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Contents

Metallographic examination of Medieval and Post-Medieval Iron Armour

Colin W Brewer

Introduction

During the first half of 1979, the author was overseas on study leave, and after a tour of archaeological museums in the Middle East, he worked in the Department of Metallurgy and Materials Science, of the Imperial College of Science and Technology, London. There he carried out metallographic examination of ancient bronze artifacts from the City of David Excavation, Jerusalem[1] and also collaborated on metallography with Professor P L Pratt of the Imperial College on a study of the penetration of medieval plate armour by steel-pointed arrows. A tour of Museums in England by the author, with the object of obtaining some small fragments of medieval plate/armour for metallographic examination, was unsuccessful, due to the fact that when a museum has a complete suit of medieval plate armour, or a valuable steel helmet, it is not often willing to cut out even a very small sample for metallographic examination. None of the museums had any spare parts of armour, nor any incomplete suits of armour. For this reason little metallography has been carried out on armour. An approach was made to the Department of the Environment, London, and through the co-operation of Mr John W G Musty, the Head of the Ancient Monuments Laboratory, and Mrs Marjorie Hutchinson, Conservator, the author was able to obtain a small fragment from each of five V-shaped medieval iron breastplates, from Farleigh Hungerford Castle, Somerset. The author then visited Grandson in Switzerland in July 1979, where through the cooperation of the Director, Mr Eugen Heer, he was able to obtain nine small samples of medieval European and Turkish plate armour, from the workshop of the Swiss Institute of Arms and Armour. This paper covers the metallographic examination of all these samples of armour, carried out by the author in the Department of Mining and Metallurgical Engineering of the University of Queensland, in Brisbane.

Survey of Previous Work

The success of William the Conqueror's army at the Battle of Hastings in 1066 was partly due to the fact that the Norman knights wore (chain) mail hauberks (a knee-length shirt of mail), which could not be penetrated by the wooden Anglo-Saxon arrows. Later, arrows with a bodkin-type steel point, when fired from an English longbow, could penetrate mail (Oakeshott).[2] By the fourteenth century AD, plate armour of iron or steel (later weighing up to 100 pounds) was taking the place of mail. Plate armour could not be penetrated by a steel-pointed arrow, but later it could be penetrated by a cross-bow bolt with a heavy steel point.

Cyril Stanley Smith[3] (of MIT) has metallographically examined sixteen links from various suits of mail at the Metropolitan Museum of Art, New York. Most of the links were made of soft wrought iron, often containing large amounts of slag. Only three contained enough carbon to be classed as steel, and these alone had been given a heat treatment to harden them. All the links had been annealed after the wire had been made. All of the links were made from wire, bent to a circular form and closed by either rivetting or welding. In four of the links, Smith found metallographic evidence that the wire had been made by drawing from a forged rod. Two Turkish links had transverse stringers of slag, which showed that the wire had been cut from a thin sheet of wrought iron. The rivets were all made of carbon-free wrought iron. Most of the rivets had a rectangular cross-section, not tapered in either direction, as if they had been cut from strip. As the date of manufacture is very important in comparing different samples of armour, the dates of the mail examined by Smith are summarised in Table 1.

Table 1

Properties of Mail

Smith's No	**Description of mail**	**% carbon**	**Condition**
1	German, 1525	0.0	Annealed
2	German, 1500	0.0	Annealed
3	German, 1500	0.0	Annealed
4	German, 1525	0.5	Quenched and tempered
5	German, 1525	0.2	Annealed
6	German, 1550	0.6	Quenched and tempered
7	German, 1575	0.0	Drawn wire
8	German, 1575	0.0	Annealed
9	German, 1575	0.0	Annealed
10	Turkish, 17th century	0–0.15	Wire cut from strip
11	Turkish, 17th century	0–0.05	Annealed
12	Persian, 18th century	0–0.05	Drawn wire
13	Persian, 18th century	0.01	Annealed
14	European coif, 14th century	0.05	Drawn wire
15	Turkish, 15th century	0.0	Slit wire
16	European, 16th century	0.4	Quenched

After C S Smith[3]

The present author has examined six ancient steel weapons from England, including a medieval steel arrowhead with a broad blade;[4] the arrowhead consisted of a 0.25% carbon steel, with massive slag particles. Coghlan and Tylecote[5] examined five medieval iron arrowheads at the Newbury Museum, Berkshire. The arrowheads consisted basically of low carbon wrought iron; in one barbed arrowhead, the point had been carburised and quenched to produce martensite. In Robert Hardy's book.[6] "The Longbow", there are three technical appendices: Blyth has discussed the design and materials of the bow; Pratt has discussed the arrow, and Jones has discussed the microstructure and mechanical properties of plate armour.

Pratt[6] examined English plate armour, circa 1570, and found that it consisted of low carbon steel (0.1 to 0.2% carbon) having a micro-structure of ferrite and pearlite. A German gauntlet of 1500 had been quenched to produce martensite. Carburised steel was found in an Italian breastplate, circa 1520. Jones[6] concluded that all the simple heat treatments of steel were known to the armourers of the Middle Ages, and that low carbon steel with a tensile strength range from 31 kgf/mm^2 (20 tons/sq in) to 110 kgf/mm^2 (70 tons/sq in) was available.

Campbell[7] at Columbia University, New York, examined samples of European medieval plate armour from the Metropolitan Museum of Art. All the samples consisted of wrought iron, some were carbursied, and some not; some of the carburised samples had been quenched to produce martensite. The amount of slag varied from a trace to large amounts. Henger [8] has examined six samples of medieval plate armour. One sample of Italian armour of 1400 AD and two samples of German armour of 1500AD consisted mainly of wrought iron with a lightly carburised surface, consisting of ferrite and some pearlite. Another sample of Italian armour of 1480 AD consisted of highly carburised wrought iron, and had been quenched after carburising. The case contained bainite and nodular pearlite. Two samples of late 15th Century armour consisted of high carbon steel rather than carburised wrought iron. Williams[9] examined 16th century armour from the Tower of London, and found that three samples consisted basically of wrought iron, which was shaped by hammering and then the surface was carburised to about 0.3% carbon. The maximum hardness was 210 HV. Williams[10] obtained a wide variety of samples of medieval armour from the workshops of European Museums, including samples from 1400 AD to the 17th century.

Metallographic examination revealed the following materials:

Table 2

Material	Structure
Wrought Iron	Ferrite and slag particles
Low carbon steel	Ferrite and some pearlite
Banded low carbon steel	Layers of wrought iron and low carbon steel
Medium carbon steel	Mainly pearlite
Case carburised steel	Fine pearlite on medium C faces, with a central layer of ferrite.
Carburised and hardened steel	Lightly temperated martensite

Williams' latest papers are listed at the end of the bibliography.[12,13,14]

Metallographic Technique

In Brisbane, most of the armour samples from Farleigh Hungerford and Switzerland were mounted vertically in plastic, and the thin longitudinal edge was polished and etched. Coarse polishing was carried out on 120, 240, 400 and 600 grades of abrasive paper, using water as lubricant. Polishing was continued on a coarse diamond pad (6 microns), a fine diamond pad (0.25 to 1 micron), and the final polish was obtained on a very fine alumina pad (0.05 micron). Each polished specimen was rinsed under clean running water, swabbed with soap solution, rinsed with water, then alcohol, and dried quickly. The specimens were etched in 2% nital. The microstructures were photographed on an Olympus MG metallographic microscope.

Metallographic Examination

Upper Breastplate from Farleigh Hungerford Castle

Sample/Metallography Laboratory Number A1. (DofE No 749491). Date: Civil War (1640-60). The upper breastplate was V-shaped, and visual examination showed that it was covered with corrosion product. An edge section of the small fragment available was mounted and etched. The maximum thickness of the sheet, (ie. where minimum corrosion had occurred), as measured on the microscope, was 1.00 mm, including the layer of grey corrosion product on each side of the sheet. The actual section shown in the photomicrographs, (Figs 1 and 2), was 0.5 mm in thickness including the corrosion product, and the residual metal was 0.30 mm in thickness.

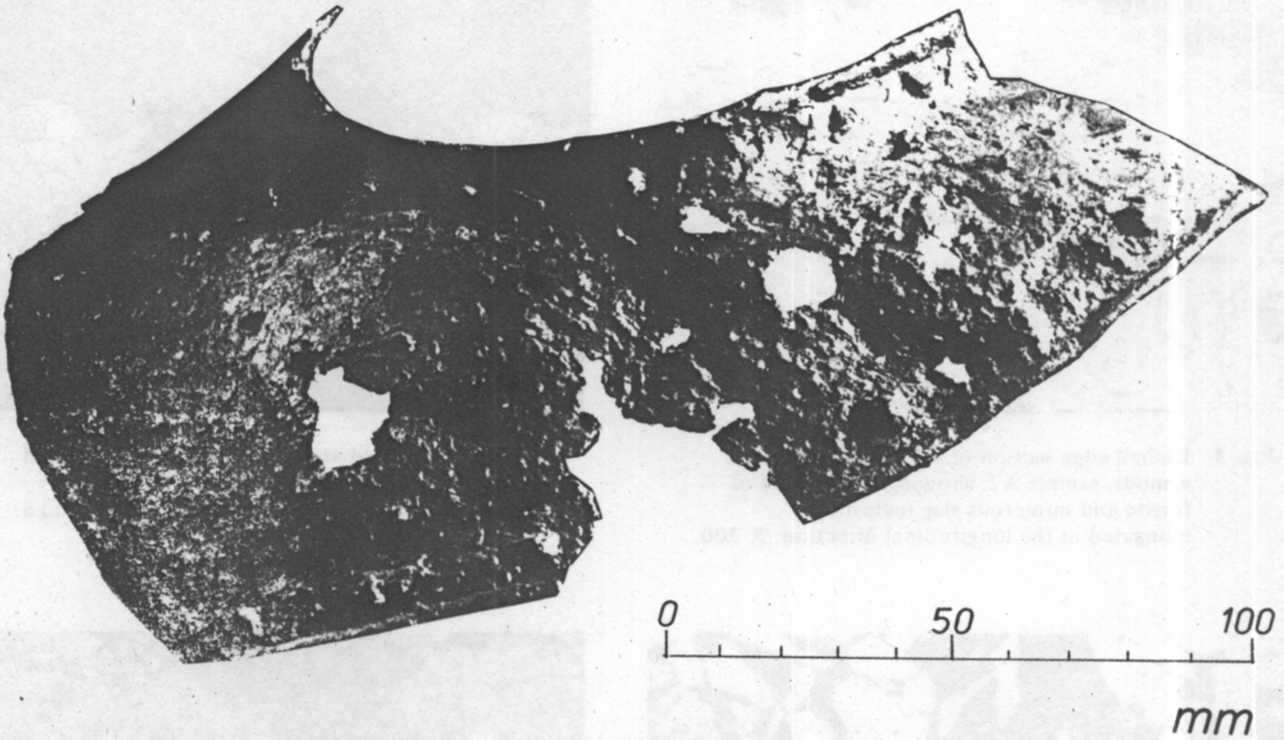
The unetched edge section showed slag particles elongated in the longitudinal direction. (See Fig. 1).
The etched section showed a banded structure, composed of alternate layers of wrought iron, (pure ferrite), and low carbon steel (consisting of small grains of ferrite and some smaller grains of pearlite). (See Fig. 2).

There was a layer of low carbon steel on each of the outside faces of the sheet. The micro-hardness was measured on a Leitz Micro-Hardness Tester, using a 50 g load. This instrument uses a diamond indenter and gives results on the Vickers scale. The calibration of the instrument was checked by carrying out tests on standard hardness test pieces of wrought iron and steel, and testing the same specimens on a standard Vickers hardness machine, using a 1 kg load. For the hardness tests on the armour samples, five micro-hardness tests were carried out on each area of the sample tested, and the average taken. The Vickers hardness of annealed ferrite, (ie. pure BCC iron saturated with 0.08% carbon in interstitial solid solution), is approximately 150. The annealed ferrite in commercial wrought iron or commercial steel may have a greater hardness owing to the presence of phosphorus and silicon as dissolved impurities.

In this sample A1 of the Farleigh Hungerford armour, the micro-hardness number of the ferrite in the wrought iron layer was 132, and of the ferrite in the low carbon steel band was 155. Referring to Fig. 2, the slag particles elongated in the longitudinal direction indicate that the breastplate was shaped by hammering. The lack of preferred orientation ie. recrystallisation of the grains of ferrite in the microstructure indicates that the breastplate was made by hammering while hot, or was annealed after cold hammering. The alternate layers of ferrite and low carbon steel show that the breastplate was made by hot hammer-welding together plates of wrought iron and low carbon steel, as in the manufacture of steel sword blades by the process of piling (Brewer[2]). The ductile wrought iron would give increased toughness and flexibility, while the low carbon steel would give increased strength and hardness. This suggests that the armourer was trying to adapt plate armour to the age of the cross-bow and possibly the hand-gun.

Upper Breastplate from Farleigh Hungerford Castle

Sample/Met Lab No A2 (DofE No 749491).
The five breastplates from Farleigh Hungerford Castle on visual examination looked identical. However the individual microstructures were quite different. They may have been made by different armourers. The maximum thickness of the



Iron Breastplate from Farleigh Hungerford Castle DofE Reference FHC2 (749491)

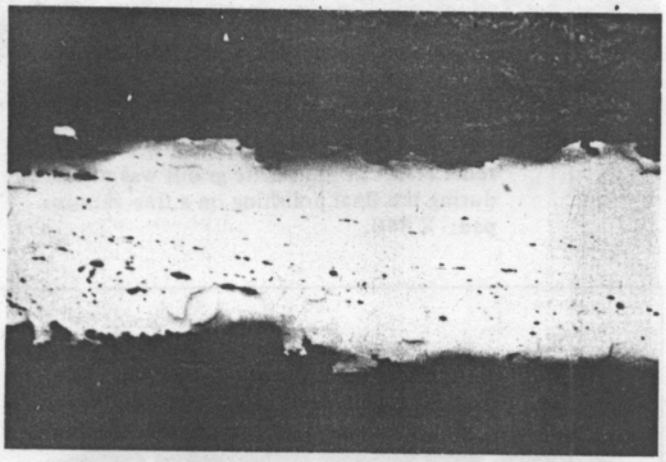


Fig.1 Unetched edge section of Farleigh Hungerford armour, sample A1, showing elongated slag particles. X100

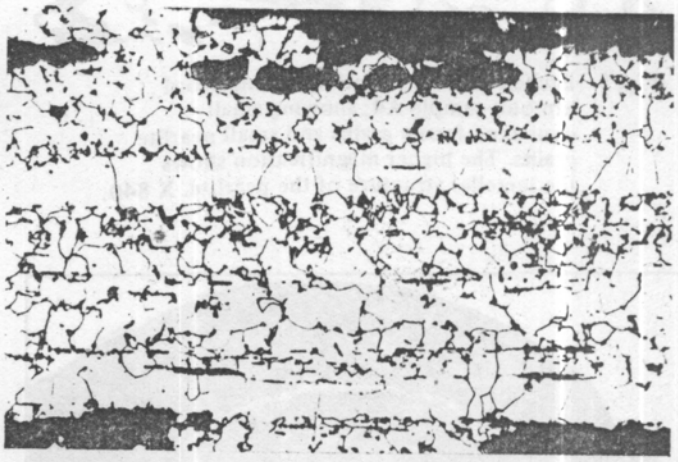


Fig. 2 Etched edge section of Farleigh Hungerford armour, sample A1; showing alternate layers of low carbon steel (ferrite and small pearlite grains), and wrought iron (pure ferrite), and some elongated slag particles. X 200.

Fig. 3 Etched edge section of Farleigh Hungerford armour, sample A2; showing large grains of ferrite and numerous slag inclusions elongated in the longitudinal direction. X 200.

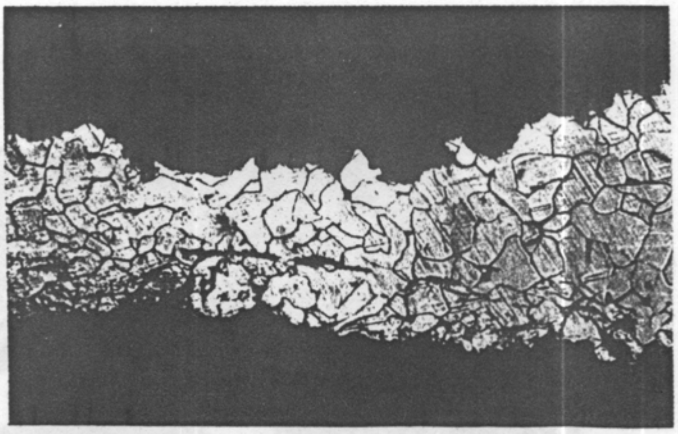


Fig. 4 Etched section of Farleigh Hungerford armour, sample A3; showing fairly large, equi-axed grains of ferrite, and a few strings of slag. X 100.

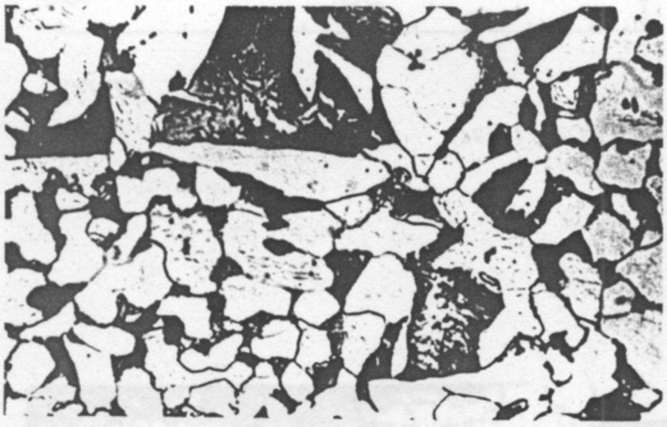


Fig. 5 Etched section of Farleigh Hungerford armour, sample A4; showing small equi-axed ferrite grains and small pearlite grains. The higher magnification shows the lamellar structure of the pearlite. X 840.

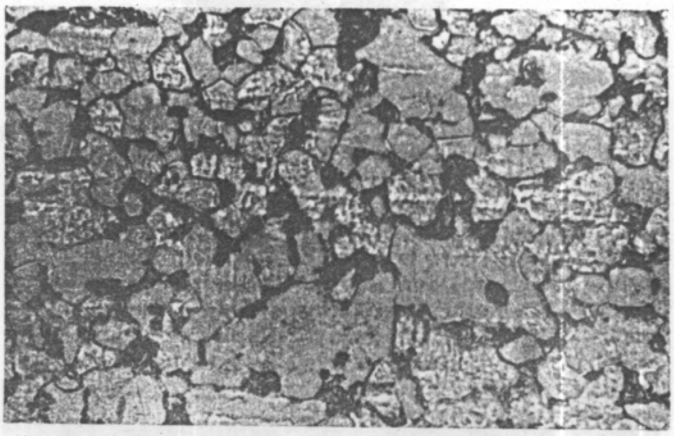


Fig. 6 Etched section of Farleigh Hungerford armour, sample A5; showing small equi-axed grains of ferrite, and very small grains of pearlite. The relief effect in the ferrite grains was produced during the final polishing on a fine alumina pad. X 840.

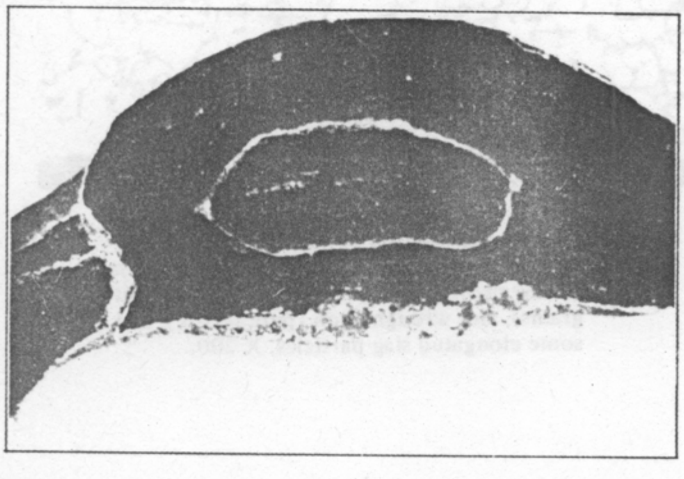


Fig. 7 Photo-macrograph of unetched horizontal longitudinal Section 1, showing plan of rivet in lap joint in (chain) mail. X 30.

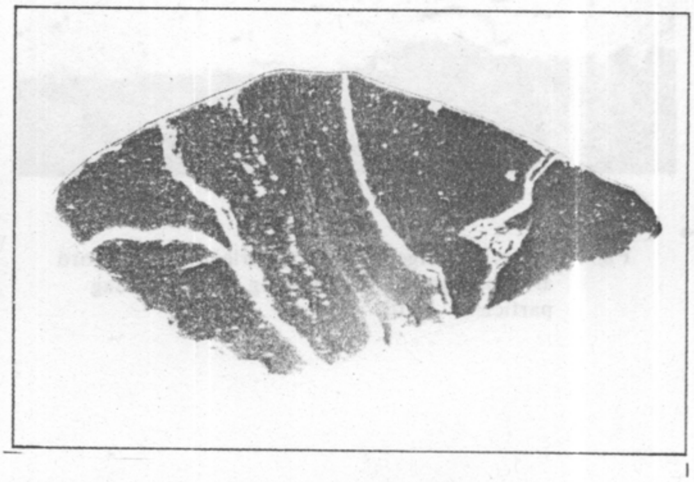


Fig. 8 Unetched vertical transverse Section 3, showing vertical rivet holding lap joint together, in mail. X 40.

A2 sheet was 1.14 mm. The structure of this sample consisted mainly of large grains of ferrite, with numerous slag particles elongated in the longitudinal direction. (See Fig 3). Higher magnification (x 840) showed the presence of a few very small grains of pearlite in the ferrite grain boundaries. The material could be described as wrought iron with a trace of carbon, rather than a very low carbon steel. The ferrite grains showed no preferred orientation; recrystallisation had occurred. The average micro-hardness of the ferrite was 138. The structure indicates that the breastplate was probably made by hot hammering a slab of wrought iron into a thin sheet.

Upper Breastplate from Farleigh Hungerford Castle

Sample/Met Lab No A3. (DofE No 749493).
The maximum thickness of sheet in the sample examined was 0.86 mm.
The etched edge section of this sample showed that the structure consisted mainly of fairly large equi-axed ferrite grains, with a few stringers of slag, ie. wrought iron with a little slag (see Fig 4). The micro-hardness of the ferrite was 15%. The structure indicates that this breastplate was probably made in the same way as the previous breastplate A2.

Upper Breastplate from Farleigh Hungerford Castle

Sample/Met Lab No A4. (DofE No 749494). The maximum thickness of sheet in the sample examined was 1.06 mm.
The etched section of this breastplate showed very small equi-axed grains of ferrite and very small grains of pearlite, with a few stringers of slag. From the relative proportions of ferrite and pearlite in the microstructure the material is a mild steel, containing approximately 0.25% carbon. See Fig 5.
An interesting feature of the microstructure was a layer of ferrite, with large grain size, on one outside face of the sheet of armour. This breastplate was probably made by hot hammer welding a thin slab of wrought iron on to a thicker slab of mild steel; the wrought iron would give greater toughness to the armour. The MHN of ferrite in the mild steel layer was from 205 to 232, while that of the ferrite layer on one side was 146; the average hardness of the ferrite was 194.

Upper Breastplate from Farleigh Hungerford Castle

Sample/Met Lab No A5. (DofE No 749495).
The maximum thickness of sheet in the sample examined was was 1.02 mm.
The etched section showed small equi-axed grains of ferrite and very small grains of pearlite, with rows of small slag particles. (See Fig. 6). From the proportions of ferrite and pearlite, the material is a low carbon steel, containing between 0.15 and 0.2% carbon. The micro-hardness of the ferrite was 176. The structure indicates that the breastplate was probably made by hot hammering a slab of low carbon steel into a thin sheet.

Steel Point of a Cross-bow Bolt

Sample/Met Lab No A6. An excellent steel point of a cross-bow bolt from the Battle of Grandson, Switzerland, 1476, was left with Professor Pratt, in London, for his experiments on the piercing of plate armour.

(Chain) Mail Shirt

Sample/Met Lab No A7. The sample consisted of portion (100 mm x 30 mm) of a mail shirt of the 15th–16th century AD, obtained from the Swiss Institute of Arms and Armour. The mail consisted of steel wire links, each 7 mm outside diameter; the wire was elliptical in cross-section, being 1 to 1.1 mm wide and 0.85 mm in thickness. Each link passed through four other links. Visual examination showed that each link was made from a length of steel wire, with its two ends flattened, overlapped to form a wide lap joint (Fig 7) and joined by a rivet. There was a small hemispherical protuberance (0.9 to 1.1 mm in diameter) on one side of each lap joint. (See Fig. 9). The lap joint could be prized apart, only with difficulty, by means of a small screw-driver. The links were somewhat brittle, and were too hard to be cut with a hacksaw. Portions of four links were mounted in one plastic mount, and the side face of each link was polished. For the purpose of identification of the sections through the lap joints, if a link of mail be placed flat on a bench, so that the protuberance is underneath the lap joint, the plane of the lap joint will be horizontal, and the protuberance can be regarded as the bottom end of the rivet. The following sections through four lap joints were mounted separately in transparent epoxy resin;

Section 1. A horizontal longitudinal section through the upper portion of the lap joint, (looking down on the plan of the rivet. See Fig. 7).

Section 2 A horizontal longitudinal section through the lower portion of the lap joint.

Section 3 A vertical transverse section through the lap joint. (See Fig. 8).

Section 4 A vertical longitudinal section through the lap joint. (See Fig. 9).

The unetched sections Figs. 7, 8 and 9 show how the lap joint is held together by the vertical rivet. There was no evidence of welding. The cross-section of the rivet in Section 1, (Fig 7) was 0.7 mm in thickness and 2 mm wide. The cross-section of the rivet in Section 2 was 0.5 mm x 2 mm. As shown in Fig 9, the width of the rivet tapered towards a point at the protuberance. Micro-examination of six links showed, in the unetched sections, parallel rows of elongated slag particles running in the longitudinal direction; while the etched sections showed that each link consisted of martensite. The etched sections 1 to 4 of the lap joints also showed that the lap joint surrounding each rivet consisted of martensite. Fig 10 shows the martensite in link No 4 at higher magnification.

The micro-hardness of the martensite in six links ranged from 412 to 644. As-quenched or lightly tempered martensite with a hardness of the order of 600 indicates a steel of medium carbon content. The martensite was probably lightly tempered to remove some of the brittleness of the as-quenched mail, but this would not affect the structure seen on the optical microscope. Wet chemical analysis on a 3 g sample of mail showed that the carbon content of the steel links was 0.49%.
The composition and structure of the rivet varied in different lap joints. The rivet in Section 4 consisted of equi-axed ferrite with numerous slag particles orientated in the longitudinal direction, ie. wrought iron. The rivet in Section 1 consisted of fairly large equi-axed grains of ferrite longitudinal stringers of slag, and a single band of martensite oriented in the longitudinal direction. The rivet in Section 2 consisted of alternate layers of ferrite and martensite, shown in Fig 11. The material in this rivet must have been made by piling strips of wrought iron and carbon steel, and hot hammering or forge welding the strips together. (See Brewer[2]).

The rivet in Link No 3 (Fig 12) consisted of a layer of ferrite on the outside, then a thick band composed of a mixture of martensite and pearlite, and then another layer of ferrite with slag particles. The presence of pearlite amongst the martensite can be explained by assuming that the layer of steel had a low carbon content, which would result in low hardenability.

There were some decarburised regions on some of the links.

We can now consider the process used for the manufacture of the mail. The mail was made from medium-carbon steel wire links. The wire was possibly made by wire drawing, and after drawing the wire probably had a circular cross-section. After cutting to the required length for a link, the ends of the wire were flattened by hammering, and the wire may have been bent around a mandrel to form the circular link, and the ends were overlapped, to form a wide lap joint. The wire was probably in the annealed condition. At some stage the link may have been lightly hammered, flattening the wire slightly. Another possibility, suggested by the elliptical cross-section of the wire links, is that the wire may have been made by hammering a thin rod of steel on an anvil. A hole may have been made in the lap joint by means of a sharp hard punch. For rivets the armourer apparently used any ferrous material available in his workshop. Each rivet was made from a flat strip of iron or steel, and the width tapered to the pointed end. After placing four adjoining links through a particular link, the rivet, probably in the annealed condition, was hammered into the eye of the lap joint, and the neat hemispherical protuberance at the end of the rivet was formed. After completion of the mail shirt, the entire shirt was hardened by heating to the austenite temperature range, probably in a charcoal fire, and then quenched in cold water. It was then probably tempered lightly, perhaps at about 200°C.

Link from Turkish Plate Armour

Sample/Met Lab No A8. The sample consisted of a single wire link from Turkish plate armour of the first half of the 16th century AD. The iron wire circular link was 12 mm in external diameter and 1.2 mm thick; the wire was circular in cross-section. The specimen was mounted for polishing the side face of the entire link. The unetched section showed long parallel stringers of slag, running in the longitudinal direction. The etched section showed mainly ferrite, with numerous stringers of slag concentrated on the inner side of the link. (See Fig. 13). As there was no pearlite the material was wrought iron. An unusual feature of the microstructure was the presence of very small equi-axed ferrite grains on the inner side of the link, and very large ferrite grains on the outer side of the link. Fig. 14 shows a portion of the cross-section at higher magnification. Impurities are segregated in the small grain boundaries on the right, and may have inhibited grain growth. The micro-hardness of the ferrite ranged from 160 to 175. A Vickers hardness test carried out on the sample, using a 1 kg load, showed that the Vickers hardness of the wrought iron was 150. Wire drawing was practised in South Germany during the 14th century AD (Derry and Williams[11]). The structure indicates that the link was made from dirty wrought iron wire, probably made by wire drawing, then annealed resulting in the large grain size.

Turkish Plate Armour

Sample/Met Lab No A12; consisted of a small flat, thin sample of Turkish plate armour of the 16th century AD. The specimen was mounted for polishing of the flat surface. The unetched surface section showed numerous small slag particles. The etched section showed fairly large equi-axed grains of ferrite, small slag particles, and no pearlite. (See Fig.15). The micro-hardness of the ferrite were 183 and 197. The plate armour was probably made by hammering a hot slab of wrought iron into a thin sheet.

Breastplate

Sample/Met Lab No A13; (SWI 2069).
The sample consisted of a small cube, with 1.5 mm sides, from a 14th century breastplate. The sample was mounted for polishing one face of the cube. The unetched section showed small slag particles in random positions. The etched section showed large equi-axed grains of ferrite, and random small slag particles. See Fig 16. The micro-hardness of the ferrite was 178. The breastplate was probably made by hammering a hot slab of wrought iron into a thin sheet.

Iron Spur

Sample/Met Lab No A14. The sample was a small flat portion from the side arm of an iron spur, circa 1450. The specimen was mounted for polishing the edge of the sample. The unetched section showed a number of slag particles. The etched section showed fairly large equi-axed ferrite grains, similar to those of Fig 16, but not so large. There was no pearlite. The micro-hardness was 195. The spur was probably made by the hot hammering of wrought iron.

Conclusion

Two of the Farleigh Hungerford plate armour samples were made from low carbon steel sheet; two samples consisted of wrought iron sheet (composed of ferrite, slag particles and a trace of carbon) while the remaining Farleigh Hungerford sample had been made by piling strips of wrought iron and low carbon steel and forge welding the strips together. The mail shirt was made from links of medium-carbon steel wire rivetted together, using various ferrous materials as rivets; the entire mail had been hardened by quenching. The link from Turkish armour had been made from dirty wrought iron, ie. ferrite with numerous stringers of slag. The Turkish plate armour, the 14th century breastplate and the iron spur were made from normal wrought iron.

Acknowledgements

The author wishes to thank Mr J W G Musty, Head of the Ancient Monuments Laboratory, Department of the Environment, London, for making available samples of the Farleigh Hungerford armour. He also thanks Mr Eugen Heer, Director of the Swiss Institute of Arms and Armour for the samples of medieval armour.

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6 Robert Hardy, The Longbow: A Social and Military History. 1976, Cambridge, Patrick Stephens Ltd.
Appendices:
1. p 194 P H Blyth, The design and materials of the bow

Fig. 9 Unetched vertical longitudinal Section 4, of mail, showing rivet holding lap joint together. Width of rivet is tapered towards bottom. Note hemispherical protuberance at bottom of rivet. X 30.

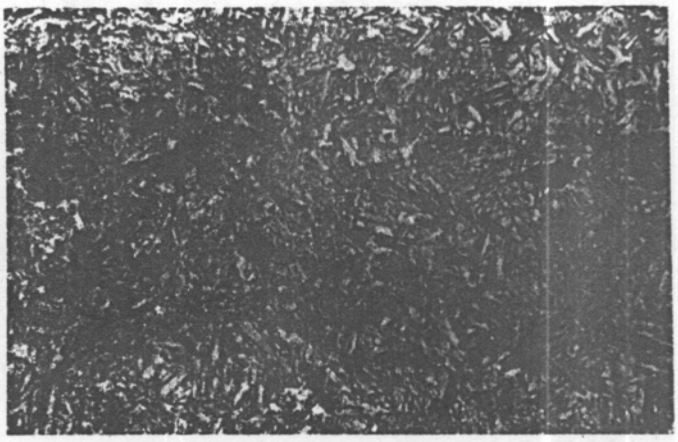

Fig.10 Structure of Link No 4, of mail, showing martensite or lightly tempered martensite and slag particles. Steel contains approximately 0.49% carbon. X 840.

Fig.11 Etched horizontal longitudinal Section No 2, of mail, showing alternate layers of ferrite and martensite in rivet. The lower portion shows martensite in the link surrounding the rivet. X 100.

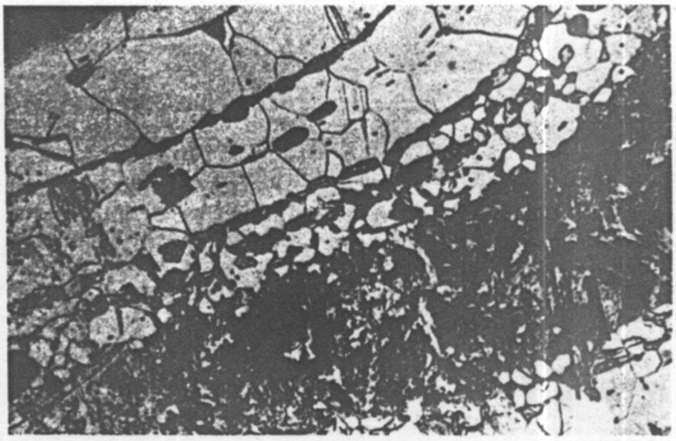

Fig.12 Structure of rivet in Link No 3, of mail, showing outer layer of ferrite, a wide band consisting of a mixture of martensite and pearlite, and another wide layer of ferrite with slag. X 200.

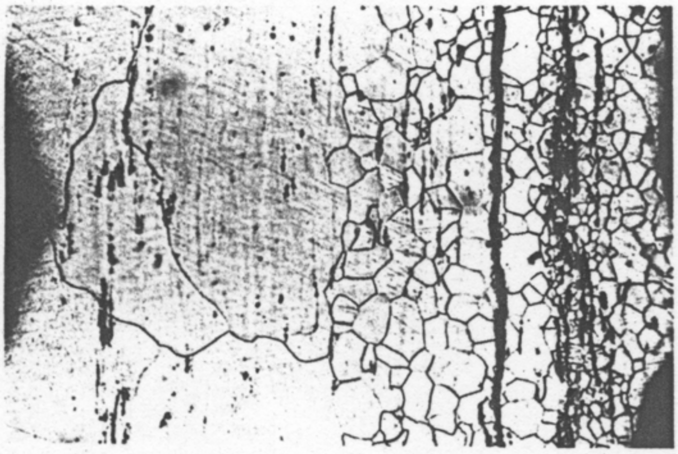

Fig.13 Wrought iron from Turkish plate armour, sample A8; etched section showing numerous slag particles, very small ferrite grains on inner side of link, and very large ferrite on outer side (left) of link. X 100.

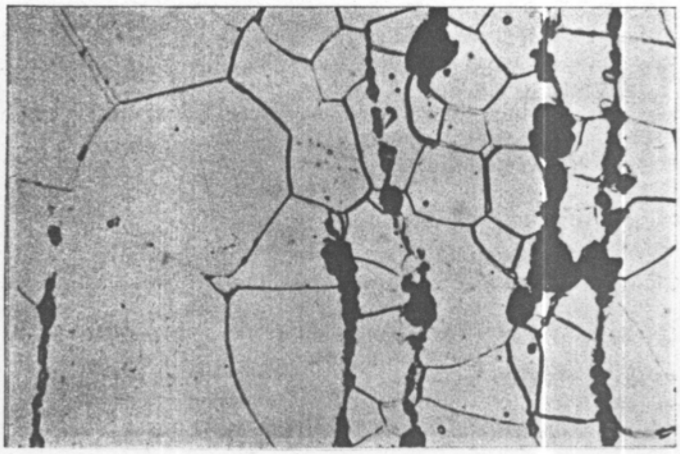

Fig.14 Wrought iron link from Turkish plate armour, sample A8; etched section at higher magnification showing segregation in boundaries of small ferrite grains on right, and slag particles. X 840.

Fig.15 Etched surface section of Turkish plate armour; sample No A12; showing large grains of ferrite, and small particles of slag. X 100.

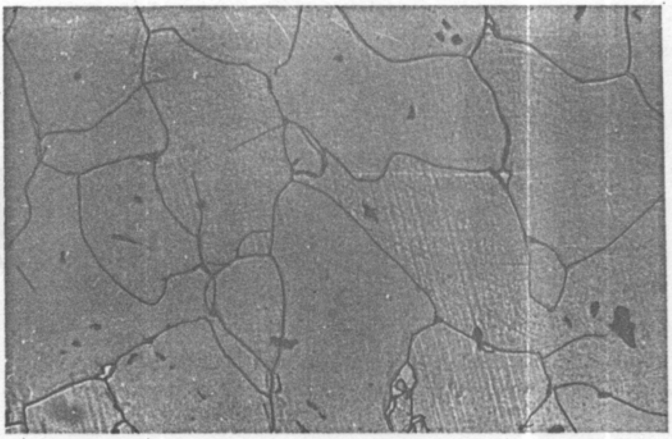

Fig.16 Etched section of iron breastplate, sample A13; showing large equi-axed grains of ferrite and slag particles. X 200.

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Ironmaking in Ringwood, New Jersey

Jack Chard

There has been ironmaking in the Ringwood area since 1736, when Cornelius Board, an Englishman of Welsh descent who was prospecting hopefully for precious metals, discovered instead the local magnetite iron ore. With a partner, Timothy Ward, he purchased land and built a bloomery at what is now known as Sterling Lake, about five miles north of Ringwood. In 1740 Board sold his interest in the Sterling ironworks and moved to what is now the Ringwood area, where he bought three tracts of land from the Proprietors of East Jersey and erected a forge. Less than two months after buying this land he sold sixteen acres to the Ogden family of Newark, New Jersey; one cannot help wondering whether there was some family connection involved. The Ogdens also purchased land from the Proprietors, and in 1742 formed the Ringwood Company and built the first blast furnace in the area.

Thus the name Ringwood has been associated with the ironworks since 1742. The origin of the name presents a challenge; it is tempting to think that it is named after Ringwood in Hampshire, England. Contact was established with Dr R H Little in Ringwood, England, who had transcribed the church registers of Ringwood and seven neighbouring parishes, in the hope that some connection with the Board, Ward or Ogden families could be established. There was no record of Boards or Ogdens, but there were numerous records of baptisms of Wards in the 1730's and 1740's, so that there was apparently a flourishing family of that name then. Unfortunately there is no prior record of Wards, so the family presumably moved into the area around 1730 about the same time as the first mention of Ringwood, New Jersey. However, it seems that Timothy Ward, Cornelius Board's partner, did not come from Ringwood in England. The mystery remains unsolved. There was a 1737 reference to the 'Busseton Forge by Ringwood Cold Spring' (the name is also spelled 'Busselton'). This was presumably the bloomery of Board and Ward, as the word 'forge' was also used to refer to a bloomery. This establishes the name of Ringwood in the area in 1737. Dr. Little was asked if there was any clue in the name 'Busselton'; he suggested that this might be a corruption of 'Bursledon' and that there was a place of this name near Southampton which had a flourishing shipbuilding industry in the eighteenth century. Attempts to make contact with an historian in Bursledon have proved unsuccessful. Another intriguing fact is that a locality just outside Ringwood in Hampshire is known as 'Ogden's', but it has not yet been possible to ascertain how far back this name has been in use. The mystery remains.

