungary, the Ozd ironworks, established 1847.

The role of Carthusian developments in the progress of Alpine metallurgy. L. Charnet (Rev. Hist. Sidér, 1967, **8**, (3), 187-192) [In Fr.] Documents relating to the role of the ecclesiastical iron-masters of Chartreuse, in the development of iron and steel in Alpine regions, are reviewed.

The last years of the 'Providence Russe'. R. Jollin (Rev. Hist. Sidér, 1967, 8, (3), 145-186) [In Fr.] The history of this Belgian Company, engaged in exploiting the coal and mineral resources of South Russia, is traced from 1914-1919.

Asia

The Philistines and iron. C. Böhne (Rev. Hist. Sidér, 1967, 8, (4), 237-244) [In Fr.] In the 12th century B.C. the Philistines, originating from the North, came and settled on the border between Egypt and Palestine. They were unique at the time in that they were using iron as the prime material for arms etc. and were thus able to establish military superiority over neighbouring peoples. There is no evidence, to date, of the country of origin of the Philistines or whence they obtained their iron. Metallographic examination of a piece of a sword from a Palestine tomb shows that it is extremely low in S and P, and contains more than the usual quantities of Ni and As. The metal had been annealed but was extremely hard.

Study of an iron slag, presumably Hittite, found at Sirzi (Malatya), Turkey. H. G. Bachmann (Arch. Eisenh., 1967, 38, Nov. 809-812) [In Ger.] Slag and mineral samples taken from Sirzi were examined by microscopy, X-ray analysis, and other methods. The slag indicates a low metal yield from a bloomery hearth process, probably using furnaces with natural draught. The slag consisted of wüstite in a fayalite matrix, thus indicating that hematite was used as starting material. (12 refs.)

Australia

Blast Furnace in the Bush. Anon (The BHP Review) Describes the furnaces built at Lal Lal near Ballarat in about 1875 to supply the increasing demands of the goldfields. Two furnaces were built; the second one which replaced the first was 50 ft high and much of it still stands. It has a circular firebrick-lined shaft with a stone casing. It used local limonite and limestone and had in 1881 an output of 560 tons. It ceased in 1884 as it was not competitive with British pig iron sent out as ballast to Australia in wheat clipper ships.

Metallurgical Investigations

Excavations at Wall (Staffordshire) 1964-1966. J. Gould (Metallurgical notes on some finds. M. M. Hallett.) (Transactions Lichfield and South Staffordshire Archaeological & Historical Society, 1966-1967, 8, 36) Detailed examination was made of a number of pieces of iron ore, slag, and iron. The iron was typical of normal bloomery production, without heat treatment. One sample was unusually high in phosphorus, and showed what seemed to be nitride needles.

Non-ferrous articles included pieces of lead and of silver, and a piece of galena. One interesting find was of two parallel rows of iron studs wrapped in clay, surrounded by a blue coloration which at first was thought to be due to a silver coating, but was finally found to be due to the iron phosphate, vivianite.

Metallographic studies of Roman-Noric iron excavations. A. Neubeck and O. Schaaber (Freiberger Forschungsh., 1965, (B111), 7-26) [In Ger.] Details of a metallographic study and chemical analysis of objects from excavations from Roman site at the Magdalensberg in Austria are reported. These were so numerous that samples for destructive testing methods could be used. (11 refs.)

Nail or drum plate? P. Rump (Draht-Welt, 1967, 53, June, 393-397) [In Ger.] Two draw plates excavated in East-Siberia and on show in a museum in Hamburg were examined with the object of establishing whether they were nail plates or wire drawing dies. The age of the plates could not be established but it is thought they they were used for wire drawing. It might be that they were used for drawing gold or silver wire. (15 refs.)

A Roman coiner's stamp found at Trier. G. Becker and W. Dick. (Arch. Eisenhüttenwesen, 1967, 38, 351-354) [In Ger.] The paper describes the metallographic examination of a coiner's stamp found in dredging operations at Trier (Augusta Treverorum). It describes its manufacture and heat treatment, and discusses the method of use.

Conservation

Conservation of iron recovered from the sea. E. Eriksen, S. Thegel, and Tojhusmuseet (Royal Danish Arsenal Museum) (Tojhusmuseet Skrifter, 8, 1966, Copenhagen, 134) A discussion of methods of conservation and prevention of corrosion in such big sea-reclaimed iron objects as cannon. Investigations and experiments at the Royal Danish Arsenal Museum on cast and wrought iron guns and cast-iron balls dating from the 15th-18th centuries are described.

Biography

Floris Osmond: man of science and man of letters. G. Delbart (Rev. Mét., 1967, Dec., 1043-1056) [In Fr.] The life and career of this French metallurgist are briefly reviewed.

Book Notice

'A History of Platinum from the Earliest Times to the Eighteen-eighties'. D. McDonald (Johnson, Matthey & Co. Ltd., London, 1960.) Outlines story of platinum fabrication which, with Wollaston, led to supposed first boiler for sulphuric acid sold to Sandman of Thames Bank, 1805. This major outlet handled by Wollaston was pursued from 1805 to 1819 – fuller details in paper by L. F. Gilbert. Rise of French competition and forge-welding; Breant's introduction of siphon with cooler 1827. New French competitor Quennessen gained 1851 Exhibition Medal. Johnson, Matthey responded by employment of an 'eminent chemical engineer' Petrie who made analysis of evaporation design needs (reminiscent of practical batch still designs in 1799 Commission Report) and correspondence gives much insight. George Matthey introduced fusion-welding 1861 which supported three further design advances, including the Prentice and the Delplace patents. Outside fabricators are named: Kepp, the first important coppersmith, being succeeded by Benham & Froud.

The early outlets for concentrated acid are obscure. In Great Britain glass vessels returned to favour, followed by the use of silica in the 'cascade'.

(Reprinted from the IChemE History NEWSLETTER no. 2, 1967)