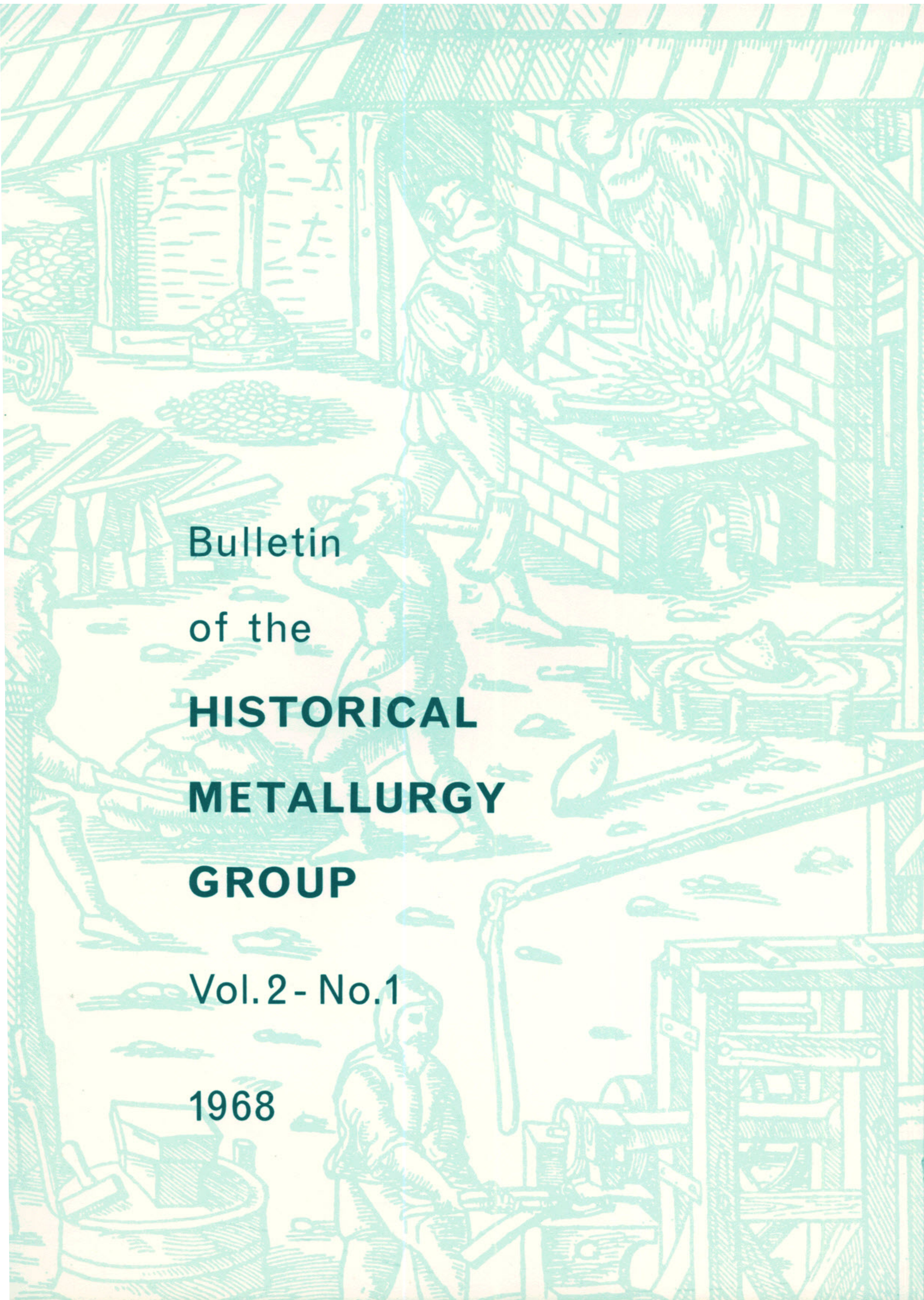

Bulletin of the HISTORICAL METALLURGY GROUP

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Contents

Forest of Dean 1967

Report of the Third Annual Conference

The Third Annual Conference of the Group was held at Littledean House Hotel in the Forest of Dean, Gloucestershire, from Friday evening till Sunday lunchtime, 22-24 September 1967; it was attended by about 70 members.

The aim of the programme was to provide an historical background to the various industries and associated activities in Dean, together with some technical description, with the emphasis on the iron and steel industry, and to supplement this information with tours to representative sites in the Forest. An additional feature was to foster an appreciation of the natural beauties of the district.

HISTORY AND GEOLOGY

The first evening opened with an introduction by the President, Mr M. F. Dowding, followed by a paper on the historical aspects of the Forest iron-working industries by Dr Cyril Hart. This paper dealt successively with the bloomery and blast-furnace periods, and with the associated industries developed in the late 19th and 20th Century. Being a native of the Forest and now Senior Verderer, Dr Hart's knowledge of silvicultural practice and of local history provided a fascinating story of the exploitation of Dean's resources in relation to iron-working.

The second paper was a lucid and interesting exposition of the general geological development of the iron and coal strata both in the Forest and the neighbouring South Wales area, by Mr R. J. Piggott, a Divisional Surveyor and Minerals Manager of the National Coal Board. One important point that arose was that the hard-coking coal was not present in the Forest, as at Blaenavon and Merthyr, otherwise Dean would have become pre-eminent in the coke blast-furnace industry.

IRON AND RAILWAYS

The first paper on the Saturday morning was by Mr Norman Bridgewater, in which iron mining and iron working in and around the Forest were discussed. This covered in detail present knowledge of the bloomery era, arising from archaeological excavation and field work, chiefly in the Archenfield territory adjacent to the Forest. Several sites were listed and described. Remaining sites of the blast-furnace period were also described.

Next followed an account of the development of Dean's tram road and railway system, in a paper by an authority on this subject, Mr Harry Paar, who then described its association with the local coal and iron industries. Some interesting exhibits of tramroad castings were later described by Mr Alec Pope.

Arising from the preceeding papers, a technical discussion developed around the processes operating in the contemporary blast furnaces. It was also concluded that it may have been technically possible for Roman bloomery 'cinders' to be used in medieval bloomeries, thus accounting for the historical references to the re-use of such cinders.

On Saturday afternoon, various sites were visited, these including sites of blast furnaces and forges. The experimental iron works at Darkhill and the Titanic Iron and Steel Company premises, the scene of the Mushets' epoch-making discoveries, were also a feature of this trip.

CHARCOAL AND CHEMICALS

The final paper of the Conference was given by Dr Hart, who related the history and practice of charcoal burning, chemical works and wood distillation in Dean.

On the Sunday morning, as a prelude to the second tour, an interesting film on the excavation of a 13th century bloomery site in Sweden was shown by Dr Fru Inga Serning.

The second tour embranced a visit to the famous Bream Scowles, the scene of ancient iron-mining, followed by a tour of the Redbrook valley associated with iron and copper working and tinplate manufacture.

Finally, after visiting the well-preserved Whitecliffe blast-furnace, the Group went to Staunton church, where the Chairman placed a wreath on the grave of David Mushet.

EXHIBITION

In addition to the papers and tours, numerous exhibits were available for study in the conference room. These included period distribution maps of the sites covered, drawings of certain sites, old mining equipment (for iron and coal), slag and ore samples, and a display of material from Samuel Osborn and Co. Ltd., of Sheffield, illustrating the work of the Mushets.

The conference closed with a vote of thanks to the committee and organisers, by Sir Frederick Scopes.

NOTES ON SITES VISITED

The following notes give historical and descriptive details of the sites visited and mentioned during the conference. There are also some additional points included which have arisen as a result of subsequent discussion. The notes have been prepared by Dr Hart (C. E. H.) and Mr Bridgewater (N. P. B.)

Whitecliff Furnace Towards the close of the 19th century, Samuel Botham, a Quaker residing in Uttoxeter, was in partnership with the brothers Bishton of Shifnal, Shropshire. He and his wife Ann were the parents of Mary Howitt, poetess. In 1798 his partners induced him 'to exchange his share in the very advantageous iron-forges in which they were concerned for a principal share in some ironworks in Gloucestershire'. [1] Late in that year Botham arrived to reside in Coleford where, at nearby Whitecliff, the erection of a blast-furnace had begun. Considerable capital was invested in the project, all furnished by Botham.

The works were sited on the west of Thurstan's Brook which runs through Coleford to Newland and thence continues as the Valley Brook, to Lower Redbrook and the Wye. Much progress had been made in the erection when in 1799 deep snow fell, followed by such heavy rains, that the brook swelled, flooding all the buildings and in one night wrecking much work. Botham's South Wales associates refused to help and having lost his investment, he withdrew from the undertaking; by 1801 he had returned to Uttoxeter. His associates together with Thomas Halford and Moses Teague took over the works and eventually completed them. [2] 1804 is the date on the extant furnace, which is free-standing but buttressed back to the hill by a membrane wall, to facilitate charging from above.

The furnace was the reason for the coming to Dean of a brilliant Scot and early metallurgist, who with his son were to bring fame and notability to themselves and the Forest. David Mushet (1772-1847), the discoverer in 1801 of the Blackband ironstone in Scotland, while working at the Clyde Ironworks near Glasgow began to experiment on the scientific determination of various properties of iron, but his work terminated suddenly when his employers pulled down his little experimental furnace. He moved to the Calder Ironworks, then to Derbyshire. In 1810 he entered the association at Whitecliff, and nearby in Coleford purchased Tump House, later renamed Forest House (still standing).

He helped to run the Whitecliff ironworks for only a short while, continuing his experiments all the time; 'he had grave reasons for being most dissatisfied with his partners, and he withdrew'. [3] The works were dismantled, except the furnace, which is still standing though devoid of the hearth and ironwork. A large quantity of the castings, including blast apparatus, were taken to the Cinderford blast-furnaces in 1827. [4] CMU & PR Plans of 1852 show the furnace as 'old ruin', but the outline suggests that a fore-part or covering over the approach to the hearth then existed; a warehouse was adjacent.

This furnace was clearly designed for coke smelting and must have had a capacity of about 1200ft^3; thus it is considerably larger than that at Guns Mill. It certainly represents the latest practice at the time of its building and presumably its financial failure is connected with the high prices of coke and ore at this time relative to those elsewhere. The furnace had two tuyeres (the small opening opposite the tymp arch was for some other purpose). It was steam-blown and the shaft was lined with firebrick. Its height was 40ft. The shaft, bosh and crucible would all have been circular. The casing is of square plan, 40ft wide by 45ft in the side, and most of the external masonry is intact, although the keystone is missing, probably having been loosened by the heat from the taphole. The hearth and bosh system are missing. A small building situated to the east of the casting floor may have been a pattern shop, and the engine house probably lay behind this. C. E. H.

Guns Mill A furnace had been erected there by 1628-9, on the Westbury Brook, and was owned by Sir John Winter of Lydney. In 1644 during the Civil War, it was run by Capt. John Braine. It was probably destroyed by order of the Commonwealth in 1650, and certainly in ruin in 1680. [5]

The derelict furnace was rebuilt in 1683 – the date on the cast-iron upper lintel-beam above the casting aperture. In 1701-2 'the mill' there, comprising two grist mills and a fulling mill, were mortgaged to Thomas Foley for £100. [6] The furnace was in the Foley partnership account 1705-6, with a make of 779 tons, [7] and made 562 tons in 1710/11, 153 in 1711/12, 467 in 1730/31, and 401 in 1731/32. Information is lacking for the interim years. By 1743 it was a paper-mill (q.v.), the wheel being supplemented by a steam engine. [8]

Although this furnace was rebuilt in 1683, it would seem that the rebuilding was based on the earlier design. It has a square-section inwall with slight curvature on the faces, as shown in Warren Marsh's drawings, which resembles the furnace at Rockley, near Sheffield. Although the hearth is missing, the remains suggest that there was no attempt to fit a circular bosh and crucible as at Coed Ithel, Sharpley, and Cannock, but that the original square hearth was retained. It is therefore the best remaining furnace of the earliest phase of British blast-furnace practice. It would seem to have been 22ft to the charging floor, 7ft across the bosh, and to have a capacity of about 530ft^3. It is in better condition than the furnace at Rockley, and the openings through the walls allow one to appreciate the shape of the furnace more easily. C.E.H.

Flaxley In 1634 there were two single forges, run by John Typper.[9] They were probably owned by Sir John Winter (as was Guns Mill), who had the woods previously belonging to Flaxley Abbey. A furnace stood here in 1680,[10] and there were two, possibly three, forges on the same watercourse, the Westbury Brook, in addition to Guns Mill. The furnace, probably about 300 yards below the Abbey, was held by Richard Knight in 1695 and 1710.[11] By 1712 all the ironworks there were owned by Mrs Catherine Boevey,[12] and in 1717 her furnace produced about 700 tons.[13] The forges produced on average 100 tons annually pre-1736, and about 80 thereafter, rising to about 150 in 1750.

By 1802, Flaxley's iron was 'esteemed peculiarly good – and its goodness does not arise from any extraordinary qualities in the ore, but from the practice of working the furnace and forges with charcoal, without any mixture of pit-coal'; however, the quantity of charcoal required was so considerable that the furnace 'cannot be kept in blow or working more than nine months successively, the wheels which work the bellows and hammers being turned by a powerful stream of water,[14] Lancashire ore, brought to Newnham by sea, furnished the principal supply, the Forest ore 'being either too scanty to answer to expense of raising it, or when raised too difficult of fusion, and consequently too consumptive of fuel, to allow the common use of it'. A ton of Lancashire ore required 15 or 16 sacks of charcoal. The 20 tons of pig iron produced each week was carried to the forges, where about 8 tons a week 'were hammered-out into bars, ploughshares, etc. ready for the smith'.[15]

The furnace closed early in 1802, one of the last locally to use charcoal.[16] The forges continued for a while longer. In the 1850's, 'aged people of the neighbourhood well remembered when the furnace was in blast, and told of the cinders and pickings of the old mine holes being taken down to it,[17] but by 1858 the ironworks had long since been discontinued, and with the removal of the furnace and forge buildings, and of the pools, the whole appearance of the valley changed – for the better.[18] A solitary heap of Lancashire ore alone remained.[19] The stream which arose at St Anthony's Well and which turned the wheels for the bellows and hammers, is now of small proportions and much of it is out of sight underground. The site of the furnace and, above, one of the forges, cannot be found with certainty, but the names 'Furnace Yard', 'Mill Field', 'Forge Cottage', 'old Pool Cottages', and one of the dams, bear witness to the past. The furnace probably stood at the right-angle bend near the pound on the N.W. of the narrow road adjacent to Waldron Cottage (1878), now a farmhouse. It is believed to have been supplied with water by a leat cut into the hillside.[20] The one forge which is certain, is adjacent to the above farmhouse, and was noted by Bryant in 1824 as 'Lower Forge'. The modern lane which crosses the stream also passes over the dam of a former pool, which is now a large field. The arched culvert passing beneath the dam is still well preserved, and the tapering channel (for increasing water velocity) and the large chamber are noteworthy. Remains of buildings to the south of the road, now farm buildings, must be part of the forge, and the channel leading from the former wheel-pit can be distinguished. The end wall of the present dairy is dated 1693. In 1925 a fireback dated 1633 stood in the estate workshop, and another dated 1685 in the Abbey, while in the garden of the estate foreman was a cast-iron block, 11½in x 5½in x 5½in, lettered 'Flaxley Woods, 1812' – presumably a weight (90.44lb).[21] C.E.H.

Soudley The furnace, built on the Cinderford-Soudley Brook for the King in 1612 by Pembroke's nominees, stood near the site of the present sewage works. Much slag and some remnants of a building are extant, and on part of the site stands a dead beech of some 250 years. The furnace was extant in 1634[22] and was surveyed in 1635.

The furnace was run during 1643-5, but destroyed by order of the Commonwealth in 1650. Its remains were sold for demolition in 1674. Particulars of Soudley Furnace are quoted by Schubert,[23] from an inventory made in 1635. C.E.H.

The Dean Road The Dean Road runs from Highfield, near Lydney, to Mitcheldean, a distance of 10¼ miles. A well-preserved intact stretch is seen at Blackpool Bridge.

The road was thoroughly surveyed in 1932-5 by Trotter and Hicks, several small stretches being uncovered for recording. The details of this work can be seen in Trotter's book "The Dean Road" (published by Bellows, 1936).

The road was originally paved and kerbed and the general method of construction appears to have been as follows: A trench 8ft wide and 1ft deep was first made and the roughly dressed kerbstones were set in position, the top edges being flush with or just above ground level. About 6in of earth were put in the trench and the paving blocks were well rammed down on this. No foundation material, such as sand or gravel, was used. The kerbstones, mostly sandstone and conglomerate, were 6-14in long and 3-6in wide. The paving blocks were rough cubes with 5-9in face.

Although this road is now commonly referred to as Roman, Trotter, in his book, does not describe it as such. In my view, based on extensive excavation of local roads, it has none of the characteristics of a Roman road. A local Roman road would undoubtedly have been surfaced with iron slag, and there would have been several re-surfacings to effect repairs. The type of road shown here has a typically pre-turnpike road surface, with kerbstones, and Trotter's reference to Pepys' writings in 1662, where he believes the road to have been constructed for hauling timber, is more convincing. (This does not, of course, preclude the existence of an earlier road). The reference to the road having been named the 'via Regia', in 1281, seems to me rather vague and inconclusive. It should also be mentioned that the discovery of a stray coin of Constantine near the road at Soudley Camp is of no use for dating; in fact, even if the coin had been found in the road surface, this would not date it. The dating of the road, therefore, in my opinion, must be left open. N. P. B.

Lower Soudley Ironworks In 1837 at the Bullo tunnel's mouth in Lower Soudley, coke-furnaces were erected by Edward Protheroe & Co. (Protheroe was M.P. for Bristol) at a cost of upwards of £10,000.[24] By October that year two new furnaces 'of the usual size' and two steam engines were completed.[25] The Protheroes, with Mr Broad as manager, worked the coke-furnaces for four years, but the works were idle in March 1841[26] and 1842.[27] In 1857, Benjamin Gibbons of Staffordshire purchased the works, and kept them in blast for a year or so;[28] they were idle from 1856 to 1860. He sold to Alfred Goold in 1863, but in 1864[29] and 1866 only one furnace was in blast, producing about 20 tons of Forest iron at each cast.[30] South Wales coke was used; William Trafford was manager, and there were 80 employees.[31] Goold Bros. tried to sell the works by auction at Gloucester on 15th November 1866, but they were withdrawn at the highest bid (£8,000[32]) and apparently sold soon after to Mr Maximillian Low.[33] One furnace was in blast from 1871 to 1875,[34] when the Great Western Iron Co. acquired the works, and made improvements, 'successfully introducing waste gas utilisation plant'.[35] Pig-iron was produced 'absolutely without coal for raising steam or heating the air, which is required at 800°F; with the engine working at 40lb, steam is blowing at 4lb pressure of blast; and at present only one of the two furnaces are put in blast, and the daily saving with the new system is at least £10 a day'.[36]

The managing director was A. D. Morrison, and the general manager J. Yorke Jarrett. The works were under lease to Morrison, Beauclerk & Co., who had opened them that year,[37] but in 1876 and 1877 only one furnace remained in blast,[38] and the whole plant was idle by September 1877. Bradley Villa, opposite on the west side of the stream, was according to its iron plate ('1876 J. Y. J. ') built by or for the general manager of the Great Western Iron Co. The top step up to the crossing-keeper's cottage on the north side of the railway is lettered 'S. I. Co. ', i.e. Soudley Iron Co.

In January 1891, the two furnaces were reported as 'under careful supervision' but 'the rooks are the only sign of life'.[39] By 1895 a crusher had been installed (reached through the furnace arch) with three sidings, used to clear slag for ballast purposes; after which the sidings were removed, by (and probably well before) 1920.[40] The chimney-stacks were felled c. 1900. C. E. H.