The Ogdens continued to operate their ironworks and in 1762 built a new blast furnace. However, in 1764 the works were offered for sale by advertisement in the 'New-York Mercury' of March 5th 1764.

The next character to come upon the scene was a remarkable man called Peter Hasenclever. Born in Remscheid in Germany in 1716, he worked as a boy in the local ironworks, but later became a travelling salesman in cloth and needles, and established a business at Cadiz in Spain. In 1763 he arrived in England and became a British citizen. Although he had not been to America he was convinced of the tremendous potential of the new world. He formed a partnership (Hasenclever, Seton and Crofts) with a capital of £20,000, and in April 1764 he sailed for New York, arriving six weeks later. It seems probable that he had received word that the Ringwood Ironworks would be for sale; he purchased it on July 5th, 1764 and proceeded energetically to repair and improve it.

Before leaving Europe Hasenclever had already contracted with a large number of skilled German ironworkers to be brought over with their families, and they started to arrive in the autumn of 1764. (More than five hundred were involved in this ambitious operation). Meanwhile Hasenclever had bought 122 horses, 214 draft oxen, 51 cows and a 'vast number of implements for the works'. With great energy and remarkable organizational ability Hasenclever had within two years established four blast furnaces, at Ringwood,* Charlottesburg, Long Pond and Cortland, all within a radius of about twenty miles of Ringwood, seven forges, two stamping mills, together with all the necessary water-wheel systems, charcoal houses, etc; and all the necessary buildings for housing the workers and animals; and a network of roads with bridges connecting the plants, with supporting saw-mills and carpenters shops. All this represented a tremendous investment. The winter of 1765 brought great floods and washed out many of the dams which had to be rebuilt. The German ironworkers demanded more money. A shipment of iron from Ringwood received high praise in England, but the expected large profits did not materialise. However, the foundations of a large and potentially efficient enterprise had been laid. In addition to his ironmaking projects Hasenclever had also purchased much land for proposed hemp, flax and madder plantations.

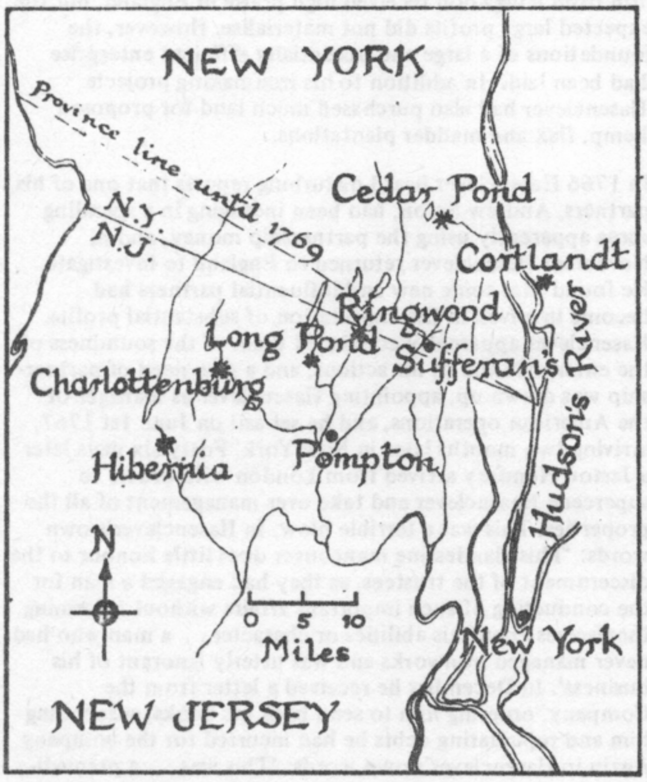
In 1766 Hasenclever heard disturbing reports that one of his partners, Andrew Seton, had been indulging in a spending spree apparently using the partnership money, and in November Hasenclever returned to England to investigate. He found that some new and influential partners had become involved in the expectation of substantial profits. Hasenclever apparently convinced them of the soundness of the enterprise and of his actions, and a new deed of partnership was drawn up, appointing Hasenclever as manager of the American operations, and he set sail on June 1st 1767, arriving two months later in New York. Forty-six days later a Jeston Humfray arrived from London with orders to supercede Hasenclever and take over management of all the properties. This was a terrible blow. In Hasenclever's own words: 'This clandestine manoeuver does little honour to the discernment of the trustees, as they had engaged a man for the conducting of such important affairs without informing themselves about his abilities or character . . a man who had never managed ironworks and was utterly ignorant of his business'. In December he received a letter from the Company, ordering him to send back his books, suspending him and repudiating debts he had incurred for the company. Again in Hasenclever's own words: 'This was. . . a premeditated deceit . . . a plot which they had formed before they signed the deed of partnership with me . . . They acknowledge

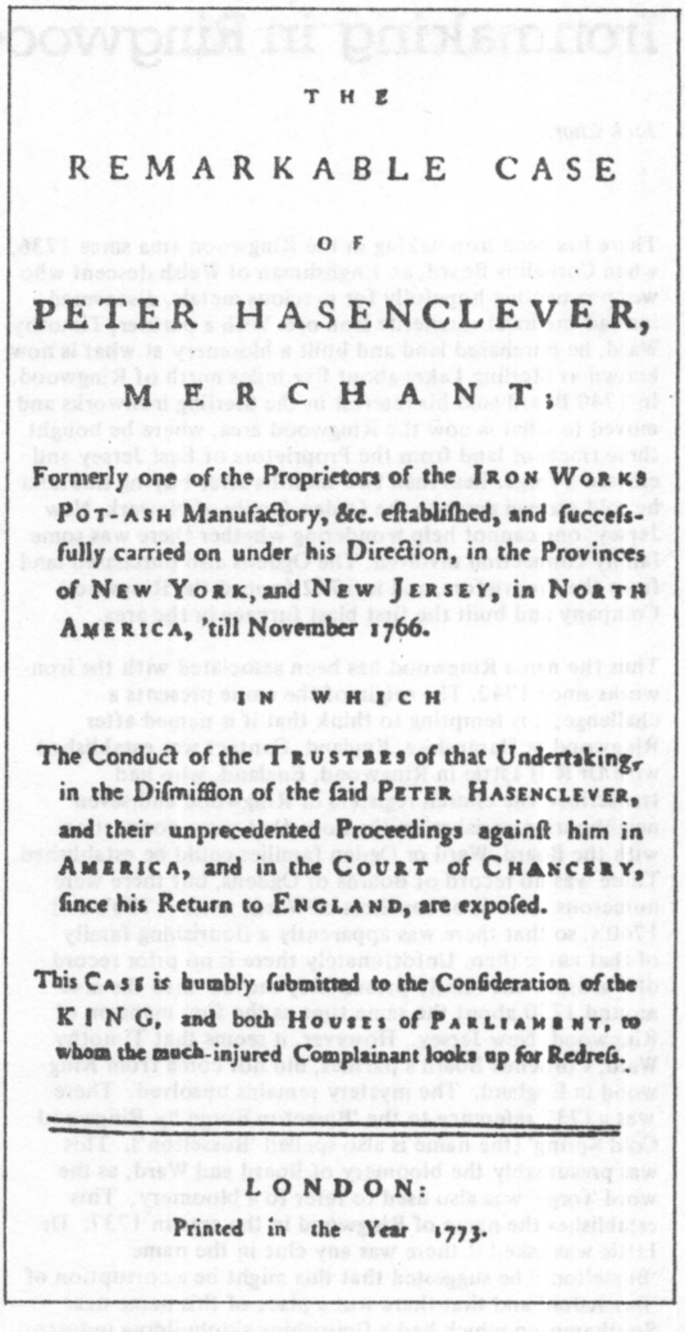
"* *at Ringwood, Charlottenburg, Long Pond, and Cortland. Cortland was soon abandoned due to unsatisfactory ore; Charlottenburg (later called Charlotteburg) and Long Pond, like Ringwood, had discontinued operations by 1778 during the Revolutionary War.*"

(in their petitions in Chancery) that they made this deed of partnership that I might return to America and assign the lands and estates to them, which I never refused to do'. There seems no doubt that Hasenclever was treated very badly. He returned to England and there ensued years of legal proceedings including indications of some very questionable activity to Hasenclever's disadvantage. Finally in despair he left London in 1773 to return to Germany, where Frederick the Great gave him the assignment of reorganising the linen industry, in which project he appears to have been very successful. He died on June 13th 1793. Less than seven months later the long-drawn out legal proceedings in England ended with a decision in his favour, awarding heavy damages. Unfortunately the American Company was in bankruptcy so that there was no money to collect.

Hasenclever was highly respected by his contemporaries in America. At the time of his recall by the Company he asked the Royal Governor to appoint a commission of important ironmasters and industrialists to inspect the ironworks he had established. The report was highly favourable to Hasenclever, stressing the technical innovations and efficient operation.

There seems no doubt that he received a dirty deal from his partners. He published in England an account of his activities in America in justification of his conduct under the title 'The Remarkable Case of Peter Hasenclever, Merchant'. This 1773 book was reproduced in facsimile by the North Jersey Highlands Historical Society in 1970, with a brief introduction and map. He had the vision and energy of of a great industrialist and it is tragic that he was not able to complete the undertaking he started so well.




THE

REMARKABLE CASE

OF

PETER HASENCLEVER,

MERCHANT;

Formerly one of the Proprietors of the IRON WORKS POT-ASH Manufactory, &c. eſtabliſhed, and ſucceſsfully carried on under his Direction, in the Provinces of NEW YORK, and NEW JERSEY, in NORTH AMERICA, 'till November 1766.

IN WHICH

The Conduct of the TRUSTEES of that Undertaking, in the Diſmiſſion of the ſaid PETER HASENCLEVER, and their unprecedented Proceedings againſt him in AMERICA, and in the COURT of CHANCERY, ſince his Return to ENGLAND, are expoſed.

This CASE is humbly ſubmitted to the Conſideration of the KING, and both HOUSES of PARLIAMENT, to whom the much-injured Complainant looks up for Redreſs.

LONDON:
Printed in the Year 1773.

The Company was still concerned about getting results from its large American investment and in 1771 engaged Robert Erskine, FRS to take over management and report on what should be done with the property. Erskine was no ironmaster, but a well regarded engineer who had been granted a patent for a new type of pump. He spent some months visiting ironworks in England to acquire some practical knowledge of the art and practice involved. On arrival in Ringwood in June 1771 he found the works under the direction of an experienced ironmaster John Jacob Faesch (one of Hasenclever's men); they were supposed to run the works jointly, but as would be expected, friction developed, and in the following year Faesch left to set up his own ironworks at Mount Hope.

Erskine's recommendation to the Company was to sell the works, but there were no takers. Meanwhile, events were leading up to the American Revolution. Erskine's sympathies were with the colonists and he warned in letters that the policy of the Government in England would inevitably lead to a break. In 1755 he raised a company of militia from his workmen with prime responsibility of defending the works. When war came he supplied iron to the revolutionary cause. However, his request for deferment of his men from military duty was turned down, and he soon lost many of his men. By the end of 1777 iron production had ceased.

Among his acomplishments, Erskine had some surveying skills and at the request of George Washington was appointed Geographer and Surveyor-General to the Continental Army on July 27, 1777.Throughout the war he provided invaluable service making maps of the areas involved in hostilities. After a mapping trip in the autumn of 1780 he developed 'a severe cold' and died two weeks later.

After the end of the Revolutionary War the Ringwood estate passed through a number of hands but was not apparently operated as an ironworks until it was bought in March 1807 by Martin Ryerson, who already owned and operated the Pompton Ironworks about ten miles south of Ringwood. Under Ryerson the works prospered, but soon after his death in 1839 his sons were in debt and the property was up for sale by the Sherrif. Finally in 1853 Ringwood was bought by Peter Cooper as a source of iron ore for the Phillipsburg blast furnaces of his Trenton Iron Company. The purchase was negotiated by Abram Hewitt, business partner of Peter Cooper's son Edward, and manager with the latter of the Trenton works. Abram Hewitt married Peter Cooper's daughter Amelia in April 1855. Abram and Amelia took a fancy to Ringwood and decided to make it their summer home. The original manor house (ironmaster's house) had been pulled down by Martin Ryerson and a small 'modern' house built in about 1810. The Hewitts extended this house and moved in in 1857. The house was again enlarged in 1878, forming the elegant Victorian country house that can be seen and visited to-day. The blast furnace at Ringwood was never run again after the Ryerson period and the remains were in due course tidied away as part of the landscaping for the new house.

The Ringwood estate had been purchased primarily for its iron mines. But under the pressure for iron during the American Civil War two blast-furnaces were built at the Long Pond site (about five miles away). But by the end of the war the economic advantages of cheaper raw materials in the Pittsburgh area forced the closing of all the eastern furnaces, and the Long Pond furnace went out of blast on May 28th. 1880, ending the long history of ironmaking in the Ringwood area. The ruins of the furnaces remain, together with the skeletons of the old water wheels. Nearby, the ruins of the older, 18th century blast furnace were excavated in 1963. All the furnaces were built of stone and all had water-powered blowing machinery. A huge new 50-foot water-wheel was planned at Long Pond in 1873 but never completed. Charcoal was used throughout the period until one furnace at Long Pond was converted to anthracite and operated on this briefly in 1879.

The iron mines still continued in operation until 1931. During World War II the US Government spent much money in restoring one of the mines but peace came before it was used. Now all the mines are empty and deserted. An era has closed.

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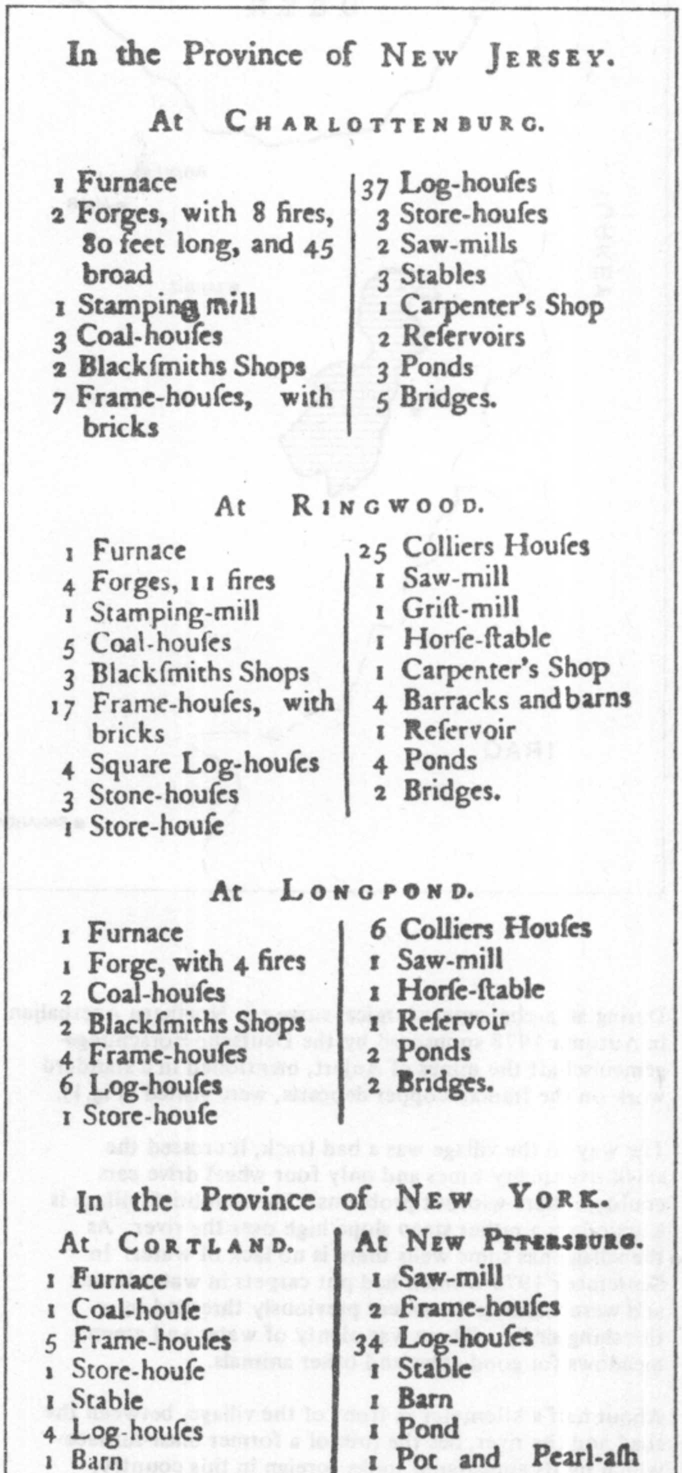


In the Province of New Jersey.

At Charlottenburg.

1 Furnace
2 Forges, with 8 fires, 80 feet long, and 45 broad
1 Stamping mill
3 Coal-houſes
2 Blackſmiths Shops
7 Frame-houſes, with bricks

37 Log-houſes
3 Store-houſes
2 Saw-mills
3 Stables
1 Carpenter's Shop
2 Reſervoirs
3 Ponds
5 Bridges.

At Ringwood.

1 Furnace
4 Forges, 11 fires
1 Stamping-mill
5 Coal-houſes
3 Blackſmiths Shops
17 Frame-houſes, with bricks
4 Square Log-houſes
3 Stone-houſes
1 Store-houſe

25 Colliers Houſes
1 Saw-mill
1 Griſt-mill
1 Horſe-ſtable
1 Carpenter's Shop
4 Barracks and barns
1 Reſervoir
4 Ponds
2 Bridges.

At Longpond.

1 Furnace
1 Forge, with 4 fires
2 Coal-houſes
2 Blackſmiths Shops
4 Frame-houſes
6 Log-houſes
1 Store-houſe

6 Colliers Houſes
1 Saw-mill
1 Horſe-ſtable
1 Reſervoir
2 Ponds
2 Bridges.

In the Province of New York.

At Cortland.

1 Furnace
1 Coal-houſe
5 Frame-houſes
1 Store-houſe
1 Stable
4 Log-houſes
1 Barn
1 Blackſmith's Shop
1 Bridge
1 Pond.

At New Petersburg.

1 Saw-mill
2 Frame-houſes
34 Log-houſes
1 Stable
1 Barn
1 Pond
1 Pot and Pearl-aſh manufacture.

A19th Century Scottish Blast Furnace in Iran

Gerd Weisgerber

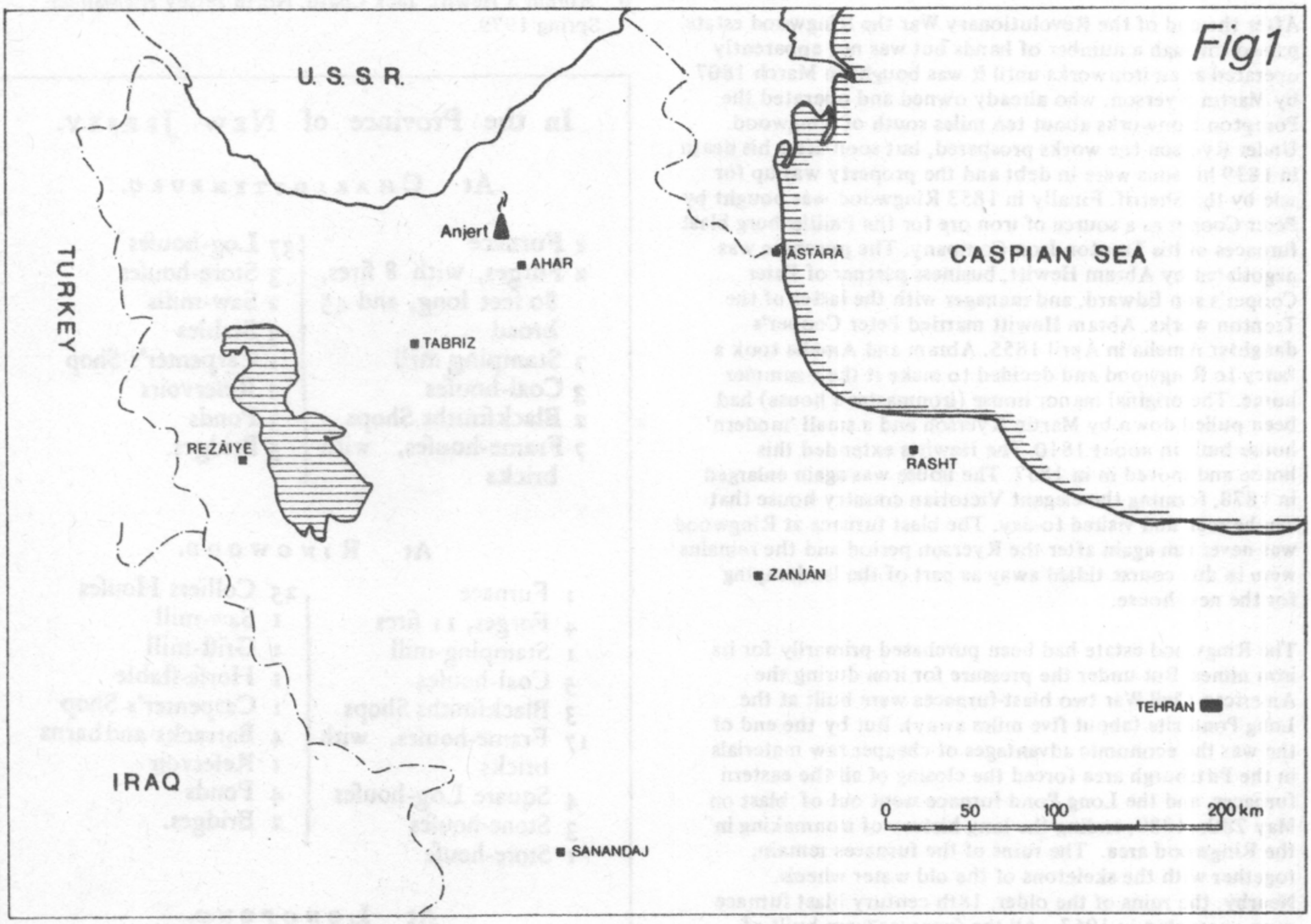


Fig1

During an archaeometallurgical survey in Northern Azerbaijan in Autumn 1978 sponsored by the Deutsche Forschungsgemeinschaft the mines of Anjert, mentioned in a standard work on the Iranian copper deposits, were visited (Fig.1).

The way to the village was a bad track, it crossed the small river many times and only four wheel drive cars could go there without problems. The mudbrick village is situated on a rather steep slope high over the river. As the village has some wells there is no lack of water. In September 1978 women had put carpets in water-basins and were washing the wheat previously threshed by a threshing-sledge. There was plenty of water and green meadows for good cows and other animals.

About half a kilometer in front of the village, between the road and the river, lies the ruin of a former blast-furnace which by its appearance looks foreign in this country, especially considering its fired brick structure. A ramp leads up to its rear; its interior and arches are covered by debris. Today it is named Qalemaden which means "mining or smelting fort (tower)". Indeed there is a report by Richard Wilbraham telling us about smelting there in 1837.

"Having taken the precaution of sending forward one of my servants with my passports to the Russian frontier, I accompanied my friend Dr. Riach on a visit to the mines of Karadagh, or the Black Mountain, where a body of Scottish miners had recently commenced their operations. Our road led us across a hilly country, well cultivated, and enlivened by numerous villages.

It was on the morning of the second day that we reached Angird, a distance of about fifty miles from Tabreez; and on entering a narrow valley, we saw with pleasure a row of English-looking cottages built on the edge of a clear mountain-stream. A little lower stood the foundry, with its tall chimney, certainly not a picturesque objects, yet pleasing to us, as evincing an industry foreign to the country.

On the following morning we visited the mines, under the guidance of Mr. Robertson, the superintendent, a clever, intelligent Scotchman - who informed us that in no other country had he ever seen such mineral wealth. Within the compass of a few miles are found the richest veins of iron, tin and copper ore, apparently inexhaustible. The *iron mines alone were being worked, and preparations were making for casting guns of a large calibre, but the steam-engine had not yet been put together. The iron-ore contains upwards of ninety per cent. of metal; whereas, if I mistake not, sixty per cent. is considered a rich ore in England.*

After remaining one day with Sir Henry Bethune, who was then on a visit to the mines, I returned to Tabreez on the 14th, and on the 16th I commenced my march for the Russian frontier." [1]

Obviously, the ruins of the blast furnace mentioned above are identical with Wilbraham's foundry. The former English-looking cottages have disappeared, no ruin could be seen on the slope above the road.

The superintendent Robertson was indeed a clever, active and courageous person if one thinks about the difficulties and obstacles he and his Scottish miners had to surmount. First of all there were no local people for nearly all the work he had to do: mining, burning charcoal, smelting and casting. In fact, there did not exist any reasonable way to transport the parts of the steam-engine in this valley.

To build the furnace he himself had to produce the fired bricks, which were quite unknown in this part of the country. Probably he could buy the lime-mortar as lime burning is normal for the whitewash which sometimes can be seen there.

The blast-furnace itself was a massive construction of fired bricks, once 8 m high and about 6.70 m along each side of the square ground-plan. Today the ruin still has a height of 7.50 m. There are three sizes of bricks. The lowest part 1.50 m high, the arches in front, and at the two sides as well, are built in large bricks (20 x 24 x 8 cm): above this level square ones were used (19.5 x 19.5 x 5 cm) or oblong ones of the same thickness.

These bricks were laid in a white mortar. The massive walls which on top once were more than 1.00 m thickness were crossed by rows of hollow channels which had to let out the evaporating humidity. There is one inclined channel on the west side (Fig.2, section 2-2).

The once square furnace is today only half preserved. Its foundations were not strong enough, obviously the south front broke during its production period, because the crack was repaired by a more yellow mortar. [2]

The missing back half of the furnace, the inside, the corners and parts of the front were later broken away by the villagers for getting the rare hard material for re-use.

As the interior is heavily damaged, form and sections of the shaft remain uncertain. Regarding the different size of the rounded horizontal sections a developed slight biconical shape of the shaft has been assumed. But the original internal diameter remains unknown without excavation.

Less than 1 ton of slag could be seen around on the heaps of collected stones and reused building material in the waterchannel of a now destroyed mill beside the river nearby. In contrast to Wilbraham's report on iron working, it seemed to be cupriferous slag. And only copper ores were mined in the mines shown to us by the villagers. The mineralization in this part consists mainly of chalcopyrite and pyrite in a garnet skarn, but also magnetite

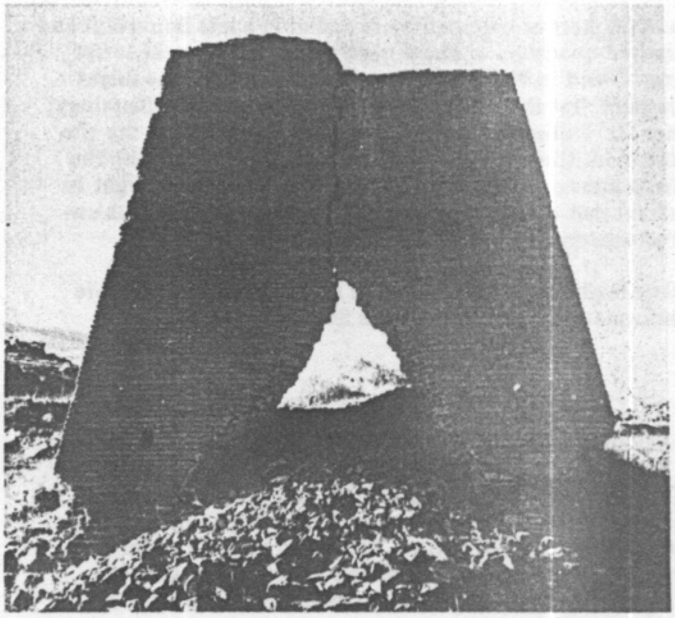


Fig.3 South side of Anjert furnace ruin. Robbing of bricks clearly visible.

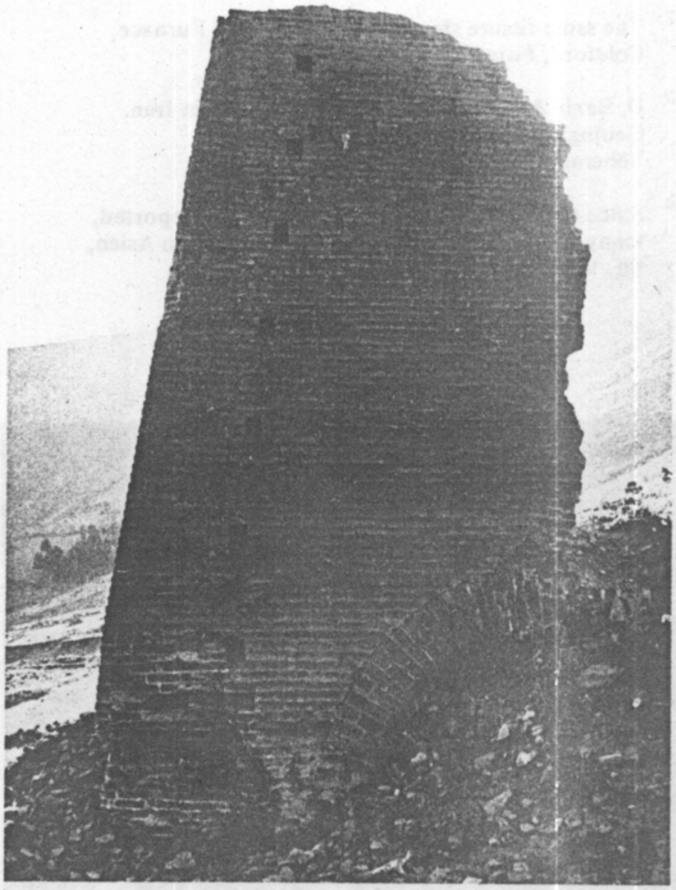


Fig.4 East side of Anjert furnace ruin

and pockets of specularite are found in a less important and limited quantity.[3] There is no tin![4] Finding the latter mentioned in Wilbraham's enthusiastic report one might suspect that the author had no good notion of mineralogy, nor Mr. Robertson too. When Wilbraham visited the site the work there had recently been started. Regarding the little mass of slag and the few mining works one might be afraid that those big efforts and financial investments unfortunately met with little success.

One might hope that historical research could find more information on these overseas Scottish activities.

Acknowledgments

The author was accompanied by Ludger Koester, Berlin. He was guided by Dr. Morteza Mommenzadeh from the Geological Survey of Iran. He has to thank him for the enjoyable collaboration and to his institution for being allowed to stay in its branch-house in Ahar.

Reference

[1] Richard Wilbraham. Travels in the Transcaucasian Provinces of Russia, London 1939, p.70-71.

[2] The same fissure shows in the Whitecliff Furnace, Coleford, Forest of Dean.

[3] D. Bazin & H. Hubner. Copper Deposits in Iran. Geological Survey of Iran, Report No.13, Teheran 1969, p.29.

[4] Since the false occurrence of tin has been reported, many times, i.e. C. Ritter, Die Erdkunde von Asien, Bd. VI, 2. Abt., 3. Buch, p.800.

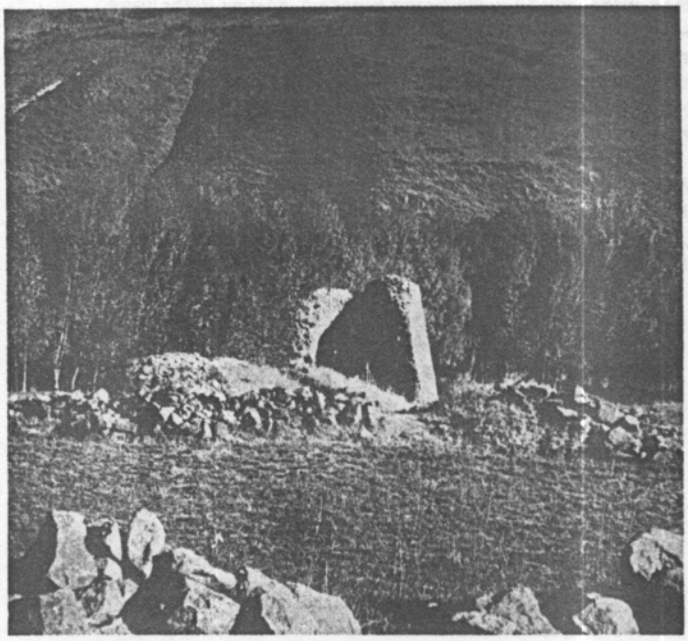


Fig.5 Ramp and destroyed rearside of Anjert furnace ruin.

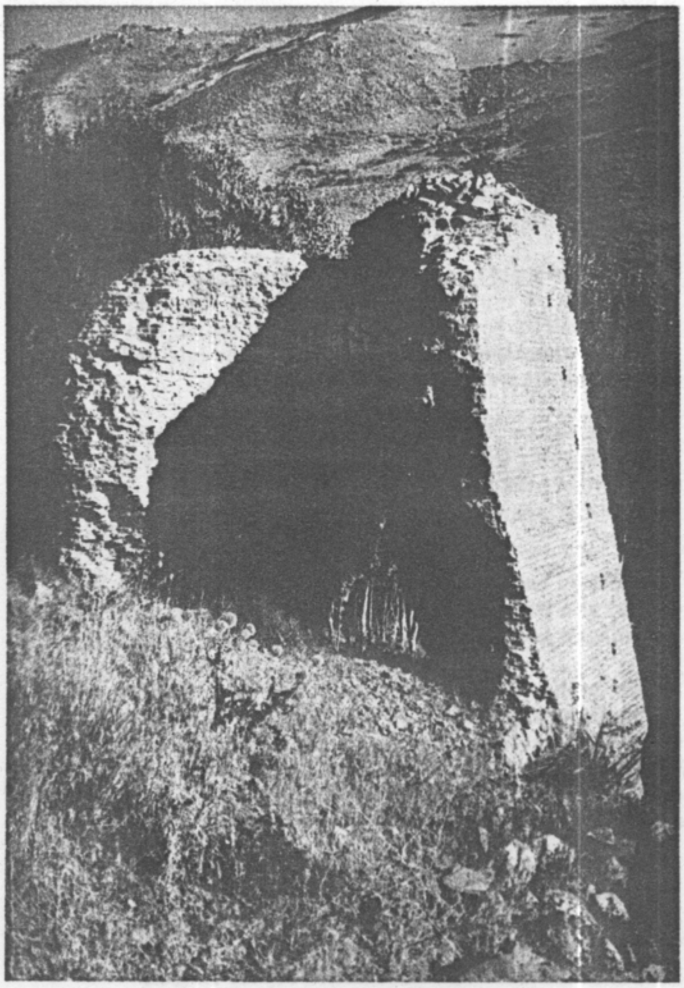


Fig.7 Rear and west sides of Anjert furnace ruin.

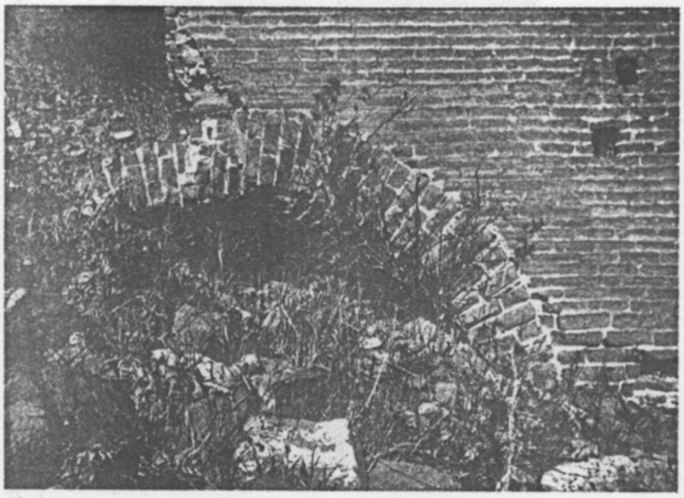
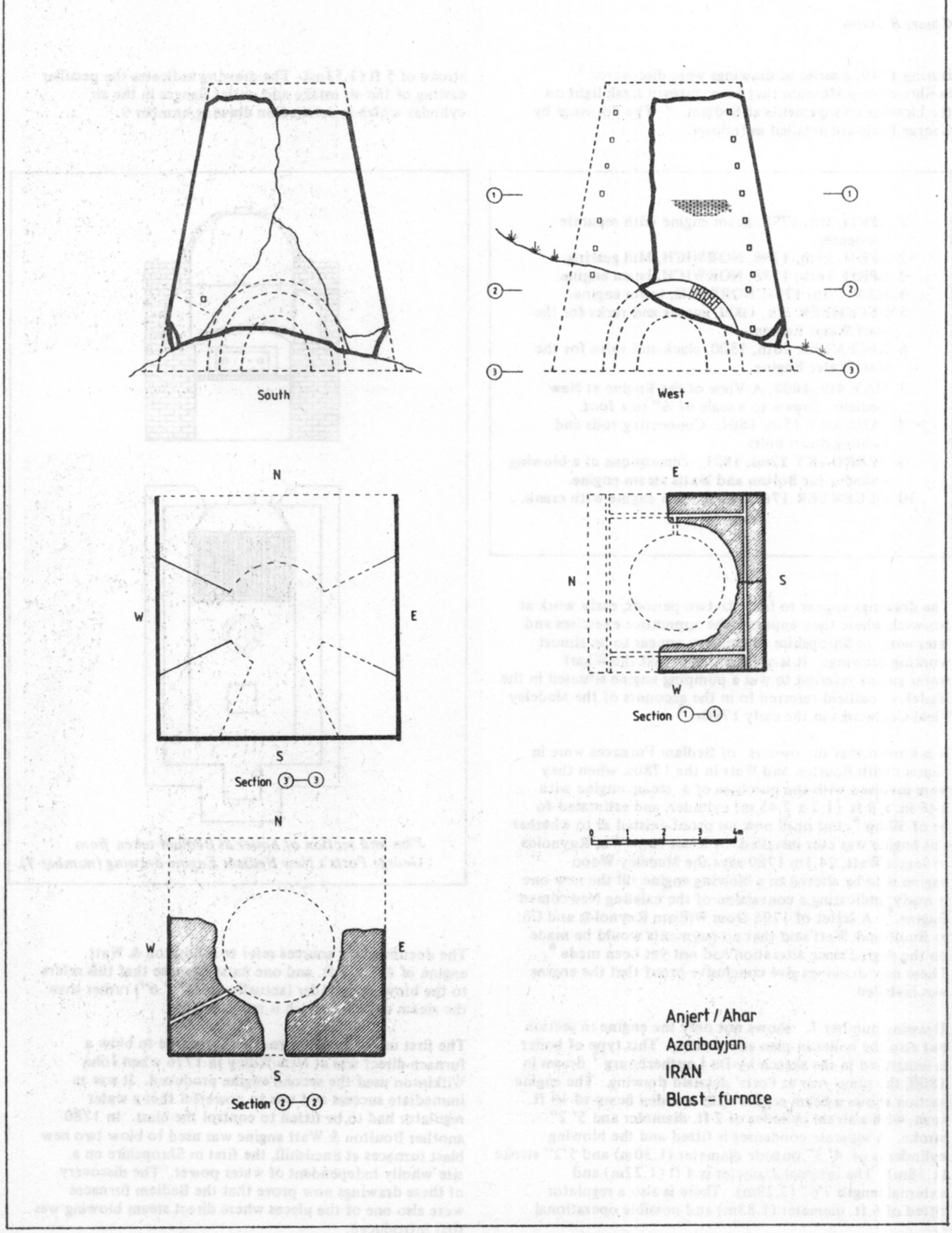


Fig.6 West side of Anjert furnace ruin with bellows opening and evaporation channels.