Bromley Hill (Oakwood) Furnace) The first we hear of this furnace is the indication in the Proposed Development Plan, 1852, for the Dean Forest, Monmouth Union and Private Railway, of 'Oakwood Furnace, Ironworks, of John Passand Litchfield and the Bromley Hill Company', by 10 July 1856 the Ebbw Vale Co. were about to put the furnace in blast,[41] and it probably worked until c. 1865-70. Evidence given in connection with the Coleford Railway Bill 1872 shows that the 40ft high furnace was not in work (and had not been for many years), but that the Ebbw Vale Co. wanted ironstone carried to South Wales and coke brought back for use at the Bromley furnace. The Company were opening ore mines in the Oakwood Valley, and would build a second furnace when the time was authorized. Edward Wilson stated he had laid out the railway to let about 5 tons of ore, coke and limestone into the top of the furnace without hoisting, and to take 1 ton of iron from the bottom by means of a steeply graded siding. The Proposed Development Plan, 1872, indicates 'Pit, furnace, chimney, shaft, engine house' of the Ebbw Vale S. & Iron Works Co. Ltd. The plans for the furnace did not mature. It was certainly out of blast during 1871-80[42] and not even acknowledged as existing in 1877-80.

Some of the remnants are visible. It was a three-tuyere furnace contained in a square structure 40ft by 34ft in plan, built into the hillside to the north. The northern and eastern tuyere-arches are blocked, whilst the hearth and fore-hearth are buried by rubble. The lining and most of the external stone facing has gone, but we still have the charging level, about 40ft above the casting floor, which lies to the south.

The blast was by engine, housed a little to the east. The slag heap has been removed, but there are traces of ore, limestone, coke, charcoal and iron. Probably a cold blast operation was used. C. E. H.

Darkhill Ironworks and the Forest Steel Works After severing his connections with the Whitecliff Ironworks, David Mushet continued to reside at Forest House in Coleford. Just above his home he built a large stone shed, and equipped it with 'a blowing engine and a furnace for melting';[43] there he carried on numerous experiments with iron, the building becoming the scene of epoch-making discoveries.[44]

On 17 July 1815 he took out a patent on a process of producing 'refined iron' direct from the blast-furnace without the refinery. It was not until the latter part of 1818 or the beginning of 1819[45] that to test his theories he built a furnace some two miles from his home, at Darkhill near Fetterhill between Milkwall and Parkend. He records "I erected a cementing-furnace which was capable of containing 2½ tons, and in which, from first to last, I made a good many batches, not only with the rich ore of Dean Forest, but also with the ore obtained from Cumberland".[46]

There he succeeded in producing an excellent quality of refined iron, practically free from phosphorus and sulphur, superior to that obtained by puddling.[47]

We are uninformed how long Mushet continued the Darkhill Works. By April 1824 Moses Teague had successfully made iron there 'in the cupola formerly used by Mr Mushet'.[48]

Shortly after the death of David Mushet on 7 June 1847, his son Robert Forester Mushet went into partnership with Thomas Deykin Clare, a Birmingham merchant, in a new venture, 'R. Mushet & Co. ', Forest Steel Works. This 'small experimental steel-work'[49] is believed to have been situated either in part of the Dark-Hill Furnace premises or in a building erected adjacent to it – probably the long smith's shop shown on a plan of October 1866. It included 'a crucible furnace of ten melting holes, and a pair of wooden helves or old-fashioned tilt-hammers; the melting holes were square so as to hold four crucibles or pots in each'.[50] The walls of the structure were formed of local red frit stone. The process used by Mushet is on record.[51]

In 1856 Mushet with the aid of S. H. Blackwell of Dudley added to the steel works 'a cupola for melting pig iron, a small Bessemer hearth or converter, 15in. square by 5ft. deep, and a blowing apparatus driven by a belt from a large pulley fixed on the end of the flywheel shaft which worked the tilt hammers'.[52] In that year, Mushet by introducing spiegeleisen accomplished the direct method of producing Bessemer-Mushet steel. His other experiments, failures, and successes were many.

On 22 October 1862 the Titanic Steel and Iron Co. Ltd was formed, promoted by Mushet to provide badly needed capital for expansion. It is believed that the new company at once built the large ornate works a few hundred yards W.N.W. of the Darkhill premises. Some of the products were made and despatched under the greatest secrecy.[53] The iron base for the manufacture of the steel was processes at the 'brickyard', part of the adjacent site. In August 1870 the company was refused by the S. & W. a reduction of tolls on blooms, to bring the rate in line with that on pig iron,[54] and in November of that year claimed £6 odd for damage to iron plates on transfer from the broad gauge at Parkend, where they were unloaded.[55] All seems to have gone well with the Titanic Company until 1871 when the works was closed; the company was voluntarily wound up in August 1874.[56] About 400 tons of its old iron was purchased in December 1871 by R. Thomas & Co. of the Lydbrook Tinplate Works to whom the S. & W. gave a special rate of 1s. a ton, by tramway.[57]

By March 1874 the S. & W. were discussing tenders for the sale of materials from the old Darkhill furnace etc., purchased off Goodrich Landham, and also for tramplates and blocks about to be removed.[58] The following month the S. & W. minuted their willingness to accept £420 from Vernon & Shepherd, iron merchants of Smethwick, for the furnace, which they wished to retain for smelting.[59] It is not known whether the deal was completed. Certainly the premises were shown as disused on the 1877-8 O.S.

Thereafter the buildings and site probably lay neglected. In 1908 the Commissioners of Woods advertised the Titanic property for lease.[60] No enterprise was attracted, but by 1926 the property was on lease to Lydney District Brickworks & Collieries Ltd, who in 1928 sublet to Milkwall Brickworks Ltd.[61]

Photographs taken in 1935 and 1951 show the ornate arches. A gasometer was shown on the OS plan for storing producer gas for the heat treatment of steel.

The buildings were bulldozed level by the Forestry Commission c. 1964/5, having for many years been open to the sky and used for such humble purposes as a chicken run. C. E. H.

REFERENCES

1. Autobiography, Mary Howitt (1889) i, pp. 36, 39.
2. Rudge, Vol. II, p. 104, records: 'At White Cliff is an iron blast furnace, belonging to Messrs. Teague & Co'.
3. F. M. Osborn, The Story of the Mushets (1952) p. 24.
4. Nicholls, History, p. 225.
5. Hart, Free Miners p. 103.
6. Information from Dr Jennifer Tann to Dr Hart
7. Johnson, p. 338.
8. Information from the late Rhys Jenkins to Dr Hart
9. P. R. O., S. P. 16/282.
10. Hart, Free Miners, p. 103
11. Johnson, p. 137
12. Flaxley Cartulary, p. 34
13. Hulme
14. T. Rudge, History of Gloucestershire, ii p. 96 quoted by Nicholls, Ironmaking, p. 55, and in Flaxley Cartulary, p. 34
15. Ibid
16. See deliveries in Hart, Royal Forest (1966)
17. Nicholls, History, p. 190, Ironmaking, p. 55
18. Flaxley Cartulary, p. 35
19. Nicholls, Ironmaking, p. 55

20. Information from Rhys Jenkins to Dr Hart
21. Ibid
22. P.R.O., S.P. 16/282.
23. Schubert The Kings' Ironworks in the Forest of Dean. Journal of The Iron and Steel Institute, Feb. 1953, p. 157.
24. Mining Jnl., 21/11/1866
25. Nicholls, History, p. 228, Iron Making, p. 59
26. G.R.O., Q/Rum/175.
27. Mining Jnl., 1842, p. 53
28. Nicholls, History, p. 229, Iron Making, p. 59
29. Letter from Charles Greenham
30. Nicholls, Iron Making, p. 60
31. Ibid
32. Mining Jnl. 21/11/1866
33. Iron, 11/7/1875
34. Insole, &c p. 88
35. The Forester, 9/12/1875
36. The Forester, 9/12/1875
37. Iron, 23/10/1875
38. Insole, &c p. 88
39. Iron, 2/1/1891
40. H.W. Paar The Great Western Railway in Dean (1963) p. 66
41. S. & W. Min. Bks
42. Insole, &c p. 88
43. F.M. Osborn, The Story of the Mushets p. 33
44. 'Mushet's Barn' was demolished in 1966
45. On 14 Apl. 1819, S. & W. agreed to provide rail facilities to Mushet's works (S. & S. Min. Bks. 14/4/1819)
46. (D. Mushet, Papers on Iron and Steel 1840, pp. 551-2).
47. Osborn, p. 25
48. H.G. Nicholls The Forest of Dean p. 225
49. Osborn, p. 140
50. Osborn, pp. 33, 140
51. Osborn, pp. 33-35
52. Osborn, pp. 46, 152
53. John Murray, A Handbook for travellers in Gloucestershire, 1st Ed., 1867, records: 'Edgetools and cutlery are manufactured at the Cyanogen Steelworks near Coleford'. This is doubtless the Titanic works.
54. S. & W. Min. Bk., 8/8/1870
55. Ibid., 11/11/1870
56. Osborn, p. 79
57. S. & W. Min. Bk., 9/12/1871
58. S. & W. Min. Bk., 5/3/1874
59. Ibid., 14/4/1874
60. F. 3/902; S. & W. Officers Min. 20/10/1908
61. F. 3/1093

Conference Paper

A resumé of the history of the Forest of Dean's ironworking industries

Cyril E. Hart

THE CHARCOAL IRON INDUSTRY (to 1794)

The Bloomery Period (to 1611) Some iron is believed to have been made in Dean before the advent of the Romans, and certainly much was produced here during their occupation. However, the whole organization and economic basis of Dean's large iron industry in that period is somewhat obscure, and many important points need investigation; some are touched upon by N. P. Bridgewater in his paper "Iron mining and iron-working sites in and around the Forest of Dean" (see below). How far an iron industry continued throughout the Dark Ages and in Anglo-Saxon times cannot yet be answered, Probably only local needs were met, though there is some suggestion of slightly increased activity by early in the 11th century.[1] Certainly with the advent of the Normans the industry developed apace.

By c. 1244 (and probably much earlier) permission to win ore in Dean was regulated by the king through his 'keeper of the gawle' (gaveller).[2] Thereafter we have abundant records of such privileges and of bloomeries and forges which were set up in places near the iron-ore deposits, or where the least labour was required in transporting wood or charcoal. No clear distinction is made in the records of the various types of plant used in the industry. We frequently read of fabricae (and gross fabricae), forgiae arrantes, and blissahis, but we cannot always be sure which indicate forges, or bloomeries, or a combination of the two. Often the king's 'great forge' is mentioned, as well as itinerant plants – though it may be the business, or the operators thereof, rather than the works, which was moved owing to wood and ore in the immediate vicinity being exhausted. There is no evidence of roasting or crushing before smelting but the personal name of le stampere is met. Intriguing records (from 1246) are those mentioning sales of slag, termed 'cinders' (cineribus). It cannot be proved that the cinders were used for resmelting.

Many locally important people, lay and ecclesiastical, were granted licence to have forges and furnaces, with wood to sustain them. Other people set them up without permission or in actual defiance of orders. In the first half of the 13th century the king wavered between willingness to avail himself of rents from these private plants and of iron to supplement the nation's supply, and unwillingness to sacrifice the large number of trees consumed and to tolerate the disturbance of his deer. At times he would order all works to be removed; sometimes he showed much leniency. By the middle of the 13th century there were between 25 and 30 'forges' (probably combined with bloomeries), in 1270 at least 43, in 1282 60, but only 45 in 1283-4. Licensees paid usually 7s. a year for each works. If we take an average of 40 forges-cum-bloomeries as in work, and an average of 3 tons of iron annually from each, the total production in Dean would be 120 tons – about one-sixth of the country's annual output. The amount of ore needed would be at least five times (in weight) the amount of metal produced. Supplementary to this would be the ore supplied to forges outside the Forest.

The demand for iron which Dean satisfied ranged from the king's constant requirements for arms and military stores (particularly quarrels for crossbows) to the needs of the textile industries in Gloucester, Bristol and Coventry. Probably the most sustained, though unmeasurable, demand was that of the smiths of numerous villages working on plough and cart parts and other items of agricultural equipment. Nor must the building industry be forgotten. Every excavation of a medieval site, whether occupied by mainly stone or timber-built structures, produces a considerable crop of iron nails, spikes, hasps, bolts, locks, hinges, knives and other products of the nailers, cutlers, lockyers, and other workers in iron, many of whom were urban specialists, unlike the all-purpose rural smith.[3]

The king's inconsistent policy continued throughout the 14th century but in the following century restrictions appear to have been few, provided rents were paid on the plants and dues on the winning and transporting of ore and cinders. There were 33 'forges' in work during 1436. In the 16th century many 'smyth holders' were in evidence, and even in dispute with each other. No technical information relating to the industry can be derived from Dean documents, but an account of a forge worked for Henry VIII at Llantrisant, Glamorgan, by men from Dean represented the local practice.[4] Already there were restrictive practices: the rules of the organized smiths of Coventry (dating from 1540) ordered that 'no smith shall shoe a horse with Forest-shoes or Forest-nails.[5]

In 1540, Leland recorded of Dean that 'the ground is fruitful of iron mines, and divers forges be there to make iron'.[6] Some curtailment of release of wood for charcoal took place in Elizabeth I's reign, with the effect in Dean of restricting supplies to that obtained from coppices, underwood and by debranching of standing timber-trees. (This, and on other effects on the woodland cover, is enlarged upon in my paper "Charcoal-burning in Dean"). Sales of wood were made to the 'ore-smiths'.[7] Iron was apparently in plentiful supply,[8] but after 1575 the local bloomeries had to meet increasing competition from not too distant blast furnaces at Whitchurch, Lydbrook, Whitebrook, Tintern, and Lydney.

The First Blast Furnace Period (1612-1679) Only three of the early voracious blast furnaces of the late 16th century were set up near Dean's woods: one by 1575 across the Wye at the west end of Whitchurch, owned by Gilbert, Earl of Shrewsbury, and the other two from the 1590s at Bishopswood, owned by Robert Devereux, second Earl of Essex.[9] The lintels, beams, and other ironwork for some furnaces of the time were made by Francis Watkins of Lydney; for instance, in c. 1597 he made the ironwork for furnaces at Monkswood, Pontypool, and Abercarn, all for Richard Hanbury.[10] He probably also supplied the ironwork for the Lydney furnace owned in 1604 by the Winters, and possibly for the two furnaces in Upper Redbrook owned about the same year by William Hall.

By 1611 it was obvious that many benefits would accrue to anyone who could obtain from the King concessions (if not a monopoly) relating to Dean's resources – ore, wood, and waterpower; besides, there were tens of thousands of tons of bloomery slag (cinders) which could be resmelted. The Earl of Pembroke's nominees obtained such a monopoly, and in 1612 built the 'King's Ironworks' – 4 furnaces and 3 forges at Lydbrook, Cannop, Parkend and Soudley.[11] Activity in the industry was great (some 1,400 tons of ore were sent to Ireland alone in 1612-13[12]). However, disputes with the miners and the illegalities of the ironmasters led to intermittent working in the industry and to changes of lessees, among whom were such well-known figures as Sir Basil Brooke, Sir Sackville Crowe, and Sir Baynham Throckmorton.

By 1634 the King's Ironworks were supplemented by two forges, one at Bradley and the other at Whitecroft. Thus the king owned 4 furnaces and 5 forges. Private individuals (Sir John Winter, Benedict Hall, Sir John Kirle, Sir Richard Catchmay, and a Mr Typper) held 7 furnaces and 6 forges at Lydney, Rodmore, Guns Mill, Newland, Lydbrook, Bishopswood, Brockweir (? Coed Ithel), and Flaxley.[13] The huge fines imposed on these and other ironmasters during the forest eyre of 1634 show the widespread misappropriation of trees. For 1635 very detailed surveys of the King's Ironworks are extant.[14] Thereafter the works were on lease to Crowe, Throckmorton, Taylor and Gonning, but the sale to Winter in 1640 of practically the whole of the Forest and its resources, and the turmoil of the Civil War which followed (when many cannon balls were cast in Dean, particularly at Soudley furnace), put the iron industry in chaos. During the Commonwealth some of the works were repaired and others built, from which immense quantities of iron products were forthcoming.[15]

<u>The Cementation Process</u> By this process, which possibly dates back to 1556 in Italy or to 1613 in Holland,[16] steel was produced from pig-iron through the addition of carbon to wrought iron. In 1614 a patent for the process was obtained by William Ellyott and Matthias Meysey. Two years later they gained another patent, for carrying out their invention with pit-coal instead of wood. The patents were transferred to Sir Basil Brooke, one of the 'farmers' (Essex) of the King's Ironworks in Dean; from 31 May 1615 he had a lease of the two furnaces and two forges at Parkend and Soudley. He may have sent from Dean iron for the production of steel by the cementation process, and in 1635 he claimed that he had settled the new invention of making steel in the Kingdom. In 1622 he was spoken of as 'the great steel maker' in Gloucestershire.[17] The process may have spread to Dean – 'the best steel is made about the Forest; it breaks fiery, with somewhat a coarse grain, but if it be well wrought, and proves sound, it makes good edge tools, files and punches, it will work well at the forge and takes a good heat.'[18]

Following the Restoration in 1660, two re-grants to Winter brought more chaos, but after the Dean Forest (Reafforestation) Act of 1668 and the demolition by Foley in 1674 of the King's Ironworks some temporary order was brought to Dean, including its iron industry.

With the assistance particularly of George Hammersley and Harry Paar, reasonably full histories have been ascertained of each of the foregoing works, and their now infrequent remnants have been noted.[19] Much useful relevant information on the Dean iron industry in 1677-78 is available.[20] One question which has not yet been answered is, at what period of time was limestone added to the charge in the Dean furnaces?

THE SECOND BLAST FURNACE PERIOD (1680-1794)

Despite the constraints following the Act of 1668, activity continued in the ironworks on the fringe of the woods – at Lydney, Rodmore, Rowley, Barnedge, Redbrook, Lydbrook, Bishopswood, Flaxley, Soudley, Longhope, Blakeney, and Guns Mill (rebuilt 1683). Though the Boeveys at Flaxley and the Winters in Lydney and district held a prominent share of the industry, the Foleys controlled most of the remainder from 1692, and abundant records of their activities are available.[21] Incidentally, the Foleys had two anvil works in the Forest, one at Lydbrook (from 1692 to 1694) and the other at Gatcombe (from 1695 to 1705). The techniques of the making have been described.[22] There was also an anvil works at Ruardean, not connected with the Foleys.

From 1717 Lancashire ore was coming to the Forest, suggesting that local accessible supplies were running low; matters would have been even more serious if there had not been abundant bloomery slag (cinders) still available. Pig iron was sent chiefly to the Midlands (the Stour Valley in particular), the bulk from the nearest Severn ports of Ashleworth, Newnham, and Gatcombe. By sea, supplies went to Blackpool Forge in Pembrokeshire. Although pig iron was the main product of the furnaces, a small portion of their make was firebacks, pots, plates, weights, and troughs, in the form of light castings. The commonest functions of the Forest forges was the refining and drawing out (in charcoal-burning hearths) of merchant bar-iron, which was sold in Bristol and in the Severn towns of Gloucester, Tewkesbury, and Bewdley. Lydbrook Upper Forge, at least until the 1730s, had a specialized function: a large portion of its production was in the form of Osmund iron or wire iron, which used more charcoal and required more working than merchant bar iron and which was mostly sent to ironworks at Tintern and Whitebrook.

Charcoal was still the exclusive fuel in the furnaces and in the finery forges, with the single exception that at Upper Redbrook the furnace in 1716-17 cast four tons of pig iron 'that was made with stone coal', previously 'charked'; the coke-smelted pig iron was priced at £6 a ton, compared with £7. 15s. 0d. for that smelted by charcoal.

Although the Foley partnership had almost a monopoly in Dean from 1692 till the 1750s, other ironmasters tried, some successfully, to break it. Lydney ironworks were let to John Ruston of Worcester in 1723 and to others in 1733. In 1747 there was an abortive proposal by Thomas Daniel and Richard Reynolds, ironmasters of Bristol, to erect a furnace at Mitcheldean. After the 1750s, the Tanners, Partridges, Daniels, and Pidcocks entered the field. We have abundant records of their leases, etc.[23] and a very useful description of the industry in 1780 is available.[24]

All the charcoal furnaces except Lydney, Redbrook, Bishopswood, and Flaxley, and all the forges except Lydney, Lydbrook, and Flaxley were closed by the end of the 18th century.[25] The furnace at Flaxley, the last locally to use charcoal, ran till about 1802; there is some evidence that Redbrook ran till 1816. When the Industrial Revolution inaugurated a new period in the history of Britain, the Forest was the chief area of charcoal iron production, some 2,600 tons a year.[26] The long distances over which much of the ore had now to be brought to Dean, chiefly by sea from Whitehaven, was compensated by all the other elements being within easy reach – limestone flux, water-power, cinders, and abundant charcoal. A traveller in 1781 noted that wood in Dean was still plentiful 'notwithstanding the frequency of the iron furnaces, whose smoke impregnating the air, felt to me very wholesome and agreeable.[27]

The works at Lydney, Lydbrook, and Redbrook, gradually enlarged and improved, together with new works at Parkend and Cinderford, subsequently entered the coke-furnace, wire, and tinplate eras, all dealt with later in this paper.