Fig 2



Anjert / Ahar
Azarbayjan
IRAN
Blast furnace

Blowing Engine at Bedlam Furnace, Ironbridge, Shropshire

Stuart B Smith

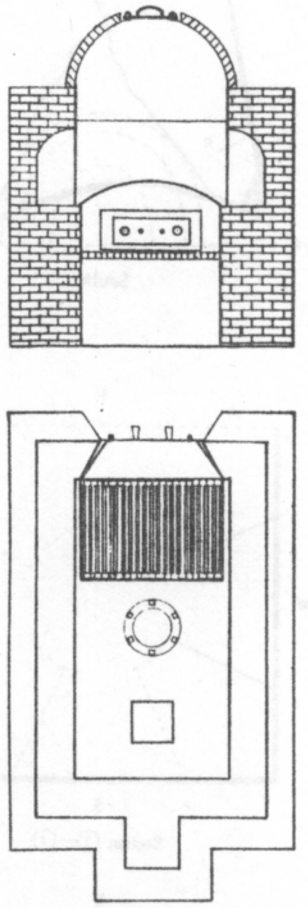
During 1979, a series of drawings were discovered [1] in Shrewsbury Museum that have thrown fresh light on the blowing arrangements at Bedlam. [2] The drawings by George Potts are detailed as follows:

1. APRIL 3rd, 1798, beam engine with separate condenser.
2. APRIL 15th, 1798, NORWICH, Mill gearing.
3. APRIL 16th, 1798, NORWICH, beam engine.
4. MAY 27th, 1798, NORWICH, beam engine.
5. DECEMBER 5th, 1800, guards and racks for the Warf Water Engine.
6. DECEMBER 16th, 1800, clack and valve for the Warf Water Engine.
7. **MAY 4th, 1800, A View of the Engine at New Bedlam. Drawn to a scale of ½" to a foot.**
8. JANUARY 15th, 1801. Connecting rods and holding down bolts.
9. **FEBRUARY 22nd, 1801. Dimensions of a blowing cylinder for Bolton and Watts steam engine.**
10. **DECEMBER 17th, 1802, beam engine with crank.**

The drawings appear to fall into two periods, early work at Norwich where they appear to be apprentice exercises and later work in Shropshire where they appear to be almost working drawings. It is quite possible that the Wharf water engine referred to was a pumping engine situated in the Madeley coalfield referred to in the accounts of the Madeley Field Coalworks in the early 1790s. [3]

It is known that the owners of Bedlam Furnaces were in contact with Boulton and Watt in the 1780s. when they were involved with the purchase of a steam engine with a 48 in. x 8 ft. (1.2 x 2.45 m) cylinder, and estimated to be of 50 hp [4], but until now no proof existed as to whether this engine was ever installed. A letter from Wm Reynolds to James Watt, 24 1m 1780 says the Madeley Wood engine is to be altered to a blowing engine till the new one is ready, indicating a conversion of the existing Newcomen Engine. [5] A letter of 1796 from William Reynolds and Co. to Boulton & Watt said that no payments would be made on the engine since alteration had not yet been made [6]. These new drawings give conclusive proof that the engine was installed.

Drawing number 7, shows not only the engine in section but also the boiler in plan and section. This type of boiler is illustrated in the sketch by De Loutherbourg [7] drawn in 1800, the same year as Potts' detailed drawing. The engine section shows a beam engine with wooden beam of 18 ft. span, with a steam cylinder of 2 ft. diameter and 5' 2" stroke. A separate condenser is fitted and the blowing cylinder is of 4' 3" outside diameter (1.30m) and 5'2" stroke (1.58m). The internal diameter is 4 ft (1.22m) and external length 7'6" (2.29m). There is also a regulator fitted of 6 ft. diameter (1.83m) and possible operational stroke of 5 ft (1.53m). The drawing indicates the peculiar casting of the air intake and outlet flanges in the air cylinder which is detailed on drawing number 9.



Plan and section of boiler at Bedlam taken from George Potts's New Bedlam Engine drawing (number 7).

The documentary sources refer to a Boulton & Watt engine of 48" x 8 ft. and one must suppose that this refers to the blowing cylinder (actually 48" x 7' 6") rather than the steam cylinder which is much smaller.

The first use of Boulton and Watt's engine to blow a furnace direct was at New Willey in 1776 when John Wilkinson used the second engine produced. It was an immediate success and was so powerful that a water regulator had to be fitted to control the blast. In 1780 another Boulton & Watt engine was used to blow two new blast furnaces at Snedshill, the first in Shropshire on a site wholly independent of water power. The discovery of these drawings now prove that the Bedlam furnaces were also one of the places where direct steam blowing was first introduced.

[1] Courtesy of Mr E.J. Priestley, Curator of Shrewsbury Museums and David de Haan, Curator of the Elton Collection, Ironbridge Gorge Museum Trust.

[2] See Stuart B Smith, New Light on the Bedlam Furnaces, JHMS, 1979, 13 (1), 21-30.

[3] B S Trinder, Industrial Revolution in Shropshire 1973, Phillimore, p.171. (Shropshire Record Office 271/1).

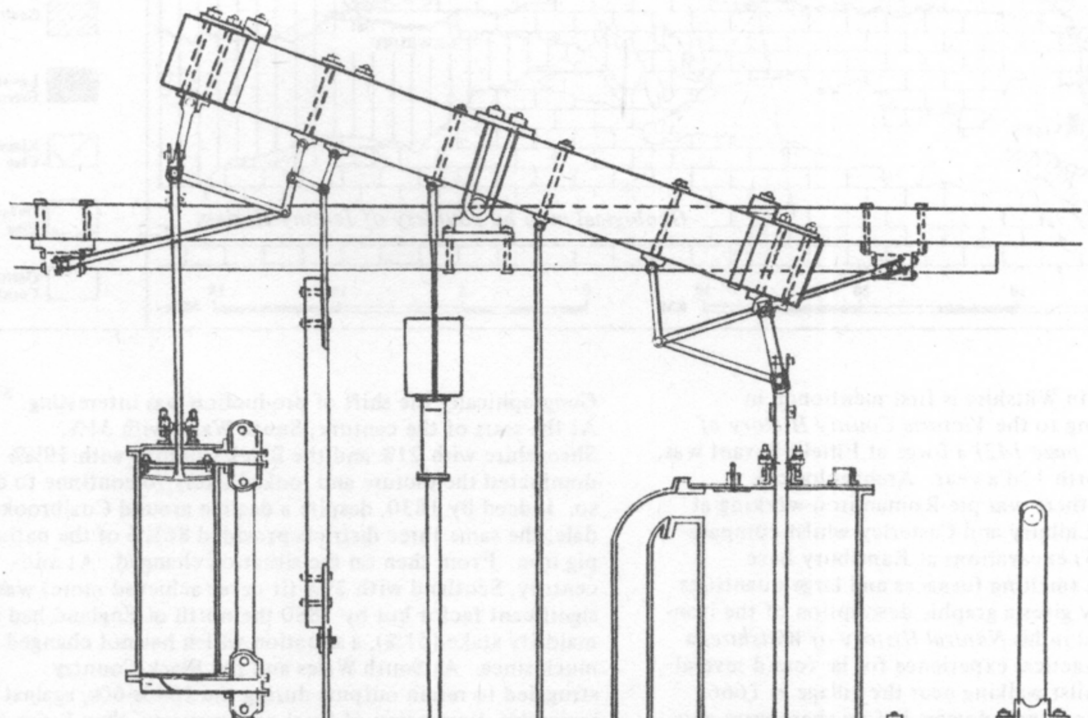
[4] B S Trinder, ob.cit. (letter from JAMES WATT to WM. REYNOLDS 3 Jan.1781).

[5] B & W Collection, Box 2 'R'.

[6] WM. REYNOLDS & CO', B & W 26 August 1796, B & W Colln. Box 2 'R'.

[7] JHMS, 1979, 13 (1), p 27.

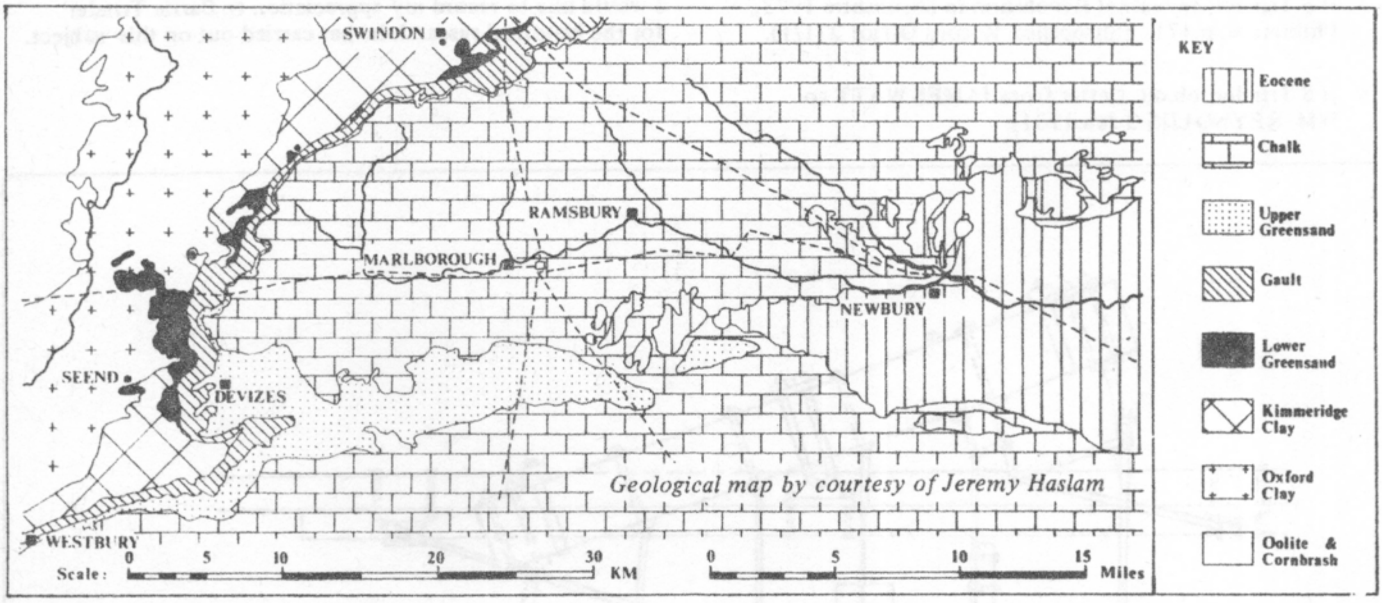
I would like to record my appreciation to Barrie Trinder for the historical research he has carried out on this subject.



A view of the Engine at New Bedlam. Taken from the drawing by George Potts dated May 4th 1800 and listed as Number 7.

Wiltshire iron: 1855-1949

Roy Day (with appendices by Keith Gale)



Geological map by courtesy of Jeremy Haslam

The working of iron in Wiltshire is first mentioned in Domesday. According to the *Victoria County History of Wiltshire (Volume 2, page 142)* a forge at Fifield Bavant was, in the year 1086, worth 12d a year. Archaeological evidence shows that there was pre-Roman iron-working at All Cannings Cross, Lidbury and Casterley whilst comparatively recently (1975) excavations at Ramsbury have revealed three Saxon smelting furnaces and large quantities of slag. John Aubrey gives a graphic description of the iron-ore available at Seend in his *Natural History of Wiltshire,* a narrative based on practical experience for he found several pieces of iron-ore whilst walking near the village in 1666. But it was almost two hundred years before there were any further developments and these, small by the standards of the well known iron-working districts, gave the Wiltshire ore-field and more especially the district round Westbury, a place in the history of the British Iron Industry which deserves to be known more widely than it is.

'The form of iron-ore known as brown hematite, existing abundantly in this country in the Lias, Oolitic and Lower Greensand formations, has in recent years given rise to the important iron-producing districts of Middlesborough, Northampton and Wiltshire.'

These words were written by Richard Meade for *The Coal and Iron Industries of the United Kingdom,* published in 1882. With hindsight, he was being more than kind to Wiltshire for there the industry has vanished almost without trace.

During the 19th century Britain was hungry for iron. In 1806 the output from UK blast furnaces was 258,206[1] tons By 1835 it had risen to one million tons [2] and by 1850 to two and a half million.[3] Inevitably there were recessions but the upward trend continued throughout the century reaching 9,400,000 tons in 1899. By 1906 it had passed the ten million mark.[4]

Geographically the shift of production was interesting.[5] At the start of the century, South Wales with 31%, Shropshire with 21% and the Black Country with 19½% dominated the picture and looked likely to continue to do so. Indeed by 1830, despite a decline around Coalbrookdale, the same three districts provided 86¾% of the nation's pig iron. From then on the situation changed. At mid-century, Scotland with 29% (it never achieved more) was a significant factor but by 1880 the north of England had the majority stake (51%), a situation which has not changed much since. As South Wales and the Black-Country struggled to retain outputs during the 1840s-60s, against inevitable diminution of local ore resources, they began to buy ore and later pig-iron from several new iron-producing areas including Wiltshire.

During 1854, the statistical returns from the various mineral and metalliferous mining areas became regularised by the establishment of an organisation directed by the Geological Survey and administered by Robert Hunt.[6] The resulting *Mineral Statistics* enable us to see the interplay between the old and new iron producing districts and show the emergence of Wiltshire industry. *The Mineral Statistics* returns depended for their accuracy on mine and smelter owners sending in annual totals and, in common with all new systems, took a few years to settle down. By 1859 Wiltshire returns, for ore and manufactured iron, assume a regular pattern and show that 28,993 tons of ore and 5,500 tons of pig-iron had been mined/smelted in the county. By the following year the two figures had risen to 76,201 and 21,875[7] and it becomes apparent that Wiltshire was a serious contender in the supply of part of the country's iron requirements.

When Prince Albert gave support to the concept of a great international exhibition to be held in 1851, he initiated events which reverberated through British trade and industry. Included among the items in the Exhibition Schedule was Class 1, Section C/1a Raw Materials[8] which eventually

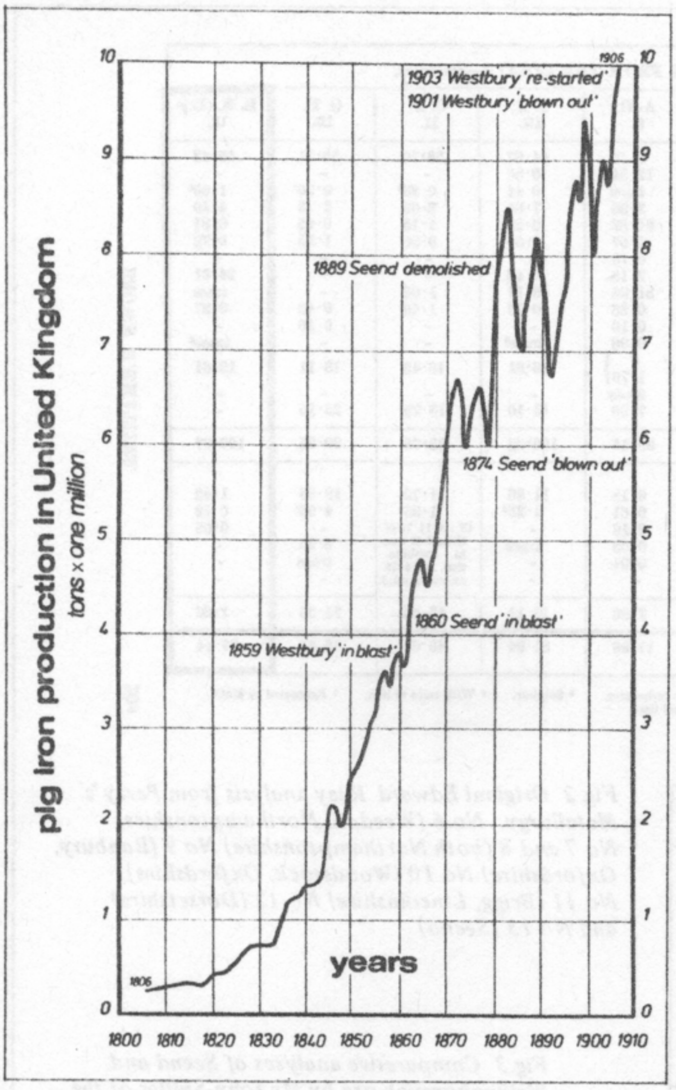


Fig. 1

resulted in nearly 500 examples of British iron-ores[9] being collected by John Percy of the Royal School of Mines. They needed to be analysed for comparative value, a process which was made possible by a donation of £500 from Samuel Holden Blackwell, iron-master of Dudley whose brother, John Kenyon Blackwell,[10] selected the samples. The analyses were carried out by well known men, amongst them Edward Riley, works chemist at Dowlais who examined a specimen, later to be classified as 'exhibit 13' in Table 4 (brown haematites, chiefly from the oolite) which came from Seend in Wiltshire.[11] Comments added by John Percy and which could well have been quite significant, remarked on the similarity between the Wiltshire ore and those originating from Northamptonshire and Oxfordshire.

At the time of the 1851 Exhibition the Black-Country and South-Wales iron industries were suffering from declining iron resources and men like Blackwell and Riley were probably looking for additional supplies. Tomlinson's *Cyclopaedia* (1856) devoted considerable space to this subject and commented that, 'The clay ironstones of the lias are only just beginning to be added to our iron-making resources. They furnish an example of the unexpected development of natural wealth arising from the facilities afforded by railroads ... Mr Blackwell has recently shown the vast extent and importance of the silicious (sic) ironstone from the oolite near Northampton.'[12]

One can speculate on the effect of the Northamptonshire ore field on South Wales. In February 1852,[13] the Welsh ironmasters were given first-hand information about the extent and richness of the Northamptonshire iron-ore and how it could be transported by rail to the Black-Country smelters. By then, there was an undoubted demand for additional iron-ore and/or pig-iron in South Wales and Staffordshire and by then, there were railway links between the Wiltshire iron-ore fields and Bristol, and the Midlands.

The Wiltshire Industry, Seend Developments

Prior to 1856 a Mr J E Holloway, described as a coal and iron merchant from Christchurch in Hampshire,[14] bought a piece of land near the Bell Inn at Seend in Wiltshire and started to strip it for ironstone. He had previously been mining for iron at Hengistbury Head (near Christchurch) but coastal erosion has caused him to abandon this. At Seend his experience was put to good use for he raised some 4,000 tons of ore which was sold to the Tredegar Iron Company in South Wales.[15]

Holloway's success resulted in William Sarl, of Cornhill in the City of London, bidding for the mineral rights at Seend and obtaining leases for three parcels of land owned by Wadham Locke.[16] This committed him to an annual rent of £469.10 and royalty payments of £2,020 in a full year. Nevertheless, Sarl had every reason to be satisfied for in the succeeding twelve months from signing the leases in November 1856, he made a profit of between £5,000 and £6,000 by selling iron ore to South Wales and the Black-Country. This was achieved after he had sub-contracted the extraction to Rowland Brotherhood of Chippenham at 1/- per ton with a minimum payment of £25 (500 tons) whether or not this amount was raised.[17]

At about this time Brotherhood himself was involved in the setting up of an iron mining and smelting company at Westbury, about ten miles from Seend and in his, so far unpublished, autobiography writes: 'Twelve of us, known to each other, formed a Company to build works and smelt the iron-ore at Westbury Station, and I made the sidings, fittings etc. also the large boilers, blast tubes, hoists, furnace bands and other works'.[18] This marked the start of the construction of the Westbury Iron Company, the relevant paragraph being written early in 1857.

The ore sales achieved by Sarl, approximating to three times the cost of winning, increased his determination to exploit the Seend ore. During 1857 he was actively encouraging the creation of a limited liability company for smelting Seend ore, an action which apparently was not entirely altruistic in its motives.

The *Devizes Gazette* of 5th November 1857 carried an article about Seend ore announcing that the successful mining activities of the previous twelve months had prompted two groups of 'prospectors' to consider setting up works to smelt the ore in situ. One of these groups (the other apparently came from Westbury but could not have included Rowland Brotherhood as we shall see) were proposing to float a company known as the Great Western Iron Ore, Smelting and Coal Company Limited. They had already organised themselves into a working body with four provisional directors (three local and one from Liverpool) and invited 'Persons favourable to, and desirous of joining the Company, to meet the shareholders at the Bear Hotel, Devizes at one o'clock in the afternoon on

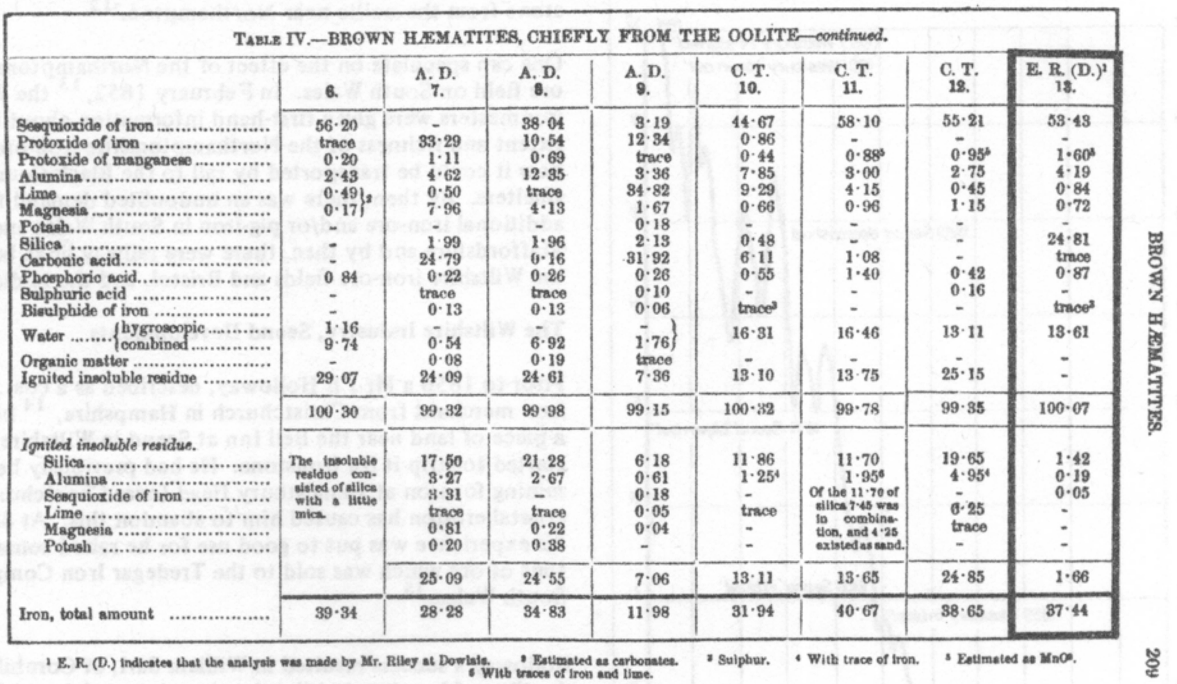


TABLE IV.—BROWN HÆMATITES, CHIEFLY FROM THE OOLITE—*continued.*

	6.	A. D. 7.	A. D. 8.	A. D. 9.	C. T. 10.	C. T. 11.	C. T. 12.	E. R. (D.)[1] 13.
Sesquioxide of iron	56·20	–	38·04	3·19	44·67	58·10	55·21	53·43
Protoxide of iron	trace	33·29	10·54	12·34	0·86	–	–	–
Protoxide of manganese	0·20	1·11	0·69	trace	0·44	0·88[5]	0·95[5]	1·60[5]
Alumina	2·43	4·62	12·35	3·36	7·85	3·00	2·75	4·19
Lime	0·49[2]	0·50	trace	34·82	9·29	4·15	0·45	0·84
Magnesia	0·17	7·96	4·13	1·67	0·66	0·96	1·15	0·72
Potash	–	–	–	0·18	–	–	–	–
Silica	–	1·99	1·96	2·13	0·48	–	–	24·81
Carbonic acid	–	24·79	0·16	31·92	6·11	1·08	–	trace
Phosphoric acid	0 84	0·22	0·26	0·26	0·55	1·40	0·42	0·87
Sulphuric acid	–	trace	trace	0·10	–	–	0·16	–
Bisulphide of iron	–	0·13	0·13	0·06	trace[3]	–	–	trace[3]
Water — hygroscopic	1·16	–	–	–	16·31	16·46	13·11	13·61
Water — combined	9·74	0·54	6·92	1·76				
Organic matter	–	0·08	0·19	trace	–	–	–	–
Ignited insoluble residue	29·07	24·09	24·61	7·36	13·10	13·75	25·15	–
	100·30	99·32	99·98	99·15	100·32	99·78	99·35	100·07
Ignited insoluble residue.								
Silica	The insoluble residue consisted of silica with a little mica.	17·50	21·28	6·18	11·86	11·70	19·65	1·42
Alumina		3·27	2·67	0·61	1·25[4]	1·95[6]	4·95[4]	0·19
Sesquioxide of iron		3·31	–	0·18	–	Of the 11·70 of silica 7·45 was in combination, and 4·25 existed as sand.	–	0·05
Lime		trace	trace	0·05	trace		6·25	–
Magnesia		0·81	0·22	0·04	–		trace	–
Potash		0·20	0·38	–	–		–	–
		25·09	24·55	7·06	13·11	13·65	24·85	1·66
Iron, total amount	39·34	28·28	34·83	11·98	31·94	40·67	38·65	37·44

[1] E. R. (D.) indicates that the analysis was made by Mr. Riley at Dowlais. [2] Estimated as carbonates. [3] Sulphur. [4] With trace of iron. [5] Estimated as MnO^2. [6] With traces of iron and lime.

BROWN HÆMATITES.

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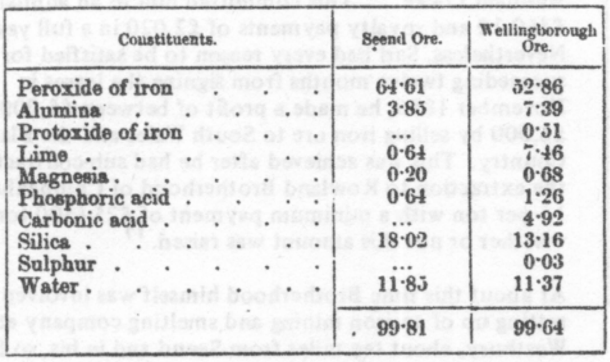
Fig.2 Original Edward Riley analysis from Percy's Metallurgy. No.6 (Weedon, Northamptonshire) No 7 and 8 (both Northamptonshire) No 9 (Banbury, Oxfordshire) No 10 (Woodstock, Oxfordshire) No 11 (Brigg, Lincolnshire) No 12 (Dorsetshire) and No 13 (Seend)



Constituents.	Seend Ore.	Wellingborough Ore.
Peroxide of iron	64·61	52·86
Alumina	3·85	7·39
Protoxide of iron	...	0·51
Lime	0·64	7·46
Magnesia	0·20	0·68
Phosphoric acid	0·64	1·26
Carbonic acid	...	4·92
Silica	18·02	13·16
Sulphur	...	0·03
Water	11·85	11·37
	99·81	99·64

Fig.3 Comparative analyses of Seend and Wellingborough ore by Mr John Spiller of the Royal School of Mines

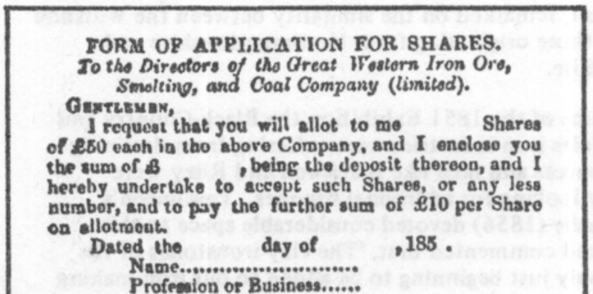
Saturday, 7th November 1857 when every information connected with the undertaking will be laid before the Meeting and an allocation of Shares will be made.'

This share allocation was based on selling one thousand shares valued at £50 each to raise an initial sum of £50,000 which would be used as follows: Purchase of land and leases, cost of contracts, plant and machinery at £17,500, cost of erecting four blast furnaces capable of yielding 150 tons of pig-iron per week at £12,400 and labour (working capital) of £20,100.

To encourage subscribers, profits attainable were estimated at £31,380 in a full year or a 62% return on capital. This was based on producing 30,000 tons of pig-iron per year (576 tons per week) at an average cost of £2.16s.7d per ton and selling it at £3.17s.6d per ton. As iron made from Seend ore during 1857 had apparently already sold at up to £5.0s.0d. per ton and average 1857 prices for Welsh pig were £3.15s.0d per ton, this seemed reasonable.

The Seend smelting consortium had appointed Arthur Davies, a Merthyr Tydfil consulting engineer, to report on geological and iron-smelting aspects. He gave evidence of how easy the Wiltshire ores would be to 'fuse' in the furnace, how 20 tons of Seend ore, smelted at John Bagnall's works near Bilston (in the Black-Country) had produced 10 tons 18 cwts of pig and 2 cwts of castings, a reduction rate of 44%, validated by an independent witness, Henry Hart of Newnham in Gloucestershire. He also gave the result of a further analysis carried out by John Mitchell FCS of Bishopgate Street, London and ended his report by saying 'There will be four and a half million tons of iron-ore beneath your field'. Davies had also investigated the costs involved in producing pig-iron at Seend (with very similar results to those prepared

Fig.4



FORM OF APPLICATION FOR SHARES.
To the Directors of the Great Western Iron Ore, Smelting, and Coal Company (limited).

GENTLEMEN,

I request that you will allot to me Shares of £50 each in the above Company, and I enclose you the sum of £ , being the deposit thereon, and I hereby undertake to accept such Shares, or any less number, and to pay the further sum of £10 per Share on allotment.

Dated the day of ,185 .
Name...............................
Profession or Business......
Place of Abode................

by the 'prospectors') and he used Welsh coke in his calculations. This may possibly have been because he had easy access to Welsh coke prices but it seems likely that it reflected a difficulty which had already beset the 'Great Western' men.

An essential ingredient for the successful smelting of iron-ore in the blast-furnace is load-bearing coke, a supply of which the Seend prospectors just did not have available to them. It will appear, later, how dominant, as far as coal supplies were concerned, the rival iron company at Westbury were. But be that as it may, the Seend 'prospectors' were very concerned over this aspect of their plan.

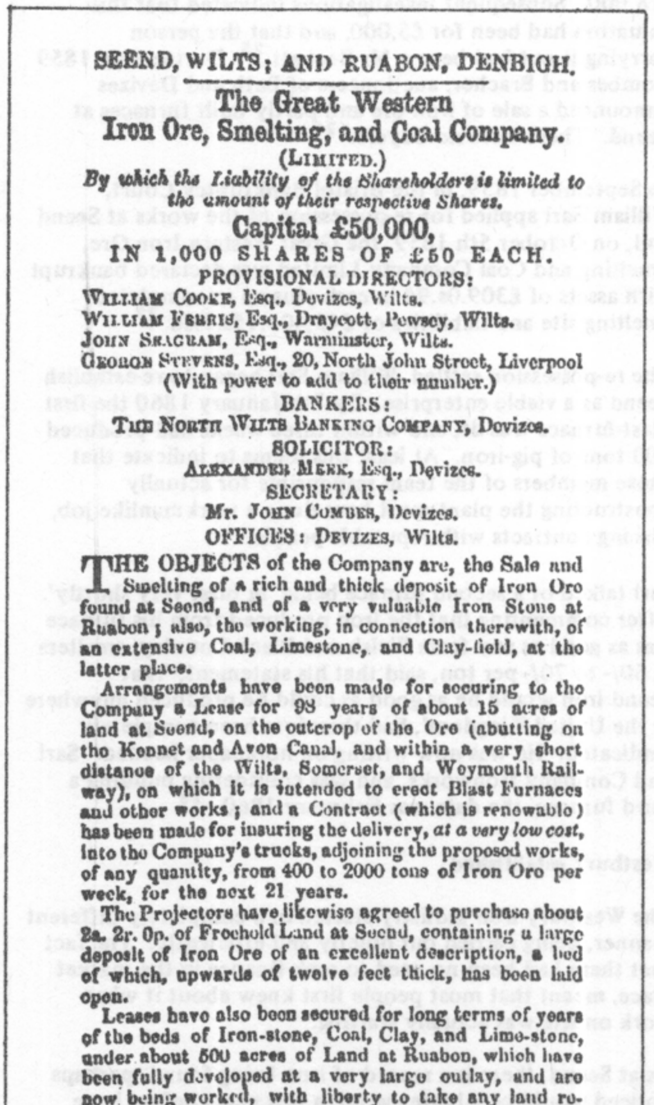
A scheme was prepared by Josiah Harris, one of the original prospectus signatories who searched for a source of coking coal and found it, 196 miles from Seend, in North Wales at Ruabon. There he claimed to have discovered a valuable mineral laden property in the Trefor and Dolydd area and negotiated a 'long lease' on 500 acres of land.[19] A contract was agreed with the Great Western Railway Company to carry coal from there to Seend at 7/16th of a penny per ton/mile, plus broad gauge transfer charges, etc. in the iron company's own wagons. It must be emphasized, that as far as is known, there was never any connection between the GWR and the Wiltshire company which carried a similar name and that this agreement came into being because it fitted well with the GWR's plans to increase their freight traffic from North Wales.[20] To make the scheme more productive it was envisaged that, after being emptied at Seend, the trucks should be loaded with Wiltshire ironstone and returned to Ruabon, where this could be smelted in furnaces to be built by the Great Western Iron Ore, Smelting and Coal Company.

This information was presented to the meeting at Devizes on 7th November 1857 and had the desired effect. According to the *Devizes Gazette* (19 November 1857) 'A meeting of about twenty gentlemen . . . was held at the Bear Hotel on Saturday last and so satisfied were they that the project is capable of yielding a large profit, that the whole of the capital (£50,000) was at once subscribed. As a matter of interest a further press report eighteen months later revealed that only 815 shares (£40,850) were taken up at the Bear Hotel meeting, but nevertheless the 'prospectors' had been successful in obtaining local support.

One can reflect on how unhappy some members of the now-confirmed board of directors must have felt as ominous rumblings had already been heard. Once the prospectus had been prepared, and before the Devizes meeting, the 'prospectors' had approached Rowland Brotherhood to 'Do all the work . . . as at Westbury and also to make coal and iron-ore wagons to the extent of £10,000.' Quoting again from Brotherhood's autobiography he says:'The day was named for us to meet in Devizes, to ratify the agreements but as I did not like the look of the two strangers, I made some little private enquiries in London and Ruabon . . . All seemed to be going well until it came to the agreement with me when I told them that not a single thing would be done by me until I had been down and had a look at the coal in the [Ruabon] pit. I had before seen the old merchant (who had been introduced as a person willing to put money into the project) as a cad in a scheming office in the City . . There was a great noise, but it was agreed to meet and go down the pit at Ruabon which we did and soon found it was a dead sell, and the whole thing burnt up . . . Some little time after another company was got up at Seend and I did all the work for them as at Westbury.'[21]

	Per cent.
Peroxide of iron	57.150
Protoxide ditto	1·800
Oxide of Manganese	0.315
Alumina	1.072
Lime	0.314
Magnesia	0.721
Potash	0.512
Soda	0.384
Phosphoric acid	0.210
Sulphuric acid	Traces
Silica	26.830
Water	10.412
Loss	0.268
	100.000
Metallic Iron	41.55

Fig. 5 John Mitchell's Seend analysis



SEEND, WILTS; AND RUABON, DENBIGH.

The Great Western
Iron Ore, Smelting, and Coal Company.
(LIMITED.)
By which the Liability of the Shareholders is limited to the amount of their respective Shares.
Capital £50,000,
IN 1,000 SHARES OF £50 EACH.
PROVISIONAL DIRECTORS:
WILLIAM COOKE, Esq., Devizes, Wilts.
WILLIAM FERRIS, Esq., Draycott, Pewsey, Wilts.
JOHN SEAGRAM, Esq., Warminster, Wilts.
GEORGE STEVENS, Esq., 20, North John Street, Liverpool
(With power to add to their number.)
BANKERS:
THE NORTH WILTS BANKING COMPANY, Devizes.
SOLICITOR:
ALEXANDER MEEK, Esq., Devizes.
SECRETARY:
MR. JOHN COMBES, Devizes.
OFFICES: DEVIZES, Wilts.

THE OBJECTS of the Company are, the Sale and Smelting of a rich and thick deposit of Iron Ore found at Seend, and of a very valuable Iron Stone at Ruabon; also, the working, in connection therewith, of an extensive Coal, Limestone, and Clay-field, at the latter place.

Arrangements have been made for securing to the Company a Lease for 98 years of about 15 acres of land at Seend, on the outcrop of the Ore (abutting on the Kennet and Avon Canal, and within a very short distance of the Wilts, Somerset, and Weymouth Railway), on which it is intended to erect Blast Furnaces and other works; and a Contract (which is renewable) has been made for insuring the delivery, *at a very low cost*, into the Company's trucks, adjoining the proposed works, of any quantity, from 400 to 2000 tons of Iron Ore per week, for the next 21 years.

The Projectors have likewise agreed to purchase about 2a. 2r. 0p. of Freehold Land at Seend, containing a large deposit of Iron Ore of an excellent description, a bed of which, upwards of twelve feet thick, has been laid open.

Leases have also been secured for long terms of years of the beds of Iron-stone, Coal, Clay, and Lime-stone, under about 500 acres of Land at Ruabon, which have been fully developed at a very large outlay, and are now being worked, with liberty to take any land required, and the fullest powers for working;—and the extensive and valuable Plant and Machinery thereon have been purchased. It is intended to erect on these premises Blast Furnaces and other Works, the Iron Ore being abundant, and of a *very superior character*, and the coal well adapted for smelting, for which purpose it is now being used.

Fig. 6

By June 1859 the iron company owed Sarl some £4,000 in rent and royalties,[22] although the *Mineral Statistics* indicate that 4,103 tons of ore valued at £1,950 were extracted during 1858, compared with the 5,719 tons raised at Westbury.

In July 1859 at the Wiltshire Summer Assizes, Salisbury, before Mr Baron Bramwell, it was stated that one of the original promoters, Mr James Huby, manager of the North Wiltshire Banking Company, Devizes and bankers for the iron company had personally bought two and a half acres of land at Seend for £500 and sold it to his own Company for £2,500.[23] Later that month, the local press under the heading 'The road to ruin' reported that the 'land laiden with minerals at Ruabon and sold to the Great Western Iron Ore, Smelting and Coal Company Limited by Josiah Harris for £10,000 had been disposed of for £600 having first been assessed as a 'mineral property' by a Mr Beckett, who described it as 'worthless'.[24] Not unreasonably Josiah Harris was called upon to explain and, during the ensuing legal proceedings, said he had paid £50 for a pre-purchase valuation at which the mineral rights had been priced at £18,000. Subsequent investigations indicated that this valuation had been for £5,000, and that the person carrying it out had been a Mr Beckett.[25] During July 1859 Combes and Bracher, auctioneers of Bath and Devizes announced a sale of iron-ore and partly built furnaces at Seend. There were no buyers.[26]

In September 1859, in the Bristol Bankruptcy Court, William Sarl applied for re-possession of the works at Seend and, on October 5th 1859, the Great Western Iron Ore, Smelting and Coal Company Limited was declared bankrupt with assets of £309.0s.9d in cash plus an uncompleted smelting site and liabilities of £43,401.15s.7½d.[27]

The re-possession settled, William Sarl began to re-establish Seend as a viable enterprise. By 7th January 1860 the first blast-furnace was lit, and within three weeks had produced 200 tons of pig-iron. At least this seems to indicate that those members of the team responsible for actually constructing the plant must have done a workmanlike job, placing contracts with reputable people.

Sarl talked of a second furnace being 'in blast very shortly'. After commenting that the iron produced from his furnace was as good as any from Welsh and Black-Country, smelters at 60/- to 70/- per ton, said that his statement, 'that Seend iron would be as good as could be produced anywhere in the United Kingdom', had therefore been completely vindicated. He was now writing on notepaper headed: Sarl and Company Ironworks, and was considering building a third furnace, the date was February 1860.[28]

Westbury established

The Westbury iron industry started in a completely different manner, being carried out quietly and efficiently. The fact that there had been no need to seek finance in the market place, meant that most people first knew about it when work on site was actually starting.

As at Seend, there is a record of iron being found, perhaps noticed would be a better word, a few years before large scale extraction began. The Victoria County History states that ironstone was discovered when the Wilts, Somerset and Weymouth Railway began shallow excavations between North Bradley and Westbury. A date of 1841 is quoted but this cannot be substantiated. The line received the Act of Authorisation on 30th June 1845,[29] with the fourteen mile section from Thingley, near Cheltenham, to Westbury being opened on 5th September 1848.[30] However, the 'discovery', whenever it may have been made, does not seem to have caused any excitement.