Copper Works (Redbrook) At Redbrook (from about 1690) there were two copper works using ore brought from Cornwall to Chepstow and then up the Wye. Some of the history of these works has been made available.[28] With the assistance of Dr Tylecote it will soon be possible to amplify some of the history.

THE COKE IRON INDUSTRY (1795-1894)

While blast-furnaces using charcoal were still producing pig iron on the fringe of Dean's woods at Lydney, Redbrook, Flaxley, and Bishopswood, other parts of Britain were experimenting with coke-smelting. Subsequently the prosperity of the iron industry no longer depended on charcoal, but on an abundant supply of coke, which soon became the major factor of location, making the coalfields the centres of the iron-smelting industry.

Dean, producing a poor or middling coking coal, was not at first affected by the inventions. There was not the incentive near the Forest to adopt the new processes, for the abundant supplies of wood and water induced the neighbouring ironmasters to adhere to the 'charcoal and water-power process' for many years; indeed, the furnace at Flaxley used charcoal until 1802, and that at Redbrook probably until 1816. Coke had been tried at Redbrook in 1716-17, as previously noted, and also in about 1773 at Lydney where it had been 'found not to answer'.[29]

When coke was eventually used in Dean for smelting, furnaces once more arose both within and almost adjacent to the wooded areas – in 1795 at Cinderford, in 1799 at Parkend, and in the same year one was planned for Whitecliff, to be followed by others at Darkhill, Soudley and Bromley Hill. At the Lydney furnace in about 1803, much ore was smelted by coke, but 'where pitcoal was used the iron was of inferior tenacity and ductibility'.[30] The furnaces procured coke by 'charking' coal in heaps in the open air. Contemporaneously steam power raised by small coal overcame the unreliable supply of blast by water and wheel, though at Parkend a huge water-wheel continued to assist with blast until about 1827.

The use of coke, and the introduction of the steam engine and blowing cylinders in place of bellows, led to new designs in blast-furnaces. In only four cases (Parkend, Whitecliff, Soudley and Bromley Hill) were sites chosen where the terrain provided a natural point for charging the furnace. Elsewhere, an incline from ground level had to be introduced, up which the charge, loaded in small wagons, was pushed, a development which later became mechanized. G. R. Morton[31] has described modifications to the shape of the furnaces and pointed out that re-melting units became a necessity, in the form of air furnaces and cupolas.

The re-establishment of iron production in Dean in the late 18th and early 19th centuries led to much local development of industries that used iron as a raw material, in particular the industries of tinplate and wire, both discussed later. Although deposits of easily won ore in Dean were dwindling (the deeper deposits had not as yet been fully tackled), and supplies were being brought in from Whitehaven, there began large-scale integration of iron, coal and tramroad (later railroad) interests, ably recorded by H. W. Paar.[32]

Abundant records of our coke-furnaces are available. Suffice it to say here that the Cinderford Ironworks ran for a few years from 1795, were enlarged in 1827 and operated to 1832, and were resuscitated in 1835 by the Allaways and the Crawshays. In 1841 they had three furnaces and a melting finery; the annual output of iron during the two previous years was 12,000 tons. By 1858 there were four furnaces, three always in blast, 43ft in height and an extreme breadth of 14ft, that of the hearth being 6ft. The works closed in 1894.

Parkend furnaces dated from 1799, and the Protheroes held them by 1824. The now picturesque Cannop Ponds were built to supplement power by coke, in effect to supply water-power for a water-wheel 51ft diameter and 6ft wide, weighing 60 tons, and said to be nearly the largest in the kingdom. Each furnace was 45ft high, 9½ft diameter at the top, 14ft across at the bosh, and the hearth 5ft diameter. The works closed in 1877. The engine house is now used as a Foresters Training School.

Whitecliff furnace was begun by Samuel Botham in 1798 but before completion it was ruined by floods in 1799. It was made usable by Halford and Teague in 1806, and they were joined by David Mushet in 1810, but the unfortunate furnace was soon discarded.

Darkhill Furnace and Ironworks was where Mushet went after the Whitecliff fiasco. Lower Soudley Ironworks (coke-furnaces) were erected by the Protheroes in 1837; they were idle by 1877. Bromley Hill (Oakwood) furnace was in blast by 1856, and worked till about 1865.

Thus the coke blast-furnace period in Dean began in 1795 and ended in 1894. The collapse of the industry can be partly explained as follows.

Until 1856 Dean's iron-smelting industry slowly adapted itself to the changing conditions brought about by the great inventions of Darby, Cort, and Watt. In that year Bessemer discovered a method of converting specular cast iron into steel, but the process demanded the use of an ore with a low phosphorus content. Very little of such ore exists in Britain but a process of Robert Forester Mushet, using manganese, in the compound 'spiegeleisen', to remove the occluded oxygen, obviated the need for ores with very low phosphorus content. Thus Dean (whose ore was of that low content) no longer held an advantage. Furthermore, improved processes made it possible to utilize low-grade iron ore in other parts of the country, putting Dean's ore still less in demand. Later when much ore required to be imported, the most favoured ironworks were those located on or accessible to the seaboard and within easy reach of the coalfields, and Lydney, situated so much farther up the Severn estuary than the ports of South Wales, and with very limited facilities, being geared mainly to coal exports, was at a disadvantage. Concentration on the production of Bessemer steel took place between 1865 and 1870. Within two decades Dean's iron-smelting industry was virtually extinct, and only its tinplate works, wireworks, and foundries survived. It was Dean's iron for which demand fell rather than its ore. Doubtless it was her small scale of iron production, coupled with indifferent transport facilities, which led to decline. The furnace units in Dean were fewer and probably smaller in dimension than those elsewhere, and failure to modernise and mechanize had ill effects (Soudley did not introduce a locomotive until c. 1875). Transport facilities were delayed for many years (it seems significant that Cinderford, the biggest unit, with railway facilities from 1854 and with the most energetic management, was the longest lived).

Thus ended in 1894 a history of iron-smelting in Dean which had begun before Roman times. Professor Albion[33] avers that Dean was 'the most famous of the nurseries of naval timber' and that 'the name Dean was more closely associated with naval timber than that of any other woodland in England, and it furnished a more constant supply of oak than any of the other Crown forests'. So much for ship timber. I would hope that it may be recognized that Dean likewise played important roles in the iron industry at times when the resources were important in Britain's industrial economy. But the story is not yet over! Dean's role in the iron industry had further diversifications.

THE IRON-WORKING INDUSTRY IN THE LATE 19TH AND 20TH CENTURIES

Stamping of Slag ('Cinders')

By 1780, and probably well before, the best of the scruff from the early and later blast furnaces were used in Dean as 'an ingredient in the making of common green glass, for which purpose it is picked out and reduced to a fine powder by pounding with large stamping engines, and at the same time washing away the lighter substances by a stream of water. There is also found amongst the scruff, on stamping, considerable quantities of granulated iron, and also of ragged lumps, which are called shot and scrap iron. These, in the clearing of the furnaces, are thrown off with the grosser and less fluid scoria, and, after being separated by the stampers, are taken to the forges and worked up with pig iron'.[34]

Thus the stampers provided an ingredient in glass-bottle manufacture, and salvaged iron which would otherwise have been wasted. For the manufacture, bloomery slag was apparently not used, because the iron content, some 40%, was far too high. It appears that only charcoal furnace scruff (dark green glass) and cold-blast coke scruff (lighter green to cream glass) were suitable; the iron content of these slags would be less than 30%.

It is not known in how many places in Dean stamping was carried on. It certainly took place by 1810 at Parkend (Isaac and Peter Kear) from where the product was sent to Bristol for bottle-glass manufacture.[35] The stampers stood on or near the site of the 17th century blast-furnace. David Mushet saw there in c. 1826 8,000 to 10,000 tons of slag[36] and, writing of the manufacture he says:

> The superior quality of the Bristol black bottles has been attributed to the immemorial use of a portion of the slags of the charcoal furnaces from the neighbourhood of Dean Forest. The consequence of this long standing practice has been to carry from the furnaces not only the old slags [of the charcoal period] but those currently made [of the cold-blast coke period].

By 1841 the Kears, with John Morse, were 'stamping ancient cinders with a 24ft water-wheel and 12 stamp-heads, capable of returning 700 tons if there was a demand for it'.[37] The work went on till 1850, and after a recession due to undercutting of price by stampers at Upper Redbrook, carried on till about 1863.[38]

As to the contemporary industry at Redbrook, there were the 'Upper Stampers', ore-crushing apparatus, which stood by 'The Foundry'. On 1 September 1762 Viscount Gage when letting his Upper Redbrook furnace (with two Lydbrook forges) to Richard Reynolds of Bristol and John Partridge senior and John Partridge junior of Ross-on-Wye, gave them 'liberty to use the Stampers belonging to the [Upper] Copper Works without paying rent until Lord Gage shall let the Copper Works or want it for his own use'.[39] Such stamping was probably to condition the ore or cinders for smelting or re-smelting. Not till about 1850 is there evidence for the stamping being done for the bottle-industry. In 1853 the contemporary industry at Parkend was complaining that a company at Redbrook had for the last five been competing at a lower price.[40] The company was the proprietor of 'Redbrook Iron Foundry', which stood above the Stampers, and 25 February 1864 one of the partners, Thomas Burgham, wrote:[41]

> I am stamping up some old cinders which I send to Bristol for making glass bottles that came from a Blast Furnace that used to melt the Forest Iron Ore, and also the Lancashire Iron Ore with Charcoal. The Furnace was supposed from the Cinders that have been made to be in work for 500 or 600 years or more [more likely 200 years]. The Furnace to my knowledge worked up till the year 1816.

At Bishopswood in 1805 cinders were being 'stamped with powerful engines.[42] Outside the Forest at Tintern in 1781, 'the dross, already a crystal, is sent to the glass houses of Bristol: much is employed in mending roads'.[43]

FOUNDRIES

It is necessary to be clear as to the difference between forge and foundry, as establishments of both types existed in Dean in adjacent localities (e.g. Bradley Forge and Bradley Foundry). A foundry was, and is, a building in which metals are formed by casting. The widespread need for intricate machine parts, which could only be made by casting, led to the growth of the factory. The Dean foundries were of modest proportions, casting for the local market such simple items as tramplates, mile-posts, and tram wheels, although small mechanical items were also sometimes produced. Soem of the foundries had a cupola (a vertical coke-fired shaft furnace similar to, but smaller than, a blast furnace, used for re-melting pig iron). A brief statement of the Dean foundries is given below:

Bradley Originally a 17th century forge. By c. 1810-12 was a 'forge' (Samuel Hewlett). A cupola was built c. 1822. Supplied tramplates of 'foundry iron'.

Camp Mill (Soudley) Originally a 17th century forge. By December 1838 there was a foundry (Samuel Hewlett). Supplied tramplates and 'sundry castings', E.G. in 1839, '5 tons of plates to be cast from air furnace'. In 1861 the premises were used as a wood-turnery, and thereafter as a flour mill and a leatherboard mill.

Upper Bilson (in Lower Cinderford) This third foundry of Samuel Hewlett was held by him sometime before 1852. In 1838 the premises had been used by Timothy Harris as an 'engine house, blacksmith house and casting house'. The works were probably 'the iron foundry at Upper Bilson' owned in March 1841 by Timothy Bennett, which included 'one air furnace, one cupola, stove, and a turning and boring machine driven by a 10-inch high pressure steam engine'.

Lydney A foundry stood here in 1810. In 1856 it was owned by Talbot & Grice, and in 1872 leased by the S. & W. R. to T. G. Pearce. From 1892 the premises were used as a warehouse for beer, wine, spirits and mineral waters (Arnold Perrett & Co.).

Cannop (Howler's Slade) This foundry was in use by 1835 (Trotter, Thomas & Co.). The owners from 1893 were Herbert & Young who continued there until 1957 when they moved the works to the old Cinderford Gas Works, where they are still operating.

Redbrook A foundry was in work in Upper Redbrook by 1858, when Thomas Burgham was ironfounder there. In a letter of 1864 he writes' 'I am not in the habit of using the Forest iron ore in the Foundry Business. The pig iron I use is of different sorts and old castings'.

Steam Mills (Lower Cinderford) An engineering works which included a foundry was begun in 1888 by the Teague family. The works are now owned by Teague & Chew Ltd.

Bilson (in Cinderford) This foundry, owned by the Tingle family, was in existence by 1887, lasting until 1924. It stood just off Station Street, above the East Dean Grammar School.

Cullamore (in Ruspidge) This small foundry (owned by Crawshays for Lightmoor Colliery) was in use at least from the 1940s. It had a cupola furnace, and castings were made there.

Bromley Hill (Oakwood) The date on a wall of this foundry was 1852. It closed about the time of the 1914-18 War.

It appears that very little has been written on the technical aspects of such foundries.

STEEL

The Forest of Dean witnessed two projects in the making of steel. We have already referred to the cementation process. The second project is described below:

Shortly after the death of David Mushet on 7 June 1847, his son Robert Forester Mushet went into partnership with Thomas Deykin Clare, a Birmingham merchant, in a new venture, 'R. Mushet & Co'., Forest Steel Works. The enterprise, 'a small experimental steel-work' is believed to have been situated either in part of Darkhill Works previously noted under coke-furnaces, or in a building erected adjacent to it – probably the long smith's shop of which there are still remnants. It included 'a crucible furnace of ten melting holes, and a pair of wooden helves or old-fashioned tilt hammers; the melting holes were square so as to hold four crucibles or pots in each'. The process used by Mushet has been recorded by Osborn.

In 1856 Mushet with the aid of S. H. Blackwell of Dudley, added to the steel works 'a cupola for melting pig iron, a small Bessemer hearth or converter 15in square by 5ft deep, and a blowing apparatus driven by a belt from a large pulley fixed on the end of the flywheel shaft which worked the tilt hammer'. In that year Mushet successfully deoxidised Bessemer's metal by using spiegeleisen. In 1862 Mushet formed The Titanic Steel & Iron Co. Ltd., and built large ornate premises a few hundred yards W.N.W. of the Darkhill premises. By 1868 he was producing his self-hardening tool steel, by alloying it with tungsten. Most of his steel products were made under the greatest secrecy. The works closed in August 1874.

Tinplate

Andrew Yarranton, on his return from a visit to Saxony in the 1660s to obtain information about tinplate making, canvassed the idea that the distressed condition of both the Cornish tin-miners and the Dean iron-miners could be relieved by the establishment of a tinplate industry in Great Britain.[44] As an experiment, 'many thousand plates made of Forest of Dean iron and tinned with Cornish tin were produced, and the plates proved far better than the German plates, the true reason being the toughness and flectibleness of our Forest iron'.[45] However, experiment was not followed by commercial development until early in the 18th century, and even then, while charcoal remained the fuel in use, tinplating was not generally introduced. Immediately after the Industrial Revolution, most iron-smelting areas (but not Dean) had tinplate works as a subsidiary industry.

By late in the 18th century tinplating, using charcoal, spread to Dean. One unsubstantiated source implies that the first local manufacture was in 1760 at Lydbrook,[46] another source asserts that it took place at Lydney in 1789,[47] while Redbrook may have begun manufacture in 1771.[48] Certainly tinplate was being produced at Redbrook by 1774, at Lydbrook by c. 1806, and at Lydney by c. 1810 (indeed there is evidence of a 'Tin Work' there by 1781).

Early in the 19th century, new tinplate works using coke as fuel were begun in South Wales. Dean soon followed, coke gradually replacing charcoal. The records of the five individual local works show that at Lydney the manufacturers were the Pidcocks, or John James, and at Lydbrook the Partridges and the Allaways. Richard Thomas and his company followed in the early 1870s at both places. At Parkend, works were established by James and Greenham (c. 1853) and at Hawkwell by Chivers and Bright (1879). At Redbrook the works were held by Townshend & Wood. In 1880 the five works comprised 17 mills, 15 at work.[49]

> In these works the iron is made from pig iron on the spot. At one of the works, the iron made in the Forest being too tough to be used alone, it is mixed in equal quantities with pig from Middlesborough or Bristol and is then puddled, rolled into plates, cleansed, annealed, tinned and packed into boxes. The thickness of the plate varies from 24 to 38 Birmingham Wire Gauge.
>
> The annual production may be calculated upon an average of 450 boxes per mill per week, giving for the 15 mills 351,000 boxes per annum, and as each box weighs a cwt., the weight will be 17,550 tons, in the manufacture of which about 1,050 hands are employed. A great part of this production finds its way to the United States, the proportion of the Forest with that of Great Britain being one-seventeenth. No Terne plates (i.e. iron plates tinned with a mixture of tin and lead) are made in the Forest, but some Black plates (i.e. thin plates not tinned at all) are manufactured and sent to America where they are varnished and returned to England to be used for photographic purposes.

The tinplate works used sulphuric acid (made at the Cannop Chemical Works using sulphur from Sicily) to remove the ferric oxide and other impurities on the iron plates, previous to their being tinned.[50] Some of the acid was brought from Swansea, where it was made from pyrites, after the copper had been extracted; being a waste product of the copper works, it was cheaper than the acid made from sulphur, but contained impurities in which arsenic was a great objection.[51]

The histories of the five tinplate works have been ascertained and will be published in due course.[52]

The tinplate era in Dean extended from about 1800 to 1961 – some 160 years. The works at Parkend and Hawkwell were almost at an end by the 1880s, particularly through the local ore having been found unsuitable for Bessemer's process of converting specular cast iron into steel. Furthermore, competition from South Wales and failing markets greatly harmed the Forest. The works at Lydbrook, Lydney and Redbrook weathered the change successfully. Lydbrook continued till 1925, while Lydney, although latterly depending for raw material on steel bars brought by rail from Scunthorpe, survived till 1957. The Redbrook works closed in 1961, the last victim of the modern giant strip mills.

Wire and Cable

By 1565 wire from iron, some probably drawn by manual strength and some by primitive machines powered by water wheels, was being made at Tintern and Whitebrook by the Company of Mineral and Battery Works under the patent granted that year to Humfry and Shutz.[53] John Challoner had a lease of the Tintern wireworks from 1591 to 1594.[54] In Dean a contemporary industry was being carried on only at Soudley,[55] but the trade did not develop much in the Forest, though what little there may subsequently have been was by 1608 allied with that of nail and pin making.[56] When in 1611 the Earl of Pembroke's nominees were empowered to build ironworks in Dean, wireworks were expressly excepted. By 1640 Sir John Winter had a slitting mill on the Newerne Stream towards Lydney; it may have produced iron rods for wire-making.

From 1672[58] Thomas Foley made wire at Tintern and Whitebrook, drawn from bar iron made in forges fueled by charcoal. By then it was a trade diverse in the range of its products and its technical vocabulary.[59] Coal was used in drawing, and the wireworks also rolled and slit bars into nail rods as a sideline. The Foley's interest in the trade persisted until at least 1712, when Thomas Foley certainly held Whitebrook works. By 1715, however, Thomas Dix (Dicks) was at the Tintern works.[60] A wireworks was in being in Ayleford, some half-mile below Bradley, from c. 1765, the proprietors being Purnell & Co. It probably ceased about the year 1800.

By 1815 wireworks had been established at Lydbrook by James Russell. In 1864, under the management of his son Edward, they employed about 100 people making fencing and telegraph wire, of which 40 to 50 tons were rolled each week. The works continued in the hands of the Russell family until their closure in about 1895. The same family built up the Cinderford Wireworks ('Forest Vale Ironworks'), at least by 1856. In 1880 about 100 people were employed, making about 100 tons each week. The works closed towards the end of the last century.

Cable making at Lydbrook, down by the Wye, grew out of the experience gained by Harold Smith during 1900-1911 in making leads for fuses, wire-covering and allied developments at the Electric Fuze Factory near Trafalgar Colliery. Smith began his cable making at Lydbrook in 1912. Great progress was made until 1920 when he became bankrupt. In 1925 Edison Swan Electric Company (Siemens Bros. Edison Swan) took over the works, expanded them, and built up an immense business. They vacated the premises in 1965, being followed by the Reed Paper Group.