More interesting is a statement made by George Greenwell, mine manager to the Countess of Waldegrave's Radstock Coal Company, who presented a paper to the South Wales Institute of Engineers in 1858 entitled 'On the ironstone of Wilts and Somerset'.[31] In it Greenwell claimed that he 'accidentally found' the ore in the Coral Rag a short distance south of Westbury Railway Station some three years earlier. If this is so, and it appears to be confirmed by Down and Warrington in their research into the Somerset Coalfield,[32] this marks the start of the Westbury Iron Company. Greenwell claimed with justifiable pride that he was 'the first person to attribute a commercial value to the discovery' and he did, in fact, become a Director and Secretary of the Company when it was founded in 1857.

The Westbury ore 'discovered' by Greenwell consisted of two types which were called 'green' and 'brown' ore. According to Greenwell the first type was '. . . of a dark green colour abounding with oyster shells, compact and moderately hard: and, where acted upon by the weather, presented an incipient oolitic structure and slightly ochery appearance. The 'green' and 'brown' ores were both analyzed by several people and tabulated figures for investigations by a Dr Richardson of Newcastle-upon-Tyne are shown in Figs.7 and 8.

	Per Cent.
Protoxide of Iron	44.53
Lime..	3.37
Magnesia	Trace
Alumina	1.40
Silica	16.55
Loss by Heat	29.77
	95.62
Metallic Iron	34.5

Fig.7 Dr Richardson's Westbury 'green-ore' analysis

Fig.8 Dr Richardson's Westbury 'brown-ore' analyses

	DR. RICHARDSON.			WALTON
	P. C.	P. C.	P. C.	P. C.
Protoxide of Iron	55.80	49 26	...	...
Peroxide of Iron...............	...	...	...	65.00
Lime	4.94	Traces	1.12	...
Magnesia.........................	2.87	...	...	...
Oxide of Magnanese	Trace	...	...	...
Clay...............................	5.50	...	20 10	...
Alumina	...	14.24	...	4.90
Silica	...	17.10	...	14.00
Phosphorus......................	0.35	...	...	...
Water	...	...	...	15.90
Sulphur	...	...	...	vy. slt Trace
Loss by Heat	28.00	17,50	27.00	...
	97 46	98 10		99.80
Metallic Iron	43.40	38.31	36.04	45.50

The South Wales Institute of Engineers was formed at Merthyr Tydfil in October 1857[33] and Greenwell, who came to Radstock from Durham, regularly took part in the Institute's affairs. Consequently he would have been friendly with the giants of the South Wales iron industry, such men as William Mendalaus of Dowlais, George Parry of Ebbw Vale and, of course, the Seend ore analyst, Edward Riley. He would have been aware that the South Wales iron masters were looking for additional sources of ironstone and pig and would have known that if the ore could be taken out of the ground at Westbury, there would be little difficulty in disposing of it. In fact the *Mineral Statistics* record that over 5,000 tons of ore were mined in 1856, the year before the Westbury Company was formed and this probably went to South Wales.

Greenwell's fellow directors included Rowland Brotherhood[34], Charles and William Hollwey, Thomas Pilditch, John Parfitt, Stephen Steeds, John Smith, William Parsons, John Rees-Mogg, W B Naish[35] and William Evans. Most of these had financial interests in the collieries near Radstock and Coleford and were used to dealing with the geologically tortuous and economically precarious Somerset Coalfield. In addition William Evans was connected with the Paulton Foundry which supplied much of the ironwork required by local collieries.

On Monday 13th April 1857 a newspaper commented[36] 'A large number of labourers commenced removing the topsoil which varied in depth from two to three feet. The mine is in close proximity to the railway station and offers many advantages . . . The discoveries have already enhanced the price of the land in the immediate neighbourhood . . . [and] will prove to be one of great value and benefit to the inhabitants of Westbury.'

Mr W B Naish of Ston Easton, near Radstock was elected Chairman and on Wednesday 5th August 1857 he laid the foundation stone of the blast-furnace complex,[37] which seems to have been the first indication that local people had that smelting would actually take place on the site.

The method of financing the Westbury Company is interesting when viewed alongside the Seend project. Both companies were registered under the Joint Stock Companies Act of 1856 and 1857 but whereas Sarl and his friends used the facilities provided by these new acts to enable capital to be subscribed by the public, 'risk capital' in the truest sense of the phrase, the Westbury 'gentlemen' acted as if Joint Stock legislation had never even been mentioned. Each of the twelve directors held one £1,500 share which made up the initial authorised capital of £18,000, very much as they would have to have done under the old partnership laws.

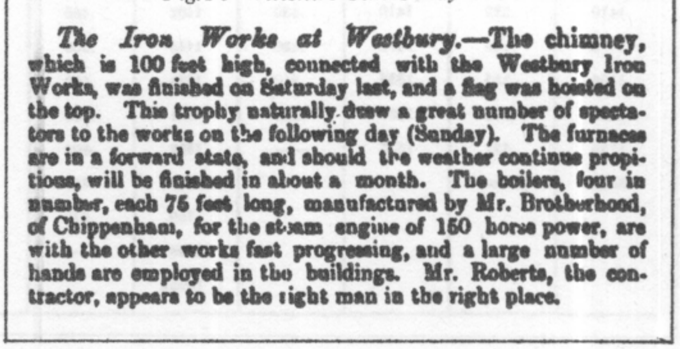
TROWBRIDGE.—On Saturday evening, Samuel Hancock, a superintending mason at the erection of the lofty chimneys just built at the Westbury Iron Works, for the purpose of smelting furnaces, &c., was brought to his home in this town, having escapel an imminent dreadful death. About 12 o'clock, as Hancock was engaged at his work on the cap of the chimney, at the height of nearly 100 from the base, the running rope of a pulley became jammed between the sheave and shell. In attemping to remedy the defect he was suddenly compelled to hold on by the rope, swinging to and fro. This he managed to do for some minutes; looking down to the bottom, where he knew he must soon fall, as it was impossible to have assistance rendered to him by his fellow workmen, and among them was a brother waiting the dreaded result. At last, his strength gave way, and he fell from a height of more than 70 feet. It was in the inside of the chimney, having a flue of about 8 feet wide, without touching either side, which no doubt saved his life. Immediately after coming to the ground, he was lifted up by those around the scene, and hobbled away, to the surprise and gratification of all present. The injuries he received were a complete smash of the ankle and small bones of the right foot, with nothing of a serious nature elsewhere.—The unfortunate young man bears a good character for industry and ability as a mechanic. He has expressed himself grateful for his escape and says that the state of his mind while holding the rope and looking down to where he must inevitably fall was as bad as the effects. He is now doing well.

Fig. 9 Wiltshire Times December 1857

Unlike the Seend project which continually found its way into the local papers, often because of alleged nefarious happenings, Westbury was hardly mentioned. Occasionally there was a flurry of excitement such as took place in the first week of December 1857 (Fig.9) but even then the unfortunate man 'fell on his feet'. In May 1858 the local press gave a mention of the continuing good progress at the works (Fig.10) and two months later the Westbury Iron Company's two blast furnaces were 'officially tapped' although they had previously produced some iron. At 3.30pm on Wednesday 14th July 1858 (an hour and a half late because of a 'slight breakdown') the 'red-metal' flowed for the first time in public, a cannon was fired and the Bradford-on-Avon Brass Band struck up. Later that day there was a dinner for about 40 gentlemen at the Lopes Arms Inn, presided over by Mr W B Naish, with Mr William Ferris (Chairman of the Great Western Iron Ore Smelting and Coal Company) amongst the guests. The entire Westbury work-force of some 70 men, was also entertained to an excellent repast at a local hostelry.[38]

In August 1858 a slight problem was reported by the *Wiltshire Times*. The furnace stacks had developed cracks owing to 'using [them] before they were sufficiently dried and seasoned to the heat'. Such incidents were at the time not unknown. The local press talked of 'pulling down and completely rebuilding after being rendered useless'. In a less sensational footnote, the reporter added 'that the delay in operations will be more serious than the cost of repairs'.[39]

Fig.10 Wiltshire Times May 1858



The Iron Works at Westbury.—The chimney, which is 100 feet high, connected with the Westbury Iron Works, was finished on Saturday last, and a flag was hoisted on the top. This trophy naturally drew a great number of spectators to the works on the following day (Sunday). The furnaces are in a forward state, and should the weather continue propitious, will be finished in about a month. The boilers, four in number, each 76 feet long, manufactured by Mr. Brotherhood, of Chippenham, for the steam engine of 160 horse power, are with the other works fast progressing, and a large number of hands are employed in the buildings. Mr. Roberts, the contractor, appears to be the right man in the right place.

In contrast to the methods adopted by the Seend directors in publicising what they hoped their furnaces would produce, the Westbury Company marketed their iron by tests and tabulated results. Very early in the life of the works they stated that the practical yield of one of their furnaces had been established, at 34.48%. Apparently 3987 tons 10 cwts of mine had been weighed 'accurately' into the furnace and this had produced 1375 tons 10 cwts of pig. Perhaps the quantities seem too good to be true, when one realises the accuracy of charging in the mid-nineteenth century, but one must admire the systematic approach. In a similar way a load of Westbury pig was taken to the Wick Iron Works near Bristol in order to ascertain the conversion ratio of their Number 4 iron by puddling. The answer, (which was not accepted by George Parry or William Menelaus) was 1½% waste or 98½% conversion. The figures claiming to

WEIGHED INTO FURNACE.			PUDDLED BARS.		
Cwt.	*qrs.*	*lbs.*	*Cwt.*	*qrs.*	*lbs.*
4	2	4	4	1	20
4	2	2	4	1	25
4	2	0	4	1	21
4	2	4	4	1	27
18	0	10	17	3	9

Fig. 11 South Wales Institute of Engineers

substantiate this experiment are shown in Fig. 11. Also a number of test bars were made from Westbury and other iron, each measuring 4 ft 6 inches long by two inches deep by one inch in breadth. They were taken to Messrs Cockey and Sons Foundry at Frome in Somerset and tested for deflection using an instrument devised by George Greenwell and capable, he said, of measuring to 1/100th of an inch. Four bars were tested, two using the same proportions of Westbury Number 1 iron and scrap (unspecified) and two with differing compositions. Again the results were tabulated and are shown in Fig. 12. A little under two years later the *Wiltshire Independent* told its readers that there was, in the Westbury Iron Company, 'A brisk little business with 250 tons a week of pig-iron consistently being produced from two furnaces'. The information came from Mr T H Anderson, manager of the works and the date was 10th May 1860.

Westbury No. 1...2 pts. Scrap ....1 " Staffordshire ......1 "		Westbury No. 1.		Westbury No. 1 .... 1 part. Scrap................................... 1 "			
Weight.	Deflect.	Weight.	Deflect.	Weight.	Deflect.	Weight.	Deflect.
lbs.	ins.	lbs.	ins.	lbs.	ins.	lbs.	ins.
150	.020	150	.000	169	.000	169	.000
654	.100	654	.162	673	.180	673	.175
780	.135	...	...	...	...	...	...
843	.150	...	...	...	...	...	...
906	.168	906	.260	925	.280	925	.264
969	.182	...	...	...	...	...	...
1032	.202	1032	.300	1051	.320	1051	.320
1095	.222	1095	.330	1114	.348	1114	.346
1158	.238	1158	.350	1177	.373	1177	.366
1221	.265	1221	.383	1213	.400	1213	.398
1284	.278	1284	.410	1276	.415	1276	.412
1347	.300	1347	.432	1339	.450	1339	.438
1410	.322	1410	.460	1402	.485	1402	.461
1473	.345	1473	.490	1465	.509	1465	.505
1536	.355	1536	.510	1528	.520	1528	.505
1599	.395	1599	.530	1591	.580	1591	.538
1725	.425	1635	—	1618	.600	1618	.547
Broke	Broke	Broke		1717	.642	1717	.603
				1780	.670	1780	.620
				1798	—	1798	—
				Broke		Broke	

Fig. 12 The tabulated results of George Greenwell's deflection tests. He says: 'They were conducted by myself with much care with a little instrument admitting of great accuracy. It is 10 inches long and 1 inch in breadth at one end, tapering to a point at the other. It is divided equally into ten parts and each part subdivided into tenths. It is applied by being inserted between the deflected bar and a straight edge touching its upper side at its point of support. The length of the instrument which can be inserted can then easily be read off; each inch representing .1 of an inch of deflection and each tenth representing .01 of an inch.

Coke Supplies

To produce iron in a blast furnace one needs four basic ingredients, iron-ore, which both sites had in abundance, limestone, which could be quarried within a very short distance in both cases, about six tons of air per ton of iron produced, and coking coal. We have seen the extraordinary lengths which the Seend Company had to go to in order to indicate a source of coke for its potential production. From the start, the men responsible for floating the Westbury company were involved in the business of winning coal, but even so, the provision of considerable quantities of coke of a consistent quality with no delays in delivery must have posed a problem. A blast furnace is a voracious animal. The requirement was initially met by the purchase of Newbury colliery near Coleford and the construction of a broad gauge railway line from the pit-head and its nearby coke-ovens to the GWR freight line running from Radstock to Frome. As there was no requirement for a formal agreement with the GWR, the exact date of this line has not been established, but Down and Warrington quote 'about 1857 and certainly by 1864'.[40] In view of the efficient way in which the pre-planning was carried out and the fact that Newbury is known to have belonged to the Westbury Iron Company by at least 1860, I suggest that the acquisition of both the colliery and its attendant feeder line were part of the original plan. Later in the working life of Westbury, when it was producing around 500 tons of iron a week, coke consumption was quoted as 700 tons/week, but even in 1858 the company would have required about 350 tons/week.

Once the output from the Westbury furnaces had increased the Company probably had difficulty in satisfying their coke requirements from Newbury and its near neighbour, Mackintosh colliery. In 1864 there were only four pits working in the Vobster area with a total daily production of about 290[41] tons of raw coal, which, had it all been carbonised, would have only resulted in around 200 tons of coke.[42] The Newbury/Mackintosh combination, which for statistical purposes was regarded as one colliery, was fairly big and it would seem reasonable to assume its share of the combined production figures as half of the available total. Even so, working seven days a week (which the coal-mines probably did not do) the iron-works could only just have achieved their 700 tons/coke/week requirement, a potentially difficult situation. Some time after 1864 the Westbury Iron Company spent £7,000 sinking a new shaft at Moorwood,[43] near Downside Abbey, where incidentally there is also a record of clay-ironstone being worked, but mine-flooding prevented this from succeeding.[44] It is also mentioned that they bought coke from South Wales.[45]

The Plant

Prior to 1830 blast furnace design had stagnated. In 1832 John Gibbons, a very experienced Black Country iron-master erected a new furnace at Corbyn's Hall, near Brierly Hill,[46] pioneering a new design with a round, rather than square, hearth/crucible and steeper boshes. Gibbons had previously noticed that square hearths invariably became round with use, and boshes became steeper. His successful innovation started a phase of furnace building, during which this type of 'Staffordshire furnace' became dominant throughout the industry, erected in all the 'new' iron-producing districts.[47] Such furnaces were erected at Seend and Westbury, the former being attributed to Samuel H Blackwell[48] who, it will be remembered, was responsible for introducing Wiltshire ironstone at the 1851 International Exhibition, and starting the Northamptonshire iron industry.

Blackwell's participation could explain an apparent omission for examination of a contemporary picture of the Seend works indicates that the furnaces did not have the 'bell and hopper' apparatus for sealing the furnace top after charging. Developed by George Party of Ebbw Vale in 1850, this had been generally introduced to improve fuel economy and furnace production, but Blackwell had been troubled by the production of 'white iron' (hard, brittle and difficult to machine) in a furnace of which he had charge, and which had been fitted with a bell and hopper.[49] At the same time Seend was being equipped, S H Blackwell built himself a furnace at Russell's Hall ironworks near Dudley, which bears a considerable resemblance to his Wiltshire design.

Both Seend and Westbury had hot-blast installations from the start. Before Neilson had patented his method of heating the air blown into the furnace (1828) the blast introduced through the furnace tuyeres (nozzles in non-technical language) had been at ambient temperatures. Opinion was divided as to the respective merits of cold or hot blast but there was no doubt that it significantly lowered coke consumption.[50] However, the early hot-blast stoves were a mixed blessing. They contained a hundred feet or so, of 18 ins diameter cast-iron pipe, cut into convenient short lengths doubled back and forth, and joined by 'U' bends and flanges. With uncompensated expansion and contraction they almost always leaked. John Percy, enthusiastic as always about this innovation, admitted that 'A difficulty had now crept in unawares, destined to be highly mischievous and to test the ingenuity of a whole generation of furnace managers'.[51]

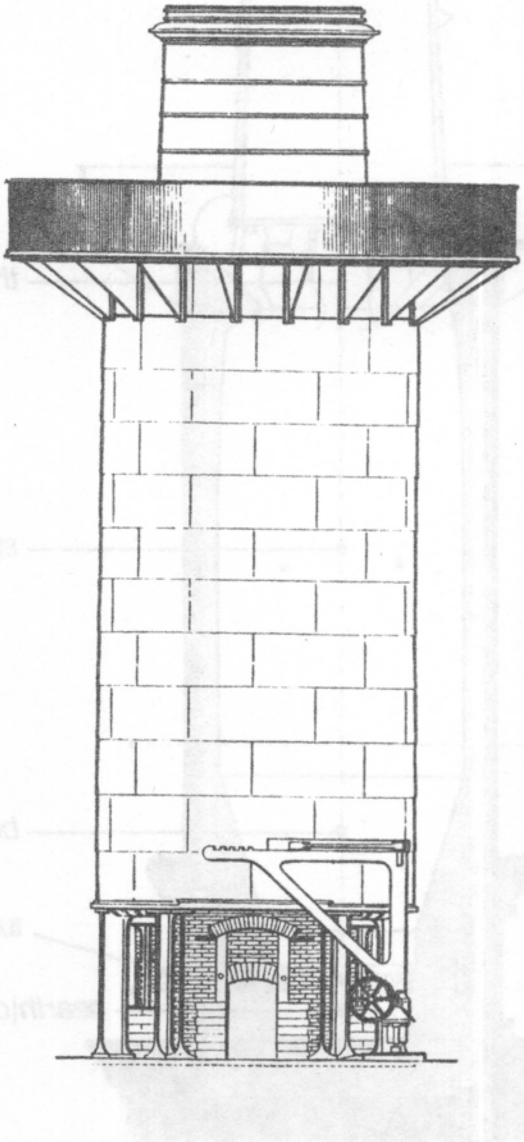


Fig. 13 The blast furnace erected at Russell's Hall ironworks, near Dudley, by Samuel Blackwell.
It was 19 ft 6 inches diameter inside the tuyeres.

In the Black Country, however, by 1851 Martin Baldwin of Bilston had produced a new design of pipe stove 'Very greatly superior to any others as far as freedom from fracture or leakage of joints.'[52] Samuel Blackwell installed Baldwin stoves at his Russell's Hall iron-works near Dudley whilst a further improved version (with a brick ore) was installed at Allaway's iron-works at Cinderford in the Forest of Dean.[53]

The man supervising the erection of Seend was Frederick Vernon-Smith, brother of Josiah Timmis Smith of Schneider and Hannay's, Barrow-in-Furness[54] and himself a hot-blast stove innovator.[55] It seems reasonable to assume that the two brothers would have discussed hot-blast problems and likely that modified Baldwin stoves were purchased for Seend.

The air blast at both Seend and Westbury, was provided by a steam driven beam engine and one can only speculate as to the makers. Samuel Griffith of Wolverhampton, well

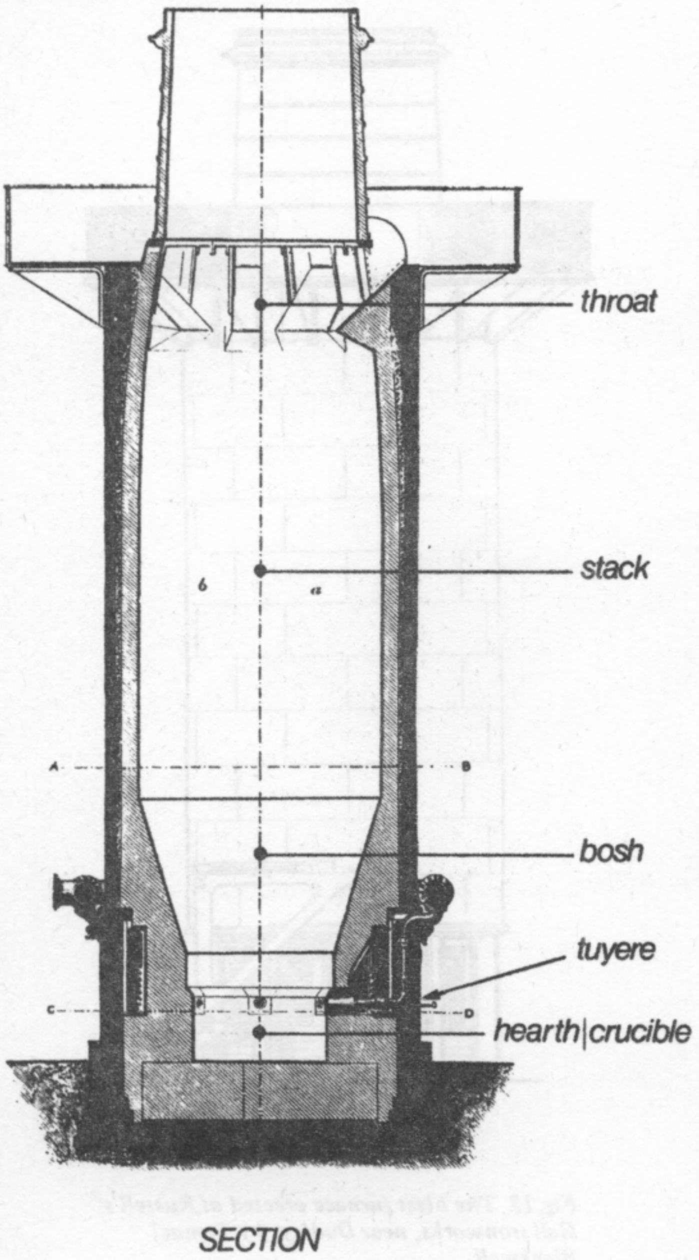
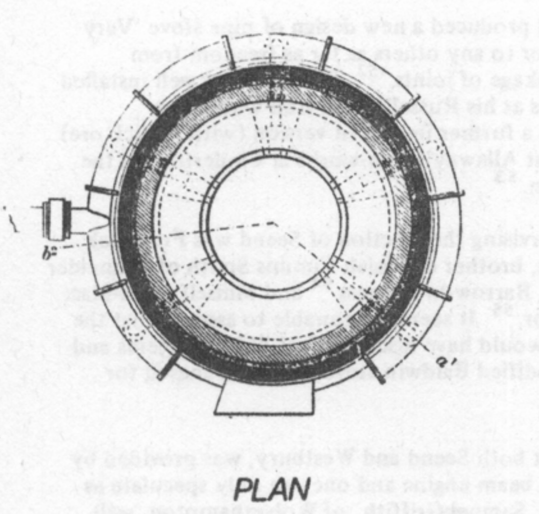


Fig. 13 (continued)



known as a 'trade journalist' visited Seend in April 1861 [56] and wrote of a '120 horse power blast engine, substantially erected on the most modern plan, working with beam, flywheel, and slide valves, three boilers . . . being used to generate the steam'. At Westbury however there was apparently seven boilers producing the steam at 40 lbs/sq inch and a beam 26 ft in length with a flywheel about 24 ft in diameter. Neither of these descriptions are helpful in identifying the type of installation but in John Percy's *Metallurgy of Iron and Steel* (1864) there is an engraving showing an engine, made by the Haigh Foundry Company of Wigan, which is described as 'an example of the kind of blast apparatus most commonly used in this country for iron-smelting furnaces. It is a condensing beam engine with a 24 ft diameter flywheel and a beam some 30 ft long. It drew steam from seven boilers (including one for stand-by and cleaning purposes) and worked with steam 30 lbs/sq inch above atmosphere,[57] which is not so very different from the 40 lbs/sq inch mentioned at Westbury. The Haigh engine could have been similar to those used in Wiltshire.

At both Seend and Westbury the furnace charge of iron-ore, coke and limestone, was taken to the furnace throat by means of a vertical lift, carrying iron hand-barrows. It was a water-balance lift at Seend,[58] with water supplied from the blowing engine condensate pit, and mechanical at Westbury with its own small engine.[59]

Coke from Newbury Colliery, near Vobster, was taken direct to the smelting area at Westbury until the production of iron outstripped the resources of the Newbury and Mackintosh pits and coke ovens. From later illustrations it is known that there were two banks of coke ovens at Westbury which were probably built after 1870 as, until then, the beehive type of oven was almost universal. Seend however, must always have had a problem with fuel supplies. William Sarl's difficulties with coke probably became well-known as, in May 1860, the lease of Old Grove Colliery, near Timsbury, was offered to the Seend company who declined it.[60] Sarl did, however, negotiate a contract for the supply of coal and Old Grove is reported to have bought five tons of iron rails from Sarl. On a 25 Ordnance Map (c.1880) a circular object annotated as a coke-oven, is shown adjacent to the broad gauge connection to the GWR. It seems to be too large for a type of contemporary circular fire-brick coke-oven described as about 10 ft in diameter but, at that time, the coking of coal in circular piles of around 30 ft diameter was quite usual. These were often called 'coke-hearths' or 'coke-fires' and this was one of the ways S H Blackwell produced coke at his Russell's Hall iron-works.[61]

Seend's Fluctuations and Closure

Within sixteen months of the first successful cast at Sarl's furnaces another attempt was made to raise capital. This time (June 1861) the target was £100,000 in £5 shares, the objective being the building of three more blast-furnaces, coke-ovens and housing for his workers. A new company was formed, to be known as the Wiltshire Iron Company and amongst those quoted as Directors were Sir R W Camden, Col Hay and William Neal, MP. S H Blackwell was principal manager.[61] No details have been discovered of this venture but the company must have fallen into dispute with Mr Wadham Locke. On the 10th September 1863 Locke wrote to his friend William Cunnington of Devizes: 'The iron-ore is now to be let in any quantities or sold, and now is the time for your friend to come and see me. The deputation from the Wiltshire Iron Company came here last Saturday and we did not come to terms . . . the furnaces are no use to them without my ore lands.'[63]

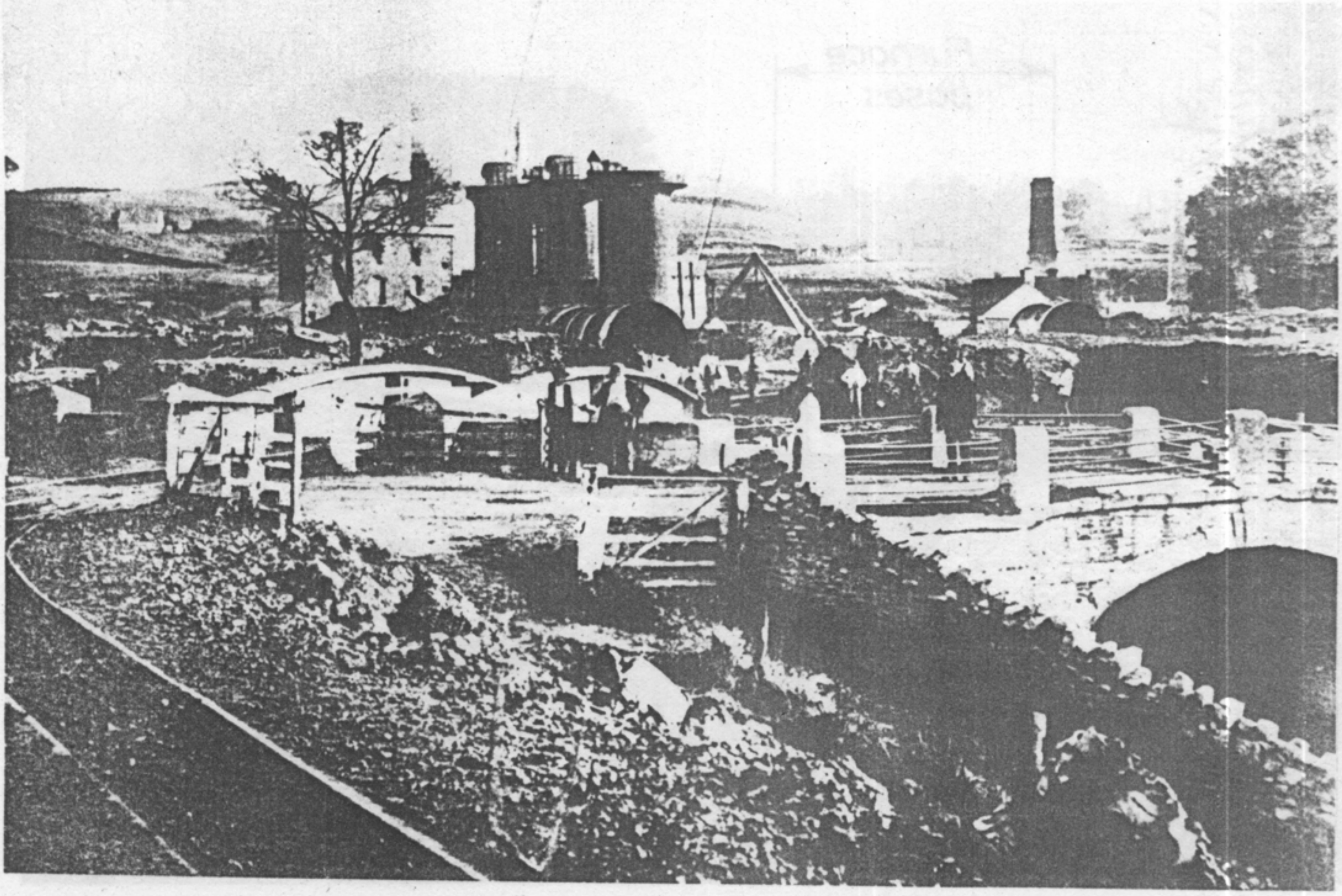


Fig. 14 Seend ironworks photographed in 1871. The picture was taken from near the bridge over the Kennet and Avon Canal, which is still very much the same today.

Six months later a notice appeared in *The Times* 8 March 1864, stating that an Extraordinary General Meeting of the Wiltshire Iron Company would be held at the office of Sir Robert Camden at Cornhill in the City of London on Thursday 24th March 1864. A resolution would be considered requiring the iron company at Seend to be voluntarily wound up under the provisions of the Joint Companies Act, 1882. There are no records of Seend in the *Mineral Statistics* between 1862 and 1871 but for the years 1865 and 1866 (when presumably under direct control of Wadham Locke), 42,266 and 40,917 tons of ore respectively were raised. On 3rd September 1868 Wadham Locke wrote a particularly interesting letter to William Cunnington, in which he stated, 'That the works employ approximately 60 men and that there are three blast furnaces'. It is significant that from 1862 until 1871 as the *Mineral Statistics* quote two furnaces built but none in blast, and only then was a third furnace recorded. Possibly a further remark in Wadham Locke's letter is relevant for he said: 'The blast engine (which he added was of 84 hp fed from six boilers) has only ever blown two furnaces but it could easily be altered to blow three.'[64]

There was a change in 1870 when a Glasgow firm, Messrs Malcolm and Coy began operating the iron-works.[66] They lasted for less than three years, however, and on 7th January 1873 the Devizes Gazette reported the failure of William and Samuel Smythe Malcolm of 19 St Swithins Lane, Glasgow with liabilities of £350,000 presumably accruing from their other business interests.[66] A month later the *Devizes Gazette* commented that 'Work has been resumed at Seend iron-works which employs 300 men and the furnaces are in full blast.[67] Later that year the works were taken over by Richard Berridge, a partner in Sir Henry Meux and Company's London Brewery and a Mr Osborne Alids, private secretary to Richard Berridge, was installed as iron-works manager. It is not clear how a brewery man came to be involved in iron production but his interest must have been short lived. The *Mineral Statistics* have an 'estimate of 500 tons of ore extracted' down for 1874 and after that silence. In the Wiltshire County Record Office there is a notebook which begins enthusiastically in September 1875 to record tonnages of iron-ore extracted from the Bradley and East End quarries. The entries dwindle, and cease a mere ten months later (June 1876) but even so they only total 3,107 tons and with the monthly variation of between 185 and 574 tons, it is obvious that no furnace could have survived. In 1888 a steam launch the *Little Sabrina*, made the journey from Bradford-upon-Avon to Devizes along the Kennet and Avon canal and her Log records: 'Saturday 5th May . . . at Seend there is the melancholy spectacle of iron-ore smelting furnaces falling to ruin.'[68] In October 1889 'Machinery and plant . . . engines, boilers, steam and water fittings etc.' were offered cheap on the 'Dismantling of Seend iron-works' and on application to T W Ward on the site at Seend or Fitzalan Chambers, Sheffield.[69]

In 1905 a firm based at Midsomer Norton, near Radstock, bought the property and extracted ore for some

Fig. 15 A picture taken in 1968 from the far parapet of the same bridge.

considerable time, certainly until well after the 1914-18 war, sending most of this to South Wales. Press cuttings in the Devizes Museum Library indicate that there was some activity at Seend until as late as 1939. These show that the 'New Seend ironworks', as it was called, began operations in 1921, 1922, 1928 and 1936 (when it was opened by the Westbury Iron Company) and closed in 1922 (twice) and 1923 and 1939. None of these activities had any effect on the iron industry but occurred because of a secondary use for the ore as a purifying agent for gas works. Until quite recently, sulphurous compounds present in town gas produced the traditional way in retorts from coal, were absorbed in oxide of iron.[70] There are scattered records of ore from Seend quarries being so used until the 1960s and at Westbury from 1920. The ore was calcined and despatched to London, Liverpool, Birmingham and Swansea etc for use in gas-purification plants.

Steady Progress at Westbury

As might have been expected after its carefully-planned start, the Westbury Iron Company continued more soberly. For twenty years, from the time that the Westbury furnaces first came into blast, it is difficult to find iron-works news in the local papers, in itself an indication that nothing untoward happened.

On 1st February 1872 a block of shares in the Westbury Iron Company valued nominally at £2,500, formerly the property of the late Mr H J Smith, were sold by auction at the Commercial Rooms, Bristol, for £3,005,[71] and this in a year before Seend went bankrupt, yet again.

There was a set-back in March 1877 when a fall in pig-iron orders resulted in wages at the Westbury Iron Company's works being reduced,[72] and by August of that year the *Wiltshire Times* was reporting only two of the four furnaces in blast.[73] (the *Mineral Statistics* had recorded only two in blast in 1875, this situation continuing until 1882), and in 1878 the newspaper described tales of hardship in the town.[74]

At the beginning of 1880 there was a 'revival of trade', the iron works took on 40 to 50 extra men and there were rumours of an increase in wages.[75]

In 1884 both the *Bristol Times and Mirror* and the *Warminster Journal*[76] carried articles about the Westbury ironworks and which provided evidence of several technical advances which had been made since iron-smelting started. There had originally been two blast-furnaces in 1857, a third was added in 1862 and a fourth in 1866.[77] Then about 1882 two of the quartet (perhaps the original two) were replaced by one larger furnace and this only was working when the press reports were made. It was producing 400/500 tons per week. The early cast-iron pipe stoves had been supplemented by three Whitwell regenerative stoves, capable of heating the blast to around 600°C. The GWR was taking the bulk of the slag as track ballast, with a little also going to road-making contractors. The site covered 400 acres, with the furnace complex occupying about 12 acres, the Company's capital was £90,000, and they employed 200 men, and no women.

According to the *Bristol Times and Mirror* reporter, the furnace 'make' was about 140 tons. With the main GWR lines running within a few hundred yards of the pig-beds getting the iron away was no problem and, apparently, it was quite usual for a tapping to be loaded and despatched the same day to Staffordshire, South Wales or local foundries, with the bulk going to the Midlands.

In 1891 workers at the iron mines struck for a ¼d a ton increase on their basic wage of 2½d per ton, returning to work when the Directors agreed to consider raising the rate if earnings dropped below 3s.6d per day.[78] Ten years later a shiver went through Westbury when the iron works closed. In February 1901 the *Wiltshire Times* reported that 'It is stated on, we believe, good authority that the Westbury Iron Company have decided to close their iron-works, temporarily at least.[79] In this they are only following the example of many other iron works throughout the country who have had to close due to foreign competition and an increase in the cost of materials. A large amount of men are in this instance affected.' On 21st February the official announcement came: 'Meetings of the directors and shareholders have been held in Bristol and it was decided that it was not possible to continue business owing to liabilities. It has been decided to continue the working of the collieries at Coleford for the time being, and it is hoped that a new Company may be formed in the future.'[80]

The furnaces were 'blown out', 180 men immediately became unemployed and the loss of wages, amounting to over £250, which was mostly spent in Westbury brought an air of gloom to the town. It seems typical of the Company that the assets of the stricken Company were amply sufficient to pay creditors 20/- in the £1.[81]

This was done, and very soon moves were underway to start a new company. On 12th December 1901 a public meeting was held at which Mr William Henry Laverton, the chief local landowner and public benefactor, announced that a small group of local men (J Calloway, G H Knight and himself) had a plan whereby it would be possible for the physical assets of the iron works to be purchased at a 'break-up' price of £9,500. £5,000 had to be found by the end of that week and the remainder by the close of the year. There would need to be a further £10,000 as 'working capital' but if the first sum could be realised, he and others, would arrange the rest.[82]

The New Westbury Company

There were no difficulties. £1,500 was promised by the close of the meeting and two days later the fund had topped £4,000.[83] The iron works was saved and negotiations began immediately to find new owners. In September 1902 satisfactory arrangements were made with a new group of business men; in June 1903 the 'New Westbury Iron Company' was formally registered,[84] the works 'completely overhauled with electric light fitted throughout' and on the 11th October 1903 the wife of Mr J E Fisher, the new works manager, from Cardiff, 'turned on the blast'. The Westbury iron works and its two hundred strong labour force, were back in business.[85]

When the original Westbury Company went into voluntary liquidation they did not immediately give up working the Newbury and Mackintosh coal mines, but probably did so soon afterwards. Mackintosh had been quiescent since 1895 and it is likely that Newbury ceased winding temporarily sometime after 1901 with both collieries being sold to John Wainwright and Company Limited.[86] Presumably the new owners of the iron works made arrangements to guarantee their coke supplies but in any case the whole colliery complex was now operating under new management.

It has not yet been possible to find records covering the years during which the New Westbury Iron Company ran the resuscitated works. An undated plan of the site exists and possibly could give some indication of what the new management hoped to achieve as it seems likely that this drawing dates from the early 1900s. Keith Gale comments on the plan in the Appendix but the overall picture remains obscure. In 1908 the furnace(s) were once again shut down[87] and, as far as is known, remained so until the 1920s. One can hazard a guess that the political situation, coupled with 'dumping' of iron and steel and the dramatic reduction of the UK share of the world market, made the market predictions very difficult for a small West-Country merchant ironworks and it seems as if the Company reverted to the pre-1858 practice of supplying ore to whoever would buy it.

The returns of ore quarried, given in the *Chief Inspector of Mines' Annual Report,* (Mineral Statistics under a new name) show an interesting pattern from which one could make several tentative suggestions. The most logical is that Westbury was overcome by financial problems in 1908 but found a small but regular customer for raw ore. In 1914, as the outbreak of hostilities caused a shortfall in the United Kingdom ore supplies, new requirements culminated in a peak of 24,470 tons quarried and sold in 1917. During the war years the Government encouraged (and often financed) the use of low-grade, home-based, iron-ore[88] by an expansion of open-hearth furnace facilities and possibly the Westbury oolitic haemetite became popular with the then increasingly monolithic industry.

Something of this sort seems to have happened because in 1921 the assets of the small Wiltshire company were bought by Guest, Keen and Nettlefolds. To be strictly accurate the shares became the property of GKN, a Newport firm of Partridge, Jones and John Paton and John Lysaght Limited, who had themselves been taken over by GKN in 1920.

There is a record[89] of an attempt made in 1922 to restart the smelting of iron but this was quite quickly abandoned. From the 1920s at least, there had been an outlet for calcined, crushed and screened ore, to various gas-purification plants[90], as at Seend but I am inclined to think that GKN had other plans.