Meanwhile, Harold Smith had quickly recovered from the personal financial blow and, in 1920, he formed H. W. Smith & Co. Ltd., manufacturers of electric cables, in new premises a stone's throw from his earlier Lydbrook works. He and his family became successful in business and, as Temco Ltd., sold out in the 1960s to the B.I.C.C. group of companies. Smith died in 1964, well into his eighties, but his factory still flourishes – truly a triumph over adversity, and a reward for endeavour.

The histories of all these wireworks have been ascertained and will be published in due course.

SOME CONCLUSIONS

Over 2000 years ago, man in Dean first dug, smelted, and hammered out his meagre requirements of iron. Since then Dean has sustained bloomeries, charcoal and coke blast furnaces, and manufactories for steel, tinplates, wire, and cables. Tramroads and railways have come and gone. Ironmining has ceased and, but for a few small adits, so has coalmining.

One conclusion is inescapable; in spite of vast mineral wealth, the conservatism of those responsible for industrial developments kept the scale of enterprise small, and generally in the train of technical progress, compared with other districts, and hence it was vulnerable to competition. As exampled may be cited the longevity of charcoal smelting, the late introduction of both tramroads and railways, the tardy use of waste-gas utilization plant, and finally the failure to adapt the ironworks to steel production (often talked about but never done). There is a time for prudence and a time for risk, in industry as in other spheres of life, and failure to suit the mood to the moment exacts a price in gradual stagnation, and collapse in the face of competition.

Today, the working of metals still contributes to Dean's economy, in the form of Temco cableworks, Steam Mills engineering works, and (perhaps symbolically embracing modernity) Engelhard Industries Ltd. of Cinderford, processors of rare metals, but the Forest's traditional basic iron industries are all but dead, represented only by Cinderford Foundry and Brico Engineering Ltd. of Lydney. Nevertheless, those industries were diverse and economically important. It is to be hoped that this and other papers will serve to record and appraise some of their history and achievements.

REFERENCES

1. Vict. C. Hist. Glos., ii, pp. 216, 217.
2. C. E. Hart, The Free Miners.
3. R. H. Hilton, A Medieval Society, (1966), p. 214.

4. C. E. Hart, Royal Forest, (1966), p. 74.
5. W. H. B. Court, The Rise of the Midland Industries 1600 – 1838 (1938), p. 52.
6. Trans. BGAS (II), pp. 221-284.
7. Hart, Royal Forest, p. 79.
8. Hart, Ibid, p. 83.
9. Hart, Ibid, p. 87.
10. M. B. Donald, Elizabethan Monopolies, (1961), pp. 100, 132.
11. Hart, Royal Forest, p. 90
12. Hart, The Free Miners, p. 172.
13. P. R. O., S. P. 16/282.
14. North Mss. quoted by Nicholls and Schubert.
15. Hart, Royal Forest, pp. 146-148.
16. K. C. Barraclough, 'The cementation and crucible steelmaking processes', Bull. Hist. Met. Gp., No. 8, Jan1967, pp. 24-34.
    See also Gale, Mushet, and Schubert, pp. 324/5.
17. Fuller, Worthies of Gloucestershire, 1662.
18. Moxon, Mechanick Exercises, 2nd ed., 1693, p. 54.
19. They will form part of a chapter in a projected book The Industrial Archaeology of Dean.
20. Henry Powle, Philosophical Transactions, 1677-78, vol. 12, No. 137, pp. 931-935.
21. Foley MSS., Hereford Record Office. Many, but not all, of these MSS have been reported on by B. C. L. Johnson.
22. B. L. C. Johnson, BGAS 72 (1953), p. 140.
23. See for example, G. R. O., D. 36, E. 16.
24. George Wyrral in BGAS, 2 (1877-8), pp. 216-234.
25. The history of these and the other works, and a note of their remnants, will form part of a chapter in a projected book, The Industrial Archaeology of Dean.
26. N. Scrivenor, A History of the Iron Trades (1854), p. 86
27. The Torrington Diaries (1954), p. 36.
28. Rhys Jenkins, BGAS, 63 (1942), pp. 145-167.
29. S. Rudder, New History of Gloucestershire (1779).
30. T. Rudge, History of the County of Gloucester (1803)
31. 'The early coke era', Hist. Met. Gp. Bull., 6 Jan. 1966.
32. The Severn & Wye Railway (1963); The Great Western Railway in Dean (1965).
33. R. G. Albion, Forests and Sea Power (1926), pp. 107, 108.
34. George Wyrral (1780), BGAS. II (1877-8), p. 217.
35. Reports of Commissioners of Woods, 1810, 1814.
36. Papers on Iron and Steel, 1840, p. 387.
37. G. R. O., Q/RUM/175.
38. P. R. O., F3/223.
39. G. R. O., Gage MSS., G. G. 1557 and Vizard MSS.
40. F. 3/223.
41. Letter penes me
42. E. Wedlake and J. Britton, The Beauties of England and Wales, vi, 1805, p. 527
43. The Torrington Diaries 1954), p. 40.
44. A. Yarranton, England's Improvement, 1681, quoted by W. E. Minchinton, The British Tinplate Industry: A History, 1957, pp. 6, 7.
45. Yarranton, op. cit., pt. ii, pp. 173-4.
46. E. H. Brooke, Chronology of the Tinplate Works of Great Britain, 1944, p. 152.
47. Letter from Richard Thomas & Co. Ltd., 2. 8. 1907 (penes me.)

48. Brooke, op. cit., p. 99.
49. Insole, pp. 88, 89.
50. Insole, p. 89.
51. Insole, p. 90.
52. In a projected book The Industrial Archaeology of Dean.
53. Rhys Jenkins, op. cit., p. 7; Nicholls, Ironmaking, pp. 29, 30.
54. P. R. O., Exch. Deps. by Coms., 39 Eliz., Hil. 23; Br. Mus. Lansdown MS
55. Nicholls, Ironmaking, p. 28.
56. Men and Armour for Gloucestershire, 1608.
57. G. R. O., D421/T. 22.
58. Johnson, op. cit., p. 132.
59. Ibid.
60. Ibid., p. 133, which contains a list of terms and

Conference Paper

Some notes on the geology of the coal and iron deposits in the Forest of Dean

R. J. PIGGOTT, F.R.I.C.S., C. Eng., A.M.I. Min. E., F.G.S.

INTRODUCTION

The history of the mining of coal and iron ore in the Forest of Dean has its roots in a past of such early beginnings that much of it has become lost. Some of it, however, has been salvaged and become recorded in such notable works as Dr Cyril Hart's "The Free Miners of the Royal Forest of Dean and Hundred of St Briavels" (Gloucester 1953).

It is not the purport of these notes to deal with the history of mining operations in the Forest, but rather to introduce to the members of the Historical Metallurgy Group some aspects of the geology of the district.) In the preparation of these notes, I have drawn heavily on the comprehensive information contained in two H.M.S.O. publications:-

(1) Memoirs of the Geological Survey – Special Reports on the Mineral Resources of Great Britain (Second Edition) Volume X. by F. Franklin Sibly, D.Sc. 1927

(2) Memoirs of the Geological Survey – Geology of the Forest of Dean Coal and Iron-ore field by F. M. Trotter, D.Sc. 1942

and also the Mining Records of the National Coal Board and the records deposited with H.M. Inspectorate, Cardiff.

What has been conveniently described as the 'basin' of rocks, which includes the iron-and-coal-bearing district of the Forest of Dean, is situated geographically speaking between the River Severn, below Gloucester, and the River Wye, below Ross (Fig. 1a). The strata, in the main, are of Carboniferous Age and, broadly speaking, the succession is as follows:

Alluvium		RECENT
Keuper Marl		TRIASSIC
Supra-Pennant	Coal Measures	CARBONIFEROUS
Pennant	Coal Measures	CARBONIFEROUS
Trenchard Group	Coal Measures	CARBONIFEROUS
Unconformity		CARBONIFEROUS
Drybrook Sandstone		CARBONIFEROUS
Carboniferous Limestone		CARBONIFEROUS
Old Red Sandstones		CARBONIFEROUS

STRUCTURE

Two main periods of crustal instability have affected the area of the Forest of Dean: an intra-Carboniferous period during which the Carboniferous Limestone series and older rocks were folded, faulted, and denuded, and a pre-Triassic, post-Carboniferous period when the Coal Measures were involved in folds of a similar trend to those of the earlier movements and faulting also occurred. In addition, a post-Triassic movement is represented by a solitary fault which brings in Keuper Marl at Aylburton.

INTRA-CARBONIFEROUS EARTH MOVEMENTS AND UNCONFORMITY

Folding

The major uplift of intra-carboniferous strata lies to the east of the area under description and is usually referred to as the "May Hill Anticline".

In outline, the Carboniferous Limestone of the Forest of Dean may be regarded as lying in the complementary syncline to the West. In detail, however, neither the anticline nor the syncline are simple structures. The anticline is formed by several elongated 'domes' of north and south trends arranged en-echelon, and although the central part of the syncline is marked by Coal Measures it is clear from evidence around the margin that this Carboniferous Limestone syncline contains several subsidiary north and south folds.

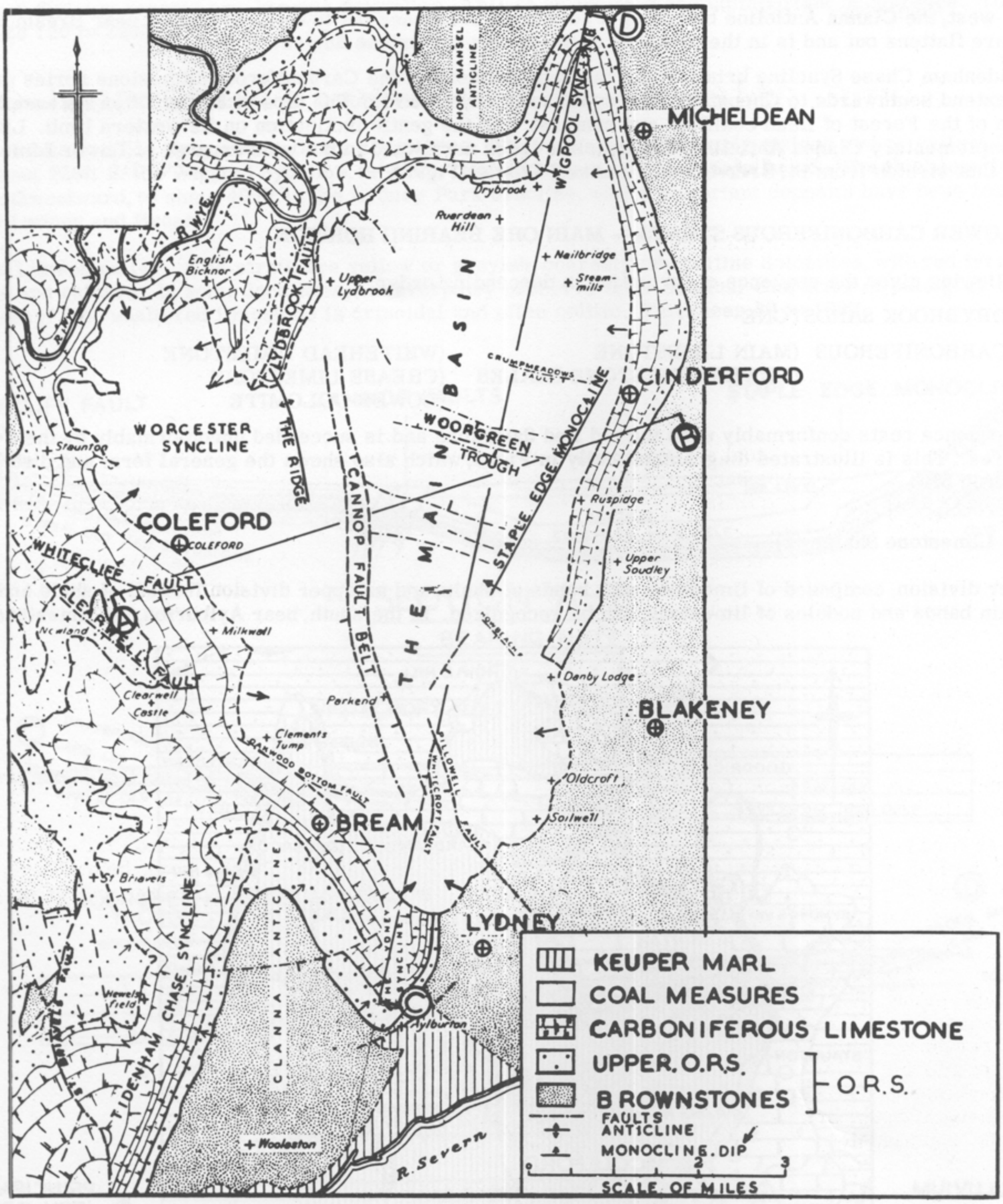

Fig. 1a – The main formations and structural features of the Forest of Dean

Along the eastern margin of the field from Wigpool to Danby Lodge, near Blakeney, the Old Red Sandstone and the Carboniferous Limestone dip Westward of the May Hill Anticline at steep angles of 50° to 80°. In the north these steeply dipping measures from the eastern limb of the elongated Wigpool Syncline and the same rocks are displayed in the western limb of this syncline, where dips range between 35° to 50°.

The Wigpool Syncline is flanked on the west by the Hope Mansel Anticline, a pre-Coal Measure structure which has a core of Brownstones ringed by outcrops of Upper Old Red Sandstone rocks and Lower Limestone Shales. Dips on both limbs of the anticline are of the order of 25° to 40°.

A shallow pre-Coal Measure syncline lies to the west of the Hope Mansel Anticline. An anticline which brings in a core of Brownstones to the east of Newland is probably of intra-Carboniferous age. It is associated with two faults, which bound it to the north and south, that are considered to be of pre-Coal Measures age.

In the South, the Clanna Anticline separates the Lydney Syncline from Tidenham Chase Cyncline.

On the eastern limb of the Lydney Syncline, Carboniferous Limestone and Old Red Sandstone beds emerge from beneath the Coal Measures with high dips that approach the vertical. The dip on the western limb of the syncline varies between 20° to 30°.

To the west, the Clanna Anticline brings up a core of Brownstones but towards the north, near Bream, the structure flattens out and is in the outcrops of the Lower Limestone Shales.

The Tidenham Chase Syncline brings in all the sub-divisions of the Carboniferous Limestone series and these extend southwards to Chepstow. The syncline is asymmetric. The dips of 30° to 70° on its eastern margin of the Forest of Dean coalfield and contrast with the gentle inclination on its western limb. Like the complementary Clanna Anticline, this syncline fades northward into a wide expanse of Lower Limestone Shales that stretch from St. Briavels to Clearwell Castle (Fig. 2).

THE LOWER CARBONIFEROUS STRATA – MAIN ORE BEARING HORIZON

The following gives the sequence of formation in descending order:

DRYBROOK SANDSTONE		
CARBONIFEROUS	(MAIN LIMESTONE	(WHITEHEAD LIMESTONE
	(LOWER LIMESTONE SHALES	(CREASE LIMESTONE
		(LOWER DOLOMITE

This sequence rests conformably upon the old Red Sandstone and is succeeded unconformably by the Coal Measures. This is illustrated diagrammatically in Fig. 3, which also shows the general form and distribution of the iron ore.

Lower Limestone Shales (2)

A lower division, composed of limestone with bands of shale, and an upper division formed of shale and clay with thin bands and nodules of limestone, can be recognized. In the south, near Aylburton, the limestones of

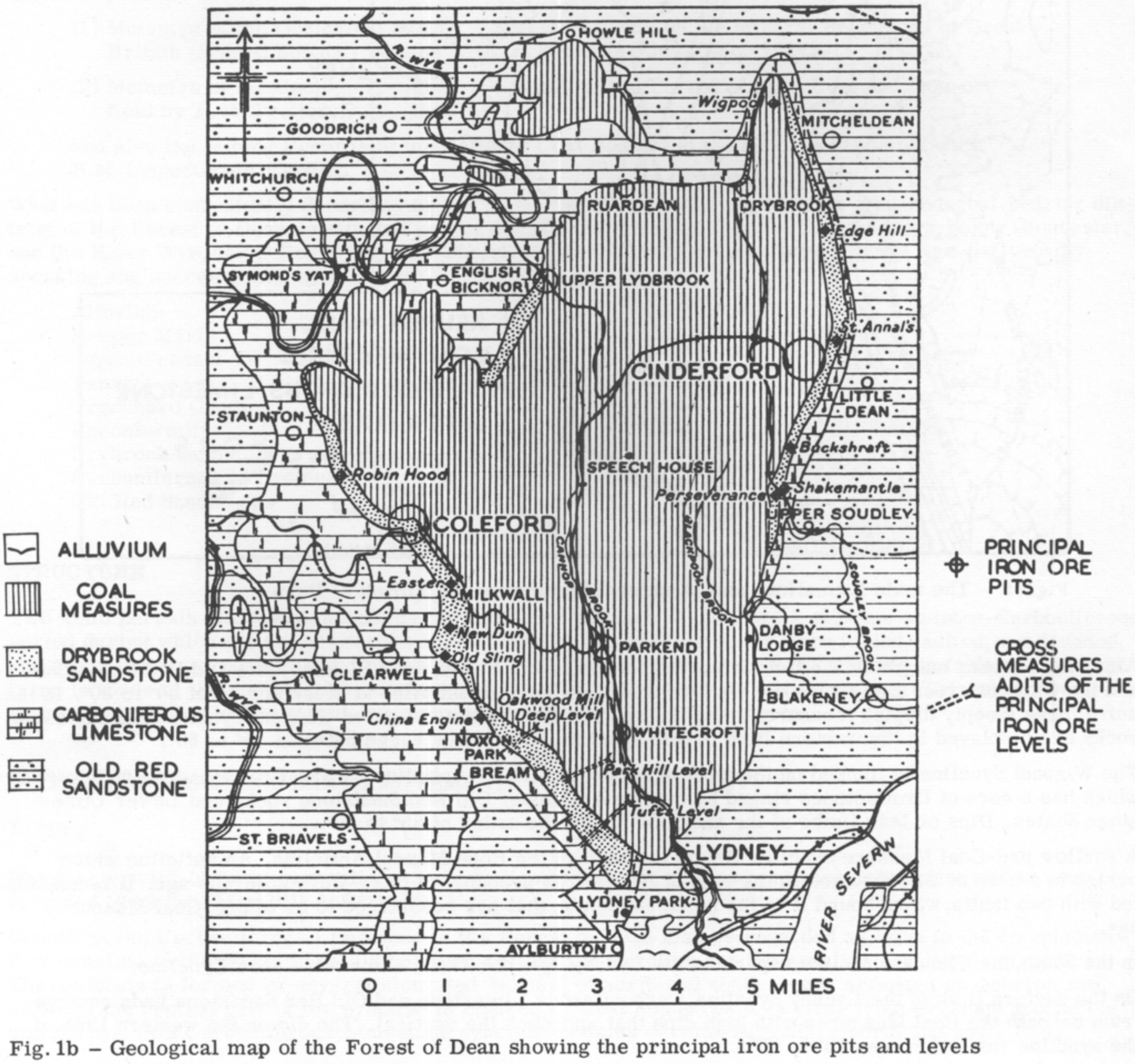

Fig. 1b – Geological map of the Forest of Dean showing the principal iron ore pits and levels the lower division become ore-bearing dolomites. This is an isolated and unimportant occurrence. Total thickness 180 to 220ft.

Main Limestones (Contemporaneous Dolomites)

Lower Dolomite (3) Grey rocks, finely crystalline. The rocks are extremely stained red or yellow. Thickness about 250ft in the Wigpool Syncline, in which important deposits have been found. The thickness increases southwestward, to some 400ft in the Lydney Park Syncline, where important deposits have been found around Lydney and Bream.

Crease Limestone (4) The strata are yellow or greyish, coarsely crystalline dolomites, with red ferriferous streaks and patches. In some localities, however, they preserve their original character of pale grey or white limestones. The unaltered limestone is crinoidal and often oolitic. Thickness 30 to 100ft.

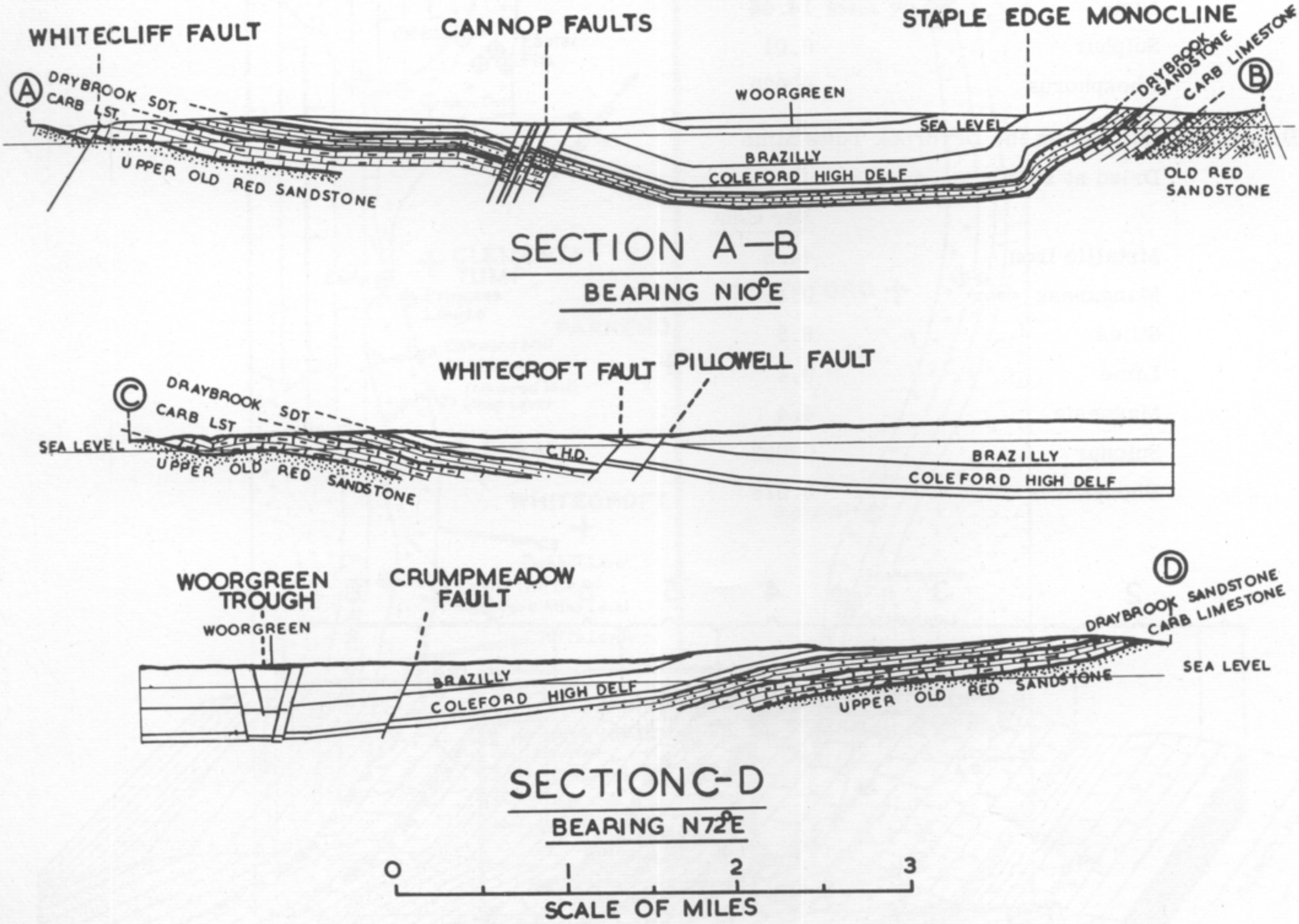

Fig. 2 – Sections across the Forest of Dean

The Crease Limestone is the chief and most important repository of the ores. The ore bodies are extremely variable in size and irregular in shape and distribution, but show some constancy in their frequent lenticular shape, parallel to the bedding planes of the country rock, and the concentration of the majority of them along the top of the Crease Limestone, with the base of the Whitehead Sandstones forming the hanging wall.

An ore body may extend from the top to the bottom of the Crease Sandstone. Large deposits of ore are known as 'churns', small offshoots are termed 'leads'.

Great quantities of Crease Limestone have been won along most of the outcrop. On the eastern side, where the dip is steep, ore has been worked to a vertical depth of 900ft. On the western side, where the dip is gentle, the occurrence of ore below 400ft is rare.

The junction between the Crease Limestone and the Whitehead Limestone is usually well defined. The difference between the beds is striking and the term 'lid' is applied by the local miners to the lowest bed of the Whitehead Limestone.

Whitehead Limestone

These beds consist largely of normal and algal limestone, dolomite, and calcite - mudstones. Thickness 40 to 60ft. in the Wigpool Syncline about 200ft. in the Lydney Park Syncline.

The basal beds 20 to 30ft thick carry ore frequently and are considered an important ore-bearing zone. The remainder is usually barren.

Typical analyses of the ores are as follows:

Brown Haematite from the Crease Limestone

Dried at 100°C

	Per Cent
Metallic Iron	35.59
Silica	3.38
Lime	14.46
Sulphur	0.01
Phosphorus	0.029

Brown Haematite from the Drybrook Tufts Mine

Dried at 100°C

	Per Cent
Metallic Iron	44.8
Manganese	0.1
Silica	8.8
Lime	8.4
Magnesia	4.4
Sulphur	0.052
Phosphorus	0.018

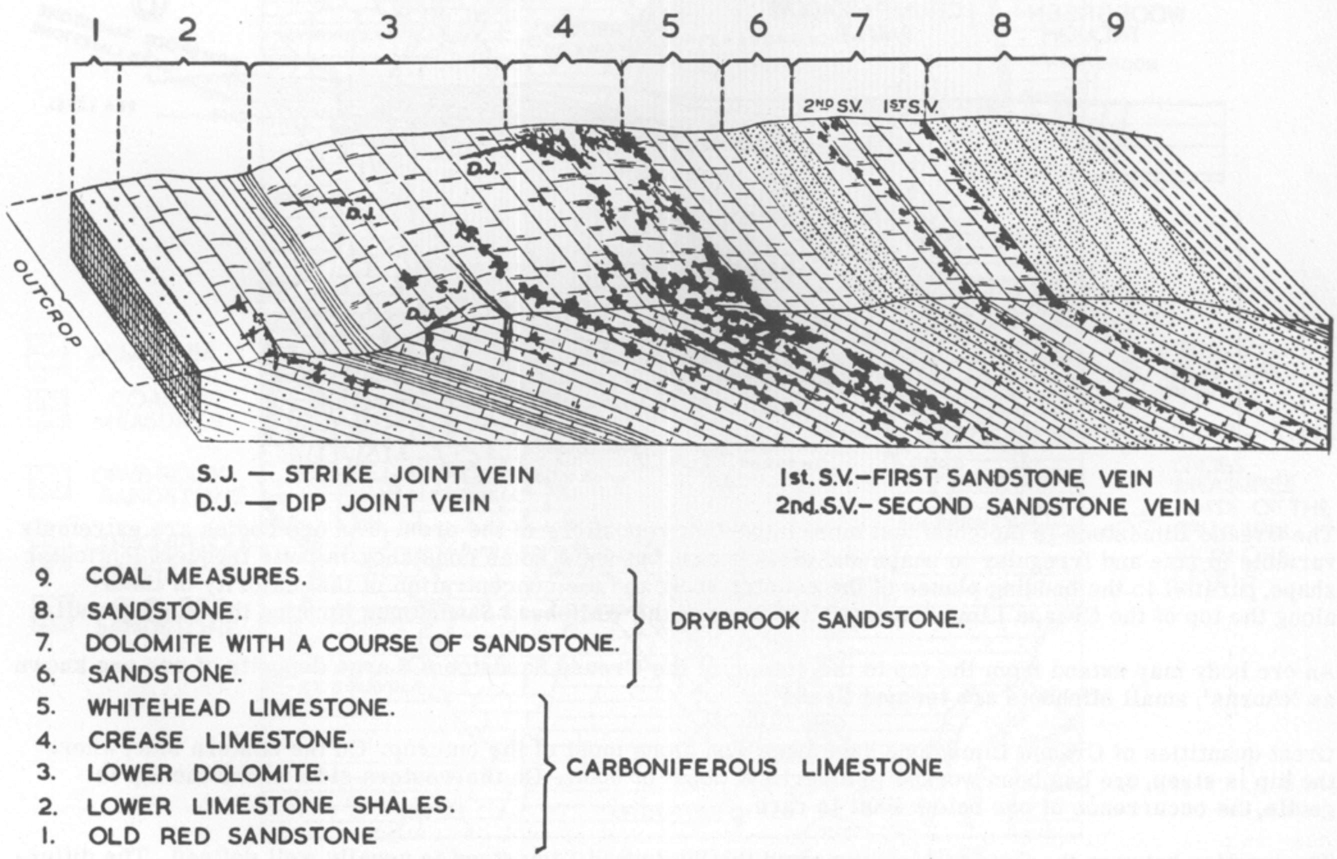

Fig. 3 – Block diagram illustrating the general distribution of iron-ore deposits

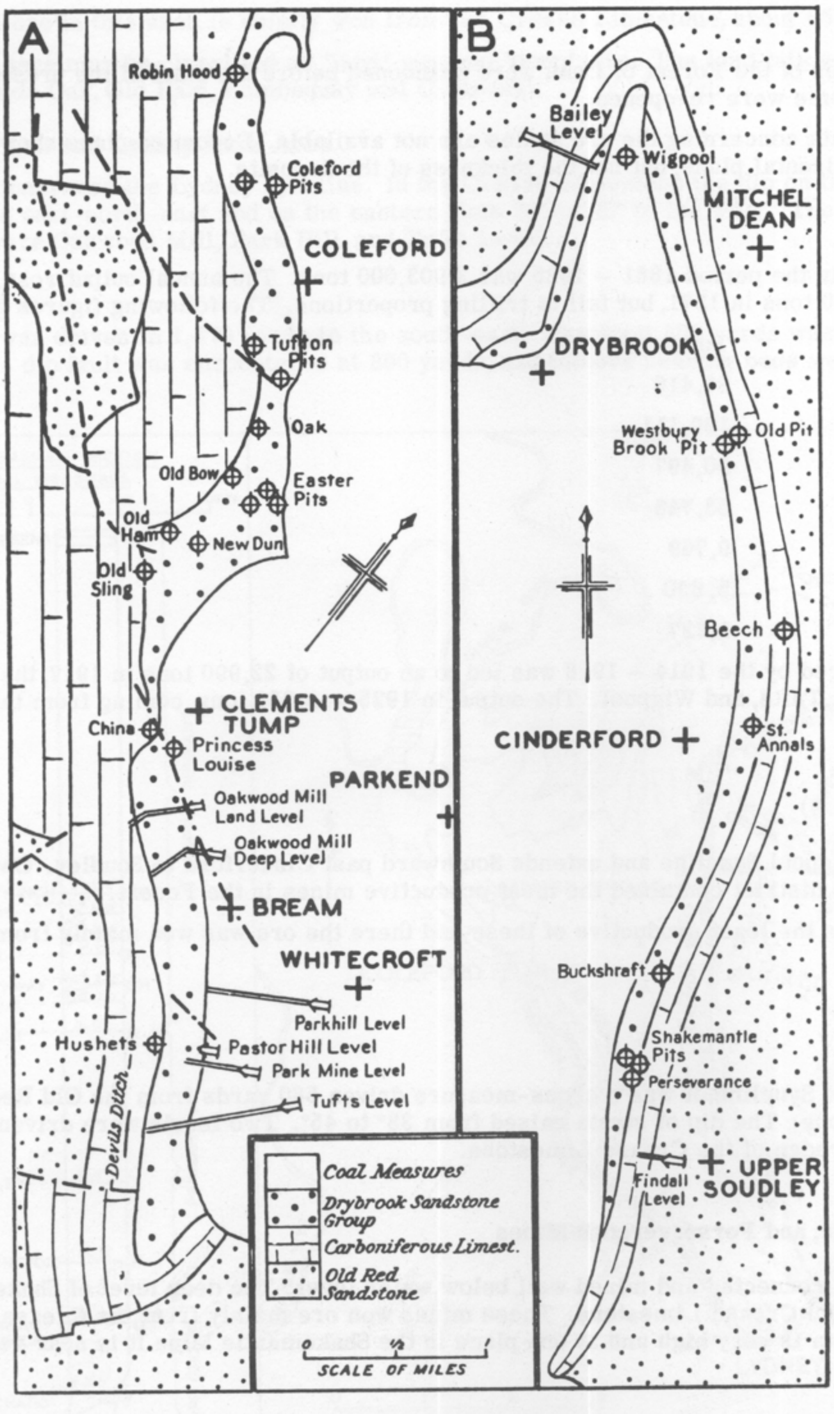

Fig. 4 – Western (A) and eastern (B) parts of the iron-ore field

Drybrook Sandstone Group

This name is given to the Lower Carboniferous beds which were incorrectly named as 'Millstone Grit'. The beds are divided into upper and lower portions by the Drybrook Limestone 170 – 400ft thick.

The lower sandstones are medium to coarse grained and are composed of rounded grains of quartz. The upper sandstone consists mainly of wind-blown rounded grains of quartz. The total thickness of the Drybrook beds is about 700ft.

The thick bed of limestone in the south-west carries ore at two horizons. Some ores have been won from the Drybrook Sandstone on the eastern side of the district.

Ore in the Coal Measures

These ores are restricted to the crop of the measures associated with the Yorkley Coal. There is no ore body in the Pennant sandstones underlying the Yorkley Coal. It would appear probable that the solutions came from above, were trapped by the impervious argillaceous measures, and were prevented by them from descending to lower horizons.

Ore Mining Districts

Most of the iron-mines of the Forest of Dean were abandoned before the start of the present century. During the 1914-1918 war, some were re-opened.

Three dimensional data concerning the ore bodies are not available. Deposited plans show the maximum area worked on a horizontal plane, but not the thickness of the deposits.

Ore Production

The total production in the period 1861 – 1925 was 3,903,000 tons. The annual output rose to a maximum of approximately 200,000 tons in 1871, but fell to trifling proportions. The following figures give the trend:

Year	Tons
1861	99,416
1871	199,111
1881	90,497
1891	63,748
1901	9,769
1911	5, 830
1921	1,727

A minor revival induced by the 1914 – 1918 was led to an output of 22,990 tons in 1917, the bulk coming from Easter, New Dunn Pit, Tufts, and Wigpool. The output in 1925 was 858 tons, coming from the New Dunn and Old Pit.

Eastern District (Fig. 4)

This extends from Wigpool Syncline and extends Southward past Cinderford to Soudley. Owing to the steep dip of the strata, this district contained the most productive mines in the Forest.

The Wigpool mine was the least productive of these and there the ore was won mainly from the Crease Limestone.

Baileys Level

Worked in the Wigpool Syncline, it was a cross-measure driven 580 yards from the Old Red Sandstone to the Whitehead Sandstone. The dip of strata raised from 38° to 45°. Two levels were driven northward on the lidstone and underedge of the Crease Limestone.

Edge Hill, Shakemantle, and Perserverence Mines

These mines were all connected and mined well below water level. The deep level of Shakemantle lies 900ft below the outcrop of the Crease Limestone. These mines won ore mainly from the Crease Limestone. The inclination of the strata is very high and at one place in the Shakemantle Mine it is near vertical.

The Western District

This part of the iron ore field is shown in Fig. 4, and in view of the number of small pits it contained, it is best dealt with in areas.

The Staunton Area

Staunton Pit: The pit is 120ft deep and won its ore from the Crease Limestone. Active from 1865 to 1878, about 13,000 tons of ore was produced.

Robin Hood Deep Pit: Depth 212ft. Sunk through Drybrook Sandstone and Whitehead Limestone into Crease Sandstone. The mine was worked for iron ore and red ochre.

Coleford Area

This area includes the ground within one mile of Coleford. The dip is to the east/north-east 6° to 12°. The ground has been explored by several mines in the Crease Limestone including Coleford, Boxbush, and Tufton.

Tufton-Clements Tump Area

The dip, north of the Clearwell Fault, is 12° to 15° to the east, but to the south of the fault the dip is up to 40°. The ore in this area is chiefly won from the Crease Limestone, about 850,000 tons.

The mines here may be classified as 'land' pits and 'deep' pits. The land pits worked at shallow depths include Oak, Old Ham, Lambsquay and Clearwell.

South of Bream and Lydney Park Area

This area conbraces the Lydney Syncline. In the Crease Limestone the dip on the western limb is 20° to 35° to the east-north-east and on the eastern limb 70° to 80° to the west. The principal levels in this area were Oakwood Mill, Park Hill, and Tufts Level.

Tufts Level

This level was driven in 1,470 yards to the south-east. The first 800 yards was driven in Coal Measures, a dip fault was encountered at 890 yards, and the ore bearing beds were thrown back some 60 yards.

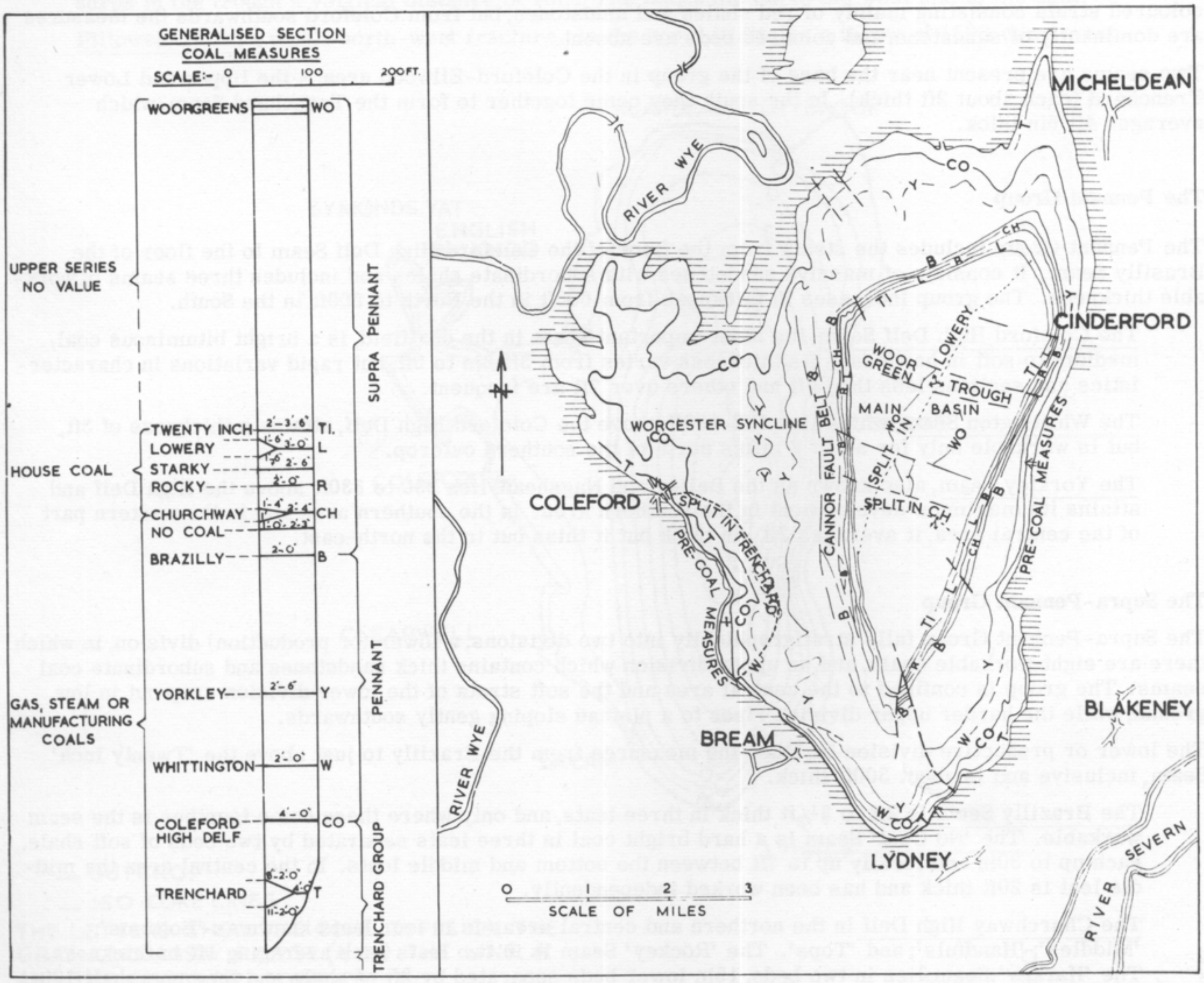

Fig. 5 – Forest of Dean Coalfield

THE COALS OF THE FOREST OF DEAN

The Coal Measures are enclosed in the complete basin-shaped syncline described earlier (Fig. 5), the measures dipping from the edge of the basin all round to the centre. There are no new formations overlying the Coal Measures, the seams out cropping to the surface. There are 22 coal seams of varying thickness from 4in to 5ft and these fall into three main groups – Supra Pennant Group, Pennant Group, Trenchard Group.