It is reported[91] that a sinter plant was constructed at Westbury in 1922, a fact that is confirmed by the sale of such equipment when the works were eventually dismantled, and in 1920 HGW (Gilbert) Debenham (until 1967 Managing Director and Chairman of the Skinningrove Iron Company Limited) went to Westbury as a technical trainee and stayed for five years before moving to Guest, Keen and Nettlefolds, Scunthorpe. It has been suggested that the Westbury sinter-plant could have been a Greenawalt rotary-pan-type machine[92] and certainly the plant eventually sold was a rotary machine. It is possible that Debenham's tour of duty at Westbury co-incided with GKN experiments into the practicability of sintering Wiltshire ore prior to transporting it to one of their other works.

It is likely that such a plan would have failed because of

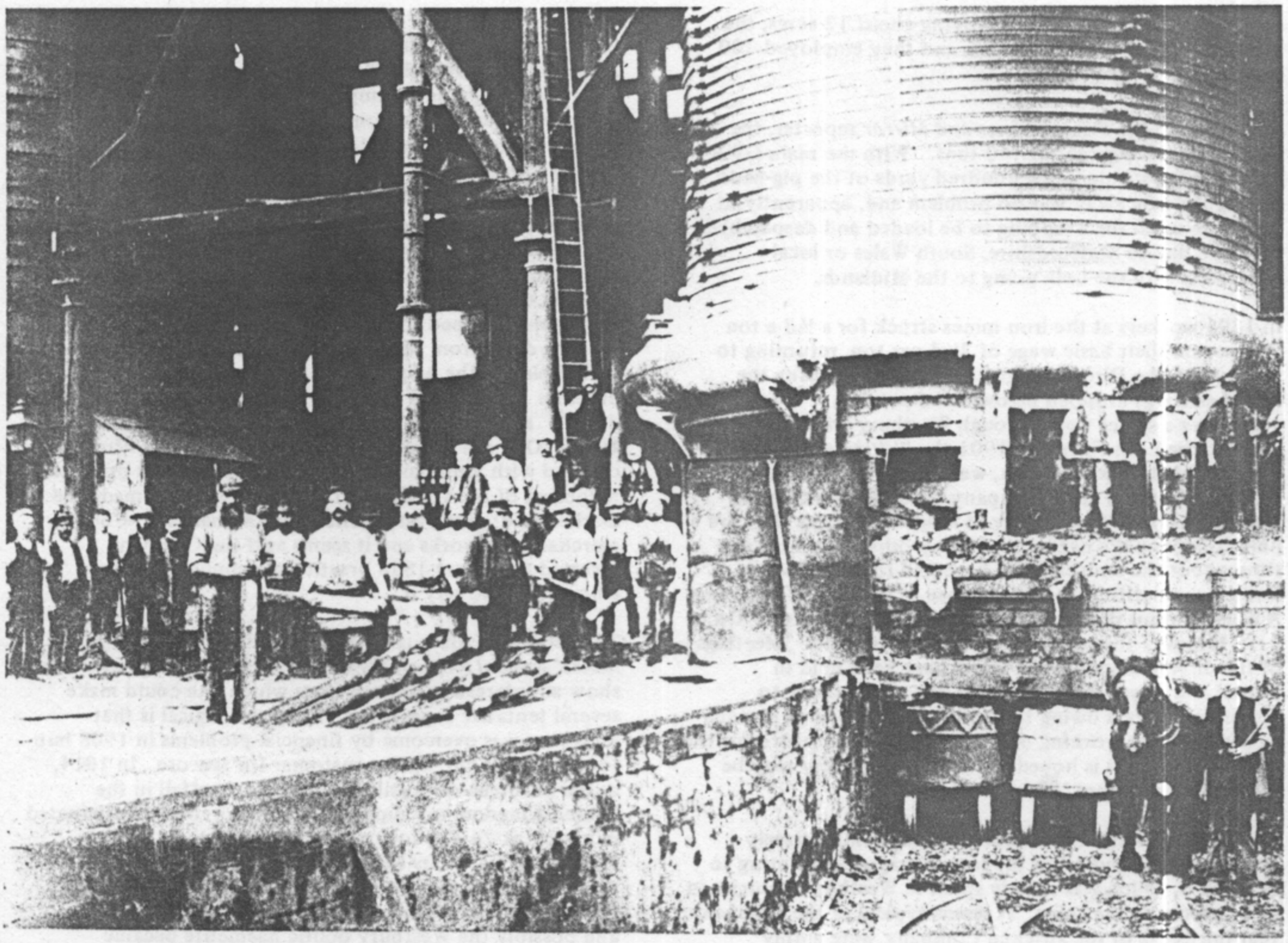


Fig.16 This picture, from the Wiltshire Archaeological and Natural History Society's collection, is captioned: 'the Westbury blast-furnace crew'. It was probably taken in the 1880s and Keith Gale comments that the strong men (left centre) were probably holding wooden pig patterns which were much lighter than a 1 cwt (50 kg) pig but equally impressive in a photograph.

the friable nature of sinter, which would have precluded a rail journey from Westbury, although the depressed economic situation of the iron trade in the 1920s would also have had an important effect. On 21st June 1929 Messrs Aerofilms took a photograph of the site which looked very dead indeed. There are four slag bogies parked behind the slag bank and two of these appear to be full. Some activity was observed on the site during the 1930s [93] and apparently the debenture holders and the National Provincial Bank decided to appoint a Receiver in 1938. Fuller, Horsey, Sons and Cassell in conjunction with HE Foster and Cranfield, in February 1939 issued an Auction Catalogue [94] containing 268 items and these included one blast furnace (it is not known when the other shown on the New Westbury plan and on large scale OS maps, vanished) and the sinter plant. Comments on this catalogue appear in the Appendix.

Also included were three 24" gauge and two standard gauge steam locomotives, and a number of side tip wagons. Twenty eight of these, together with 24" gauge track and turntables, were said to be lying at Seend and the fact that one of the locomotives, an Avonside Engineering Company 0-6-0 saddle tank was insured until the end of June 1937, indicates that ore extraction at both sites could have taken place until about eighteen months before the final sale.

Until February 1943 the site was officially in the hands of the Receivers and the name of the Westbury Iron Company finally vanished on 28th January 1949, when it was removed from the Register of Companies.

The Work Force

When Seend and Westbury became iron-making districts in the 1850s one of the problems which must have faced both companies was finding skilled workmen. There would have been plenty of general labour available but blast furnace operations require specialist experience and, for this, the Wiltshire iron-masters needed to go to the established iron-working areas. The 1861 Census Returns for Seend and Westbury show that they did just that and one can imagine there would have been many strange dialects in those Wiltshire villages in the mid 19th century.

At Westbury, James Sadler (age 56) and William Danks (34) were both recorded as blast-furnacemen. Both came from the Black-Country, Danks having been born at Bilston and his four children, the youngest only 3 years old, at Tipton. Three moulders were recorded, Joseph Wilson (Yorkshire) Sydney Jones (Shropshire) and Alfred Thomas (Clerkenwell) whilst the boiler fireman, Watkins Prosser, came from Merthyr Tydfil, Richard Gray (Newcastle-upon-Tyne) was an engine-fitter and one of the blast-furnace Keepers (responsible to the owners for the day-to-day management of the furnace) was David Baxter, born at Bath. At first glance this seems surprising but at 58 years old Baxter would have gained a deal of experience, possibly in the Forest of Dean, South Wales or the Midlands.

Seend, one is tempted to say inevitably, had a more scattered picture. There were several Irish furnace-workers whilst two men who could have been key workers, Benjamin Hyde (35) from Sedgley, near Dudley and his brother, John Hyde (46) born at Brierley Hill, lived in a cottage very near the smelting site, Ben with his wife from Kidderminster and a 6 year old son born at Rowley Regis, in the Black Country.

Inevitable Failure

Seend and Westbury were established to produce cast-iron at a time when there was a national shortage. From the available records it seems that the largest part of the production of both works was taken by the Staffordshire (Black Country) and South Wales iron-trades as foundry or pig-iron, although both districts could also have taken some raw ore, during the early and later stages.

Seend was badly managed financially, may well have been under-capitalised originally, (as even the £50,000 originally sought was only two-thirds of the initial Westbury capital) and it was not sufficiently resilient to weather market fluctuations.

There are no indications that Seend was incapable technically. During the 1860s (when it was working) Seend 'grey forge pig-iron' was regularly quoted by the Mining Journal in their Iron Trade Circular alongside Forest of Dean foundry iron. Seend was £3.00 to £3.2.6 per tone against the Forest's £3.12.6 to £3.15.0 and in May 1861 a Mr S B Rogers of Newport wrote to the M.J. commenting on the . . . fine quality of Seend iron!

Westbury was quite different and was remarkably consistent. There were a few problems, in its early life due to the high silicon content, with George Parry of Ebbw Vale Ironworks commenting adversely on the weakness of Westbury iron under impact, whilst William Menelaus of Dowlais said that it 'worked to a bad yield in puddling'[95]. But iron-masters generally came to terms with high-silicon iron, and by the peak years of Westbury men such as C Wood of Middlesbrough and J E Stead, chemist of Bolckow Vaughan, had produced evidence that silicon pig could be used to advantage[96].

Why then did the Westbury company fail. The complex reasons for the nationwide dispersal of small, local iron-producing units are beyond the scope of this article but when Henry Bessemer and Sydney Gilchrist Thomas took Britain into the steel age, decline was inevitable. Low-cost foreign ore which could only be taken into the deep-water ports in addition to the fall in demand for wrought (puddled-pig) iron, combined to drain the life blood from such places as Westbury, whilst nationally, pig-iron production, which had risen to 10¼ million tons in 1913 declined steadily until 1937. With an enormous availability of scrap and an influx of cheap foreign steel, there ensued a highly redundant capacity and a 20% level of unemployment in the British iron and steel industry in the 1920s. The decline and eventual closure of Westbury was unavoidable and irreversible.

But between 1856 and 1885, after which year the *Mineral Statistics* ore returns for Wiltshire were combined with Oxfordshire and Rutland and became impossible to quantify, over two million tons of iron ore valued at £580,496 were taken from the ground at Westbury[97]. The blast furnaces continued to work for 23 years, the iron mines for at least a further 25, with the site contributing much to the prosperity of Wiltshire in general and the town of Westbury in particular.

Year.	Westbury.	Seend.	Heywood.	Total.
	Tons.	Tons.	Tons.	Tons.
1858	5,719	4,103	...	9,822
1859	16,947	1,381	10,665	28,993
1860	40,112	32,000	4,088	76,200
1861	37,529	15,000	3,250	55,779
1862	47,900	...	...	47,900
1863	72,612	...	...	72,612
1864	79,918	...	...	79,918
1865	77,291	...	...	77,291
1866	75,645	...	...	75,645
1867	82,586	...	...	82,586
1868	75,084	...	...	75,084
1869	104,795	...	...	104,795
1870	101,423	...	...	101,423
1871	109,151	50,743	...	159,894
1872	95,117	1,000	...	96,117
1873	105,929	34,200	...	140,139
1874	86,120	500	...	86,620
1875	87,152	...	...	87,152
1876	83,957	...	...	83,957
1877	79,176	...	...	79,176
1878	84,756	...	...	84,756
1879	47,623	...	...	47,623
1880	67,500	...	...	67,500

Fig. 17 A table showing the iron-ore raised in Wiltshire between 1858 and 1880. Heywood was actually part of the Westbury Company's site and after 1862 Heywood totals were added to Westbury. Source Richard Meade.

The Industrial Archaeology

After a noisy start followed by a short-tempestuous working life, Seend was abandoned as an iron-smelting site. This had the result of fossilising the internal transport features which can still be traced quite easily. Early in its life Seend iron-works had a tramway from the main iron-stone quarry to the blast-furnace complex, and this can be followed without difficulty.

It has an easily identificable over-bridge (ST 936 611) under which horses used to haul ore wagons from the quarry to the top of a self-acting inclined plane. From here the full wagon descending pulled up an empty truck to the waiting horses whilst the un-coupled loaded wagons were then moved to the smelting/calcining area at the bottom of the slope. All this can be visualised from the grassy embankments. Similarly, the broad-gauge branch line which took the pig-iron away and also brought coal/coke into the works, can be walked for its entire length.

The furnace remains are a different matter. When a blast furnace comes to the end of a campaign, it is 'blown out'. Afterwards the liquid mass below the level of the tapping hole eventually becomes solid, a mixture of metal and refractory forming a conglomerate which has traditionally become known as 'blast furnace bear'[98]. These masses were often a considerable weight and examples taken from a furnace, of the size of those at Seend, have been found to be about 25 tons each[99]. Using the post-

1870 picture as a guide, and viewing the present day scene from the Kennet and Avon Canal bridge, it is possible to locate the bases of the Seend furnaces and substantial amounts of 'bear'. These alone give a fairly reasonable guide to the situation of all three furnaces as they are probably in their original positions. It would have been difficult to move them. Ferrum Towers stands alongside the site, a perpetual reminder of the first chairman of the Great Western Iron Ore, Smelting and Coal Company Limited.

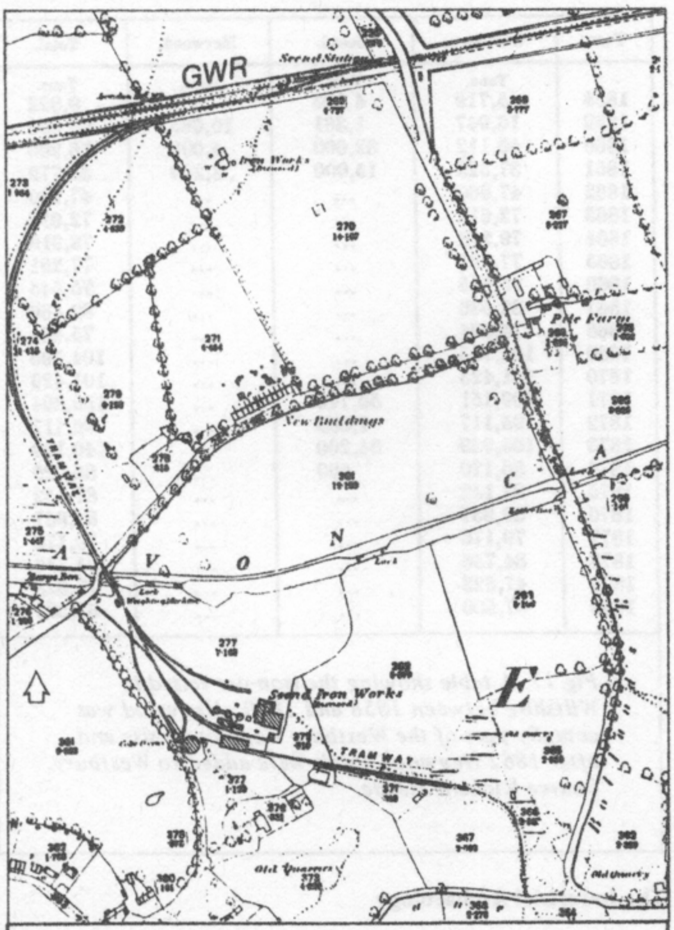


Fig.18 Seend ironworks as shown on the OS First Edition. 25 inch sheet XXXIII/15 surveyed 1885.

The site of the Westbury Iron Company works was well placed both for internal and external transport requirements. From the start there were no difficulties in moving coal and coke, limestone or pig iron. Consequently when the iron works was no longer, the site was used for alternative purposes and nowadays is part of a thriving industrial estate. Some time after the 1939 auction A E Farr, a Westbury-based firm of civil engineering contractors founded in 1906[100], moved in using a part of the site as their plant depot. This use of the blast furnace area has made difficulties for any identification of remaining Westbury Iron Company smelting structures. There is now almost nothing which can be established with certainty as belonging to the iron industry era. The writer was given free access to the site in 1969 and spent many hours wandering and pondering with Aerofilm's picture and the New Westbury Iron Company plan. I think I found parts of the sinter-plant structure which may still be there. Perhaps the only positively identifiable remains are large ponds near Westbury station which are the water-filled remains of shallow pits created when iron ore was removed.

There is more to see at the colliery sites connected directly with the iron company. At Newbury (ST 696 498) the coke ovens and headgear have gone, demolished in 1950 , but there is a good example of a limestone beam-engine house and a less good brick built horizontal winding engine building. The line of the railway link to the GWR at Mells Road can be traced quite easily for most of its length and indeed for the last few hundred yards (ST 713 572), is still in use within the Associated Roadstone Company's works. Further west at Moorewood (ST 642 496) the horizontal engine house is used as part of a residential site and it is possible to trace sections of the tramway.

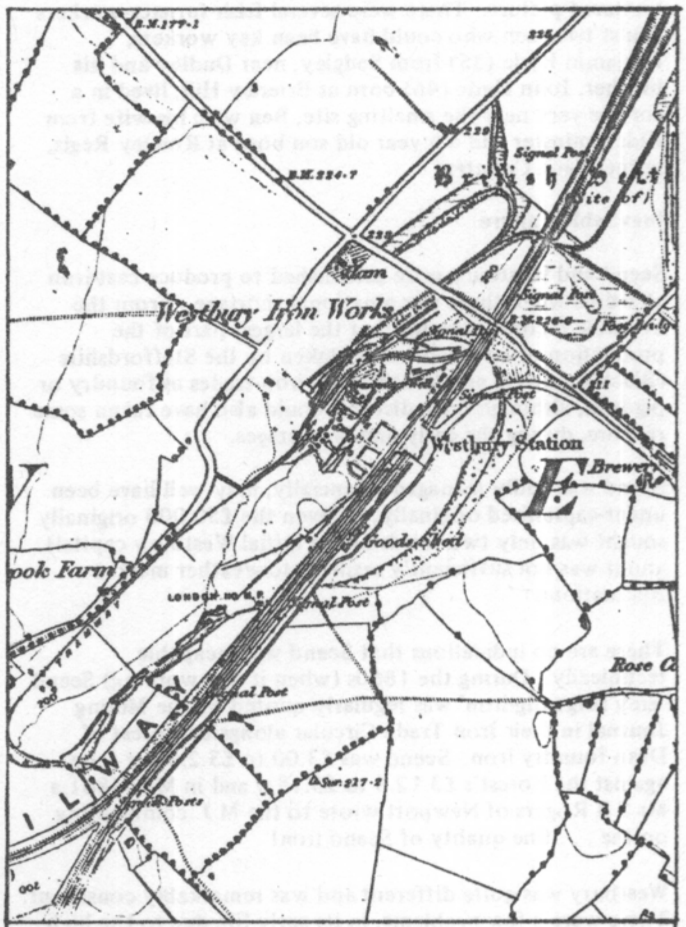


Fig.19 Westbury ironworks on the OS First Edition. 6 inch XLIV (NE) surveyed 1884-6.

What we do not know, and possibly never will, is the impact that Wiltshire iron must have made on the iron-based manufacturing firms in the area. Many firms would have benefited from the availability of a local iron-producing industry and there must be bollards, bridges, cranes and gate-posts still existing in the district.

Appendices (by Keith Gale)

During the research which made this article possible two interesting documents were discovered. The first was a dyeline print of a plan, undated but obviously post-1903, as it was titled *The New Westbury Iron Company Limited: Plan of Westbury Ironworks*, and the second was a copy of the auction catalogue issued at the time of the public sale in February 1939. Both of these items were passed to Keith Gale for his comments which are printed below.

Appendix A

The New Westbury Iron Company site plan

Introduction

This plan was certainly prepared before 1929, for an aerial photograph taken in that year shows considerable differences in the layout of the plant. It is unlikely to have been drawn after 1920, when the furnaces were blown out. The most likely date for it is c1902/3, as the New Westbury Co was formed in that year to restart the Westbury furnaces, which were then idle. There is evidence that prior to the restart the works was overhauled and 'electric light was fitted throughout'. A lighting station is shown on the plan. It is therefore reasonable to assume that the plan represents the Works as it was when restarted in 1903.

Points of interest (general)

1) *In broad terms the plan shows a typical late 19th/early 20th century two furnace plant. Having said that, it is necessary to point out that in detail there was no such thing as a typical plant of the period - or of any other period. It has been said that there have been as many blast furnace layouts as there have been blast furnace managers and this is substantially true.*

2) *It is typical in that, like many other two furnace plants it could not work more than one furnace at a time. Even if the blowing engine could blow two furnaces (we have no details, so it is impossible to say) at least three hot blast stoves were needed for each furnace - one on air and two on gas at any one time. The plan shows five stoves. It was useful to have a fourth stove. This could be cleaned and be ready to put back into service when required. Cleaning was quite a problem when raw gas was used. This was the case at Westbury; there was no sign of even a primary dust catcher. Raw gas firing of stoves and boilers was common at the time; Westbury was in no way unusual in this respect.*

3) *Another typical feature is that some items of plant were badly sited for both operation and maintenance. Thus, for example, No 1 furnace is too close to the blowing engine house for a third stove to be installed. The 'New Kilns' are so sited as to make the incline approach awkward and the haulage arrangements are far from good. In fact the haulage rope drum is driven by an extension of the water pumping engine shaft. Two independent engines would have been much better.*

But it is easy to criticise and the matter must be seen in context. It is known that the furnaces were rebuilt more than once before 1900. Ideally, when making extensive alterations the thing to do would be to build a completely new plant on a separate site. If unlimited space - and more importantly, money - had been available, this might have been done. There are some instances where it was, but there are many more where it has clearly been necessary to improvise and adapt. The Westbury management must have had to do the best it could with the money available and the plant just 'grew' over the years, like many of its contemporaries.

Points of interest (specific)

a) *The slag crusher and engine (presumably with its own boiler, which is not shown) calls for little comment. It is sited adjacent to the slag tip and has its own standard gauge sidings off the GWR. There is no indication how the slag, which would include some fairly large lumps, was moved from the tip to the crusher. Presumably it was done manually, with wheelbarrows. No screens are marked but there must have been something to grade the crushed slag, if only a simple trommel. A building marked 'Mould house' adjoins the crusher; it is not clear what purpose this served.*

b) *The slag tip is absolutely orthodox for the period. Slag was tapped into narrow gauge rail bogies with lift off sides - typically the box so formed was 6 ft square by 2 ft high (1.8 x 0.6 m) - and allowed to solidify before being hauled to the tip. When it neared the tipping point it passed under a gallows-type hoist and the sides were lifted off, leaving the block of slag exposed. At the tipping point one rail was shorter than the other and the bogie tilted sideways, shooting its lump of slag off. On its return to the furnace the bogie sides were replaced by the hoist. Haulage was usually by horse, the animal stepping smartly out of the way just before the bogie reached the tipping point. This arrangement lasted at Level New Furnaces, Brierley Hill, until they were blown out finally in 1954, though in the last few years of operation a Fordson tractor had replaced the horse.*

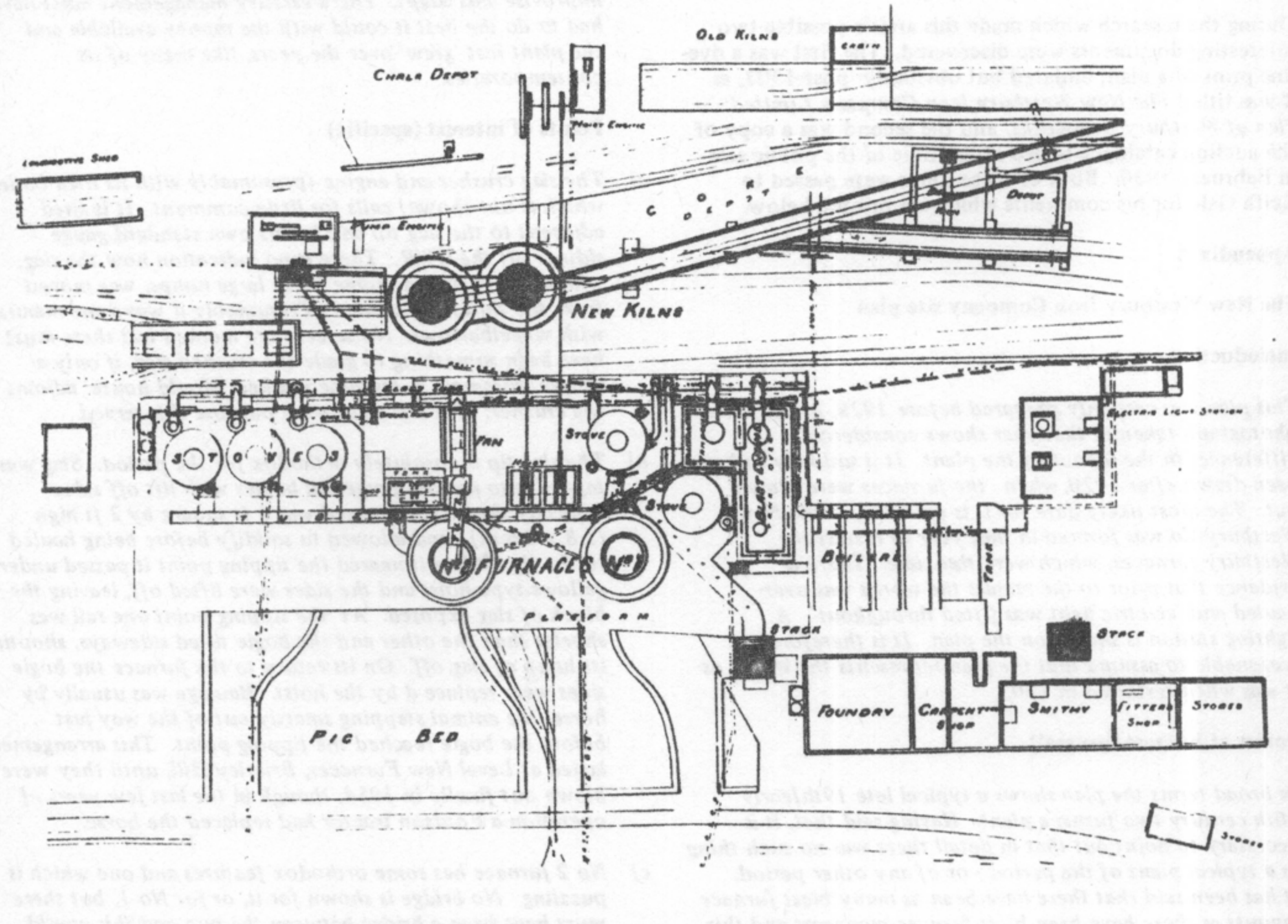
c) *No 2 furnace has some orthodox features and one which is puzzling. No bridge is shown for it, or for No 1, but there must have been a bridge between the two and this would connect with the hoist to carry the charging barrows. There is a pig bed at No 2 suitable for two furnaces but may have been partly left over from a previous layout. Or it may have been put down to allow for a third furnace to be built later. The layout of Nos 1 and 2 furnaces and the hoist is orthodox. So is the standard gauge rail siding across the front of the pig beds.*

As for the stoves, they have clearly been put where there was room for them. They are quite well sited for use with No 2 furnace but awkward for No 1, and for the stove stack, which stands in front of the blowing engine house. Long flue runs, however, were not uncommon.

The puzzling feature of No 2 furnace is the 'Tube' extending from the centre of the furnace to the gas main at the back. This seems to indicate that the gas was taken off from the centre of the tunnel head. It could have been; The Darby gas offtake, used at Brymbo in the second half of the 19th century (and into living memory), had a central offtake and an annular bell, but it was rare. It was more expensive to build and maintain than the orthodox throat port and downcomer and had no particular operating advantages. To add to the mystery there is an item marked 'Fan' underneath the 'Tube' between the furnace and the gas main.

Whether or not the plan is intended to show a Darby gas offtake it is not possible to say. Gas was certainly taken off the Westbury furnaces but the question of how much must remain unanswered unless further evidence is discovered.

d) *The plan shows, from the relationship of the pig beds to the slag roads, that the tap holes and slag notches were at about 45^{o} to each other; this was orthodox.*



Part of the New Westbury Iron Company plan.
The complete plan measures 60 inches (1.5m) by 30 inches (0.76m) and could not satisfactorily be reduced for publication. The slag-tip, coke-ovens and railway sidings are not therefore shown.

e) *No 1 furnace was, as shown, incapable of working, for there are no slag roads. They could, however, have been laid quickly if required.*

f) *The blowing engine house, of L shape, had two engines, as is shown by the two connections to the cold blast main. One engine was, from the shape of the house, a rotative beam. The other engine was smaller and, judging from the plan, of the vertical tandem type. The engine house is marked 'Tank over'. This was almost invariable with condensing engines.*

g) *'Pipes' are shown leading from the engine house tank, and from another tank near No 2 furnace, to a point marked 'Water supply' in between the two furnaces. A pipe also leads from this point to each furnace. These are clearly for the tuyere water and is a very good idea to supply it from elevated tanks. There is a constant supply and head without interruption from pump failures (provided that the tanks are kept full) and the arrangement is better than direct pumping.*

h) *Only four boilers are shown, which seems a bit on the low side. But underboilering was not uncommon; boilers cost money. It is impossible to say from the plan what type the boilers were or, since no scale is given to estimate their size. The gas main is connected to the boilers, as would be expected. A point which is not generally known is that when a boiler was fired on raw gas, a small coal fire was always kept burning on the grate. This prevented explosions if the gas supply was interrupted (as at tapping time) and the gas was sometimes so dirty that it would only burn with a bit of help.*

i) *In front of the boilers is a range of buildings marked 'Foundry, carpenters' shop, smithy, fitters' shop and stores'. These would be used for maintenance purposes, though the foundry, which appears to have two cupolas, could have made castings for sale. Some of the simple maintenance castings, such as bogie wheels, would have been made in open sand in the pig bed; this was normal practice. But the more complicated shapes and cored castings would go to the foundry. There is no indication that any form of mechanical power was provided in the workshops, though something must have been installed to blow the cupolas. One might expect that the fitting shop would have at least a lathe and a drilling machine, but if it did these machines could have been hand or foot powered. Some of the little maintenance shops at ironworks were astonishingly versatile and self-sufficient.*

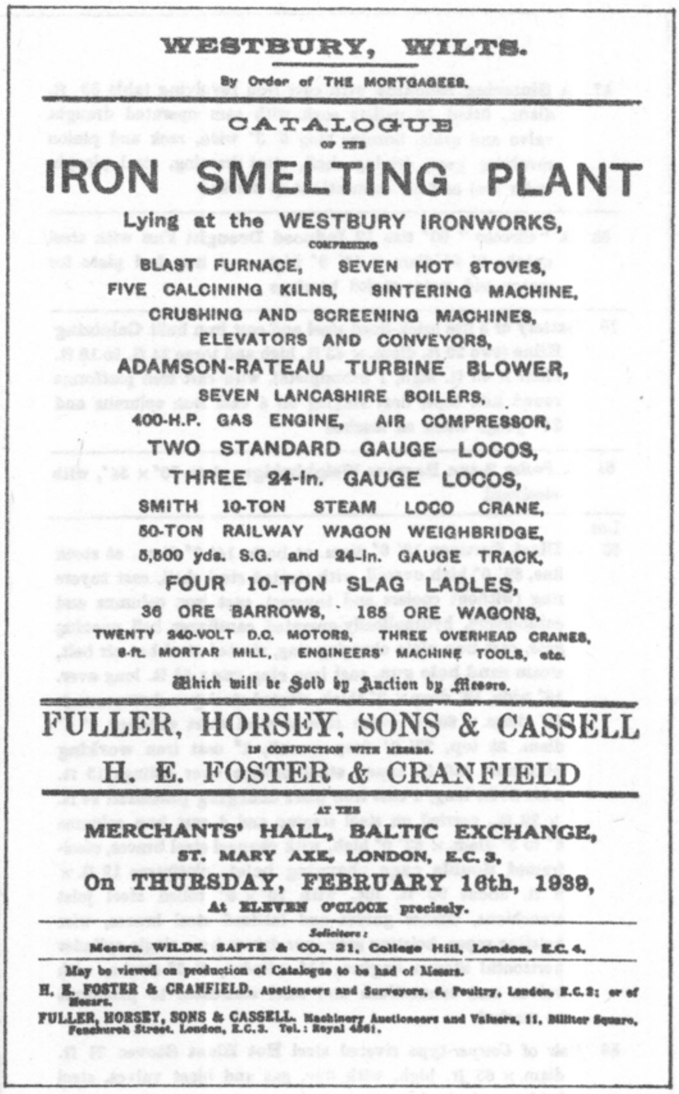
j) *The 'Electric light station' near the boilers is not shown in sufficient detail to give any idea what the equipment was. There appear to be two vertical engines belted to dynamos; that is all that can be seen.*

k) *There are two batteries of coke ovens (24 and 25 ovens respectively) but no indication of their type. A 'Disintegrator plant and elevator', complete with steam engine, is at the end of the 25 battery. It is not clear what this is but it might be a coal crusher. Nor is it clear how the coal got to the coke ovens. There is a narrow gauge track across the top of each battery and it would appear that wagons were lifted to these tracks by the 'elevator'. Coal came to the works by GWR and in the bottom corner of the site there are standard gauge sidings, one with a narrow gauge track parallel and close to it, which could have been used for coal reception and storage, though the area is not identified on the plan. From this area it was possible to get, by a rather roundabout route, to the 'disintegrator'.*

l) *Movement of the coke from the ovens to the furnaces is easy to follow. The two batteries faced each other and the flat areas, or benches, on which the coke was quenched, were only separated by a standard gauge rail track. This led to what is called, on the plan, a coke 'depot' behind No 1 furnace, partly underneath the incline leading to the new kilns. This is a congested area but the coke, if tipped out here, could have been hand loaded to barrows and wheeled to the furnace hoist.*

m) *It is obvious from the plan (if we did not know it already) that the operation of Westbury was labour intensive. But in this it was only following the custom of the times. Labour was fairly cheap, machines were expensive and, in some cases, not then available.*

n) *Westbury had one other feature in common with ironworks of the period. If it employed, of necessity, quite a lot of labour in the works, it expected and got, a useful contribution to production from all its employees there. In the office it was very different. Five rooms sufficed to house the manager and his clerical staff, which could have been no more than five or six and they did all the clerical work necessary to control upwards of 200 men. It might be interesting to compare this producer/non-producer ratio with the practice of today.*


WESTBURY, WILTS.

By Order of THE MORTGAGEES.

CATALOGUE
OF THE
IRON SMELTING PLANT
Lying at the WESTBURY IRONWORKS,
COMPRISING
BLAST FURNACE, SEVEN HOT STOVES,
FIVE CALCINING KILNS, SINTERING MACHINE,
CRUSHING AND SCREENING MACHINES,
ELEVATORS AND CONVEYORS,
ADAMSON-RATEAU TURBINE BLOWER,
SEVEN LANCASHIRE BOILERS,
400-H.P. GAS ENGINE, AIR COMPRESSOR,
TWO STANDARD GAUGE LOCOS,
THREE 24-In. GAUGE LOCOS,
SMITH 10-TON STEAM LOCO CRANE,
50-TON RAILWAY WAGON WEIGHBRIDGE,
5,500 yds. S.G. and 24-In. GAUGE TRACK,
FOUR 10-TON SLAG LADLES,
36 ORE BARROWS, 165 ORE WAGONS,
TWENTY 240-VOLT D.C. MOTORS, THREE OVERHEAD CRANES,
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Appendix B

Sales Catalogue for New Westbury Ironworks

Crusher section Lots 1-33

This includes a coke crusher as well as one for iron ore, which I should expect as the works had a sinter plant. A blast furnace needs lump coke of reasonably uniform size. Small coke (breeze) is a nuisance and too much of it could cause serious operational difficulties. But a sinter plant needs breeze. Coke is broken during transport and the small pieces could be screened out and used in the sinter plant. This, however, would not provide all that was needed, so some coke crushing had to be done.

Storage house Lots 33-54

Lot 47, sintering machine, is interesting. It was quite small and would not be capable of providing all the furnace burden but this again is in keeping with the practice of the time. Sinter burdens of 100% were not used before 1952 and even after that not widely at first.

I do not know why Westbury used sinter but presumably the ore was friable and produced a lot of fines. Ore fines are an even bigger source of trouble in a blast furnace than coke fines. A proportion could be used or they could be screened out and discarded. If the fines content was high the best idea was to sinter the fines.

Fan house Lots 55-70

Lot 58, Sirroco induced draught fan was for the sinter machine. To sinter iron ore it was crushed (if necessary) and mechanically mixed with coke breeze. This was fed to a travelling grate box or pallet and passed under an ignition hood where burning gas (blast furnace gas as a rule) ignited the breeze on top. As the pallet travelled on it passed over a series of suction chambers (wind boxes) and the combustion was completed right through the coke/ore layer. This caused the mixture to agglomerate into an open-textured mass or 'cake'. At the end of its travel (or when it had nearly turned through a complete circle as on the Westbury machine) the pallet was inverted and the sinter cake fell off into a hopper. As it fell, it broke into pieces. Lumps were sent to the furnace, fines were screened out and returned to the sinter machine.

Blast furnace Lots 76-106

Nothing out of the way here. Calcining kilns were common with carbonate ores (as Westbury must have been). Calcining drove off combined carbon dioxide and converted the ore to oxide, in which form it was suitable for reduction in the blast furnace. Only the ore used in lump

47 A **Sintering Machine** with cast iron revolving table 33 ft. diam., fitted 16 pallets each with cam operated draught valve and grids, burning ring 6' 3" wide, rack and pinion revolving gear, driving shaft, steel framing, steel plough, water seal and air connections as marked

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58 A "**Sirocco**" 60" size 12 **Induced Draught Fan** with steel uptake 2' 6" diam. × 48' 0" high, cast iron bed plate for motor and water-cooled bearings

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78 Battery of 5 fire brick-lined steel and cast iron built **Calcining Kilns** (two 20 ft. diam. × 43 ft. high and three 24 ft. to 18 ft. diam. × 43 ft. high, 1 incomplete), with cast iron platforms round kiln tops, deal staging on 4 cast iron columns and 24" gauge track as marked

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81 A *Pooley* **2-ton Barrow Weighbridge**, plate 70" × 34", with steelyard

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Lot
85 A **Blast Furnace** 18' 6" diam. at bosh, 14' 0" diam. at stock line, 82' 0" high overall, with riveted steel shell, cast tuyere ring (without coolers and tuyeres), cast iron columns and entablature, hydraulically-operated cantilever bell opening gear, cast iron plate charging ring, riveted steel hot air belt, steam **mud hole gun**, cast iron **slag runs** 58 ft. long aver. 18" wide, 18" deep × 2" thick, riveted steel **gas downcomer** 45" diam. × 60' 0", with riveted steel **dust catcher** 7' 6" diam. at top, 27' 0" deep overall, 1" cast iron **working platform** 650 ft. super, **steel bridge** over sidings 13 ft. wide 21 ft. long, a cast iron plate **charging platform** 24 ft. × 22 ft., carried on steel staging and 4 cast iron columns 6" to 3" diam. × 62' 0" high, with channel steel braces, steel-framed **double cage charging hoist**, platforms 12 ft. × 9 ft. about 90 ft. lift, with 10" × 6" rolled steel joist stanchions, timber guides and latticed steel braces, wire hoisting ropes, hoisting gear spur driven by a single-cylinder horizontal steam engine, 15" cylinder, 2' 3" stroke, with valves and connections and steel staircases to platforms as marked

86 Pair of *Cowper*-type riveted steel **Hot Blast Stoves** 21 ft. diam. × 65 ft. high, with flue, gas and blast valves, steel ladder and staging as marked

87 **Three ditto** (one 20 ft × 65 ft., one 18 ft. × 65 ft. and one 20 ft. × 60 ft.), with flue, gas and blast valves and connections as marked

88 **Pair ditto**, *Whitwell* type, 18 ft. diam. × 50 ft., with valves and connections as marked

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Lot
104 A **6-ft. Underdriven Mortar Mill**, by *C. D. Phillips*, with cast iron runners 36" × 14", cast pan, scrapers and single pulley drive

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122 An **Adamson-Rateau Turbo-Blower** (designed for an output of 20,000/22,000 cubic ft. free air per minute, 6 to 10 lbs. pressure at 2,700/3,100 r.p.m.) with **high pressure impulse-type steam turbine direct coupled to a single flow turbo blower**, *Hick Hargraves* **Jet Condenser**, *Brequet* **air ejector**, belt-driven **centrifugal pump** with 8" outlet, outer bearing, band pulley and half coupling for motor drive, tubular oil cooler, atmospheric exhaust, valves, gauges and connections and fittings as marked

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128 A *Kynock* **400-h.p. 4-cylinder Horizontal Gas Engine**, type KM1, with magneto ignition, *Jahn* governor, flywheel 8' 0" diam. × 18" face with hand barring gear, outer bearing and half coupling, 4 starting bottles, forced lubrication, variable gas admission, valves and connections as marked

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Lot
133 Two 200-h.p. **Suction Gas Plants** with generators 5' 6" diam. × 7' 0" high and 1 hand blower, 2 riveted steel scrubbers 4' 6" diam. × 10' 0", 1 ditto 2' 6" × 10' 0", 2 vaporisers, valves and connections as marked

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form was calcined, not that for sintering, which had the same effect.

Lot.81. A barrow weighbridge I would expect to find; furnace charges were proportioned by weight.

Lot 85, the blast furnace, was quite modern for its day. The 'mud hole' gun should be, properly, 'mud gun'. It was used for stopping the tap hole after tapping.

Lots 86, 87, 88. Total 7 hot-blast stoves more than enough for one furnace which needs only three with, perhaps, one for spare. But the stoves were obviously for a two furnace layout, although by 1939 only one remained.

The Cowper stove was the first (1857) of the regenerative type and the most popular. It is still used, in modified form, today. The Whitwell stove was one of several variants of the Cowper principle introduced in the 19th century. It was fairly widely adopted but never really competed with the Cowper.

Lot 104 Mortar mill. *A common blast furnace ancillary. It was used for mixing clay for stopping the tap hole.*

Blower house Lots 122-127

I would expect to find a turbo-blower at that time. There must have been a beam engine at one time for the house was still there (Lot 92).

Power House Lots 128-133

Lot 128. To find a Kynoch gas engine is interesting. I knew that Kynoch (the ammunition firm) made gas engines from about 1901 to 1921 but I have never before come across one installed. It would take its gas from Lot 133 Suction Gas Plant. Partly cleaned blast furnace gas would not do for an engine.

Oxide plant Lots 135-143

Evidently Westbury had a trade in iron ore (oxide), which was used for town gas purification and in open-hearth steel furnaces and puddling furnaces.

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An Oliver at Warley, West Yorkshire, AD1349-50

Helen Jewell, David Michelmore and Stephen Moorhouse[1]

Any addition to the small number of documented medieval tilt hammers in England deserves our attention. The project to publish the Wakefield court rolls, one of the most extensive runs of English manorial records,[2] has produced the earliest reference to an oliver yet found,[3] although machines of this sort were adopted at an earlier date on the continent.[4]

Two fourteenth-century references to English olivers have previously been recorded, both in the north-eastern part of the country.[5] The earlier of these is in a lease of a bloomery at Creskeld, in Wharfedale, dated 1352,[6] and the second is contained in a lease of 1375 of another bloomery, situated in County Durham.[7] The purpose of the present note is to draw attention to the presence of an oliver in the Calder Valley in 1349/50, the earliest English reference yet found to such a machine by some three years. One of the two Wakefield court rolls for that year records the sale of underwood for an oliver for a period of twelve weeks:

Subboscum venditum xviiis. De subbosco vendito pro uno olyver per xii septimanas, per septimana xviiid.[8]
(Sale of underwood 18s. From underwood sold for one oliver for 12 weeks at 18d per week).

The reference to fuel indicates that the word oliver is here used to describe the whole bloomery rather than just a tilt hammer, as has already been suggested both with regard to this word and to **martinet**, its French equivalent,[9] and is parallelled by the use of the word 'hammer' to describe Sussex forges at a later period.[10] It is nevertheless likely that the bloomery in question included a tilt hammer and that this was water-powered.[11]

Other, near-contemporary, references to forges in the manor of Wakefield are usually described by the word **forgia** and these were leased at a higher rent than that for the oliver recorded in 1349/50. For example, in 1342 two forges in the Outwood of Wakefield were leased to Richard Short and Simon Brown for a period of thirteen weeks and two days at a rent of 15s. per forge per week.[12] In the following year Richard was leased one and a half forges in the same area for a period of thirteen weeks at a rent of 20s. per week, as well as a forge and ironstone mine in the New Park of Wakefield for eighteen weeks at a weekly rent of 14s.[13] The Outwood and the New Park, which sustained a major iron-working industry during the Middle Ages, were situated in gently rolling countryside to the north and west of Wakefield.[14]

The oliver recorded in 1349/50 was leased without the right to mine ironstone, as only payment for underwood was due to the lady of the manor rather than rent for the forge itself, although the unusual form of the entry may be partly due to the division of the manor following the death in 1347 of John, eighth and last earl Warenne. His estranged widow, the Countess Joan, retained dower rights in part of the manor, but the remainder was in the custody of Queen Philippa, having been granted by Edward III to his son, Edmund Langley, whilst the latter was still a minor. The roll recording the existence of the oliver relates to the portion of the manor held by the countess and is the first such roll produced during the period when the lordship of the manor was divided. It shows a number of other unusual features, but some of these are due to a dearth of tenants as a result of the Black Death.

The oliver of 1349/50 cannot be precisely located, although since the reference to it follows two entries recording rent from Warley mill and from the tolls of Halifax, it evidently lay in Warley graveship.[15] This area, situated on the Pennine gritstones, consists of part of the northern side of the Calder Valley and its tributaries and possesses numerous streams eminently suitable for driving water-powered machinery. It is possible that water-driven tilt hammers would be adopted in hilly terrain of this sort in advance of the flatter parts of the manor to the east. A fifteenth-century reference in the court rolls indicates that olivers were later to be found on the Coal Measures also, as in 1479 a parcel of land called **Olyver**, near **le Smethys** in **Thurstonhagh**, was leased for three years to John Woderove. Included in the grant was a newly constructed pond and the provision that if the lord erected any other forges there, the lease was to be void.[16] This provision indicates that the place-name **Olyver** was applied to an active forge and that it probably contained water-powered machinery, necessitating a pond to maintain a head of water for the water-wheel. **Thurstonhagh** was the name of a now cleared demesne wood in the south-eastern part of Crigglestone township, in the graveship of Sandal. The location of the forge is probably indicated by the adjacent field-names of Cinderhill and Lancar Smithy recorded in the Crigglestone tithe apportionment, respectively centred at SE 32261505 and SE 32301486, both fields significantly being located within the area of the wood of **Thurstonhagh**. The area has been open-cast mined, but a now filled-in pond shown on the 1st ed. 6 in OS map, sheet 248, immediately to the north of the fields indicated by the tithe map, may be that created c 1479.[17]

The manor of Wakefield extends over geological formations rich in iron-ore deposits. The court rolls show that these were extensively exploited by its tenants throughout the Middle Ages.[18] There is abundant evidence to suggest that geographically widely dispersed smiths and charcoal burners were working under a single entrepeneur. Many of the licences granted were of short duration, often no more than a few weeks and those mentioned above for work in the New Park and the Outwood appear to be exceptional Evidence for over sixty forges on the demesne lands has been identified from the court rolls. Little recent fieldwork has been carried out to identify them on the ground, and most of the iron-working sites located earlier this century in the upper Calder Valley[19] cannot be related to these new references. Systematic searching of the unpublished court rolls, coupled with fieldwork, is likely to reveal evidence for many more sites and shed further light on the organisation and operation of the extensive and intensive iron-mining and iron-smelting industry in the manor during the Middle Ages.

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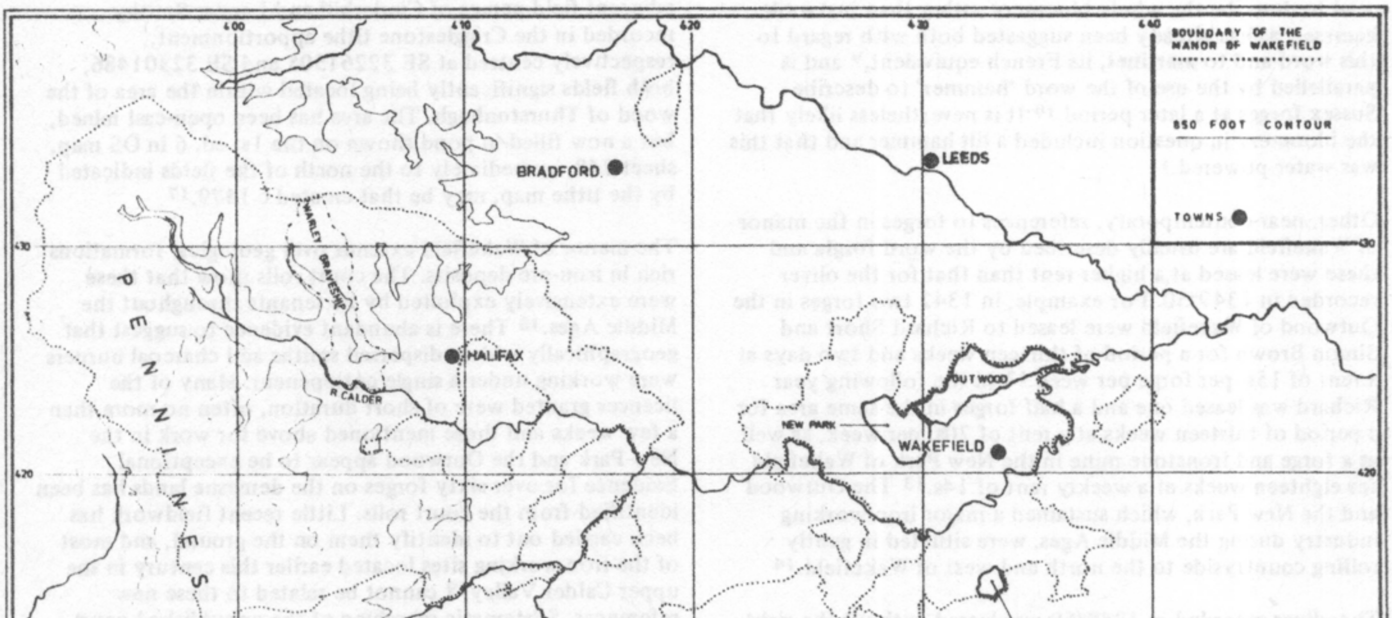

Some medieval forge sites in the manor of Wakefield

Iron smelting at Isthmia

W Rostoker and E R Gebhard

Abstract

A substantial quantity of slag has been recovered during excavations at the Sanctuary at Isthmia at a level that can be dated to or before the 5th c. B.C. The slag is characterized as typical of a "bloom iron" smelting furnace. Inasmuch as slag is usually a residue left on the site of the processing it is concluded that iron smelting was performed at or near the Sanctuary. Other artifacts recovered from the excavations demonstrate that various manufacturing activities functioned at or near the Sanctuary..

Introduction

The Sanctuary of the god Poseidon at Isthmia stands with Olympia, Delphi and Nemea as one of the four great panhellenic religious centers of Greece. The sanctuaty lies about 10 miles east of the city of Corinth on the narrow isthmus that connects the Peloponesus with central Greece. Corinth controlled the festival and cult place from as early a time as tradition records and may well have been responsible for its founding. The first temple of Poseidon was built shortly after 700 B.C., but the presence of a few earlier votive objects shows that a cult had been established there perhaps a century earlier.

In honor of the Isthmian Poseidon, contests which were predominantly athletic were held every two years. They assumed the form they were to retain for most of their history as the result of a reorganization in 582 B.C. (or 580 B.C.), although some additions were made in later years, (Broneer, 1973, p.4, n.14). At the time of the biennial festival large numbers of visitors from all over the Greek world would have gathered there to celebrate the games and honor the god. They would have brought offerings and sacrifices, perhaps many of them actually purchased at the site and even manufactured there.

Around 480-470 B.C. fire destroyed the first temple which was replaced within 10-20 years by a new shrine on the same site. (Broneer, 1971, p.3, n.7). Debris from the earlier temple was removed from the rocky plateau and dumped in the deep gully lying immediately to the north and in the depression to the east. These two areas thus constitute a rich deposit of building materials from the temple and objects that had been housed in or near the temple at the time of its destruction. These latter include bronze and terracotta figurines, fragments of armor and weapons and some pieces of sculpture. Fire continued to plague Poseidon's shrine. In 390 B.C. the classical temple was badly burned; its roof collapsed and fire severely damaged the cellar walls and peristyle. Material from this destruction too was buried in the depressions north and east of the temple. After extensive building repairs were carried out in the later 4th c. B.C., the sanctuary appears to have been undisturbed until its sack by Roman troops under the command of the consul Mummius in 146 B.C. following their devastation of Corinth. This brings to an end the period of Corinthian domination for the next century or more and concludes the time period covered by this study.

Discovery of the sanctuary came in 1952 when Oscar Broner uncovered the foundations of the ruined temple to Poseidon. In the decade following, systematic excavations under his direction laid bare the temple and the area surrounding it, including a smaller Roman temple to the wrestler god Palaimon, which was built over the first stadium.

At some distance from the sanctuary a later stadium and theater came to light. (Broneer, 1971, 1973: Gebhard, 1973: including references to all earlier publications). The objects from the sanctuary are housed in a museum near the site.

In this and following papers the slags found at Isthmia have been analyzed to show the nature of the manufacturing operations carried on at or near the sanctuary. These analyses are a part of a project wherein all artifacts recovered from the sanctuary and dated to the period ca.800 to 146 B.C. were inspected. Our objective was to determine as far as possible what raw materials were used, the methods of manufacture, and where were the objects made. The project was supported by a grant from the National Endowment for the Humanities and gifts from private individuals. Permission to work at Isthmia was granted by the Greek Archaeological Service through the ephor for the Argolid-Corinthia, Mrs. Krystalli. Our gratitude for valuable assistance rendered goes to Professor Henry Immerwahr, director of the American School of Classical Studies at Athens and to Dean Karl J. Weintraub of the University of Chicago.

The need for water must always have been a problem at Isthmia, one which would have been especially acute when large crowds gathered for the festival. One attempted solution to the problem appears to have been the digging of a large circular pit to serve either as a well or reservoir. The pit is located 43 m. south of the SW corner of the classical temple and measures 5 m. in diameter with a depth of 19.75 m. (Broneer, 1973, pp.22-24; 135-136). Evidently it was a failure since it was soon abandoned to be used as a rubbish dump. Below the first 2.20 m. of mixed fill the pit contained material from Mycenaen times to the middle of the 5th c. B.C., including a large quantity of pottery, objects of terracotta and bronze, a few inscriptions, fragments of sculpture and a large number of uncut stones mixed with earth. Pottery belonging to the latest period was found in the lowest levels, showing that the pit was filled in a relatively short period of time, perhaps in connection with landscaping of the site after the classical temple was completed. The lowest deposit, from 15.80 to the bottom at 19.75 m. below the rim, contained a great deal of pottery, pieces of which could be joined from the highest and lowest levels of the stratum so that it was doubtless thrown in at one time. (Broneer, 1973, p.136).

In such a mixed context it is not possible to say how much earlier than 450-425 B.C. the slag was produced. Nevertheless, it is unlikely to have remained exposed for a long period without being disposed of and covered over, although the mixture of pottery and other objects from the 7th to mid 5th c., much of it fragmentary, shows that earlier refuse deposits were being used to fill in the pit. No remains of the furnaces that produced the slag have been identified, but it is not likely that such material travelled far from its place of discovery, which thus would have been in the immediate vicinity of the temple.

Metalworking would have been a vital part of the building operations for the Classical temple in the 460s. B.C. Clamps were used in the walls, dowels in the colonnades and nails held the wooden elements of the roof. Fittings for the doors and interior arrangements would also have been needed. In most cases iron seems to have been the preferred material for building needs, the rarer and more costly bronze being reserved for votive offerings and objects used in connection with the cult (large and small statues, buckets, tripods, pitchers, bowls, and the like). In Corinth, material from smelting and foundry operations has been recovered from the north and south sides of the later agora, not far from Temple Hill which was the site of the major temple of the city. The earliest remains are from a bronze casting operation in a floor dated to the 6th c.B.C. context. (Mattusch 1977, 380-382; Williams and Fisher 1973, 31-32; 1971, 23-24). Industrial activity was evidently not separated from houses and shrines in the heart of the community and Corinth was noted as a city where craftsmen were held in higher regard than was usual among the Greeks. (Roebuck 1972, 121-122). In a similar way at Isthmia, the metal workers appear to have set up their workshops near the temple to supply the needs of the sanctuary and its visitors.

Preliminary Description of the Slag Lumps

At least 50 Kg of this slag are held at the Isthmia Museum. Many of the slag lumps have a characteristic hemispherical shape with a depression on the planar surface as if the liquid slag had been run into or collected in a bowl-shaped cavity and allowed to freeze. However the shrinkage depression indicates that the whole quantity was liquid at one time and solidified in one cooling cycle. The slag is very porous typical of gas evolving during freezing and similar to the fracture appearance of a modern blast furnace slag (although of much different color). Similar specimens of slag exist at the museums of Olympia and the Athens agora.

Externally the slag lumps have the pigmentation of rust, i.e. weathered iron. A fresh fracture discloses a grey-black colour. The slag can be readily crushed to fine powder and a strongly magnetic component can be separated with a permanent magnet. The magnetic separation accounts for about 29% by weight of the slag. This is likely to be an overestimate because individual particles are likely to be partly magnetic and partly non-magnetic.

Slag Analysis

X-ray diffraction powder patterns give a clear set of well defined lines which, in all but a few cases, are accounted for by the spinel structure - typically Fe_3O_4 - and by fayalite - $2\,FeO\cdot SiO_2$ or Fe_2SiO_4.

An elemental chemical anlysis of the slag from Isthmia is summarized in Table 1. The analysis for calcium was reported as indeterminate but "very high". Since the slag has been buried deeply in an almost pure limestone environment one might expect that such a porous body would be heavily calcified by groundwater over those many years.

Table I

CHEMICAL ANALYSIS OF THE ISTHMIA SLAG

Element	w/o Analyzed	w/o Corrected*	w/o Oxide
Si	5.89	8.84	18.94 SiO_2 or 64.30 $2\,FeO\,SiO_2$
Al	1.09	1.64	3.10 Al_2O_3
Mg	0.51	0.77	1.28 MgO
Cu	0.059	0.09	
Pb	0.008	0.01	
P	0.11	0.17	0.39 P_2O_5
S		0.55	
			30 Fe_3O_4 (by difference)

* Corrected by dividing by 0.666 to account for weak acid-soluble-calcium carbonate (see text).

This was demonstrated by grinding a quantity of the slag to fine powder and adding to it cold dilute nitric acid. When the effervescence ceased despite fresh acid addition, the solids were filtered off. The remaining liquid was clear and colourless. The dried solids were weighed as representative of the original slag. The soluble portion is taken to be calcium carbonate. It was determined that the true slag portion of the recovered lumps is 66.6%, i.e. 33.4% is limestone accretion. Accordingly the elemental analyses have been corrected as shown in Table 1.

The silicon analysis (corrected) permits computation of the fayalite content in the slag. Al_2O_3 and MgO exist only in small amounts. The magnetite content is taken by difference - after acid dissolution the residual calcium content was found to be 0.28% by weight which may exist as CaO or CaS.

Sulphur analyzed at 0.55% which is more than can be associated only with CaS. However there is quite enough magnesium to account for MgS. The combined Ca and Mg is not at a high enough level to be very effective in desulfurizing. It is likely that the porous character of the slag lumps derives from H_2S expulsion during freezing. From the liquidus surface for the ternary system FeO-Fe_2O_3-SiO_2 (Muan and Osborn, 1962) the composition of the slag deduced in Table I indicates a completely liquid state between 1200°-1300°C. This is not an unreasonable temperature to expect to reach in a simple shaft furnace.

Discussion

The fayalite-magnetite slag could derive from any of three pyro-metallurgical processes: (a) "bloom iron" smelting; (b) copper smelting of chalcopyrite and related copper-iron ores; (c) lead smelting where iron ore is added as a flux.

In the case of copper and lead smelting the slag should contain significant amounts of these metals dissolved in

Table II

COMPARISON WITH PUBLISHED IRON SMELTING SLAGS *

Provenance	Date	FeO w/o	Fe_2O_3 w/o	SiO_2 w/o
Isthmia	Latest, 5c. BC	54.67	20.69	18.94
UK, Maiden Castle, Dorset	A.D.24-25	53.00	22.87	15.95
Turkey Sirzi	7-6c. BC	55.65	13.96	8.60
Austria, Noreia	7.6c. BC	48.26	24.29	14.78
Austria, Noreia	4c. BC	55.39	12.62	24.48
Austria, Noreia	Late La Tène	55.72	10.33	20.72
Czechoslovakia	La Tène	51.63	20.08	18.37

* Comparative data taken from Tylecote, A History of Metallurgy, P.43, Table 27.

oxide form. For example, the copper content of the slag in an efficient 20th century copper smelting operation is rarely much below 0.3% by weight (Bray, 1941; Haywood, 1940; Butts, 1943). Smaller operations would be less efficient and copper contents of ancient slags are more commonly nearly 1% or higher (de Jesus, 1977 and 1978; Tylecote, 1962, p.34). In an almost identical fayalite-magnetite slag produced by copper smelting a 1000 gm. batch in our own laboratory, the copper content analyzed 1.2% (Rostoker and Sadowski, 1980).

Appreciable lead is also to be expected in the slag from lead smelting. Lead levels in slag (as PbO) are reported for 20th century operations in the range of 0.72 - 1% Pb (Haywood, 1940; Butts, 1943), Ancient slags seem to run much higher (1-10% Pb) as cited by Dougherty and Caldwell, 1967; Forbes, 1971, p.231.

The levels of copper (0.059%) and lead (0.008%) for the slag from Isthmia (Table I) rules out these possibilities and the necessary conclusion is that the slag derives from "bloom iron" smelting. Table II demonstrates that the slag composition is very similar to others identified as iron smelting slags (Tylecote, 1976, p.43). Note that the oxide analyses have been converted to correspond with those used by Tylecote, 1976. The use of Fe_2O_3 in the analysis is a convenience relating to the coordinate scales of the ternary system. In fact Fe_2O_3 cannot co-exist with fayalite in the ternary system $FeO\text{-}Fe_2O_3\text{-}SiO_2$.

There is some ambiguity as to whether the slag derives directly from the bloom smelting furnace or from the bloom forging furnace. The smelted bloom will bleed slag during reheating for forging. This will be the same slag that is run off from the smelting operation. Indeed the furnaces are very similar in use of charcoal and disposition of air supply. In both cases the gas combustion products will be only weakly reducing because achievement of a temperature consistent with adequate slag fluidity is more important that a strongly reducing condition. If one reasonably assumes that the raw bloom was subjected at least to preliminary forging for consolidation on the smelting site, the actual association of the slag with either operation is unimportant.

Acknowledgements

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Letters to the Editor

Dear Sir,

Medieval Iron

Rowland Parker, in his "Men of Dunwich" (Collins, 1978) at P.79 refers to a dispute of 1228 between the men of Yarmouth and Roger FitzOsbert, Lord of the Manor of Lothingland. Yarmouth accused FitzOsbert of establishing a rival port on the other side of the river - "he causes ships to be unloaded there cum molis ascere et ferro". The author interprets this as either "a wharf, using piles of steel and iron .... or a sort of crane or winding-gear, partly of iron. 'Steel' at that date for either purpose seems most surprising. Molis ought to mean 'mill-stones', though it hardly makes sense; it must be 'mole' or jetty or wharf". Perhaps some of our Latin scholars can comment on another possibility - that the description was that of the cargoes viz. Mill-stones, steel and iron.

Against this is Prof. D. G. Tucker's findings, that "during the 18th century it came to be recognised that finer flour could be produced by the use of stones imported from the Continent" (in Post- Medieval Archaeology; Vol.11, 1977, P.2).

Some slender credence is however given to the possibility in Parker, P.247, where a wreck of 1367 is noted; "A certain ship of Prussia with a cargo of flax, bowstaves and barrels of wax of Osmund Ferro was cast by a storm upon the soil of the King at Dunwich, ...". The word "of" between wax and Osmund obscures the matter slightly, perhaps it should have been "and", or the valuable iron may have been packed in wax to protect it on the long voyage.

Schubert ("History of the British Iron & Steel Industry", 1957) notes at P.111 that comparatively little iron was imported into Britain before 1300, and that another name for Osmund iron was Danzic iron, because it was imported via that Prussian city, where English merchants had a trading station in the 14th century.

H W Paar

Notes and News

A Note on Parkend Ironworks, Forest of Dean

The last of the three blast furnaces at Parkend was blown out in August 1877, and there is no record of activity thereafter. However, in February 1880 it was made known (Lydney Observer, 13 February) that a new company was to be registered in a few days, for the purpose of making steel at the Parkend works, using a Ponsard converting furnace. The process was claimed to combine the advantages of the Bessemer and Siemens-Martin systems, and to have the ability to make steel from any pig iron regardless of the carbon, silicon or phosphorus content.

A prospectus was issued for the Ferro-Manganese Co. Ltd., one director being Edwin Crawshay of Blaisdon Hall; agreements had been made for acquiring the freehold of the works at Rifredi of Mons. Ponsard, together with his rights to work manganiferous mines in Sardinia covering 1000 acres, with an option of another area of like size. Agreement had also been made to acquire Parkend Furnaces and Works. The nominal capital was to be £100,000 in £10 shares. The Rifredi Works were in operation but quite unequal to the demand. It was noted that the steel production of the UK and USA was greatly dependant upon spiegeleisen but ferro manganese was much preferred when obtainable. (Lydney Observer, 12 March).

H W Paar

Readers will be glad to learn that "Aspects of Early Metallurgy" has been revised and reprinted by the British Museum and is now available as publication OP 17 at £5.75. Other publications on early metallurgy also available from the British Museum are "The Iron Age Moulds from Gussage All Saints" by Jennifer Foster, as OP 12 at £2.50 and "Scientific Studies in Early Mining and Extractive Metallurgy". The latter is edited by P.T. Craddock and is in preparation as OP 20.

The Institute of Archaeometallurgical Studies is organising a conference at Eilat in Israel between 14th and 19th

September 1981 which will give readers an opportunity to see the centres of early metal production and museums in this area. Further details may be obtained from S. Golan, PO Box 29784, Tel Aviv.

Book reviews

Susan M Nicholson
Catalogue of the Prehistoric Metalwork in Merseyside County Museums. *Liverpool, 1980, Price £5.00 plus postage and packing.*

Publication of this catalogue is very welcome. It is very well produced with admirably clear line drawings of high standard to a good scale, mostly at half full size. The catalogue will clearly be of much value to typologists. Recently a considerable amount of new catalogue material for prehistoric non-ferrous and ferrous artefacts has been published, and the time would now seem ripe for the production of a series of up to date distribution maps upon the lines originated many years ago by the late Miss L.F. Chitty and Cyril Fox.

From the metallurgical aspect there are specific groups of objects listed in the catalogue which would be well worthy of analyses in order to obtain the composition of the metals. For instance, in the case of the 'Hungarian Collection". The situation in Hungary concerning the nature and composition of the non-ferrous metals used during the early phases is somewhat confused, in question may be native copper, native copper high in arsenic, other alloys which may be classified also as arsenical coppers. Should it be possible to obtain a series of analyses from objects in the 'Hungarian Collection' it would be a valuable help for the solution of these problems.

H H Coghlan

Huggins, P J & R M, "Waltham Abbey: Excavation of Monastic Forge and Saxo-Norman Enclosure 1972-73". *In "Essex Arch. & Hist." 5, 1973, pp127-184. (An off-print in card cover, 56 pp + 2pp plates, by post from R C Gray, 64 Honey Lane, Waltham Abbey, EN9 3BS @ 80p inclusive).*

A careful and detailed report of rescue excavations on the site of an early monastic flint-and-stone walled 3-bay aisled bloomery forge at the monastic home farm of an Augustinian Abbey. The discoveries included evidence of iron smelting and lead and bronze working and a well, lined with oak corks. There was evidence of underlying occupation of the 10th and later centuries. Finds included iron ore, bloomery and smithing waste, bar material, blanks, tools and other iron objects, also a large group of 12th C. pottery. The work contains a good site map, plan and sections of the forge excavations and drawings of the finds.

H W Paar

Paar, H W. An Industrial Tour of the Wye Valley and the Forest of Dean, *1980, London, W. London Industrial Archaeological Society, 24pp, map, illus. bibliog, price 75p.*

This is a concise guide to many important sites for tourists. These include the ironworks of the Soudley Valley, Flaxley Valley, Cannop Valley, Darkhill and Whitecliff, Tintern Wireworks, Coed Ithel, New Weir, and Redbrook where copper was smelted in the 18th century. A series of fine line drawings illustrate the text.

Ian Standing

Gerhard Sperl. Uber die Typologie urzeitlicher, fruhgeschichtlicher und mittelalterlicher Eisenhuttenschlacken. (On the typology of prehistoric, early historical and medieval iron working slags). *Verlag der Osterreichischen Akademie der Wissenschaften, Wien 1980, 68 pp, 61 plates. A5 paperback. No price stated.*

After a dedication to that famous archaeo-metallurgist, Ernst Preuschen we have a foreword and a statement of the problem by Professor Pittioni. The main object of the book is to explain the characteristics of iron slags to the excavator, to answer his queries and to help him in deciding what questions to ask the metallurgist. This is a very laudable aim but in view of the scientific nature of the treatment will only be understood by a scientifically trained archaeologist.

Slags are artifacts which in this scientific and all embracing age of archaeology have to be understood and treated like any other artifact. Table 1 lists the types of slags such as bloom, furnace, tap, cake and smithing that the excavator will come across and gives an alphabetical type number A1 to D3 together with the compounds likely to be present.

The next section deals with the macro- and micro-structure on a level that is to be expected from a metallurgist like Dr. Sperl, but one that is too far advanced for the average non-scientific archaeologist. This section comprises individual contributions by others on such sites as Populonia, Heiligenkreuz, Nebersdorf (Burgenland), Schliefling (Carinthia), Jochberg, and some other sites in Austria. It discusses the problem of distinguishing copper slags from iron slags. Naturally we are given a discussion on the methods of investigation, analytical techniques, mineralogy, etching treatment etc.

Some of the slags from Populonia turn out to be copper slags and it is interesting to see that magnetite is present in most of these slags; iron is not common but copper is present both as metal and sulphide (not matte).

From the point of view of the archeo-metallurgist this is an excellent treatment and one that is well worth translating. It is certainly one of the best treatments of the slag problem that I know.

R F Tylecote

E N Chernykh, Gornoe Delo i Metallurgiya v Drevneyshey Bolgarii (Sofia, 1978). Mining and Metallurgy in Ancient Bulgaria. *388 pp, numerous maps, figs., tables and photographs. 300mm x 210mm. Price 8.50 leva/ 4.35 rubles.*

This very important book covers the history of the exploitation and use of copper and its alloys from c.4800 BC c.1100 BC in an area of south-east Europe which is crucial for understanding the development of prehistoric mining and metallurgy in both western and eastern Europe. It is based on the results of fieldwork and excavations in the early 1970s on ore deposits and ancient mining sites, and also on more than 1200 spectrographic analyses of artefacts from 250 sites, besides study of more than ninety per cent of all prehistoric metal stored in thirty-four Bulgarian museums. In addition, 1552 samples of ores and slags have been analysed in Moscow. Gold objects, of which there are four times as many known from eneolithic contexts in the south-east Balkans as there are of copper, are not covered by the author.

The book is divided into five parts. Part One (pp.9-55) covers methodology and a description of the known copper ore deposits in Bulgaria. A chronological approach is adopted for Parts Two to Four. The Copper Age (eneolithic) is covered in Part Two (pp.56-125), the Early and Middle Bronze Ages in Part Three (pp.126-175) and the Late Bronze Age in Part Four (pp.176-261). Each part contains a detailed description of the types of metal objects of each period. Part Five (pp.262-285) is a wide-ranging summary with a discussion of chronology, of fluctuations in production and of the role of metallurgists in prehistoric society. There follow two appendices;

The first (pp.286-321) N.V. Ryndina and L.B.Orlogskaya discusses the results of metallographic investigation of sixty-two objects, most of them dating to the eneolithic, and the second (pp.322-323) by A. Raduncheva and E. Chernykh summarizes the archaeological material recovered from eleven early mining sites. The book ends with a very useful bibliography (pp.324-329), statistical lists of analyses, and tables of results of spectrographic analyses (pp.330-386).

For the metallurgist, there is an interesting comparison (pp.14-16) of the results of spectrographic analyses carried out in Moscow with those carried out in Stuttgart and published in SAM-2 (1968). Chernykh has been able to compare directly the Moscow results with 78 of the 115 analyses of Bulgarian material carried out by Stuttgart, and he found several discrepancies (fig.2, between pp.14-15) The Moscow techniques were more sensitive than those used by Stuttgart but the results were compared to the same threshold. Tin was found to have a very good agreement between the two laboratories, and bismuth was reasonably good as were silver, antimony, arsenic and nickel. There was more difficulty with lead and a distinct discrepancy with cobalt. The latter Chernykh believes to be due to a different sampling method.

The ore-bearing zone in Bulgaria is a relatively narrow strip running diagonally from the Strandzha Mts. in the south east to the Vidin Balkan in the north-west (fig.3, p.18). Chernykh divides this into six areas - Strandzha, N.Thracian, Panagyurishte, Vratsa, Vidin and Rhodope. Of these, The N.Thracian was the most important in prehistory, as it includes the sites of Ai Bunar, Tymnyanka, Khrishteni and Rakitnitsa near Stara Zagora, and also Prokhorovo. All of these definitely were, or were likely to have been, exploited in the eneolithic. Ai Bunar is now well-published in English (**Proc.Prehistoric Soc., 1978**) though some more detail is given here. The copper ore at Ai Bunar is polymetallic and relatively rich in zinc and lead. Chernykh notes how little is known of Turkish ore deposits bordering with Bulgaria.

Throughout his book, Chernykh attempts to define geographical and socio-economic territories relating to metallurgy, which it terms Focal Areas, Provinces and Zones (pp.17, 262-3). A metallurgical **focal area** (ochag) is defined by chronological and geographical limits and is a region which has similarity in production of metal and metal objects by professional craftsmen. All operations from the extraction of the ore to the manufacture of the finished article are carried out within it (eg the Gumelnitsa focal area). By contrast, a **metalworking** focal area is one within which objects are forged or cast from imported metal (eg the Tripolye focal area). A metallurgical **province** (provintsiya) is a system of related foci which can occupy vast areas of several million square kilometres and which can exist for up to two or three thousand years. A **zone**(zona) can be a group of foci within a province linked by the character of metal production, trade or other relations.

For the eneolithic, Chernykh defines a **Balkan-Carpathian Metallurgical Province** within which there are two main metallurgical focal areas - the Gumelnitsa and the N. Balkan (fig.112, P.264).

The Gumelnitsa focal area, besides covering the territory of the eponymous culture also includes the Kodjadermen and Karanovo VI cultures, occupying central and eastern Bulgaria, the lower Danube and southern Moldavia. It is bordered by the Rhodope Mts. on the south. Within this area there is a predominance of shaft-hole axe-hammers but relatively few shaft-hole axe-adzes which are ten times more frequent in the Middle Danube and Transylvania. There is evidence of a class of highly skilled professional craftsmen using two- and even three-piece open moulds at the end of the 5th millenium BC 9pp.277, 293). These may well be the oldest moulds of this type in the Old World, though finds from Sialk III and IV in central Iran may be contemporary. Equally unexpected is the fact that the scale of metal production at this time was not paralleled again until the late Bronze Age (fig.118, p.274). This precocity implies earlier development in the preceding Karanova V/Maritsa/Vinca C period, yet there are scarcely ten copper objects associated with this period in Bulgaria. However, there are numerous finds of copper minerals from Maritsa settlements (eg Stara Zagora District Hospital). Contemporary Anatolian sites of the 5th and 4th millenium BC have relatively little copper, so we are still left with the problem of the origin of south-east European metallurgy. Chernykh (p.276) suggests a hypothetical primary Anatolian influence which led to the conception of mining and the rudiments of metallurgy, but believes that the creation of the Balkan-Carpathian Metallurgical Province and its astonishing surge of metal production was completely independent of outside influence.

The N. Balkan metallurgical focal area of the eneolithic was centred in north-east Yugoslavia and is represented only in west and north-west Bulgaria. in the basins of the rivers Osym, Vit and Iskr. It includes the archaeological cultures of Salcuta/Sadovetz/Gradeshnitsa/Vinca-Plocnik/Tiszapolgar/Bodrogkeresztur, and is characterised by tools of very pure copper of Group I (see below), and a predominance of shaft-hole axe-adzes. Axe-hammers and chisels are rare. The source of copper was probably in Yugoslavia, although Pesovetz in Bulgaria is a possibility.

The Gumelnitsa and N. Balkan focal areas correspond respectively to a south-eastern and south-western **zone** within the Balkan-Carpathian Metallurgical Province. Chernykh believes there to have also been a Transylvanian/ Mid-Danubian zone and possibly a fourth, N. Carpathian, zone.

In general. the eneolithic in Bulgaria is characterised by the

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'ochag' is most directly translated as 'hearth' but this does not have quite the correct meaning as expressed by Chernykh, so focal area is used here.

large-scale production of heavy shaft-hole axe-adzes, axe-hammers and chisels. Awls, too, are widespread. Ornaments represent only five per cent of the total assemblage. Nine double-spiralled rings are known from eastern Bulgaria. Interestingly, moulds are practically unknown which contrasts with the Early and Middle Bronze Ages.when the scale of metal production was less.

Much of Chernykh's work is based on analyses of objects and ores. He defines six basic chemical groups of eneolithic copper (Groups I-VI). These are exclusively eneolithic (Table II.2, p.79; fig.57, p.80). The impurities of Pb, Bi, Ag, Sb and As are especially important for the definition of these groups. More than twenty-five per cent of eneolithic metal falls within Group II. The distribution of objects of copper of groups II-IV coincides with the known territory of the Gumelnitsa/Kodjadermen/Karanova VI cultures. In west and north-west Bulgaria where the Gumelnitsa culture is virtually unknown, Group II copper predominates. This is the area of the Salcuta/ Sadovetz culture. Chernykh's Group I roughly corresponds to Group N of the Stuttgart analyses, and his Group II to Group E_{oo}. In Yugoslavia, the eneolithic material is mostly of very pure copper of Group I, whereas nearly three-quarters of Romanian and Hugarian objects are of Group II. As a result of the new Moscow analyses Chernykh has been able to reinterpret the chemical grouping of the well-known Karbuna material from south-west USSR, and it is clear that much of it falls within Group II. Indeed, the similarity of the Tripolye A and B and Karbuna metal with that of the Gumelnitsa region suggests that the latter was a major, though not exclusive, source of Tripolye metal. It is likely that N. Thracian copper was dispersed north-eastwards along the western shores of the Black Sea to the Tripolye culture and on to the Sredni Stog and Dniepre-Donetz cultures.

Metallurgical analysis indicates that more than ninety per cent of eneolithic metal objects in Bulgaria were manufactured from unalloyed, i.e. metallurgically 'pure' copper. However, a few objects have relatively high concentrations of arsenic and tin. Eleven objects of artificial tin bronze include two awls, a needle and ring containing 6 - 10% Sn, from an eneolithic level in the Ruse Mound, and a needle and ring containing 7% Sn from Karanovo. One probable modern forgery is a shaft-hole axe-adze from Sofia containing 1.8% Sn, 0.8% Pb and 3.0% Zn, but most of the others are from irrefutable eneolithic contexts and area of eneolithic type. They are particularly interesting examples of experimentation with tin as tin-bronze hardly occurs in Early Bronze Age contexts in Bulgaria, and even for the Middle Bronze Age there are fewer known awls and needles of tin-bronze than there are for the eneolithic.

On the basis of Carbon-14 dates (fig.116, p.271), Chernykh dates the eneolithic in Bulgaria to c.4800 BC - c.3800 BC in absolute years (c.4000 BC - c.3200 BC uncalibrated). Chernykh begins the Early Bronze Age at c.3500 BC (c.3000 BC) (fig.117, p.272), and draws attention to the gap of some 300 - 500 years between the end of the eneolithic and the beginning of the Bronze Age. He believes this to have been a period of great social change, perhaps coinciding with the end of the great 'tell' settlements. Certainly from the metallurgical point of view there are considerable differences between the eneolithic and the Early Bronze Age and very little in the way of direct links between the two.

The Early Bronze Age and Middle Bronze Age in Bulgaria fall within Chernykh's Circumpontic Metallurgical Province. The latter covers a huge area from the N. Carpathians to the Upper Volga and S. Urals, the N. Caucasus, Transcaucasia, the Balkans and also, apparently, the Aegean, Antolia and western Iran (figs.113-114, pp.266-7). It had its greatest extent in the Middle Bronze Age. Metallurgical production was based on the rich ore deposits of the Caucasus, the Balkans and Carpathians, Anatolia and the Urals. Metal-working focal areas existed in the non-mineralised parts of eastern Europe (eg the Kemi-Obinsk and Catacomb cultures).