The lowest (or Trenchard Group) consists of coals, shales, sandstones, grits, and conglomerates, and is followed by the Pennant Group of massive sandstones with subordinate shales and few coals. The uppermost (or Supra-Pennant Group) consists of shales, sandstones, and coal seams. (It must be noted that the use of the terms 'Pennant' and 'Supra-Pennant' does not imply strict correlation with the groups thus designated in the South Wales Coalfield.)

All the coals are bituminous and the total thickness of coal in the workable seams is 25ft in the Northern and 32ft in the Southern part of the coalfield, the greater thickness in the latter area being accounted for by the appearance there of additional coals in the Pennant and Trenchard Groups.

Many of the seams are split into layers or 'leats' by soft mudstone partings which may be one inch or less in the thickness, but in places may swell out to 20ft. 'Wants' or 'washouts' occur in the seams of the Pennant and Trenchard Groups, but are not known in those of the Supra-Pennant.

The principal coal seams and their relative position in the sequence are indicated in the vertical section shown on Fig. 5.

Trenchard Group

The Trenchard Group comprises the beds from the base of the Coal Measures to the base of the Coleford High Delf Seam. The group varies in thickness from 50ft to 400ft. In the north it is composed largely of coloured strata consisting mainly of red shales and mudstones, but from Coleford southwards the measures are dominantly of sandstone, and coloured beds are absent.

Two seams are present near the base of the group in the Coleford-Ellwood area – the Upper and Lower Trenchard (each about 2ft thick). In the south they come together to form the Trenchard Seam, which averages 4ft 6in thick.

The Pennant Group

The Pennant Group includes the strata from the floor of the Coleford High Delf Seam to the floor of the Brasilly Seam. It consists of massive sandstones with subordinate shales and includes three seams of workable thickness. The group increases in thickness from 600ft in the North to 800ft in the South.

The Coleford High Delf Seam, the most important seam in the coalfield, is a bright bituminous coal, medium to soft in hardness. Its thickness varies from 3ft 6in to 5ft, but rapid variations in characteristics and sections less than 2ft and others over 7ft are frequent.

The Whittington Seam, which lies 120-150ft above the Coleford High Delf, attains a thickness of 3ft, but is workable only for about 2 miles north of the southern outcrop.

The Yorkley Seam, also known as the Bailey and Nagshead, lies 230 to 330ft above the High Delf and attains its maximum development in the southern area. In the southern area and in the western part of the central area, it averages 2ft 9in thick but it thins out to the north-east.

The Supra-Pennant Group

The Supra-Pennant Group falls stratigraphically into two divisions, a lower (or production) division, in which there are eight workable coals, and an upper division which contains thick sandstones and subordinate coal seams. The group is confined to the central area and the soft strata of the lower division crop out in low ground, while the harder upper division rises to a plateau sloping gently southwards.

The lower or productive division includes the measures from the Brazilly to just above the 'Twenty Inch' Seam, inclusive and is about 300ft thick.

The Brazilly Seam is 2ft to 3½ft thick in three leats, and only where these come together is the seam workable. The 'No Coal' Seam is a hard bright coal in three leats separated by two beds of soft shale, each up to 30in and locally up to 7ft between the bottom and middle leats. In the central area the middle leat is 20ft thick and has been worked independently.

The Churchway High Delf in the northern and central areas is in four leats known as 'Bottoms'; 'Middles'; 'Handfuls'; and 'Tops'. The 'Rockey' Seam is in two leats each averaging 1ft in thickness. The 'Harkey' Seam lies in two beds, 15in lower beds separated by 2ft of shale and the upper-half 10in thick. The Lowery or High Delf Seam is 3ft thick in the south-east. To the northwest the seam splits. The Twenty Inch (known as the 'Smith Coal' in the Parkend area) normally maintains a thickness of 1ft 8in to 2ft.

A seam 8ft to 15ft above the Twenty Inch (and which varies between 1ft and 18in thick) lies at the top of the production division of the Supra-Pennant. At the northern crop it is known as the Crow Delf and in the central and southern areas is called the Dog Delf.

The upper division of the Supra-Pennant is estimated to be 800ft thick. The upper and lower Woorgreen Coals occur near the top of the division. Both seams are about 2ft thick and occur only in the Central part of the basin.

Main Structures of the Coalfield

Folding along the north and south lines is the dominant feature of the earth movements that have affected the Coal Measures. They gave use to the main basin of the coalfield and Worcester syncline lying to the west of the Cannop fault belt (Fig. 5).

In the central part of the main basin there is an area of almost horizontal strata. The area of low dip is broadest in the North and tapers Southwards. It is flanked on the west by the Cannop Fault belt and on the East by the Staple-Edge monocline, a structure in which the strata are downfolded to the west, a maximum vertical distance of 700ft. East of the monocline the dip is westwards at gradients varying between 12 to 25 degrees. On the Western side of the main basin, the strata dip eastwards at 1 and 3 towards the Cannop Fault belt. Both the monocline and the fault belt die out southwards.

The Worcester Syncline is a shallow assymetrical fold with gentle dips on its western and steep dips on its eastern limb.

The Cannop Fault belt, a zone of fracture embracing up to 25 faults, trends north by west for 5 miles. With rare exceptions the faults down-throw west. Throws along individual faults vary considerably in amount up to a maximum of 55ft.

The Woorgreen Trough, is formed by west-north-westerly faults crossing the middle of the main basin. There are two faults on each side of the trough and the net result is to throw down the measures in the trough a vertical distance of 90ft. The faults die out to the west and to the east.

Pillowell Fault, a north-north-west fracture. In the north it attains a throw of 150ft down-west.

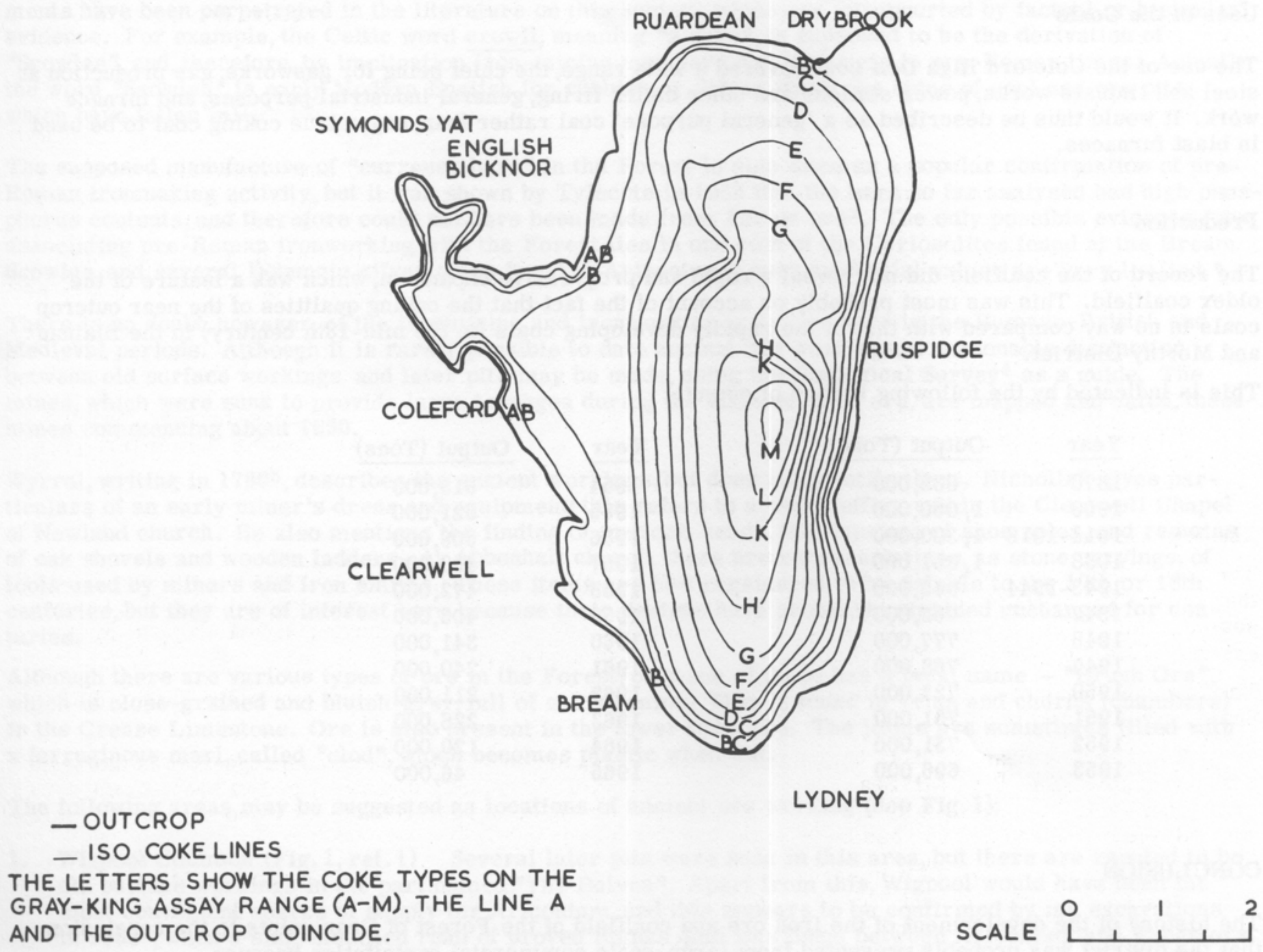

Fig. 6 – Iso-cokes of the Coleford High Delf seam

Properties of the Seams

From the utilization point of view, the seams in the Forest of Dean may be divided into lower, middle, and upper series, the lower being the most important. (This classification does not coincide with that adopted for geological purposes).

The lower series, comprising all seams from the Trenchard to the Churchway High Delf, and containing the Coleford High Delf, are, in general, gas-making and long-flame steam coals. The middle series provided true house coals (the main seams being the Rockey, Starkey, Lowery, and Twenty Inch); the upper series, or Woorgreen Coals, are of no commercial importance.

A large proportion of the output of the coalfield was drawn from the Coleford High Delf Seam. The coal of this seam is wholly bright and seems to contain no true durain. In spite of its apparent uniformity, the properties of the coal varies from point to point in the field, notably in those in coke-forming propensity, an important consideration which, amongst other things, must have had a considerable bearing on the apparent lack of expansion of development in steelmaking in the area.

The coke-forming propensity alters greatly both vertically through the seams and laterally from point to point. With the exception of the samples near the outcrop, the caking power generally increases as the seam is ascended from floor to roof. Figure 6 shows the variation in the caking properties of the seam. Coal within the area defined by iso-coke lines A to D is non-caking or weakly caking; between D and G the caking properties are marked but not sufficient to form good gas-making coal; from G to M the coals fall into the gas-making class. It will be noted that, although the coal is non-caking near the outcrop, in the centre of the field it is a gas-making coal of good quality.

A typical analysis of the Coleford High Delf Seam is as follows:

Ash	5%
Sulphur	3% to 1%
Volatile	34% to 37%
Carbon	85%
Calorific Value	13,000 – 14,000 Btu

Uses of the Coals

The use of the Coleford High Delf coal covered a wide range, the chief being for gasworks, gas production at steel and tinplate works, power stations and other boiler firing, general industrial purposes, and furnace work. It would thus be described as a 'general purpose' coal rather than, say, a true coking coal to be used in blast furnaces.

Production

The record of the coalfield did not reveal a rapid and progressive expansion, which was a feature of the older coalfield. This was most probably on account of the fact that the caking qualities of the near outcrop coals in no way compared with that of the rapidly developing coals (in the mid-18th century) in the Blainau and Morthy District.

This is indicated by the following record of outputs:

Year	Output (Tons)	Year	Output (Tons)
1870	835,000	1954	613,000
1900	1,050,000	1955	521,000
1914-1918	1,300,000	1956	509,000
1938	1,351,000	1957	480,000
1943-1944	945,000	1958	472,000
1947	753,000	1959	405,000
1948	777,000	1960	341,000
1949	768,000	1961	240,000
1950	723,000	1962	211,000
1951	751,000	1963	226,000
1952	731,000	1964	120,000
1953	696,000	1965	46,000

CONCLUSION

The history of the development of the iron ore and coalfield of the Forest of Dean points to the conclusion that the district was probably prevented from large-scale commercial exploitation because

(i) for various reasons, mainly related to the methods of mineral tenure, efforts to commute relatively small areas of workable minerals into larger worthwhile 'royalities' were not proceeded with

(ii) by a quirk of nature, the better-quality coals (from the iron and steel point of view)lay at greater depth in the basin. This fact, together with (i) above, militated against larger-scale investment in the mining developments necessary to exploit them.

(iii) The geology of the ore deposits is such that the irregular masses proved highly speculative from the mining point of view.

The year 1965 saw the end of large-scale deep mining in the Forest. However, small-scale operation by Free Miners remain to continue the long traditions.

Conference Paper

Iron mining and working sites in and around the Forest of Dean

N. P. Bridgewater, B.Sc.

THE BLOOMERY PERIOD

The Forest of Dean was one of the major areas in Britain to be exploited during Romano-British times for ironworking, and superseded the Weald in importance in the late 2nd century.

There is reasonably sound evidence for this assertion, but the belief that ironworking was an important activity in Early Iron Age times is more difficult to sustain, and it is unfortunate that fairly dogmatic statements have been perpetrated in the literature on this subject, which are unsupported by factual or historical evidence. For example, the Celtic word crowll, meaning "a cave", is supposed to be the derivation of "Scowles", and, therefore, by implication iron-mining may have had its origin in pre-Roman times. Actually the word "Scowles" is early Modern English for rubbish or debris (from the sides of coal and ore pits which have fallen in)[1].

The supposed manufacture of "currency bars" in the Forest is also cited as a popular confirmation of pre-Roman ironmaking activity, but it was shown by Tylecote in 1962 that the bars so far analysed had high phosphorus contents, and therefore could not have been made from Forest ore[2]. The only possible evidence for associating pre-Roman ironworking with the Forest lies in one coin of the Coriosolites found at the Bream Scowles, and several Dobunnic silver coins found at Ariconium[3]; such evidential values are very limited.*

There is no doubt, however, of the ironmining and ironworking activities here in the Romano-British and Medieval periods. Although it is rarely possible to date ancient ore workings, a reasonable distinction between old surface workings and later pits may be made, using the Geological Survey[4] as a guide. The mines, which were sunk to provide large tonnages during the blast-furnace era, are mapped and dated, these mines commencing about 1650.

Wyrral, writing in 1780[5], describes the ancient workings, but does not identify them. Nicholls[6] gives particulars of an early miner's dress and equipment; this refers to a brass effigy within the Clearwell Chapel of Newland church. He also mentions the finding of mattock-heads, the imprints of shoe soles, and remains of oak shovels and wooden ladders. At Abbenhall church, there are representations, as stone carvings, of tools used by miners and iron smiths. These items are now considered to be datable to the 17th or 18th centuries, but they are of interest here because their designs have probably remained unchanged for centuries.

Although there are various types of ore in the Forest, only one of these has a local name – "Brush Ore", which is close-grained and bluish-grey, full of shiny grains. This is found in veins and churns (chambers) in the Crease Limestone. Ore is also present in the lower Dolomite. The joints are sometimes filled with a ferruginous marl, called "clod", which becomes plastic when wet.

The following areas may be suggested as locations of ancient ore working (see Fig. 1):

1. **Wigpool Common** (Fig. 1, ref. 1) Several later pits were sunk in this area, but there are reputed to be old surface workings in the part named "The Delves". Apart from this, Wigpool would have been the most convenient source of supply for Ariconium, and this appears to be confirmed by my excavations in 1958[7], when a slag-metalled road of proved Roman date was found between Ariconium and Frogmore. It seems likely that this road continued through Hope Mansell to Wigpool Common.

   In passing, it may be emphasized that this stretch is the only road in the Forest and south Herefordshire which has been shown by excavation to be of Roman date. The surfacing of roads in Roman and Medieval times with iron slag was a common feature in this area, as in the Weald, and at several of the fifteen sites excavated during my investigation of the XIIIth Iter between Ariconium and Monmouth this point was amply demonstrated. Later roads were shown to have been surfaced with stone blocks or cobbles. The importance of this digression into the nature of local roads is the realization that considerable quantities of bloomery slag were produced in the area, particularly at Ariconium and Whitchurch. By calculation, it can be shown that this stretch of the XIIIth Iter alone would utilize over 6,000 tons of slag for its initial surfacing. This of course is reflected in the vast scale of smelting in the area and in the mining activity needed to support it.

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*In the Weald, fortified mining camps of I.A. date have been found. There is no evidence of this at Ariconium. The nature of the I.A. occupation at Ariconium has not been established.

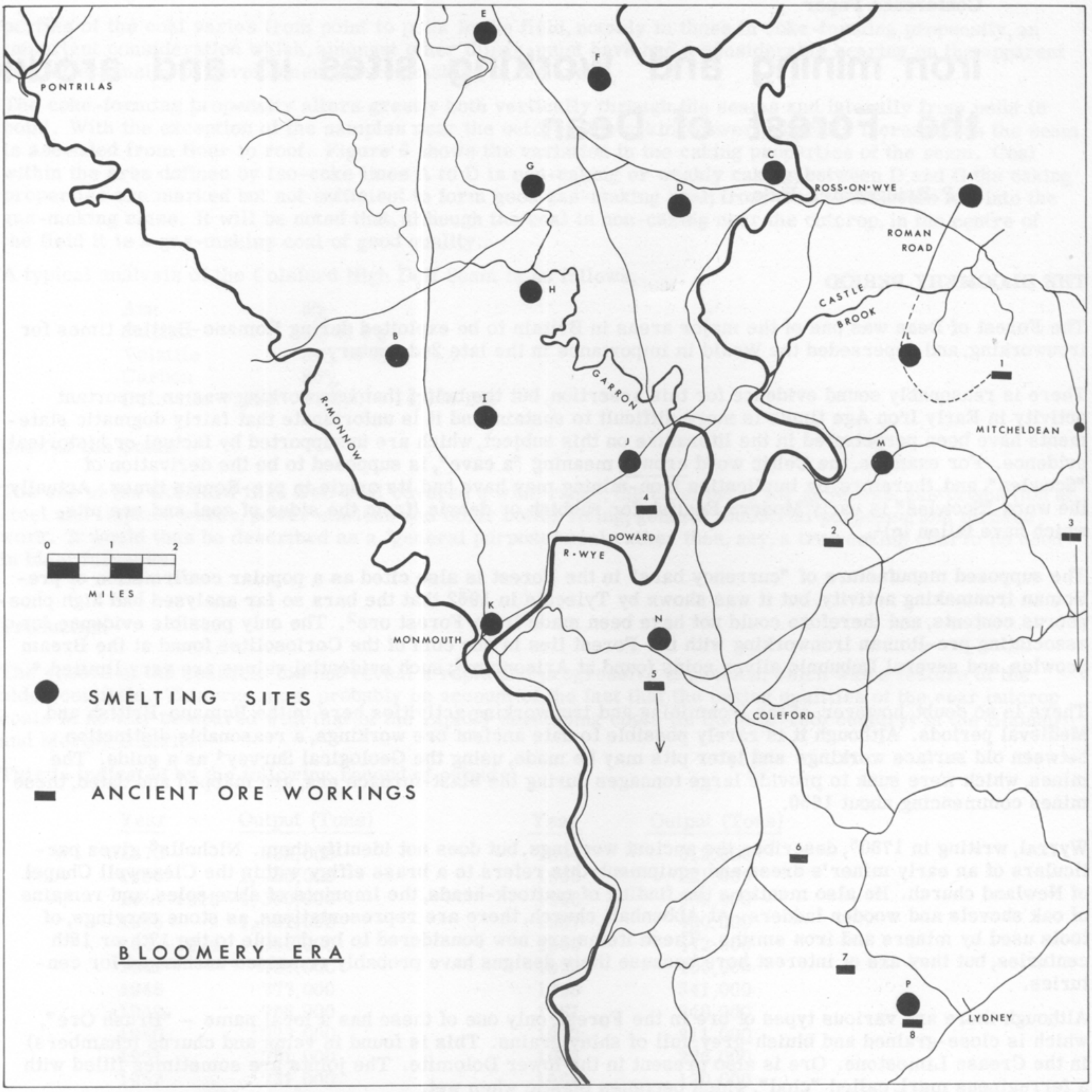

Fig. 1

2. **Hangerberry** (Fig. 1, ref. 2) Surface workings are reported in this district near Lydbrook where the Crease limestone shows haematization on the surface. This could have been a source of supply for Ruardean.