Bulgaria itself is on the western periphery of the Circumpontic Metallurgical Province. Chernykh defines two metalworking focal areas within Bulgaria - the Ezero focal area of the Early Bronze Age and the Emen focal area of the Middle Bronze Age. His conclusions are based on the analysis of 144 objects, of which 68 are chance finds. The settlement site at Ezero is vitally important as it produced 35 metal objects and three axe moulds, nearly all of which were clearly stratified. The interpretation of 70 objects from the lake settlement of Ezerovo II can only be provisional as they are affected by saline contamination.

Chernykh defines four metallurgical groups of copper within the Early and Middle Bronze Age:-

1	'Pure' copper, with As $< 0.4\%$, Sn $< 0.4\%$
2	Arsenic bronze, with As $> 0.5\%$, Sn $< 0.4\%$
3	Arsenical tin bronze with As $> 0.5\%$, Sn $> 0.5\%$, but with As $>$ Sn
4	Tin bronze, with Sn $> 0.5\%$, As $< 0.4\%$

Only ten per cent of analysed objects. were of tin bronze whereas fifty-seven per cent were of arsenic bronze. Indeed, arsenic in copper is three times as frequent as tin in copper. A shaft-hole axe from Stara Zagora is of high quality brass (Zn $> 20\%$) and is probably a modern forgery, perhaps using an Early Bronze Age mould.

The copper used is divided by Chernykh into three chemical groups (VII, VIII and IX) in which the concentrations of Pb and Bi are especially important (p.129).

More than forty per cent of all metal objects in the Bulgarian Early and Middle Bronze Age are shaft-hole axes. The only ornaments recorded are a pin from Ezero and a bracelet from Varna. All axes were cast in two-piece moulds with cores. The start of the Middle Bronze Age is marked by the introduction of closed moulds and more complex alloys. The Early Bronze Age had seen a sharp decline in the scale of production compared with the eneolithic, but in the Middle Bronze Age there was a relative increase and a shift of metal working production from south to northern Bulgaria. The use of tin also became widespread in the Middle Bronze Age.

In general, the Early and Middle Bronze Age focal areas of the north-east Balkans are by no means the most significant or richest of the Circumpontic Metallurgical Province. However, they are very important from the point of view of the richness of their moulds, especially those for shaft-hole axes. The Ezero focal area of the Early Bronze Age has interesting evidence of links with the Usatovo culture of the north-east. It had been thought that Usatovo metal was derived from a Caucasian source but in fact its copper-arsenic alloys are closer to those of the Ezero focal area (p.171). Indeed, the whole theory of Caucasian influence on Early Bronze Age metallurgy of the Balkans is now open to question (pp.278-9). The steppe region of eastern Europe is crucial here, as it shows evidence of influences from and to both the Caucasus and the Balkan-Carpathian region. It may well be a case of diffusion of metallurgical knowledge by means of the movement of a group of professional metallurgists and craftsmen rather than by the import of artefacts.

The Ezero focal area of the Early Bronze Age can be divided into two metalworking phases, with their absolute chronology based on twenty Carbon-14 dates from Ezero. EBA-I dating to c.3500 - c.3000 BC (c.3000 - c.2500 BC) is represented by the production of simple awls and a few chisels and knives, mostly of low-arsenic bronze but sometimes of 'pure' copper. EBA-II (i.e. Ezero B) dating to c.3000 - c.2300 BC (c.2500 - c.2000 BC) includes a rich variety of metal types, and the casting of shaft-hole axes. High-arsenic alloys are mostly used.

The Emen metalworking focal area of the Middle Bronze Age can also be subdivided into two chronological phases. The start of MBA-I is difficult to define owing to a lack of Carbon-14 dates, but it is a direct development of the Early Bronze Age and must date from c.2300 BC - c.1750 BC. Chernykh dates MBA-II to the second quarter of the second millenium BC.

Throughout the Circumpontic Metallurgical Province, the Middle Bronze Age is characterized by the gradual disintegration of the Early Bronze Age focal areas, and regional differences become more marked. For example, tin bronze began to be used extensively in the Balkan-Carpathian western zone while in the Steppe-Caucasian zone in the east the use of arsenical bronze was at its peak.

The conventional view is that the Middle Bronze Age finished in C.1500 BC and that the Late Bronze Age began c.1300 BC. This is based on the end of the production of shaft-hole axes and the start of production of socketed axes. However, Chernykh believes that the transition cannot be later than c.1400 BC. Three important sites which contain both Middle and Late Bronze Age material especially lend support to this view. In Bulgaria, the site of Vyrbitsa II contained a hoard of tools of both Middle and Late Bronze Age types, and at Pobit Kamyk was found a scatter of moulds including four for Middle Bronze Age shaft-hole axes and two for Late Bronze Age socketed axes. This latter site has previously been virtually unpublished (pp.254-257, Tables 67-70, pp.244-247). The third site is at Safaalan in north-west Turkey (p.261). Chernykh believes the production of shaft-hole axes could well go on beyond the 16th century BC and that the start of socketed axes could well be earlier than the 13th century BC.

The Late Bronze Age of Bulgaria falls within Chernykh's European Metallurgical Province, although the north-east Balkans represent only the extreme south western periphery of its territory (fig.115, p.269). The province probably included practically all of western, central and northern Europe, excluding the Mediterranean

Seventy per cent of all Late Bronze Age metal from Bulgaria is from hoards, and only six per cent from settlement sites. Eighteen hoards are known, the four largest being Dichevo (147 objects), Vyrbitsa I (88), Vyrbitsa II (41) and Gorsko Kosovo (29). Practically the only form of alloy used was tin bronze although 29 out of 549 analysed objects were found to be of 'pure' copper. Chernykh has defined three chemical groups of copper used (Groups X, XI and XII). Socketed axes and sickles represent four-fifths of known tools and weapons. Ornaments are insignificant.

The northward shift of production which characterised the Middle Bronze Age is even more evident in the Late Bronze Age. More than ninety per cent of all known tools and weapons of the Bulgarian Late Bronze Age are found along the right bank of the Danube and its tributaries. Chernykh defines two groups of hoards which represent two distinct metalworking focal areas. The first is the Dichevo group including the hoards of Dichevo, Suvorovo I, Isperikh, Tykach, Dibich, the mould from Branitsa, and possibly also the moulds of Esenitsa. This group has an eastern distribution and links to the north-east, especially with the Ingulo-Krasnomaya culture. For example, the hoard from Orekhovskii near Zaporozh'ya on the Dniepr is very similar to Dichevo material in type and composition. Twenty-five out of its twenty nine objects are of Group XI metal, which characterises Dichevo material. The Dichevo group has a predominance of large sickles.

The second group of hoards is the Vyrbitsa group. This includes the hoards of Vyrbitsa I and II, Gorsko Kosovo, Lesura, Prodimchetz, Strazhitsa, the moulds from Sokol and Belyakovets, and possibly the Bozhurovo hoard and the moulds from Zhelyu-Voyvoda. This group has a western distribution and links to the north-west. It is characterised by small sickles and a predominance of 'celts' (socketed axes) of metal of Group X.

Besides these groups, the Cirna culture sites of Baley and Orsaya contain metal ornaments with parallels in the Middle Danube, the Carpathian basin and Central Europe, and also the cremating Caka culture of Slovakia. Interestingly, finds of supposed Mycenaean influence are practically non-existent in Bulgaria (p.273) yet Bulgaria is closest to the supposed source of influence.

In general, the scale of metal production in the north-east Balkans in the Late Bronze Age is much less than in the more central focal areas of the European Metallurgical Province. For example, more than 320 hoards are known from Transylvania. Yet in Bulgaria there is a new peak of production exceeding that of the eneolithic (fig.118, p.274).

From the 11th century BC large-scale metalworking production practically came to an end in the north-east Balkans, indicating a sharp break between the end of the Late Bronze Age and the beginning of the Early Iron Age. There was a similar situation in south-west USSR where over 500 metal objects are known from the Late Bronze Age Ingulo-Krasnomaya culture, but only about fifty from the Kardashinski culture of the Early Iron Age.

Chernykh's attempts at geographical, typological, chemical and metallurgical groupings and definitions are very exciting. He has charted the fluctuations in metal production over some three and a half millennia in the north-east Balkans. A clear pattern of successive growth and decline emerges. Much information is given about areas beyond the limits of Bulgaria. For example, it is intriguing to note that during the peak of metallurgical activity in the eneolithic of the north-east Balkans, metallurgy in the Caucasus was going through a rudimentary stage, while the metallurgical floruit of the Caucasus represented by the Kuro-Araxes culture coincides with the relative decline in the Early Bronze Age of Bulgaria. Almost everywhere within Eurasia at the end of the Bronze Age there was a boom in bronze production followed by a decline in the Early Iron Age. The two exceptions were the Volga-Ural region and the Minusinsk basin of the Sayan Altai of south-east Siberia where the production and casting of bronze objects sharply increased at the beginning of the Iron Age.

The only major limitation of this book's usefulness to the student of European prehistory is its lack of an index. Regrettably this is usual practice among Russian and other East European publications which is insufficiently compensated by the provision of a detailed list of contents. The latter contains some minor errors of pagination.

On the whole the book is well illustrated with useful maps, diagrams and photographs, but a chart summarising Chernykh's phases of metallurgical production would have been especially useful. However, this does not detract from the overwhelming value of this book which should encourage all prehistorians to reconsider their views on the use of metals in Europe, as a result of Chernykh's admirable marrying of metallurgical, typological and geographical analysis into a coherent history.

T A P Greeves

R T Clough. The Lead Smelting Mills of the Yorkshire Dales. *(Second Ed.) pp.XXVI + 332. £24 (Published by the Author, Keighley). Available from: R T Clough, Stoneleigh, Utley, Keighley, West Yorks. £25 including packing and postage.*

Clough's first edition of this book (1962) rapidly became regarded as a classic. Its detailed line drawings were its major strength, capturing the rapidly diminishing remains before such effort became fashionable, and to a comprehensive degree still too rarely accomplished. Clough's courage also in publishing a limited edition of 1000 copies to a very high standard ensured his knowledge became widely available, and it is one of those ironies that the rewards of its present considerable second-hand value do not occur to the author.

This present edition of 750 copies is considerably enlarged, with over 140 additional photographs, illustrations from various sources, and surveys. The first and second parts follow the pattern of the first edition, apparently unaltered covering the development of lead mining and smelting, then the survey itself. The additional material, derived from Clough's continuing interest in his subject, forms a sort of appendix to the earlier work. It begins with a survey of "The Scene Today", and proceeds onto a variety of illustrations to illustrate the historical background of early mining technology in the Yorkshire Dales and wider afield. A final part deals with the Northern Pennines.

One cannot help feeling, that in enlarging the original work, rather than revising it in light of more recent research, Clough has rather lost his way, and fallen into the trap of including such material because it is attractive in itself, rather than using the criteria as to whether it strengthens his thesis. Clough believes in "a strong European influence" which has affected the building of mining and metallurgical structures from, if his photographs are any guide, Roman times (Fig.49) until the 1940s (Fig.100). How photographs of himself in camp at Arkengarthdale, eating dinner (Fig.99) help his thesis is not clear. Ironically, the rarity of some of the photographs and illustrations Clough has used mean many of us will be referring to his book for them. While a few could certainly have been used to revise and improve the work, many would have been better omitted and published elsewhere.

Quality of presentation suffer too in the new edition. Recent photographs are poorly composed for their purpose, of poor quality or worse,reproduction. Textual material is separated from the illustrations and is haphazardly laid out. There is no index.

Should one buy it: rationally, no, since for £24 this should have been a much better book. But it still has the original work within it, and the additional material might be considered an attractive bonus to us all as well as Clough.

Lynn Willies

Abstracts

GENERAL

G Sperl: Metallographic examination of Bronze Age copper. *Metals Tech. May 1980, 7, (5), 212-217.*

In the earliest times copper was produced by smelting oxide ores. Metallographic examination of metal droplets 1-5mm diameter, which jumped out of the founder's crucible 4100 years ago at Zambujal, Portugal showed the copper-copper oxide eutectic, with the copper containing 1 to 3% arsenic. Associated slag was of the iron-rich fayalite low melting point type. As the "Beaker" people spread eastwards through Europe, they found it necessary to develop techniques for smelting sulphide ores. Metallographic examination of slags and metal globules indicate how smelting techniques developed. Early slags of this period from Salzburg are of the same fayalite type as those found in Portugal, but they contain globules of metallic copper and copper sulphides. The author indicates that investigations of the iron content of the sulphides found in slags, and sulphide inclusions found in metallic copper at various stages of manufacture, provides a tool for the reconstruction of prehistoric metallurgical processes. It appears that the careful work of the metallurgists of the early Bronze Age deteriorates towards the late Bronze Age, even though the finished products are of high quality. The metallographic examination of a lance head from Kitzbuhel, Tyrol, of the period 1250-750 BC, is briefly described and illustrated. APG

G Rapp Jr., E Henrickson, M Miller and S Aschenbrenner: Trace-Element Fingerprinting as a Guide for the Geographic Sources of Native Copper. *J. of Metals, Jan.1980. 32, (1), 34-45.*

Trace elements (i.e. concentration generally below 100ppm) are analysed in samples from different locations in a large nugget of native copper, in samples of native copper taken from various carefully chosen locations in two different mines, and in a wide range of samples obtained from several locations in North America. Methods of sampling for analysis, methods of analysis, and the influence of geological factors on analysis, are all briefly discussed.

13 copper artefacts obtained from Minnesota were analysed

and the statistical methods which were available for determining the most likely source of the metal were found to be unable to provide the type of discrimination which was needed. Two new statistical methods are proposed and discussed at some length. It is concluded that the results presented indicate that further refinement and wider application of the methodology is warranted. APG

E Tholander: A Study of the Technology behind nickel alloyed prehistoric steel having a laminated structure. *Proceedings of the fifth Atlantic Conference, Dublin, 1979. M Ryan (Editor) pp.319-334.*

The usual explanation of the presence of nickel in ancient iron artefacts is that they were made from raw material of meteoric origin. Detailed examination of a socketed axe from the 4th century AD or earlier, found near Eskilstuna in Sweden showed that it had a laminated structure containing up to 6.9% nickel, about 0.7% cobalt, 0.4% carbon and 0.02% phosphorus, in martensitic streaks, 18 microns in thickness in a matrix containing about 0.5% nickel, 0.3% cobalt, and 0.1% carbon. The author gives reasons for suggesting that the axe must have been made by repeatedly forging and folding two or three plates of steel, only one of which was of high nickel content. A practical trial to assess the structures which can be produced in this way is described.

The author asserts that the composition of the martensitic streaks indicates that they could hardly be of meteoric origin, though the source of the nickel ore and the metallurgical process used for making the nickel steel are still unknown. APG

B K Tanner, D W MacDowall, I B MacCormack, R L Smith Ferromagnetism in ancient copper-based coinage *Nature July 5, 1979,* **280,** *(5717) 46-48.*

Ferromagnetism has been detected in ancient copper coinage. Consistent values are obtained for coins from the same period and region, suggesting a correlation with the ore used. This appears to be the first study of the magnetic properties of ancient coinage. Examples are given of coins from the Kushan Empire. MJH

R J Dowsing: The Platinum Group Metals. Part 1. *Metals and Materials, May 1980. pp.41-48.*

One section of the article gives a brief history of the use of the metal, commencing with an Egyptian seventh century BC ornamental box from Thebes covered with precious metal hieroglyphics. Most of the characters were hammered silver, but one was fabricated from native platinum. Pre–Columbian Indians of Ecuador and Columbia collected platinum nuggets from local streams and used them to fabricate articles of adornment. Early Spanish colonists considered the metal to be of little value, but in the latter part of the eighteenth century a platinum industry arose in Spain. Palladium was discovered as a pure metal in 1802, rhodium osmium and iridium in 1834, and ruthenium in 1844. Towards the end of the 19th century the use of platinum became firmly established in industry as a catalyst, for the production of laboratory ware, and for boilers for sulphuric acid production. APG

Anthony Smith:
A history of tinplate - 4. *Tin International, March 1978* **51** *(3),* **88, 90-91,** *9 refs.*

This instalment focuses on developments between 1900 and 1943 in England, the United States, and especially Germany. MG

W A Smeaton: Early methods of cladding base metals with platinum. *Platinum Metals Review, 1978, 22 (2) 61-67.*

This is a review of the methods used to coat platinum onto baser metals in the late 18th and early 19th centuries. WAO

Clemens Eibner: Alloys or natural deposits? *Festschr. fuer Richard Pittioni. Wien 1976,* **2,** *43-57 Fig. refs.*

Discusses the premises underlying the interpretation of results of prehistoric metallurgical analyses. BAA

BRITISH ISLES

W S Harvey and G Downs-Rose: The Leadmining Museum at Wanlockhead. *Industrial Archaeology Spring, 1980. 15 (1) 11-29.*

A description is given of the museum and plans for the future. APG

B A Fyfield-Shayler and C P Norton: Tolgus Tin: sole survivor of the traditional Cornish tin streaming industry. *Industrial Archaeology, Spring 1980,* **15,** *(1), 34-66.*

Tin streaming is a method of extracting tin residue from mine waste. This article outlines the development of the site as a working museum, with brief references to its past history, and some of the non-operating historical equipment which is on view. APG

J F Manley and K Davies: Greenfield Mills excavation 1977: introductory report. *Industrial Archaeology, Autumn 1978,* **13** *(3), 227-269.*

Industrial development of this Flintshire site commenced in 1765 when the Warrington Company erected four copper and brass battery mills operated by water power with associated coal fired annealing furnaces. Ownership was transferred in 1768 to the Greenfield Copper and Brass Company, but as the supply of copper ore from Anglesey to the associated St. Helens smelting works declined, so activity at Greenfield decreased until the works ceased to operate about 1810. Newton, Lyon and Company eventually took over, and in the period 1824-1898 operated a copper and brass foundry, rolling mills, and gas-fired annealing furnaces.

A red lead mill and a shot tower were also in operation in the site for about 30 years from 1839. From 1901 the buildings were used as a store for textiles, but fires led to demolition of many buildings on the site so that only the former shearing mill and a few walls of the copper and brass foundries remained when excavation began in 1977. The archaeological evidence now reported in detail increases the information previously available from documentary sources only. APG

D Wedderburn: A Fatal Fracture - an account of the New Hartley Colliery Disaster. *Foundry Trade Journal 1980,* **148** *(3186), 678-689.*

On the morning of January 16th 1862, the outer end of the pumping engine beam broke at the gudgeon and fell into the one and only shaft giving access to the workings below. The debris produced by 20 tons of iron falling blocked the shaft, and 199 men and boys trapped in the workings died before they could be rescued. Subsequent enquiries revealed that the accident was probably caused by the breaking of the main spear in the pumping shaft, no serious flaw being found in the cast iron of the main beam. Bend tests were carried out on bars of iron one inch square and four and a half feet long, and from the breaking load it was estimated that the Hartley beam was able to sustain a steady load 13.25 times greater than the greatest force that could, from the nature of the case, be brought to bear on it. APG

Anon. Ironbridge Gorge Museum open new Foundry Gallery. *Foundry Trade Journal 1980,* **148** *(3191). 1119-1123.*

A brief illustrated description. APG

R K Evans: Rainhill Trials - 1980 style - recreate engineering of the 1830s. *Metals and Materials. June 1980 pp.39-45.*

After a brief historical outline of the engineering developments which led to the Rainhill locomotive trials of 1830, the design and construction of working replicas of Rocket, Sans Pariel, Novelty which took part in the Rainhill celebrations of 1980 are described and illustrated. The major problems of incorporating into the design the requirements of current codes of practice are emphasized, and the differences between the fabrication techniques and materials used in the originals and in the replicas are discussed. Lion, a locomotive which first entered service in 1838, also took part in the procession, and the examination and restoration of this locomotive is described. The wrought iron boiler shell dates from 1845, and many of the original components still remain on the engine. APG

P J Davey: Bronze Age Metalwork from Lincolnshire. *Archaeologia, Vol. 104, 1977, pp.51-127.*

This is a massive compendium of the known Bronze Age metalwork of Lincolnshire provenance situated in museums and other repositaries. Much attention is given to typology etc. but very little is said about composition or methods of manufacture. A brief reference is made to the studies of the physical composition of bronzes by Brown and Blin-Stoyle (1959) and Tylecote (1968) but the author rightly concludes 'The number of analyses from the county is insufficient for firm conclusions to be drawn'. Perhaps this is a labour of love someone would like to tackle? NM

H W Parr: Tintern's Railway. *In: Industrial Railway Record, the Magazine of the Industrial Railway Society, 1977 (August), 7 (72), 58-67.*

History with map and 3 illustrations of the branch line built across the river Wye to serve the Tintern wireworks. (Author)

D Nortcliffe. The first Iron Bridge? A preliminary report on the Kirklees Iron Bridge of 1769 and its builders. *In: Industrial Past. 1980, 7 (1), 14-17.*

A well-documented illustrated account of an early iron bridge near Brighouse, West Yorkshire, built by Maurice Tobin in 1769. The structure was an arch, 6 ft wide and 72 ft in span, over an ornamental pond, and is believed to have been removed in the 1849's. HWP

T E Evans. Furness Iron - Part 1. *In: Industrial Past 1980, 7 (2) 13-16.*

A short description of iron working remains, with sketch drawings of Duddon and Backbarrow furnaces.

J Blackburn: The Tay Bridge Disaster. *Foundry Trade Journal 1980,* **148** *(3182) 282-289.*

The first Tay bridge collapsed on December 28th 1879 due to the failure of cast iron pillars braced with diagonal and horizontal tie bars. In this article, the author, as a practical foundryman, comments on the evidence presented to the subsequent Court of Enquiry, relating to the quality of the castings, which were made in a special foundry built for the purpose at Wormit, at the south end of the Bridge. APG

Brian Cooper: Smith and Wellstood Limited- Traditional Market provides Revival for Scottish Iron Founder. *Foundry Trade Journal, 1980,* **148** *(3185) 525-549.*

The original Bonnybridge foundry was started in 1860 and became famous as the makers of the Esse range of cast-iron stoves and cookers. In this article, the history of the company is outlined. APG

EUROPE

Josef Riederer: The composition of the bronze cannons of the Heeresgeschichtlichen Museum of Vienna. *Berl Beitr. Archaeom, 1977, 2, 27-40. In German.*

In 1972, chemical analysis of the bronze cannons of the Bayerische National museum, the Germanische National-museum, The Veste Coburg and the Hohenzollern-Collection at Sigmaringen indicated that regional variations of composition and variations of workshops could be detected. 254 bronze cannons from the Heeresgeschichtlichen Museum at Vienna were then analyzed. It was found that the lead-silver-ratio of the bronze is characteristic of the origin of the cannon. Cannons from Vienna with a high amount of silver can be distinguished from cannons from Nuremberg with high amounts of lead and those from Munich with somewhat smaller amounts of lead. Cannons from Innsbruck have different lead-tin-ratios. Cannons from Pavia and Turin, which are poor in lead and silver, form their own groups. Within groups of similar lead-tin-ratios, smaller groups can be connected with certain foundries. JR (AA)

Hensel Zdzislaw: Metal examination of iron objects from 9-12 c from Wolin. *Materialy Zachodnio-Pomorskie, 1975, 21, 61-93. In Polish. Tables, diagrams, drawings, illus., German summary.*

Spectrographic analyses (qualitative and quantitative) metallographic examinations and microhardness tests on 86 objects from archaeological excavations in the north-western part of Poland led to the classification of the finds into several characteristic technological groups. The results are discussed in detail, from the technological as well as the historical point of view. HJ

Konstantinos Konofagos: Melting furnaces and techniques in the melting of silver-containing lead ores in Laurion by the ancient Greeks. *Prakt. Akad. Ahtnon, 1975,* **49***, 262-95. In Greek.*

The production of silver from the argentiferous lead ore at Laurion during the classical period of ancient Greece employed a semireductive melting in bellows-worked, vertical crucible-type furnaces fuelled by charcoal. The ancient slag was rich in silica, and some pieces of slag contained drops of lead. The low sulphur content (0.3%) of the slag shows that the ancients were dealing with oxidized ore having very little galena. The analyses of the various oxidized ores at Laurion are given on a SiO_2-FeO-CaO phase diagram. Details are given on the construction and operation of the furnaces, the geographical location of the mines, etc.

H W Catling and R E Jones: Sellopoulo tomb 4: Some analyses.
Annual of British School of Athens, 1976, **71,** *21-24.*

Semi-quantitative x-ray fluorescence analysis of bronzes from the Late Minoan Tomb showed them all to be tin bronzes, usually with quite high tin contents. PTC

Richard J Harrison: A late Bronze Age grave group from Merida (Prov. Badajoz).
Sonderdruck aus der Madrider Mitteilungen, 1977, 18
18-29. In English.

XRF analysis of the four ornaments from the grave of a young girl shows them to be of gold containing 10-12.5% silver. The two bracelets are of identical composition containing 2% copper in addition to gold and silver, and the necklet and anklet also match each other, containing a low copper percentage (less than 0.05 and 0.07%). MJH

Kazimierz Beilenin: On the primitive smelting furnace site in Tarchalice.
Archaeologia Polski, 1975,20, (1) 174-187. In Polish. Figs.

The article discusses the work of G. Domanski. The author deals with the part of Domanski's work concerning the smelting oven. Analyzed in detail are the regularity of the applied terminology, the correctness of the reconstruction of the smelting appliances and the dimensions of the furnaces. PAA

J R A Bailey: The source of copper at the start of the Copper Age and of tin during the entire Bronze Age of the East Mediterranean: two 'black holes' in history.
S. Afr. J. Sci. 1978, 74 (2) 42-8.

The location of Cu and Sn deposits which were workable by the people of the Copper Age and Bronze Age are discussed. It is suggested that the only Cu workable was in the Great Lakes area of North America and that the Sn came from South East Asia, Africa south of the Sahara, and western Brazil and Bolivia.

Zoltan Hegedus: Some remarks on the foundry technology of bronze baptismal fonts of the 14th to 16th centuries.
Banyasz. Kohasz. Lapok, Ontode, 1978, 29 (6) 122-130. In Eng. and Hung.

A brief description of the shape and execution of the baptismal fonts of the 14th-16th centuries is given, and some fonts cast in Hungary are presented. AATA

Istvan Csontos, Zoltan Szarka and Laszlo Paksi: Study of Bronze Age finds from Bukkaranvos.
Banyasz, Kohasz, Lopok, Ontode, 1978, 29 (8), 183-186. In Hung.

Bronze objects, 3200 yr-old, found at Bukkaranyos (Hungary) were subjected to spectro-chemical and metallographic analysis. The Sn content in the alloy was 6%. Ni, Ag, Fe, Pb and other elements were also present. The objects were cast, and subsequently subjected to cold hammering. AATA

Jelena S Dobrosavljevic and Verica G Antonijevic: Spectrochemical analysis of antique bronze.
Glas. Hem. Drus. Beograd, 43, No.9, pp.613-619 (1978) In Serbo-Croatian.

Spectrochemical methods for determination of the composition of bronze heads of the Roman emperor Constantine 1 (4th century AD) and the Byzantine empress Theodora (6th century AD) are described. The material of the head of emperor Constantine I is a ternary alloy of Cu, Pb and Sn (Pb 13.33%, Sn 2.07%) containing Zn, Ag, Al, As, Bi, Co, Fe, Mg, Mn, Ni, Sb and Si at concentrations of 0.003–0.85%. The material of the head of the empress Theodora is a quaternary alloy of Cu, Pb, Sn and Zn (Pb 20.16%, Sn 4.26%, Zn 0.77%) with traces of Ag, Al, As, Au, Bi, Co, Fe, Mg, Mn, Ni, Sb and Si in a concentration range of 0.0015-0.08%. The results of determination of the alloying constituents of Pb and Sn obtained by spectrometry were confirmed by a gravimetric method. AATA

Otto Werner: Analysis of bronze and brass objects from the Middle Ages I.
Archaeologie und Naturwissenschaften, 1977, **1,** *144-220. In Ger. 95 photos. 176 refs.*

More than 300 objects from the Middle Ages of central Europe were analyzed by emission spectrography. It was found that copper was mined in the early periods in the Harz. First the secondaryweathering products of the ores and later the primary copper sulfides were used. In the 14th century copper from the Mansfeld region predominated. Zinc ores came from the region of Aachen. Variation in compositions of the bronzes and brasses from different regions and periods can be understood by chemical analysis. JR

Carol C Mattusch: Moulds for an archaic bronze statue from the Athenian Agora.
Archaeology, Sept.1977, 30*(5), 326-332. Photos, diagrams' bibliog.*

Moulds for casting bronze statues and statuettes were reconstructed from a firing pit in the Athenian Agora. The author explains the lost wax casting process and shows early moulds that supplied conservative, connected figures until metalcasters developed familiarity with the new technique. While large statues were often cast in many pieces, some of these moulds show that a figure was made in only two sections - head and body. CGA

Josef Reiderer: Metal analysis of flanged axes from a hoard at Beznewitz.
Berliner Beitraege zur Archaeometrie, 1978, (3), pp.43-48.

In German.168 flanged axes from a hoard of the bronze age in Eastern Germany were analyzed by atomic absorption spectrography. It was found that the flanged axes were of a very homogeneous composition. Apart from some exceptions, copper varies between 93 and 97%, tin between 1 and 6%. There is no lead in this alloy. Arsenic was found between 0 and 2%, antimony between 0 and 0.8%. From the constant As-Sb ratic, it can be concluded that ores of only one mining district were used. JR (AA)

A D Petrescu: The history of metallurgy in Romania from ancient times until 1800.
Metallurgia, Feb.1978, **30** *(2) 98-107. In Romanian, 53 refs.*

Because of its abundant mineral resources, Romania has a long history of metallurgy extending back 5000 years, having neolithic copper objects and extensive finds from the Bronze ages and the Iron age. Copper, iron, silver and lead were mined under the Romans, and the use of these metals in coinage is described. By the 15th century, seven metals were known, gold, silver, copper, tin, iron, lead and mercury; and by the nineteenth century fourteen more had been added: antimony, arsenic, bismuth, chromium, manganese, molybdenum, cobalt, nickel, platinum, tellurium, titanium, vanadium, uranium and zinc. MG

ASIA

M R Notis: Study of Japanese Mokume techniques by electron micro-probe analysis. *Masca Journal, 1979, 1 (3), 67-69.*

In the Mokume ("wood grain") technique, thin alternating layers of copper and a copper-gold-silver alloy (Shakudo) are joined to form a compact block, and the block deformed out-of-plane before cutting a flat surface which intersects the joined layers. Upon the formation of a patina, the copper surface turns red while the Shakudo turns a deep matte purple-black colour.

Electron microprobe analysis of a collar taken from the join between the blade and handle of a Japanese sword, probably early 19th century, showed that the Shakudo alloy contained 3.23 weight % gold and 3.24 weight % silver. The concentration profile of these elements at the joints between the layers indicated that the layers had been joined during manufacture by heating at 800°C for 30 minutes, consistent with good metallurgical practice for fabrication by solid state diffusion.

In another Mokume piece, dated late 19th century, a thin silver-rich layer was apparent at the interface between each of the copper and Shakudo layers. This indicates that silver-copper eutectic, melting point 780°C, formed a liquid phase between the layers in the early stage of heating, facilitating rapid bonding. As heating continued, the silver would diffuse from the liquid into the adjoining layers, so that the liquid would disappear after a short period of time. By this technique, a sound joint could be fabricated at lower temperatures and shorter times than by the earlier technique relying on solid state diffusion. APG

P R S Moorey and S J Fleming: Re-appraisal of a Syrio-Palestinian bronze female figure. *Masco Journal, 1979, 1 (3), 73-75.*

The composition of a small bronze figure of a lady, 78 mm high, purchased by C.L. Woolley in Aleppo, and thought to date from the ninth century BC or earlier, is 99% copper, with 0.35% arsenic, 0.4% tin and small amounts of silver, lead and antimony. The remains of the casting core in the head were subjected to thermoluminescent analysis, which gave a date of 1830 + 340 BC. APG

Robert A Coughenour: Preliminary report on the exploration and excavation of Mugharat el Wardeh and Abu Thawab.
Annual of the Dept. of Antiquities of Jordan, 1976, XXI, 71-78. In English.

The survey of the two sites uncovered evidence of early iron smelting of the Islamic period and possibly dating back to the Iron Age and Roman period. MJH

Bradley Dodd: The making of old Japanese swords.
J. Mec. Work. Technol, 1978, 2 (1) 75-84. In English.

The making of old Japanese swords is described. The ferrous metalworking processes involved include: smelting, forge-welding and folding (laminating), selective quenching, grinding and polishing. The metallurgical transformations that occur on quenching are discussed. AATA

Waranghk ana Rajpitak and Nigel J Seeley. The bronze bowls from Ban Don Ta Phet, Thailand: an enigma of prehistoric metallurgy.
World Archaeology, 1979, 11 (1), 26-31.

Bowls from the Iron Age site of Ban Don Ta Phet in Thailand have been found to be made of an extremely difficult to work high tin bronze. It is suggested that this particular alloy has been chosen because of its visual resemblance to gold. The relationship between these bowls and other high tin bronze artefacts of similar date from South and East Asia is discussed. Authors

J Wadsworth and O D Sherby: On the Bulat (Damascus Steels).
Bulletin of the Metals Museum (of the Japan Institute of Metals), 1979, 4, 7-23.

Damascus steels or Damascus blades were first encountered by Europeans at Damascus, but were made in Iran and other countries from Indian "wootz" steel, characterized by a carbon content in the range from 1 to 2 weight %. The surface markings after etching the final product - "the damask" were probably a method of quality control used to determine whether the product was prepared properly or not. The blades exhibited exceptional toughness and ability to retain a cutting edge.

Three aspects of metallurgical processing - casting, mechanical working and heat treatment are all important in controlling the mechanical properties of the metal. From published accounts of the processes used, and from their own work on high carbon steels, the authors suggest techniques which may have been used for making the blades. Low carbon iron was heated with carbon (charcoal) in a crucible. If complete fusion occurred (1400°C for a 1.5% carbon steel), the time at maximum temperature would be relatively unimportant, but slow cooling to 940°C would be necessary to ensure a structure of uniform austenite at this temperature, and very slow cooling from 940°C to 727°C would be necessary to ensure the precipitation of very coarse cementite, which eventually leads to the damask on some of the Damascus blades. Slow cooling below 727°C would ensure that the remaining austenite would transform to coarse pearlite.

If incomplete fusion occurred in the crucible the added charcoal would first give rise to liquid white cast iron containing 4.3% carbon. On prolonged heating, carbon from this liquid would diffuse into the remaining solid austenite at a rate of approximately 0.1 cm/hr at 1200 °C. Prolonged heating at a maximum temperature of 1200°C would then be necessary to attain the desired uniform composition of austenite which would then need to be very slowly cooled below about 1000°C (depending on the carbon content) to achieve the structure described above.

It would then be necessary to forge the material so produced at a relatively low temperature (700 - 900°C) so as to preserve this coarse cementite. The effect of forging is to spheroidize the cementite which greatly improves the mechanical properties of the steel when cold. Reductions in height between about 3:1 and 8:1 are necessary. Better mechanical properties can in fact be obtained if the steel is heated to 1100-1150°C to obtain uniform austenite, and then continuously forged or rolled as the temperature drops to about 600°C so that a fine dispersion of cementite in fine grained ferrite is obtained, but this structure would not produce a visible damask.

For best results, heat treatment of the steel in either condition would involve heating to a comparatively low temperature (about 770°C) followed by quenching. A wide range of quenching media have been reported, from quenching in brine, to quenching by a current of air. Tempering after quenching is probably the least documented of all processing steps.

Another technique of sword making which apparently originated in the near East in the sixteenth century involved the solid-state welding together of strips of different steels or iron and forging a part from such strips. This technique will also provide a damask pattern on the steel, and the production of welded Damascus swords, Japanese swords, krises (Indonesia), Merovingian blades (Europe) and Adze blades (Asia Minor) by these techniques is briefly discussed.

APG

Hisao Mabuchi, Seiji Yamaguchi, Hitoshi Kanno and Toshio Nakai: Chemical analysis of ancient Oriental coins by atomic absorption spectrometry.
Scientific Papers on Japanese Antiques and Art Crafts. Aug. 1978, (22), 20-23. In Japanese.

The amount of Cu, Pb and Zn contained in Chinese (7th-17th C.), Korean (15th C.) and Japanese (15th-18th C.) coins were determined by atomic absorption spectrometry. Contents of Sn were determined by neutron activation analysis. All the Chinese coins from the 7th to the 15th century consisted of Cu-Sn-Pb alloys, while coins from the 8th century showed the appearance of Cu-Zn alloys. The chemical composition of the Japanese coins seems to reflect that of the Chinese ones with some time lag. The 15th century Korean coin and Japanese coins (15th-16th C.) are made of copper with a small percent of Sn and Pb as impurities. TK

Masao Serizawa: Investigation on Kitamakino iron making relics by collected iron slag.
Tatara Kenkyu, 1978, 22, 31-36. In Jap.

Data on the analysis of Fe slag samples collected from Kitamakino Fe-making relics indicated an advance in technology for Fe making in the Omi period. AATA

Jesus de Prentiss: Metal resources in ancient Anatolia.
Anatolian Studies, 1978, 28, 97-102.

A geological and archaeological survey of the copper, silver and gold resources available to ancient Anatolia together with evidence for any early work.

Writing Group of the History of Chinese Metallurgy. Ironmaking technology in ancient China.
Hua Hsueh Tung Pao, 1978, 2, 111-115, 92. In Chinese.

The technology of Fe manufacture in ancient China, including the development of puddling furnaces, bellows, fuels, and types of raw materials is described. AATA

Li Chung: Studies on the iron blade of a Shang dynasty bronze Yueh-axe, unearthed at Kao-Ch'eng, Hopei, China.
Ars Orientalis, 1979, **11**, *259-289.*

This consists of a flat-axe of bronze in which is inserted a narrow piece of iron now completely rusted. By a very careful examination, the author of this most excellent article has concluded that the iron insert is meteoric. The rust contains 2.4% NiO and 0.24% CoO as well as some copper from the bronze. It is assumed that some Ni was lost during weathering. It was also noted that unlike most of the early bloomery iron it was lacking in slag inclusions which should have survived within the rust. 'Fined' cast iron also contains slag inclusions.

The rust still shows the relict structure under the electron probe of alpha and gamma iron, i.e. high nickel and low nickel phases. Diffusion between these phases is very slow in metal or in rust and it is clear that we still have the original structure of the meteorite which cannot be produced by the normal cooling rates available to man.

Concludes that long weathering can cause a loss of Ni in the alpha and gamma phases of 50-90%, and of cobalt. That the inclusion count of a meteoric iron is much less than man-made and that the distribution of high and low nickel areas in the rust reproduces the original meteoric structure.

In this case cracks in the rust were filled with bronze during casting, and earth particles were deposited on broken surfaces. RFT

N M Zinjakov: Technology of iron objects of the Yelikayev Collection. *In: Yuznaya Sibir v skifo-armatskuyu epokhu. Kemerovo, 1976, 106-114.*

The collection which is kept at the university of Tomsk, consists of objects dating from the 8th-9th centuries A.D. 79 iron artifacts (daggers, sabres, lance and arrow points, swords) were metallographically investigated. About 63% of objects were made of steel, about 30% by welding together iron and steel components. But 8 objects do reflect a more primitive working; well performed welding seams and mild hardening are common. CPSA

D F Gibbons and K C Ruhl: The metallurgical technique of the silver "Plate with figures" Gupta period.
Ars Orientalis, 1979, **11**, *177-182.*

In the Cleveland (Ohio) Museum dated to 300-500 AD. A short note showing the 45Cu - 55Ag alloy worked, etched to enrich the surface in Ag, and gilded. The total thickness is 2.5 - 3mm and the enriched Ag is spongy and 1 mm thick. Relief was cut after surface enrichment. RFT

D F Gibbons, K.C Ruhl and D G Shepherd: Techniques of silver smithing in the Hormized II plate.
Ars Orientalis, 1979, **11**, *163-179.*

Relief inserts made by means of incisions in the sheet Ag. The traced lines produce Beilby-layer-like flow. Cu content 0.4-7%. Hg gilding with electron probe trace across diffusion layer. RFT

R Pleiner: The technology of three Assyrian iron artifacts from Khorsabad. *Journal of Near Eastern Studies. 1979, 38, 83-91.*

Metallographical examination of a hoe, an adze and a bi-pyramidal iron bar from the store of the Sargon II

Khorsabad palace. Both implements were made of relatively soft wrought iron but the bar must have been manufactured from a very unhomogeneously carburized steel (eutectoid zones). Author

W T Chase and U.M Franklin: Early Chinese black mirrors and pattern-etched weapons.
Ars Orientalis, 1979, **11**, *215-258.*

Some Chinese bronze mirrors, all of leaded bronze, carry a black decorative surface. This alternates with bright regions and seems to have been intended as a contrasting surface like niello. In the blacked areas the alpha phase has been replaced by iron and the delta is unaltered. The black layer is complex and seems to be sealed by a silicate which contains Fe, Sn, Pb and some copper and has a hardness of the order of 396 HV. These mostly belong to the Warring States and Han periods. In the case of the swords some have strips of different bronze alloys, and lead is always lower at the edges.