3. **Edgehill and Westbury Brook** These surface workings can be traced for four miles from Edgehill, north of Cinderford, where they are in the form of open-cast trenches, down to the Soudley Valley.

4. **The Doward** Many surface workings are known here and must have supplied Whitechurch with ore.

5. **Staunton** There are many shallow surface workings covering the outcrop of the Crease limestone east of Staunton to west of Coleford.

6. **Clements Tump – Bream** The crop of the Crease Limestone is marked by an almost continuous line of old surface workings, many of which join up with the modern China Pit. Surface workings are also found on the crop of the Lower Dolomite where the ore was won from pockets and along joints. This includes the Noxon Park area.

7. **Bream Scowles** These extensive and spectacular workings are called 'The Devil's Chapel', and have the appearance of deep quarries. There is a tradition that these were Roman workings, and it is often stated that Roman coins have been found in these and other workings, in particular 155 silver coins, ranging in date from A.D. 54-192, at the Bream Scowles. It must be admitted, however, that the reports

in the literature of coins and coin hoards are too vague to be used for dating these various ore workings, and it is probably only permissable to say that the coins were found in the proximity of the workings. To be realistic, iron workings seem to be most unlikely places to bury coin hoards. The assumption that many of the old surface workings date from the Romano-British period is best made from the existence of the numerous ironsmelting sites and the large supplies of bloomery slag produced.

8. **Lydney Park** The crop of the Crease limestone is marked by a continuous line of workings and shallow pits between Bream Scowles and Lydney Camp. The northern half of Lydney Camp Hill, where Sir Mortimer Wheeler excavated in 1928[8], is honey-combed with blocked mine shafts. The excavation produced evidence of the only authenticated Romano-British mine in this area; the adit was found to cut through the prehistoric rampart and to be sealed by a hut floor dated by coins of the late third century. The miners had evidentally been following a band of ferruginous marl (the 'clod'), hoping to find a pocket of ore. Of particular interest was the discovery of pick marks in the clod, and an iron toy-model of a pick was found during the excavation. This pick was 8½cm long and 1cm wide at the ends.

Further observations were made by Dr Scott-Garrett[9], concerning iron-mining picks. He also examined another adit underlying the temple bath system, finding pick marks in the clod, from which a plaster cast was taken. Enquiries made showed that no authentic Roman iron-working picks are known on the continent, and that some picks found in Spain may have been used for mining other metals. The pick impressions found at Lydney suggest a tool having twice the dimensions of the toy pick obtained from the excavation.

Turning to the iron-smelting activities in the Bloomery Era, which must have been extensive in the Forest, as judged by the reports of bloomery slag deposits, Wyrral[10] distinguishes between bloomery slag "(called "cinders")" containing much unextracted iron, and blast-furnace slag "(called "scruff")" which is vitreous and less dense. He also mentions that the slag from fineries is similar in appearance to bloomery slag and contains iron. Nicholls[11], writing in 1866, testified to the presense of numerous heaps throughout the Forest, some of them near old mines. It is unfortunate that, with this abundant material at hand, no systematic investigation on a Forest smelting site has been made. Only at two sites, Ruardean and at Popes Hill, has there been a preliminary examination.

It is interesting that many iron-smelting sites lie outside the Forest mining area; these cover the district in South Herefordshire known as Ergyng (now Archenfield), stretching from Ariconium to Monmouth, and they could well have been associated with the Roman road system. Much more is known about these sites than those in the Forest, and dating is also possible. The transportation of ore from the Forest must have been a large undertaking.

A. **Ariconium** (Fig. 1, ref. A) Professor B. G. Charles says that the Welsh name Ergun, or Ergyng is derived from Ariconium, from which arose the district of Archenfield. In the mid-18th century Ariconium was covered with scrubland which, in 1785, was cleared and ploughed. This exposed stone walls, black soil, and iron slag, and a large quantity of Romano-British objects were turned up, many of which have since been lost. The small excavation by Jack in 1922[12] disclosed two rooms of a building, and the coin evidence suggested a small Flavian occupation with an active period between A.D. 250 and 350. The finding of British coins and fibuulae also show that occupation probably commenced quite early, and Ariconium must also have been a posting station, being listed in the Antonine Itinerary. Previously the site was considered to have covered 82 acres, but recent field work by the Archenfield Archaeological Group (A.A.G.) shows that 250 acres is a more realistic figure. Ariconium is popularly called a town, but there is no evidence yet, either from aerial photographs or field work, of any boundary, and a more reasonable picture would be that of a villa estate surrounded by a large belt of furnace and smithing sites. All of these would obviously not be contemporary, as the furnaces would have been rapidly expendable.

A systematic excavation in one small area of the industrial zone was carried out by the A.A.G. in 1963, which revealed four major hollows containing six furnaces with working-up hearths. Dating evidence showed that the period of operation was the second half of the 2nd century. A full report was issued last year[13], which was also summarized in H.M.G. Bulletin No. 6

B. **Llancloudy** A small excavation on land adjoining Hill Farm revealed slag deposits. In this district a hoard of 2,800 Roman coins were found in 1912.

C. **Bridstow** Large slag deposits here were reported by Wright in 1854[14].

D. **Peterstow** Two areas of slag deposits here were reported by Wright, the largest being at the Cinder Grove, where Roman coins and pottery were also found. This is probably the area now occupied by Jackson's fruit orchards. Many thousands of tons of slag have been removed for re-smelting.

E. **Llandinabo** In 1868 there were several acres of slag deposits here known as "The Furnaces".

F. **Hentland** This is another area mentioned by Wright, and recently slag deposits have been noticed here. A slag-surfaced road was found near the church, and this is on the alignment of a suggested Roman road from Red Rail. This district has yielded several Roman and Medieval pottery finds recently.

G. **Tretire** The earliest known place name here is Rythir. This may be translated either as Rhyd-hir = the longford, or Rhudd-dir = red soil. In addition to reports of large slag deposits here, the A.A.G. have located a possible smelting site. Roman coins and pottery were found in the Tretire district.

H. **Llangarron** Slag deposits were reported here, and their presence has been recently confirmed; they lie north of the Llanerch Brook.

I. **Welsh Newton** Slag deposits were discovered by the A.A.G., near Gwenherrion Farm.

J. **Whitchurch** Numerous reports of slag deposits suggest intensive smelting operations here, and several excavations by the A.A.G.[15] support this view. It seems that the whole village overlies a thick bed of slag. Smelting was carried on in Whitchurch during Roman, Medieval and Elizabethan times and many finds of the first two periods have been made here. Wyrral[16] mentions the deep beds of cinders (8-10ft) and personally inspected Roman coins, fibulae and a statuette discovered in them. In 1962, further excavations by the A.A.G. revealed decorated samian at depths of 8ft in the slag deposits. This evidence suggests villa settlement in the vicinity, but this would not be in the centre of a marsh, as originally plotted on the O.S. maps.

The ore was probably mined in the Doward Hills. Excavation in the Settarsbrook valley[17] also revealed a slag-surfaced road in three places. Although this road could not be dated, it is probably a section of the XIIIth Iter.

K. **Monmouth** Very large beds of bloomery slag existed here, and were so extensive that the recovery of the metal from them in the 18th century was a most profitable business. It is only quite recently, however, that excavation by the Monmouth Antiquarian Society has exposed sealed layers with datable finds (2nd – 3rd century)[18]. Monmouth (Blestium) is one of the places listed in the Antonine Itinerary.

L. **Hope Mansell** Ironmaking is reported here before 1270 A.D., and field work by the A.A.G. has revealed a large bed of slag near the village.

M. **Ruardean** A preliminary excavation near Warfield Farm in 1966, in a slag-covered area, suggested the existence of a medieval bloomery site. This is reported in H.M.G. Bulletin No. 8. The ore could have come from either Wigpool or Hangerberry Hill. Undoubtedly there is much scope for further work in the northern sector around Ruardean.

N. **Staunton** is known to have large slag deposits. A Roman lamp of Claudian date was found here[19]. Recently, a possible bloomery site north of the vicarage has been found.

P. **Lydney** Whilst there appears to be no evidence of iron smelting at Lydney Park, and there is no reference to slag deposits in this area, the ancient mining activity here pre-supposes smelting operations in the vicinity.

Q. **Popes Hill** (near Littledean) The actual structural remains discovered here by the Forest of Dean Local History Society[20] suggests an ore-roasting hearth of Romano-British date, but the widespread scattering of bloomery slag clearly indicates a smelting site close to this.

Iron slag is ubiquitous in the Forest and in Archenfield, so that it is only the large deposits which have any real significance. Almost all excavations in the district reveal some slag, and often roasted ore. On some of these sites there is reason to believe that small-scale iron working was undertaken. So far, it has not been possible to correlate ores, products, and slag on any given site.

THE BLAST FURNACE PERIOD

The Charcoal Era

The increased demand for iron in the 17th century, with the charcoal blast furnace now established, led to the working of deep iron mines, often in areas where the old surface workings existed.

During this period, the ore was roasted or calcined before use in kilns resembling lime kilns, as described by Powle[21]. Two structures, which are thought to have been iron-ore roasting kilns, have recently been found at Ruardean. Powle records that bloomery slag was used as part of the burden in smelting.

There are few structural remains in the Forest relating to the furnaces and forges of the charcoal era, although there sites are known. Of the fourteen recorded furnace sites only two are now visible, and of eighteen forge sites only three show fragmentary structures.

Guns Mill Furnace The second blast furnace, erected in 1683, was about 28ft square. The shaft is seen to be square in plan with slightly curved sides, but the hearth is missing. The casting floor lies to the south and the bellows room to the west, and adjacent to this is a capacious wheel-pit. The original overshot wheel was driven by a water supply contained in ponds to the west. Samples of charcoal blast-furnace slag and bloomery cinders have been found on the site.

Coed Ithel Furnace A vertical section of the square shaft and the upper part of the circular bosh are visible today, and the site has been investigated by excavation. A full report of this has been issued by Tylecote[22], and the work is also summarized in H.M.G. Bulletin No. 3.

The importance of this work was to show that the furnace design belonged to the second phase of British furnace construction and was unlike the hypothetical concept of an early furnace of this period (i.e. before 1651). This site is now thought to be the Brockweir furnace mentioned in the literature.

Bishopswood Furnace Although nothing remains of the second furnace, in the Lodgegrove Brook Valley, its site has been practically fixed during an emergency excavation made by the A.A.G., at Upper Lodge[23]. A deep stratified layer of early blast-furnace slag, together with bloomery slag, was found here. This appears to confirm the location given on a map of 1809.

Bishopswood Forge The lower forge, in the Lodgegrove Brook Valley, was probably sited between the lower and middle pools, on the site of the later cornmill. This is where the present pumphouse stands, and behind it there is a domed and brick-lined icehouse, probably used for preserving supplies of foodstuffs to Bishopswood House.

Flaxley Forge The modern lane passing Waldron cottage crosses the stream and also passes along the dam wall of a former pool which is now a large low-lying field. The arched culvert passing beneath the dam is still well preserved, and the large chamber with tapering channel, to give increased water velocity, is noteworthy. Remains of buildings to the south of the road, now farm buildings, must be part of the original forge, and the channel leading from the wheelpit site can be distinguished. The end wall of the present dairy has a stone with the inscribed date 1693. The structure must be the remains of the Lower Forge, whilst the Upper Forge probably occupied a position further upstream, where remains of several ponds are visible.

Rowley Forge Below the pool can be seen the wheel-pit and sluice system, but only fragmentary remains of walls mark the site of the forge buildings and later paper works. Iron slag can still be found on the site.

The Coke Era

Thomas Rudge[24] states that in 1806 the greater part of the ore employed in the Forest was obtained in Lancashire. The ironmasters found it more profitable to import this ore, in spite of the high carriage rates, than to use local ores. However, as the rich character of the Forest ore became better known, the deposits were more fully developed, the peak output being 170,611 tons in 1871.

Of the six furnaces and three forges recorded in this era, five sites still show some remains.

Great Western Ironworks, Soudley. A photograph of 1876 shows their extensive nature, but now only the long retaining wall remains, together with the rail track.

Whitecliffe Furnace The casting of this furnace is of square plan, 40ft wide and 45ft deep, with a highline about 50ft above the casting floor which lies to the south. The external masonry is nearly all intact but the hearth and bosh system has been robbed, leaving the circular shaft in position. The hearth was served by two tuyeres and their arches are complete. A small building situated to the east of the casting floor may have been a pattern shop, whilst the engine house was probably behind it.

Bromley Hill (Oakwood) Furnace This was a three-tuyere furnace contained in a square casing, 40 by 34ft in plan, built into the hillside to the north. The furnace lining and most of the external stone facing has been robbed away. The highlevel foundations can still be seen, about 40ft above the casting floor which lies to the south. The northern and eastern tuyere arches are blocked, whilst the hearth and forehearth are filled with rubble. The blast would have been supplied by an engine, its house probably lying to the east but not immediately adjacent to it. There is a suggestion that a second furnace was planned to be built alongside the present one, to the east.

Samples of ore, limestone, fuel, and iron were found. The ore would have come from the Oakwood Deep Level and from Noxon Park. A mixed fuel of charcoal and coke is indicated, as both of these materials were found in a deposit on the high level. The type of slag suggests a cold-blast operation. No slag heap appears to exist now, and most of this must have been taken away for other uses.

Lydney Upper Forge. Although there were works here during the charcoal era, the present remains obviously belong to buildings of the coke era and these are known to have been working until 1891. The remains are scanty and consist of the engine house, the dam wall, and walls of unidentifiable buildings. To the east there is a spectacular spillway in a minor gorge.

Darkhill Numerous building walls exist here, but until the site has been investigated by excavation the precise function of the various parts cannot be established. Remains of slag-covered walls, however, suggest some type of furnace, and one of the rooms could have housed a beam engine.

Just north of these buildings are the reduced walls of a long building, which may be either the long smith's shop of the Forest Steel Works. To the north west can be seen one section of the Titanic Iron and Steel works.

REFERENCES

1. "The Place Names of Gloucestershire", E.P.N. Soc. Vol. XL. Pt. III, 214
2. R. F. Tylecote, "Metallurgy in Archaeology", (1962), 209.
3. The Palmer Collection from Ariconium, in Gloucester City Museum.
4. "Geology of the Forest of Dean Coal and Iron Field", Geological Survey of Gt. Britain (1942) Chapter X.
5. George Wyrral, "Notes on Iron Working in the Forest of Dean", Trans. B.G.A.S. (c. 1780).
6. H. G. Nicholls, "The Forest of Dean", (1858), 217.
7. N. P. Bridgewater "Ancient Buried Roads in South Herefordshire", Woolhope N.F.C., Vol. 36(2) (1959), 218.
8. R. E. M. Wheeler, "Report on the Excavation of the Prehistoric, Roman and Post-Roman Site in Lydney Park, Glos. " (1932), 22.
9. C. Scott-Garrett "Roman Iron Mine in Lydney Park", Trans. B.G.A.S. Vol. 78. (1959), 86.
10. op cit. Note 5.
11. H. G. Nicholls "Iron Making in Olden Times" (1866).
12. G. H. Jack "Excavations on the Site of Ariconium", Woolhope N.F.C. (1923), Appendix
13. N. P. Bridgewater, "Roman-British Iron Working near Ariconium", Woolhope N.F.C. Vol. 38(2) (1965), 124.
14. Thomas Wright, "Wanderings of an Antiquary"(1854).
15. N. P. Bridgewater "The Whitchurch Vagas", Woolhope N.F.C. Vol. 36(2) (1959), 228; Vol. 38(1) (1964), 88.
16. Op. cit. Note 5.
17. Op. cit. Note 7, p. 224.
18. S. H. Clarke, "Archaeology in Wales, 1964", C.B.A. Group II, Item 33
19. C. Green, "Glevum and the Second Legion" J.R.S., Vol. 32. (1942), 51.
20. C.Scott-Garrett, "Roman-British Sites at Chestnuts Hill and Popes Hill", Trans. B.G.A.S. Vol. 75 (1956), 199.
21. Henry Powle, "An account of the iron works in the Forest of Dean", Phil. Trans. Vol. 12 (1683), 931.
22. R. F. Tylecote "Blast Furnace at Coed Ithel, Llandogo, Mon.", J. Iron and Steel Institute Vol. 204. (1966), 314
23. Report on Archaeology, Woolhope N.F.C. Vol. 38(1) (1964), 89.
24. Richard Meade, "The Coal and Iron Industries of the U.K. ", (1882), 642.

Charcoal-burning in the Royal Forest of Dean

Cyril E. Hart

EARLY CHARCOAL-BURNING:

Woodlands were the scene of men's evolution and were originally his chief source of food, shelter, and warmth. As society developed, man's attitude to woods changed. Besides previous uses, trees provided pannage for pigs and wood for charcoal with which to smelt ore, but they obstructed agricultural development and in consequence economic development has often been associated with the destruction of woodlands. This is a necessary process. As well as yielding land for agriculture and settlement, woodlands represented a form of exploitable resource which had required no human effort in its formation. While populations remained small and technology uncomplicated, the supply of wood seemed to be inexhaustible. However, over many centuries grubbing-up for agriculture and exploitation for such purposes as iron smelting brought the supply to a seriously low level, particularly of wood suitable for ship-building.

Dean, originally a forest of some 100,000 acres, was gradually eroded of trees over the first millenium A.D., by the combined effects of man, beasts, and the elements. A halt was made in the late Saxon and early Norman periods, when beasts of the forest (particularly deer) and their habitat were more prized by the King than the needs of his subjects for additional agricultural land and for trees for fuel and timber. A few centuries of this semi-conservation as a hunting reserve only partially stopped the depletion. Following the advent of blast furnaces in 1612, Dean within a century and a half was practically deforested, in the silvicultural sense of that word. Only an Act of 1668 followed by intermittent good management made the Forest a storehouse of naval timber, which proved particularly of value in connection with the Dutch and Napoleonic wars. Thereafter, another Act, of 1808, and the enlightened policies of the Office of Woods and, from 1919, of the Forestry Commission, assured Dean's survival as a great national asset. The story of her woods, from prehistoric times, through the early eras of iron- and coal-mining, and then of wooden ships, to modern commercial forestry is recounted in "Royal Forest"[1] The present paper touches only briefly upon the effect of the iron industry on Dean's trees, particularly by way of charcoal-burning.

Wood consists largely of carbohydrates (compounds of carbon and water) which burn at relatively low temperatures, and for this reason, no matter how dry, cannot be used as an industrial fuel where very high temperatures are required. If, however, wood is subjected to a process of distillation in the absence of air, the carbohydrates break down and volatile compounds are driven off, leaving carbon in the form of charcoal, and a small quantity of ash. Because the ash and impurity content of well coked charcoal is low, it can be considered essentially as available carbon. Thus wood can be turned into an ideal high- temperature fuel for smelting of iron-ore, forging of iron, and domestic heating and cooking.

Charcoal-burning is one of the oldest industries in the world. From the days when early man first conjured metals from their ores and forged them, until the invention of the coke oven in the 18th century, charcoal was essential to every smith and ironworker, and the foundations of British industrial wealth were laid by the grimy charcoal burners of the woods. All the bronze, iron, glass, and precious metals of the ancient and medieval craftsmen were refined by its use. Early man and his successors produced charcoal by firing wood in simple open-air 'stacks'. To limit the supply of air, thus obviating the wooden billets bursting into flame, earth or turf was used as covering. The charcoal was recovered, but all the by-products were wasted.