It is concluded that 4 techniques are apparent: general blackening, pattern-etching, spot colouration and the application of a thin glassy surface, applied singly or in combination. The etching of the alpha took place in fruit juice or rust and vinegar. Spot colouration was by selective tinning and the glass layer was applied by some sort of cementation of frit like faience. This was essentially an Iron Age development. Perhaps it should be noted that the heavy metal glass is not unlike metallurgical slag and the formation temperature of fayalite is only 650^{o}C. RFT

E I Savage and C S Smith: The techniques of the Japanese tsuba maker.
Ars Orientalis, 1979, **11**,*291-328.*

The guard of the sword is usually decorated by the upsetting of composite metals. These may be brass, silver-copper, copper or iron or mixtures of them. Packets may be forged and pattern-welded or inlaid to give wood-grain type decoration. This is a very comprehensive treatment with analyses and hardnesses. RFT

Crawford H Greenewalt: The eighteenth campaign at Sardis (1975).
Bulletin of the American Schools of Oriental Research, Dec.1977, (228), 47-60.

Includes a reconstruction of the Lydian gold industry by S.M. Goldstein. No platinum/iridium inclusions were found in any of the gold from the industrial area excavated. Reconstruction drawings are included of the goldworking site. MJH

Itzhaq Beit Arieh, Raphael Giveon and Benjamin Saas: Exploration at Serabit el-Khadim, 1977.
Tel Aviv, 1978, 5, (3-4) 170-187.

During a recent visit to the site to check rock inscriptions, several stone objects for metal-working were found: a large stone bowl (part of a pot-bellows), an open mould for axes containing metal residue, a stone block with an oval depression and a mould. MJH

Janina Altman: Gold in Ancient Palestine. Methods of fabrication in successive cultures.
Gold Bull, 1979, **12** *(2) 75-82.*

Gold artifacts from ancient Palestine were studied. Fabrication methods e.g. gilding, soldering of gold sheets, repoussé, casting, etc., of various cultures are discussed. AATA

Hans Gert Bachmann: The phase composition of slags from Timna Site 39.
Archaeo-Metallurgy, 1978, **1**, *21-3.*

The determination of phase composition (mineral content) of the slags from Timna Site 39 (South Negev) adds additional understanding of the processes and reactions which took place at the site. The Guinier technique with Co Kα -radiation was used. The most common minerals present were fayalite, spinel, and quartz. AATA

Shih Yeh: Steelmaking - a steelmaking method in ancient China.
K'o Hsueh Shih Yen, 1977, (6), 230, 233. In Chinese.

The earliest record of steelmaking in ancient China appeared in 113 A.D. The art of steelmaking flourished during the 2nd century in China, whereas steelmaking in Europe did not thrive until the middle of the 18th century. Many steel swords and other steel weapons dated from the era of the 3 kingdoms were discovered during recent anthropological surveys. AATA

R F Tylecote and P J Boydell: Experiments on copper smelting based on early furnaces found at Timna.
Archaeo-Metallurgy, 1978, **1**, *27-49.*

Furnaces based in Timna Sites 2 and 39 were used to study copper smelting processes of ancient times. The study included composition of the ores and slags and chemical analysis and metallography of the copper obtained. AATA

Josef Riederer: Metal analysis of Chinese mirrors.
Berl Beitre. Archaeom, 1977, **2**, *6-16. In German.*

63 Chinese mirrors from the Museum of East-Asian Art in Berlin, dating from the 6th century B.C. to the 10th century A.D. have been analyzed by atomic absorption spectroscopy. In the 6th century B.C. bronze used for mirrors contained considerably more tin (16-26%) than bronze used for vessels or statuettes. Mirrors from the time before the Han dynasty are characterized by higher amounts of copper (73-80%) while later mirrors from the Han to the T'ang dynasty are lower in copper (69-73%). JR (AA)

Earle R Caley, In Soon Moon Chang and Nilufer Parany Woods: Gravimetric and spectrographic analysis of some ancient Chinese copper alloys.
Ars. Orientalis, 1979, **11**, *183-193.*

Fourteen specimens of Chinese bronze from the Chou and Han dynasties have been analyzed gravimetrically (for major elements), by emission spectrography (for minor elements) and volumetrically (in two cases, for antimony). The accuracy of the results is discussed. The alloys vary a good deal, copper-tin (including high-tin) bronzes, leaded high-tin bronzes and copper-lead alloys with some tin all being found. The major component results are compared with those from Gettens and from Chikashige. Results on minor components are compared with those from Gettens. EWF

Hiromu Tanimura: Development of the Japanese Sword.
J. of Metals, Feb.1980, pp.63-73.

Both the beauty and utility of the Japanese sword as a weapon depend on the characteristic metallic component structure of the sword blade steel. After briefly describing the characteristics of the sword blade and the history of the Japanese sword, this paper describes the forging process for making the composite structure of the sword blade steel. according to the author's experiences. Finally, ancient ironmaking and steelmaking processes are briefly explained. The author concludes that the high purity of the iron and steel contributed to the beauty and artistry of the finished sword blade. Author

Josef Reiderer: Copper tools from Habuba Kabira and Mumbaquat.
Mitteilungen der Deutschen Orientgesellschaft, 1976, **108**, *23-24. In German.*

From an excavation at Habuba Kabira and Mumbaquat in Syria 13 copper objects from the 4th Millenium B.C. were analyzed by atomic absorption spectrometry. One sample contained 2% of tin, nine were free from tin. Zinc varied from 0 to 0.1%, nickel from 0 to 2.1%, iron from 0 to 2.8%. Antimony was absent in the four oldest pieces and arsenic varied between 0 and 2.33%. JR (AA)

K T M Hegde: Analytical study of Paunar coins.
Journal of the Numismatic Society of India, 1975, 37 (1 & 11), 180-183.

310 coins were dated to the 6th and 7th centuries A.D. When five of the coins were analyzed, they were found to contain 21 to 23% iron, and about 71 to 77% copper. The author speculates on the possible reason for the presence of iron in the alloy. The coins have a dull white colour. NH

Chueh-Ming Hu: Iron and steel making in ancient China.
Chin Shu Hsueh Pao, 1976, **12**, *(2), 222-31. In Chinese.*

A history of iron and steel making in ancient China is given. Iron tools and weapons were used by ancient Chinese as early as 13-1400 B.C., and the art of steel making was well developed by 500 B.C. AATA

Shih Hsieh: Decarburized steel made from cast iron - an ancient unique technique in Chinese steelmaking.
K'o Hsueh Shih Yen, 1977, (2), 470-1. In Chinese.

Some iron tools made in ancient China (about 200 B.C.) contain C 0.24, Si 0.16, Mn 0.41, S 0.01, and P 0.14%, a composition similar to that of steel. These steel materials were probably made by decarburization annealing of cast iron. The possible development of steelmaking techniques in ancient China is also discussed. AATA

Ben B Johnson and Jonathon E Ericson: Technical comments on the Lidow Ting.
Los Angeles County Museum of Art Bulletin, 1976. 22, 16-30. 25 ref. photo.

This analysis of an ancient Chinese bronze Ting includes the technique of crafting, casting, and inlays, the results of mass spectrographic analysis, its patination and its reparation. VG

Aharon Kempinski and Silvin Kosak: Hittite metal "inventories" (CTH 242) and their economic implications.
Tel Aviv, 1977, 4, (1-2), 87-93.

Masaaki Sawada: Non-destructive x-ray fluorescence analysis of ancient bronze mirrors excavated in Japan.
Ars Orientalis, 1979, **11**, *195-213.*

Over 2500 bronze mirrors made either in China or Japan have been excavated from Japanese tombs of the Yayoi and Tumulus periods. Chinese mirrors differ from the Japanese ones in style, manufacturing techniques, and composition (Chinese: 60-75% Cu, 17-30% Sn and 3.7% Pb: Japanese: 70-90% Cu, 2-20% Sn and 3-8% Pb). In an attempt to distinguish the two types by analysis without sampling, Sn/Pb ratios were determined by analyzing 1.5 cm spots on the surface with x-ray fluorescence. Results correlate well with those from wet analysis and those previously reported. While the two groups overlap where the ratio Sn/Pb is about 2.0-3.0 the provenance of about 80% of the mirrors can be quite reliably distinguished. EWF

C J Davey: Some ancient near Eastern pot bellows.
Levant, 1979, 11, 101-111.

The operation of pot bellows for metalworking is described. A list of 2nd millenium B.C. examples is given, along with a suggested reconstruction of their historical development. The author concludes that as their weight made them less portable than skin bellows, they were used in large scale continuous casting installations. MJH

Beno Rothenberg: Excavations at Timna Site 39, a chalcolithic copper smelting site and furnace and its metallurgy.
Archaeo-Metallurgy, 1978, **1**, *1-15.*

The archaeology, stratigraphy, dating and metallurgy of the Chalcolithic Cu smelting furnaces at Timna Site 39 are described. AATA

Masao Serizawa: Investigation on Kitamakino iron making relics by collected iron slag.
Tatara Kenkyu, 1978, 22, 31-36. In Jap.

Data on the analysis of Fe slag samples collected from Kitamakino Fe-making relics indicated an advance in technology for Fe making in the Omi period. AATA

Manfred Sachse: Damascene steel-history, legend and reality.
Arch. Eisenhuettenwes, 1978, 49 (11), 521-526. In Ger.

A history is given of Damascene steel and of the techniques used in the production of this composite steel. AATA

Raphael Giveon: Egyptian finger-rings and seals from South of Gaza.
Tel Aviv, 1979, 4 (1-2), 66-70.

Analysis of two tin bronze rings (8.12 and 8.74% Sn respectively). One contains 2.95% iron. MJH

G W Goettler, N Firith and C E Huston: A preliminary discussion of ancient mining in the Sultanate of Oman.
Journal of Oman Studies, 1976, 2, 43-56.

The authors recorded at least 44 sites of ancient mining with tools, slags, ancient working, etc. The slags had high copper contents, 1-5% typically, suggesting they were from an ancient process. Nearly all these minerals were secondary copper oxides not sulfides. Comments are made on the nickel content of the ores and correlation of Oman as the source of Sumerian copper. PTC

J E Curtis, T S Wheeler, J D Muhly and R Maddin: Neo-Assyrian Ironworking Technology.
Proc. Amer. Phil. Soc., Oct.1979, 123 (4), 369-390.

Samples taken from "ingots" or picks found at Khorsabad and Nimrud are analysed. Two samples from Khorsabad and one from Nimrud showed only small quantities of metals other than iron, but one sample from Nimrud contained 1% manganese. Metallography indicated that all the ingots were generally low carbon ferrite, but certain regions contained up to about 1% carbon. The detailed interpretation of the micrographs by the authors is to some extent confused and inconsistent, but there is evidence of quenching in certain regions, and of extensive deformation below the eutectoid in other regions. Eight finished products from Nimrud were examined, but extensive corrosion makes it difficult to be certain about the techniques used in their manufacture. However, it seems likely that many of them were carburized on the surface.

The authors conclude that the neo-Assyrian smiths of the period about 777-600 B.C. probably carburized iron deliberately. They also quenched the metal but whether this was done for safety or convenience, or because of the increased hardness which results is uncertain. General archaeological considerations indicate that iron was used for the manufacture of certain products not because bronze was in short supply, but because iron was preferred. These conclusions are consistent with observations on Assyrian ironwork from other sites in Southwest Asia and Egypt. The identification and possible uses of the "ingots" or picks is briefly discussed in an appendix. APG

Noel Barnard: The special character of metallurgy in ancient China.
Application of Science in Examination of Works of Art. Proceedings the Seminar, September 7-16, 1965, Museum of Fine Arts, Boston, Massachusetts, pp.184-204, 1967. Maps and illustrations.

In the study of Chinese bronze artifacts of ancient style, interest will gradually decline in art historical analysis and study of inscriptions, because scientific analytical tools can be used to compare alleged ancient Chinese metal artifacts of unknown provenance to the recently-excavated material for which provenance is known.

The question of the origin of metallurgy in ancient China - whether introduced or developed indigenously - is examined in light of recent archaeological data. ECW

Hisao Mabuchi, Notsu Kenji: Chemical compositions of ancient (Chinese and Japanese) coins.
Nippon Kagaku Kaishi (J. Chem. Soc. Japan, Chemistry & Ind. Chem) May, 1979, (5), 586-590. In Japanese.

Thirteen elements (Cu, Pb, Sn, Zn, Fe, As, Sb, Co, Mn, Ni, Au, Ag, Se) in 39 Chinese, 8 Japanese and one Korean ancient coin (7th century-18th century) were determined by inductively coupled plasma-emission spectrochemical analysis and neutron activation analysis. In both Chinese and Japanese coins the transition from Cu-Pb-Sn alloy to Cu-Zn alloy occurred in the 15th-16th centuries in China, and in the 18th century in Japan. Compositional ranges in Cu-Pb-Sn coins extend to 50-80% Cu, 15-35% Pb and 6-15% Sn, respectively, and there seems to be no systematic change with the age. For the Cu-Zn coins the Cu:Zn ratio of Chinese coins is distinctly different from that of Japanese coins, being about 1 for Chinese and 4 for Japanese coins. Generally Japanese coins are much more abundant in As and Sb than Chinese coins. KY

Dilip K. Chakrabart: The problem of tin in early India. Man and Environment, *c/o The Indian Society for Prehistoric & Quaternary Studies, Physical Research Lab. Ahmedabad, India, 1979, 8, 64-74.*

Geological, archaeological and literary aspects of the use of tin in early India are discussed. The author describes several sources of tin in early India. The important centers of its occurrence are: Hazirabagh, Gaya, Ranchi & Bastar etc. Archaeological data show continuous use of tin in India from the Harrapan period onwards. Mention of tin is found in Atharvaveda (c.800 B.C.) Kautilya XII, Rasaratnasmuchchaya, etc. (which was called 'trapu', 'Kastira', etc.) SPS

Vincent Pigott: The Question of the Presence of Iron in the Iron I Period in Western Iran. Mountains and Lowlands
Essays in the Archaeology of Greater Mesopotamia, Vol.7, Edited by L D Levins and T Guyler-Young Jr

Udena Publications, Malibu 1977, pp.209-234.
The discussion of population movements in this region is generally based most strongly upon the ceramic evidence. Reviewing available evidence, the author shows that only two sites can be shown to have iron-bearing contents of Iron I date. In Western Iran, iron artefacts begin to occur no earlier than the 10th century B.C. and iron appears in significant quantities over almost the entire area at approximately the same time. Lack of evidence for iron production in the area is probably largely due to a failure to search for and recognise such evidence. APG

K Kubota: White pig iron axe recovered from relics at Mu-yang Cheng castle in Lu-da City.
Bulletin of Metals Museum (of Japan Institute of Metals). 1978, 3, 16-23. In Japanese.

The white pig iron axe was found at Lu-da City in 1930 and is believed to date back to the first century A.D. The pig iron was investigated by chemical anlysis, optical microscopy, electron microscopy, scanning microscopy, microanalysis and Vickers microhardness. The results thus obtained reveal that iron casting technology in China then was far ahead of European countries under the influence of bronze casting technology.

It appears likely that some parts of the iron were forged and also that metal moulds were used in casting to produce the white pig iron. Author

AFRICA

D H Avery and P Schmidt: A Metallurgical Study of the Iron Bloomery, particularly as practised in Buhaya (Tanzania).
J Metals, Oct.1979, 31(1) 14-20. (Illustrated).

The basic difficulty of the bloomery process is that cold charcoal burning in just enough cold air to give a CO/CO_2 ratio of 3-4 in the products of combustion gives an adiabatic flame temperature of only 1250-1300°C.

If the temperature is below 1200°C, a fluid slag does not form. If the temperature is much in excess of 1300°C, metallic iron will oxidise even at this CO/CO_2 ratio. When allowance is made for heat lost from the hot zone by conduction and radiation, and the heat required to reduce FeO to Fe, it can be seen that large amounts of fuel must be burned to produce a given weight of iron. However, the heat available for reduction from a given weight of fuel will be increased if the combustion air temperature is increased. With an air preheat of 600°C, an adiabatic flame temperature of 1870°C is achieved.

The presence of many vitrified and slag-wetted tuyeres amongst the remains of iron smelting sites in West Lake

Region in Tanzania, and slags with a free flowing temperature of 1400°C, both indicated that air preheating had been used in the bloomery processes from about 200 B.C. until smelting was discontinued about 50-60 years ago. Interviews with former smelters at Buhaya indicated that preheating had been used in the recent past. After extended negotiations, arrangements were made for the Wazee (Old Men) to supervise all activities surrounding the production of an iron bloom in a traditional Hayan furnace in 1976.

The mining, cleaning and selection of the ore, the making of tuyeres 60 cm long, 7 cm o.d. and 4.5 cm i.d. from clay tempered with old tuyeres and pottery, the manufacture of charcoal from the hardwood Much wezi, the preparations of the furnace bowl 110 cm across and 60 cm deep are all described. The day before the first smelt, the ore was roasted with wet wood, which converted the monolithic ore first into a porous iron sponge and then into a permeable oxide with codeposited carbon. On the day of the smelt, swamp reeds were burned in the bowl, until the bowl was filled to the brim with fibrous reed charcoal terminating in a 45°cone above the pit rim. Eight tuyeres projecting 40 cm into the furnace were than laid round the bowl, and a conical shaft 1.5 m high built of old slag blocks and termite mud was built up round the bowl.. Upon completion of the furnace, a large meal was eaten and smelting started. The furnace was charged with charcoal and roasted ore from the top.

Conditions at the tuyeres were investigated and are described, and it is shown that an air pre-heat temperature of $500\text{-}600^{\circ}$C was attained. In the hot zone, the Pt/Pt-10%Rh thermocouples frequently melted, showing that 1820°C was exceeded. It was shown that the roasted ore was reduced in the furnace stack, small flakes of iron forming. As the temperature rises, the ore melts at 1150°C to form a fluid slag, containing iron and some impregnated charcoal. This passes down the shaft and infiltrates the bed of charred grass below the tuyeres. Here more oxide is reduced, and the bloom of iron grows. At the growth interface between the iron and slag, carbon free iron is deposited, but entrapped carbon subsequently gives a bloom containing an average carbon content in the range 0.2 to 0.6%.

At the end of blowing, about 6-8 hours, the furnace walls were knocked down and the bowl pried with poles to push out and separate slag and bloom. In the subsequent forging operation, a short tuyere was used with lighter charcoal from the Mushasha tree. The bloom was buried in the fire and then heated to above 1200°C, and held for 40 minutes, reducing the carbon content to a very low level. Possibly the reason for this extended treatment was to form FeO to flux the refractory low-wustite slag remaining from smelting.

Archaeological evidence indicated that this bloom had been produced by the techniques (with one very minor exception) which had been used for the previous 2,000 years, and with the same results. APG

J A Todd: Studies of the African Iron Age.
J Metals, Nov.1979, 31 (11), 39-45. (Illustrated).

The contribution the metallurgist can make to African Iron Age studies has been assessed by detailed investigation of the pre-industrial bloomery iron process still practised by the Dimi people of the Gemu province in southwest Ethiopia. Metal objects and slags from this process were examined metallographically and chemical analyses of the ores and slags have been obtained. Quantitative energy-dispersive X-ray analyses have shown that it is possible to relate the composition of the slag inclusions to the iron ores of the region. Such an analytical technique, when combined with archaeological, linguistic and historical evidence, may provide a valuable means of characterizing the ironwork of specific production centres and establishing trade networks of iron objects. In this context, theories of the African Iron Age are reviewed with specific reference to Ethiopia. Author

N J Van der Merwe and D J Killick: Square; an iron smelting site near Phalaborwa.
In N J Van der Merwe and T N Huffman (eds), Iron Age Studies in Southern Africa. S A Arch. Soc., Goodwin Series 3, 1979, pp.86-93.

Late iron age forced draught furnaces dated to 19th cent. Used magnetite ores with 0.5% Ti which goes into the slag to give 5% TiO_2. The rich ore was probably fluxed with silica. Woods with high alkali content were preferred. Estimates of yield, total output and fuel consumption over 30 years are made. RFT

J A Todd. The bloomery process used by the Dimi in Ethiopia.
Der Anschnitt, 1979, 31 (5), 154-165. In German

A rather more ethnographical version of the paper by Todd and Charles in JHMS 1978, 12, (2), 63-87. More illustrations and less technology. RFT

N J Van der Merwe: Field methodology and Iron Age metallurgy at Buhwa, Rhodesia.
In Occasional papers of the National Museum and Monuments of Rhodesia, Ser. A. Hum. Sc.4, November 1978, 101-105.

Smelting site at Nenga, excavated in 1975, and further 11 sites in the region of the Mount Buhwa. Magnetite pebbles, tuyeres, furnace wall fragments, slags with metallic iron ore particles. According to the reconstruction the furnaces had to be of about 1 m in diameter with several air inducing holes. Gumanga culture, 12th century A.D. CPSA

F Willett: The anomalous Ife alloy: a conflict of evidence resolved.
Archaeometry, 1979, 21 (2), 247.

Werner and Willett reported in Archaeometry 17 (2), p.143 that Wunmonije head no.4 from Ife had a brass composition unique among Ife castings, though Barker had earlier shown it to be of copper. It now appears that Barker's sample-hole was filled in with a brass rod which Willett had unknowingly sampled as the original hole was undetectable. It is recommended that in future sample-holes be filled with an inert substance quite different from the matrix and that wherever possible total disguising of the hole be avoided. Author

K Hallbauer: Witwatersrand Gold deposits.
Gold Bull, 1978, 11, (1), 18-23.

Discusses the genesis and properties of gold particles alluvially transported from primary source rocks. Compared with Rhine gold from Karlsruhe where particles from the gravels consist of heavily deformed gold with no trade of original morphology. The particles from the Witwatersrand can be jagged and formed round inert mineral inclusions. Most of these indicate short-distance transport of the order of 5-30 km. In this distance gold grains can be subject to chemical attack in sulphate-containing water of pH 6-8 with a Redox potential of +300 mV. The Ag is then leached out of the gold; thus the fineness increases with distance of transport. But this does not happen at Witwatersrand where the pH is 6-8 but E_h =-100 mV. So the fineness is the same as the original. Intergrowths occur between gold particles and compounds such as sphalerite (ZnS), chalcopyrite, pyrite, molybdenite etc. Sometimes alluvial gold is trapped in plant mats forming mixtures of gold and carbonaceous matter, and gold particles can be dissolved by bio-chemical processes. By such processes silver is often enriched by a factor of 2 compared with detrital material, but the concentration of Hg is decreased. RFT

Michael S Bisson: Copper currency in Central Africa: the archaeological evidence.
World Archaeology, Feb.1975, 6 (3), 276-292.

Ethnographic and archaeological data from central Africa show that copper was used to make status symbols, decorative objects and media of exchange throughout the Iron Age. Dates for copper-mining activity now go back as early as AD400 ± 90 in Zambia. Ingot moulds from Kipushi, Zaire, for the production of "currency" can be dated as far back as AD 1360 ± 65. The implications of these findings to African history are discussed and the hypothesis that long-distance trade was the primary force in the formation of the savanna states is questioned. APG

Peter Schmidt and Donald H Avery: Complex iron smelting and prehistoric culture in Tanzania.
Science, 1978, **201** *(4361) 1085-1089.*

Ethnographic, technological, and archaeological research into the technological life of the Haya of Northwestern Tanzania shows that these people and their forebears 1500-2000 years ago practiced a highly advance Fe smelting technology based on preheating principles and, as a result, produced C steel. This sophisticated technology may have evolved as an adaptation to overexploited forest resources. These discoveries are significant for the history of Africa and the history of metallurgy. AATA

Alessandra Nibbi: Some remarks on copper
Journal of the American Research Centre in Egypt. 1977, **14**, *59-66. 8 figs., 72 refs.*

The author argues that before the Eighteenth Dynasty, the words for "metal" in ancient Egyptian texts refer to copper *only*; after that, the words *can* refer to iron. The appearance of iron beads in Pre-dynastic tombs, prior to the Iron Age, is attributed to the droplets of iron expelled during the copper refining process. The sources for copper ore in the Eastern Desert and the Sinai are reviewed. Tomb representations of smelting and refining crucibles are illustrated and discussed. LRAZ

Udo S. Kusel: "Primitive" iron smelting in the Transvaal.
Book. Studies by the Natural Cultural History and Open-air Museum, number 3, Pretoria, 20pp, 1974. Photos., diagrams, refs.

Knowledge of iron working might have entered South Africa along the east coast. Iron was known to have been used as early as 400 A.D. and spread westward through the 1600s. Kusel gives historical accounts of iron smelting in the Transvaal, and descriptions of furnaces excavated in the 20th century. In all cases the process was to burn charcoal in a furnace built from several thin layers of clay. The iron ore became an iron crystal sponge (which is later forged) as the furnace's carbon monoxide withdrew oxygen from the ore. Also recounts an unsuccessful attempt by Bantu smelters to reproduce the traditional methods. Urges analysis of museum objects as a means of increasing knowledge about smelting history. CGA

Josef Riederer: Scientific study of bronzes in the Egyptian Museum, Prussian Cultural property, Berlin.
Berliner Beitraege zur Archaeometrie, 1978, (3), 5-42, In German.

525 bronzes from the Agyptisches Museum Preussischer Kulturbesitz in Berlin have been analyzed by means of atomic absorption spectrography. It was found that in a region between 65-100% copper, 0-15% tin and 0-30% lead all possible alloys were used . High amounts of zinc with more than 0.5% were found in only 21 from 525 objects. Arsenic and antimony go up to 3%. As a difference of the alloys used in different regions, it was found that Osiris-statuettes of upper and lower Egypt were of a similar composition with more tin and less lead than those from middle Egypt. Further it was found that some gods like Min or Hathor always were made of same alloy, while other gods consisted of a great variety of alloys. These varying compositions could be grouped again to ascertain types of alloys. JR (AA)

AMERICA

Lechtman, H: A Pre-Columbian Technique for Electrochemical Replacement Plating of Gold and Silver on Copper Objects.
J. Metals, Dec.1979, **31***(12), 154-160. (Illustrated).*

The Mochicha culture flourished on the north coast of Peru between about 0 and 600 AD. A number of gilded and silvered copper objects from this period found at Loma Negra near the Ecuadorian border have been metallographically examined. Laboratory experiments have indicated that the 0.5-2 μm thick platings were probably produced by dissolving the gold (or silver) in an aqueous solution of $NaCl + KNO_3 + KAl(SO_4)$ and then neutralising the solution by the addition of sodium bicarbonate or calcium carbonate. Copper sheet immersed in the simmering solution for 15 mins. acquired a uniform coherent film of precious metal, and the same effect could be obtained by repeatedly painting or swabbing the diluted solution on the copper. However, on flexing the sheet, the plating tended to flake away in spots. Heating the plated copper in air at about 850°C for 5-7 seconds improved the bond between plating and metal, and also gave pronounced solid state diffusion of the gold into the copper, as observed on the original articles. APG

A Sutular: Early history of Chilean mining from the Inca period.
Bulletin of the Metals Museum (of the Japan Institute of Metals). 1978, **3**, *4-15.*

Archaeological evidence indicates that gold, silver and copper have been extracted from placer deposits for at least 3,000 years. Later, lead and mercury were recovered, but these were of less significance. Metal production increased greatly after the Inca conquest (1425). The melting of gold, silver and copper was carried out in small crucibles, the furnaces being mouth blown by groups of Indians, each with a narrow pipe with a small orifice at the end.

Iron was unknown before the Spanish Conquest (1524 onwards). With their more advanced arms made of iron, horses and superior strategies, very small numbers of Spanish easily dominated the much more numerous local tribes. At first, the conquerors collected all the gold and silver which they could from local Indians in order to pay their troops and mercenaries. Later the mines were taken from the Indian who were made to provide forced labour. Tools were almost non-existent and conditions were so bad that information about the mines was withheld and production dropped drastically. Even at the beginning of the 17th century, the Spanish population was 3,600 compared with 600,000 Indians. 10% of this population with ages between 18 and 50 were forced to work in the mines but despite the opening of new mines, annual production remained low averaging 45 tons copper, 350 Kg gold and even less silver. By the end of the colonial period (1870) the figures were 1,000 to 1,500 tons of gold from 67 mines. Silver production was approximately twice that of gold coming from 35 mines. Sulphide copper ores were considered worthless, as no method of extracting the metal was available.

After independence, Chile got free access to world trade and investment. While the production of gold dropped, that of silver increased dramatically, particularly after the opening of the Chanarcillo mine. Copper mining and smelting increased until between 1850 and 1890. Chile became the most important producer, supplying 36.8% of the world output.

Illustrations show copper arms and tools before the Spanish conquest, domestic copperware of the 16th and 17th centuries, early crucibles for working copper, 19th century Chilean trapiche and stamp mills, and gold and silver furnaces used in Chile in 1840. APG

H V Michel and F Asaro: Chemical study of the Plate of Brass.
Archaeometry, 1979, **21** *(1) 3-19.*

The Plate of Brass is an inscribed brass artifact which has been attributed to the landing of Francis Drake on the California coast in 1579 A.D. In the present study the chemical abundances of the major and trace constituents in the Plate of Brass were quantitatively measured. These values were compared with measurements on both medieval and modern brasses and with the levels of impurities expected in brass-making processes from medieval times to the present. This study indicates that the Plate of Brass was made during the eighteenth to twentieth centuries and suggests that the most probable period was the early part of the twentieth or the latter part of the nineteenth century. AA

Judith Nash: The gold of El Dorado.
The Connoisseur Jan. 1979, **200** *(803) 6-12. In Eng. Notes, illus., colour and b/w.*

Includes brief description of methods of gold-working used in ancient Colombia, principally simple hammering, annealing, lost wax casting and embossing over moulds. CIL

Warwick Bray: Gold working in ancient America.
Gold Bull, 1978, **11** *(4) 136-143. In Eng.*

Gold metallurgy and technology by American Indians prior to European contact is detailed, based on analyses of museum pieces and writings of early European eyewitness accounts. Topics discussed include casting, granulation, and gilding. AA

R E M Hedges: Analysis of the 'Drake Plate'; comparison with the composition of Elizabethan brass.
Archaeometry, 1979, **21** *(1), 21-26.*

The non-destructive analysis by XRF of the so-called 'Drake Plate' is described in order to provide information on its authenticity. Analysis of a group of sixteenth and seventeenth century brass artifacts for comparison purposes is included. AA

John R White: Archaeological and Chemical Evidence for the Earliest American Use of Raw Coal as a Fuel in Ironmaking.
J. of Archaeological Science, Dec. 1978, 5 (4) 391-393.

Excavation of the furnace tipple or loading area of the Eaton (Hopewell) furnace near Youngstown Ohio revealed the presence of four primary charging materials - charcoal, limestone, iron ore and bituminous coal of relatively low ash and sulphur content. Analysis of the other raw materials, and of samples of the cast iron and slag produced, confirms that coal must have been used in combination with charcoal in the furnace. APG

John R. White: Preliminary Archaeological Excavation of Ohio's first Blast Furnace: the Eaton (Hopewell).
Ohio J. of Science, Mar. 1980, **80** *(2), 52-58.*

Built in 1802-1803, the furnace went out of blast in 1808 due to a combination of factors and fell into ruin. The results of excavations over three seasons are briefly described, the bosh and hearth being well preserved. Eaton's use of bituminous coal in combination with charcoal is the earliest use substantiated in the New World.. APG

M Urena and Ma. A B Perez: Scientific study of metal objects from Ingapirca (Ecuador).
Revista Espanola de Antropologia Americana, 1978. 19-49. In Spanish.

Fifty-nine metal objects, including rings, little bells, small discs and plaques, needles and pins, recovered from the Ingapirca site, Ecuador, dating between 900 and 1000 A.D. were analyzed. Spectrographic and metallographic studies suggested that the most common metal, copper, probably was mined from the same source, and smelted by means of the simple, indigenous "guayra" type furnace. Most objects were cast and only lightly cold hammered, indicating that ritual rather than utilitarian functions were intended for the finished pieces. More than one cultural group is represented by the sample, including Canan and possibly Inca, among other associations. JMV

Sharon I Goad and John Noakes: Prehistoric copper artifacts in the eastern United States.
Adv. Chem. Ser. 1978, **171** *(Archaeol. Chem. 2) 335-346.*

Spectrographic and activation analysis are used to identify trace elements in native Cu ores and artifacts based on data from sources throughout the U.S. and on several artifacts from Dlpena sites. The data were grouped using the statistical techniques of principal components and cluster analysis. Spectrographic data are grouped into discrete geographical clusters whereas the activation data formed 1 undifferentiated cluster. The spectrographic analysis suggested that the Cu used to fabricate the Copena artifacts was from Great Lakes deposits, and the mechanism of exchange responsible for the movement and dispersal of these artifacts from their source to Copena is described. Further applications of activation analysis to native Cu may result in more discrete cluster groups and the differentiation of specific copper quarries. AATA

Marcela Rios and Enrique Retamozo: Metal objects from the island San Lorenzo.
Book Instituto Nacional de Cultura, Lima Arqueologicas-17, Museo Nacional ade Antropologia y Arqueologia, Lima. 1978, 98 pp. In Spanish, 14 plates, 3 graphs, bibliography.

One hundred fourteen late prehispanic metal objects and fragments, including beakers, cups, plates, bowls, bottles, masks, spoons, earrings, bracelets, diadems, beads, rings and other jewelry, excavated by Max Uhle in 1906 from an island off the central Peruvian coast, were analyzed. Over 95% of the collection consists of silver objects, the remaining 5% of gold and copper. Techniques of manufacture include repoussé, incision, stamping, lamination, casting and soldering. Spectrographic analysis of two objects and a technical analysis of 10 associated textiles are given. Drawings of many decorated and modelled objects are provided. JMV

Cornelia Boensch, and Josef Riederer: Metal analysis of South American tools and weapons of copper and bronze.
Berl. Beitre. Archaeom, 1977, 2 (2) 41-49. In German.

For the catalogue "Altperuanische Kulturen 1" of the Museum of Ethnology at Berlin by D. Eisleb, a series of Peruvian weapons and tools of copper was analyzed. Two groups of metals were found: pure copper and copper with high amounts of arsenic. To find out which copper alloys were used in South America in the pre-Columbian period, a larger series of objects from the Museum of Ethnology was analyzed. It was found that bronzes with relatively high amounts of tin were also used. These results provide a reliable basis of a more detailed research on variations of the composition of these materials due to different periods and regions of origin. JR

Heather Lechtman: A pre-Columbian technique for electrochemical replacement plating of gold and silver on objects of copper.
Paper presented at the Annual Meeting of the American Inst. of Mechanical Engineers, New Orleans, Feb. 1979.

Discusses the presence and appearance of very thin films of gold and silver on the surface of copper objects from the Mochita culture which flourished in northern Peru from c.0-600 A.D. Concluded that these films were deposited by an electrochemical replacement technique. Identical coatings were reproduced in the laboratory using gold or silver dissolved in aqueous solutions of sodium chloride plus potassium nitrate plus potash alum. WAO

Josef Riederer and H G Bandi: The metallographic examination of bronze armour of the Eskimos.
Berl Beitre. Archaeom. 1977, 2,17-26. In German.

On several sites on the St. Lawrence Island in the Bering Strait between Alaska and Siberia metal plates of armour were found. By chemical analysis it was found that the plates consisted of two alloys. 73 of 108 plates were made of bronze, 32 of brass and 2 of copper. The brass contains 64-66% copper and 34-35% zinc. Brass with more than 30% zinc was not in use before the 19th century. A high amount of phosphorus indicates that these alloys were used for the decorative parts of ships. A metallographic examination showed that the sheets of metal were made with machines and not by hand. By that it was proven that the Eskimos received in trade sheets of bronze and brass which they used for making metal armour not earlier than in the 19th century. JR (AA)

TECHNIQUES

Ernst Hoke: Microanalysis of metal threads in Grave 1 of the parish church Traismauer.
Fundberichte aus Oesterreich, 1978, 16, 255-259. In German, 1 table 6 illus.

Early textile fragments with gilded silver threads from an entombment dating 8-9 centuries A.D. were analyzed microchemically and with a microprobe. Two groups were selected: one with gilding on a silver-copper base, of oriental origin, and a second set of German origin with a majority of lead. MK

Francois Schweizer and Pieter Meyers: Structural changes in ancient silver alloys; the discontinous precipitation of copper.
ICOM Committee for Conservation, 5th Zagreb, 1978, 78/23/5/1-16.

The age embrittlement of ancient silver could be due to discontinuous precipitation of copper from the supersaturated silver-rich silver-copper solid solution during the long sojourn at ambient temperatures. Microstructures of a number of ancient silver samples. AATA

Narendra Singh Rawat: A study of ancient copper and bronzes and their corrosion products.
Trans. Indian Inst. Met. 1976, **29** *(4), 254-61, 305. In Eng.*

The chemical composition is presented of some ancient copper and bronze objects, dating from 535 B.C. to 515 A.D. and excavated at Kausambia. The principal components Cu, Sn, and Pb varied. The maximum proportion of Cu was 98.21%. The objects containing a low proportion of Cu were high-Sn bronzes, with about 25% of Sn. The Cu most likely came from the Indian ores in Rajasthan and Bihar, although Afghanistan and Persian sources were not ruled out. Sn may have been derived from the alluvial deposits of cassiterite in India from places where only traces of ore occur now or it might have been obtained from Northern Iran. Pb possibly came from Zn mines in Rajasthan. Impurities included Fe, As, Ni, Sb and Zn. S was found in traces in only a few. Bronze objects were more corroded than Cu objects. The analyses of the corrosion products indicates the presence of basic Cu chloride (atacamite), and in a few, basic Cu carbonate (malachite). Microscopic examination of a completely corroded bronze object showed white Sn oxide deposited mainly in disconnected seams throughout the cuprite. Cl^- was the most potent corrosive agent and an electric conductivity method for its removal was suggested. AATA

K A Reynolds: A method for the controlled sectioning of metallic fragments for metallographic examination.
Journal of the Forensic Science Society, 1977, **17***, 265-267.*

This paper describes the use of a magnetic field to orient samples of iron in a mounting cup while the sample is being embedded in a resin for microscopic examination. Nonmagnetic samples may be oriented in the same way by first adhering them to a small piece of iron wire. WAO

J Andrews and F Celoria: A 19th-century smith's leg vice from Staffordshire, England, with a metallographic analysis of parts of its screw.
Science and Archaeology, 1976, 17, 21-34. 25 figs, 7 refs.

A blacksmith's leg or staple vice of suggested 19th-century

date, in use in Staffordshire till the 1970s is examined with regard to 17th-century and later descriptions relating to use and manufacture: and with regard to a scientific examination made of the box or nut to ascertain methods and materials of construction. X-ray examination together with optical metallography, as well as boroscopic and electron beam microprobe analysis methods were used in the examination. The wrought iron consisted of a ferritic matrix with many elongated silicate and oxide inclusions. A copper zinc brazing spelter had been used throughout.
AATA

R E M Hedges and C J Salter: Source determination of iron currency bars through analysis of the slag inclusions
Archaeometry, 1979, 21 *(2), 161-175.*

Three groups of currency bars from three separate hoards were analyzed for the distribution of 17 elements in their slag inclusions. There is a clear statistical discrimination between the three groups which can be attributed to the different ore sources. Thus chemical analysis of slag inclusions in wrought iron can be used to trace the different sources of iron artifacts, at least within the context of the geology of southern England.
AA

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