In Dean, charcoal was almost wholly used to smelt iron-ore. Its production was the chief reason for the impoverishment of the woods, yet its burning was a rational use, and natural replenishment of the cover would have followed if animals, both wild and domestic, had been fenced out. From at least the 13th century the trade maintained many people. Thus their presence was tolerated by those who administered the Forest, and thought it is evident that their occupations disregarded much forest law (beasts of the forest and their habitat were more important than trees, and almost more important than people) usually charcoal-burners were a necessary and welcome class of operatives. Grantees of woods within the Forest found the trade lucrative, although often unlicensed[2] In 1237[3] the king ordered his forest officers to 'diligently view and enquire' in what places his eight movable forges could with least damage be set up to use maple, thorn, hazel, and dead wood; oaks, beeches, ash and chestnuts were not to be used.

The great destruction committed by charcoal-burners is recorded in the eyre-roll of 1270; they 'bought wood and timber of the foresters-of-fee and made charcoal both of that which they thus bought and the other large part of wood and timber which they took furtively throughout various places'.[4] They were fined, and 'it is ordered that no one henceforth may have any charcoal-pit in the Forest'. The small effect produced by this order is evidenced by 2,290 hearths, old and new, found by the forest regarders in 1282, who drew attention to the stools obliterated by the hearths and their ill-effect of preventing re-coppicing[5]. For the year 1279-80 the constable of the Forest accounted for £7. 7s. 'for old branches and underwood sold divers times to make charcoal, which is called in these parts old charcoal-pits'.[6] The value of the wood used for making charcoal to maintain a forge for a whole year seems to have been anything from £12 to £70 according to estimates of that time.[7] Occasionally charcoal was brought in from outside the Forest.[8]

At times wood for charcoal was obtained at the king's expense, [9] at others it was carefully assessed by 'the hearth', 'the pit', or 'the week'.[10] Two documents, probably the earliest of their kind, give specific details for Dean under the heading vendico fossarum (sale of charcoal-pits). The first, of 1278[11], names 52 people who had been making charcoal; the charges against them varied, e.g. 2 pits for a total of 9 weeks at 5s., i.e. £2. 5s., and the total charges came to £58. 7s. The second document, of 1279[12], names some 48 burners; the charge against them was usually 5s for 4 or 5 weeks, and the total £43. 1s. Both documents give the number of weeks each person operated, and names the places in the Forest.

In 1325[13] charcoal was sold at 9s a dozen of 12 seams (probably 12 bushels). In the following year[14] some underwood was sold 'for the sole reason that, by an unfortunate fire from a certain charcoal pit setting light to the bracken, the wood was accidentally burned; and so that it might grow again the order was made for the cutting and selling'. In 1333[15], 9 acres of underwood were sold for 40s. 6d., and cost 20s. 3d. to cut and burn into charcoal. Thus underwood fetched 4s. 6d. an acre, cutting and charcoaling cost 2s. 3d. an acre, and it took 9 man-days to cut and convert one acre. Wages at that time were 3d. a day.

An interesting reference in 1435-6[16] is to charcoal used for domestic heating – for 'Speeches Day'[17] at Kensley. This was obviously to heat the court-room when inhabitants appeared before the verderers to speak of their privileges and requirements, particularly in respect of common and estovers (botes).

By Henry VIII's time trees were still relatively plentiful but scattered and neglected, and did not warrant too much concern. Game was no longer ultra-important; there were only remnants of the herds of earlier centuries. The woods by now were reduced to between 15,000 and 20,000 acres, chiefly of the silvicultural system known as high forest, with only a little coppice-with-standards, which came more to the fore following the Statute of Woods of 1543. The widely-spaced standards, chiefly of oak, were reserved for timber for ships and other building, and when felled their bark was used for the tanning of leather. The coppice, chiefly of hazel, field maple, thorn, holly and other inferior species, served a variety of purposes besides that of fuel for smelting, among them fences, hurdles, domestic fuel, and for use in 'wattle and daub'. Standards (termed 'stadelles' or 'storers') had to be conserved on each acre of coppice, and the new growth had to be protected by fencing or hedging. But contemporary with Dean's conserved areas must have been thinly stocked woods with 'scrub, brushwood, and thicket, where the trees were being thinned out by the action of man and beast'. No full silvicultural policy had as yet evolved, and the need for shiptimber was potential rather than current.

By Elizabeth I's reign the need to conserve shiptimber was important. Charcoal-burning, though ostensibly it took only the smaller, inferior trees and the lop and top, was in opposition to a policy of conservation. However, three important Acts in the 1st, 23rd and 27th years of the reign (though they did not apply to Dean) prohibited the felling of timber-trees of oak, beech and ash to make charcoal, if the trees were within 14 miles of the sea or of any navigable river.

Coppice and underwood, of any species below medium timber-size, were the best material for charcoal and where accessible to bloomeries and forges, were needed in uninterrupted supply. Regular customers of wood for smelting relied on the leasing or purchasing of coppice-woods 15 to 30 years old, enclosed against animals; four to eight rotations of crops could be raised instead of about 12 timber-trees which might decay before felling was permitted. Owners and lessees of coppices disliked leaving standards which limited the useful wood in a coppice; they were tempted to cut down the 12 reserved on each acre under the Statute of Woods, and to leave younger ones in their stead. Incidentally, Elizabeth's Act of 1559 defined timber-trees as at least 'one foot at the stubble' and prohibited their charcoaling. The provision for 12 standards on each acre gave room for oaks to develop big boles and crowns with large branches, ideal for ship-building; any heavier stocking would have drawn up the oaks and reduced the amounts and quality of the more saleable under-storey, the coppice; and wood for fuel was in more demand than timber.

Taverner's survey of Dean's woods in 1565 shows chiefly neglect and secondly the effect of the iron industry. Some of her woods were pure coppice, some were coppice-with-standards but the large majority were still the silvicultural system called 'high forest' – like many of its hardwood areas today, but with one major difference: the larger trees were mostly debranched, some 'well-nigh unto the top'. The effect on a tree of this debranching, termed shredding, sometimes done when the underwood was cut, would much depend on the care used in such 'pruning'. As growth in girth is proportionate to crown, excessive shredding reduced annual increment. But shredding gave some benefits: it obviated the taking of timber-trees; the tree itself had less adverse effect on the coppice under or near it; and when felled the debranched tree did less damage to the underwood. Shredding was condoned, as shown by a warrant issued by Taverner 3 November 1572[18]:

> The underwood together with the lopping and shredding of all those trees which heretofore have been used to be lopped and shred, growing in the Forest of Dean, are meet to be sold this year to the ore-smiths in the same Forest. No timber-trees nor saplings of oak likely to be a timber, to be fallen by colour hereof. And the spring reserved[19].

The voracious blast furnaces came to Dean's borders by 1575. Ironworks at Whitebrook, Lydbrook, Whitchurch, and Bishopswood made the chief demands. In 1610, coppices totalling 520 acres on the east of the Forest were leased for Winter's Lydney furnace; surveyors said that 30 cords an acre, or 15,600 in all, could be raised, reserving sufficient standards for the State; Winter asserted that no revenue had been received from the coppices for 27 years and no more than £7 yearly at any time. The price paid by Winter for his 21-year lease was £800, i.e. about 30s. an acre or 1s. a cord.

By 1611 ironmasters connected with the above and other works wished to obtain concessions of Dean's trees and permission to erect blast furnaces within her woods. The Earl of Pembrook's nominees obtained a contract for 10 years for 12,000 cords a year at 3s. 4d. a cord and induced James I to permit the building and leasing to the earl of 4 blast-furnaces and 3 forges at Lydbrook, Cannop, Parkend and Soudley. These and later ironworks led to large-scale depletion of Dean's woods despite prohibitions, committees, commissioners, and a host of forest officials high and low – all detailed elsewhere[20]. During the Commonwealth, to supplement enclosure the first sowing of seed and planting took place; this was commendable but inadequate[21]. At the time, 45s. a load was paid for producing large charcoal and 22s. 6d. for small, termed 'brazes'[22]. In 1660, 'of all bad and good wood generally there went 5½ short cords of wood to make a load of charcoal'; and 'there went to make a ton of sow iron, two loads or sacks of charcoal or thereabouts'[23].

Soon a more enlightened policy was to be projected in Dean. During the century, she had contributed towards the support of government by way of iron and shiptimber, and had been the great resource for gratifying the favourites of the monarchs, but the improvident and often ill-defined grants of concessions as to timber and ironworks, with the confused mixture of rights and privileges created by them, and coupled with rights of common, pannage, and estovers, had to worst possible effect on the woods. The whole was 'a perpetual struggle of jarring interests, in which no party could improve his share without hurting that of another'.[24] Dean's need of protection, rehabilitation and conservation was urgent, and legislation to effect this came by way of the Dean Forest (Reafforestation) Act 1668. Six years later the King's Ironworks were demolished – the end of 64 years sporadic activity[25]. Since 1610 these and other works in the neighbourhood had used immense quantities of wood – a ton of charcoal requiring about 8 tons of wood, or a load of charcoal needing 2½ to 3 long cords or 4½ short cords. Well might John Evelyn bemoan in 1663; 'Nature has thought fit to produce this wasting ore more plentiful in woodland than any other ground, and to enrich our forests to their own destruction'[26].

After 1674, only ironworks outside Dean's woods, at Flaxley, Lydney and Redbrook, and those in Monmouthshire and Herefordshire, were sustained by her cordwood. Unsuccessful attempts were made to induce the Crown to enter the iron industry, as ample supplies of cordwood were still available. In this connection it was stated that to make a ton of raw iron 4½ cords @ 8s = 36s. were required, cutting and cording would cost 12s., charcoaling 6s. 8d. and carriage to works 8s. To make a ton of bar iron £3. 12s. 6d. worth of charcoal would be needed, plus carriage of 8s.[27]

Following the Act of 1668, sowing, planting, and enclosure were effected, but little of this commendable work came to fruition (beyond producing some invaluable shiptimber) due to the opposition of commoners and the laxity of officials. Natural growth of inferior species produced much wood which was sold for charcoal to supply the works at Flaxley, Lydney and Redbrook and others further afield[28]. Thus the trade of charcoal burning on a fairly large scale continued in Dean much longer than elsewhere – indeed to at least 1795, when coke (much later than in most parts of the country) began to be used for smelting. Competition for such wood came increasingly from the coalminers.

WOOD 'CHEMICAL WORKS' ('STEWERIES')

In Dean, coke for fuel was not used till about 1795; thus quite a number of men continued to ply the ancient trade. Fortunately for the timber industry in Dean (where Flaxley Furnace in 1802 was one of the last to use charcoal) thought was given in the 19th century to undertaking charcoaling at depots in or near the Forest with the complementary aims of producing pyroligneous acid and tar, and of processing some of the charcoal. The process of distillation of wood is an old one (see Appendix).

By 1814 some at least of the processes were known in Dean, where in that year Bevington Gibbins, 'chymist' of Lydney, leased from the Bathursts land near the canal for a 'chymical factory', and agreed to purchase 1,000 cords a year at 9s. 6d. a cord[29]. Gibbins installed machinery and equipment but the process he followed is obscure. He paid his rent until 29 September 1816 and was released of his agreement the following 16 October. Perhaps his operations comprised simply the production, grinding, and treatment of charcoal, and the processing of wood-tar, much in demand in the building and repair of ships. He may, too, have been concerned in the manufacture of pyroligneous acid[30].

Though the industry at Lydney had apparently failed, other chemical works (known locally as 'steweries' or 'distilleries') were later established in Dean – at Cannop (1835), Oakwood (c. 1844), Lydbrook (1857), Whitecroft (c. 1876), Broadmoore (c. 1864), and Tufts (1887). In 1881 the works employed about 130 men, providing outlets for large quantities of otherwise unsaleable cordwood: in 1880 'mules and donkeys bearing iron cradles holding cordwood were amongst the characteristics of the Forest'[31]. The history of each of the works has been ascertained and their remnants noted[32]. Suffice it to say here that at Cannop in 1841 there were 8 retorts distilling wood for pyroligneous acid, and 'sugar of lead' (lead acetate) and wood-tar were made there. By 1880 the works were making naphtha, and 'brimstone from Mount Etna was turned into oil of vitriol' (sulphuric acid).[33] Some of the charcoal was made into lampblack; the remainder was graded for various uses. These works, and some of the others, had grinding and grading machinery.

Most of the steweries had gone by the turn of the century; that at Tufts continued intermittently until 1948. But charcoal-burning in woods (which trade had never died) continued. Furthermore, in 1913 a huge wood distillation factory, of German design, was built at Speech House Road.

THE WOOD DISTILLATION WORKS

By 1911 the Office of Woods, the precursors of the Forestry Commission, began considering the provision at Speech House Road of a wood distillation works on the south side of the road to that where the old steweries at Cannop stood. Their aim was to utilise an increasing amount of wood, particularly the lop and top of oaks and other hardwoods, and thereby to produce immense quantities of charcoal as well as wood-spirit and acetic acid which could be turned into acetate of lime – the source of acetone, much needed for the manufacture of cordite. The contract for the plant was given to F. H. Meyer of Germany; the drawings are dated October-December 1913, and the first retort was in production by the outbreak of war.

The story and techniques of the enterprise to 1940 have been recorded[34]; amplification of them and the works, subsequent history and achievements have now been ascertained[35]. The factory, later owned by Wood Distillation (England) Ltd., and subsequently by Shirley Aldred & Co. Ltd., distilled wood from 1913 to 1960, producing tens of thousands of tons of charcoal to numerous specifications as well as huge quantities of tar, acetate, wood-spirit, Esterul and other by-products. The enterprise has been invaluable both to the nation's economy and to those foresters in and around Dean who have been responsible for disposing of so-called 'offal' wood, difficult to market in any other way.

Today charcoal and stream-activated charcoal are manufactured. Part of the works has gone over to solvent recovery.

LATER CHARCOAL-BURNING IN WOODS AND KILNS

As previously noted, charcoal burning in the woods never died out. After the last charcoal furnace closed (Flaxley in 1802), and even after supplies were no longer needed by the more modern forges at Lydney and Lydbrook, there was always a market (despite the local near-monopoly of the 'steweries') for comparatively small quantities of differing grades for numerous purposes in London and elsewhere. Burning in the woods was done before, during and after the first World War by families (usually father and son) of which the more prominent were those of Faulkes, Hardwick, and Roberts. A comprehensive set of photographs (1909-12)) of the activities of the Hardwicks is available[36]. From these and other contemporary records it is clear that in general the method of making charcoal (little changed from time immemorial) was as follows.

A dome-shaped stack was made of billets of wood from small trees or branchwood of hardwoods (not conifers). It was covered with sods and earth, and a few inlet flues (mere holes) were left at ground level, with one outlet flue at the top. Skill was needed to build a stack which would char well and evenly without collapsing, and to start the fire down in the heart of it. After the fire had got under way, and the wood near the core had been burned and to some extent destroyed, the inlet flues were gradually closed. The remaining wood then received insufficient air for its complete combustion, but sufficient heat remained to force out the volatile matter as gases, leaving the carbon content behind. The charcoal burners lived a lonely life, for they could not leave their work by day or by night. The process took several days to complete and all the time the charcoal burner had to stay beside his stack, watching it every few hours for fear a sudden collapse of its earthen covering might admit too much air and so cause the whole stack to be destroyed, or to be laboriously rebuilt. Stopping the process was even more tricky than starting it off. Any sudden inrush of air before the stack was quite cold would cause the whole stack to catch fire. First the slow fire had to be extinguished by closing all the flues, which was done soon after a change in the colour of the smoke from white to blue showed the charcoal burner that the right stage had been reached. The stack was allowed to cool off for two or three days, being watched the while, whilst the burner filled in the time by building his next stack. Then it was opened, somewhat gingerly, and if it had cooled sufficiently, it was unpiled. As a rule, water was added to ensure safe cooling. Thereafter it was a question of separating the 'brunts' (partly burned ends of billets) from the charcoal, and grading and bagging the latter.

The last charcoal burner in Dean was A. E. Roberts who lived near Guns Mill between Mitcheldean and Flaxley. Two short accounts of his life and techniques are available[37]. He began his activities during the first World War, and in the 1939-45 war, despite the five-year blackout, he made charcoal for the first three years.

During the second World War batteries of charcoal-burning portable metal kilns (like a huge stove pipe with a removable lid and chimney) were worked in Dean, as elsewhere. This is an unskilled method whereby wood is thrown into a large 'drum'. A. E. Roberts was put in charge of these charcoal 'cookers'. He temporarily returned to normal burning for a few years after the war. Since his death, Dean has not witnessed a sight which had hitherto been characteristic of her woods for at least two millenia. Now only the Speech House Road Works continues to produce charcoal.

APPENDIX A Note on the early distillation of wood[38].

The process of distillation of wood is an old one and originated on the Continent, in a primitive form, perhaps in Sweden or in France, because wood or Stockholm tar, one of the products, has long been an article of commerce. It was towards the end of the 18th century that the industry came under the observation of Richard Watson D.D., F.R.S., (1737-1816) Bishop of Llandaff, well-known apart from other activities, for his chemical researches[39]. His lordship says about the matter[40]:

> About 1786, application was made to me by government, to know whether I could give any advice relative to the improvement of the strength of gunpowder; and I suggested to them the making charcoal by distilling wood in close vessels. The suggestion was put in execution at Hythe in 1787, and the improvement has exceeded my utmost expectation. Major-General Congreve delivered to me a paper containing an account of the experiments which have been made with cylinder powder (so called from the wood being distilled in iron cylinders), in all of which its superiority over every other species of powder was sufficiently established.

Another account of what took place, given by Congreve, Comptroller of the Royal Powder Mills, Waltham Abbey[41], says the form of retort was first recommended by Dr. George Fordyce, and the cost of the 'cylinder charcoal' in March 1801 was 22s. 0d. a cwt. As well as the plants at Hythe and Waltham Abbey, others were established at North Chapel near Fernhurst, and at Faversham[42]. For North Chapel we have a detailed description of the plant and process[43]:

> The 'cylinder room' was 60ft long. There were three sets of cast-iron cylinders or retorts 2ft dia. by 6ft long, three to each set, placed in a brickwork setting along the centre of the 'room'. Each cylinder was closed by an 'iron stop' 18in long, filled with sand, besides which a 'sand door' was made to project obliquely from the front of the cylinder. At the back were copper pipes 7ft long connecting the cylinders to half-hogshead barrels to draw off 'the stream or liquid which flows in large quantities into the tar barrels during the process of charring'. The cylinders were heated by coal fires. The charge consisted of 5 cwt of cord-wood 18in long, to each set. The fires were lit at 6.30a.m. and kept up for 8 hours, about 8 bushels of coal being required for each set. The retorts were drawn on the following morning into sheet-iron coolers, shut up close to prevent the charcoal smouldering. The output was 3 to 4 cwt of charcoal (i.e. 60 to 80% of the charge) and about 100 gallons of liquid, i.e. from 15 cwts in 3 sets of 3 cylinders. The tar acid they daily draw from the barrels, put into a large tub and preserve it in hogsheads; but at present it cannot be used because a patent is out for the monopoly of the sale. It is worth 6d. a gallon. The charcoal goes to Waltham and Faversham.

The above description tallies very closely with the sketches given of the plant used at Faversham in 1798, by John Ticking, "Master Worker at the Royal Mills"[44]. According to J. Morewood Dowsett[45], the wood was cut into 3ft lengths, which were packed in iron cylindrical cases known as 'slips'.

> An opening into the rear of the slip, corresponding with another in the retort, permitted inflammable gases, generated by the charring, to be carried into the furnace, where they were consumed, while other pipes removed the tar and pyroligneous acid. When the blue colour of the gas flame, indicating carbonic oxide, showed the wood to be sufficiently charred, the 'slip' was withdrawn and placed in a cooler, provided with a close-fitting lid, for several hours. When cool, the charcoal was stored for about a fortnight before grinding, to avoid the danger of spontaneous combustion.
>
> Properly made gunpowder-charcoal was jet-black in hue; when broken, it showed a clear velvety surface. The grinding mill generally resembled a huge coffee mill, from which the pulverized charcoal passed into a 'reel' or cylindrical frame, covered with copper wire cloth, of about 32 meshes to an inch. The material fine enough to pass through this fell into a bin, while the coarse particles were collected for regrinding.

Pyroligneous acid resulted as a by-product in these government gunpowder manufactories. In regard to the acid at Waltham Abbey, on 8 November 1791 John Finlay, secretary to the Duke of Richmond, sent Charles Macintosh in Scotland a sample for investigation[46]:

> I have got some of the acid of wood (pyroligneous acid), and shall send you a couple of bottles that you may see its strength. I shall at the same time send you a bottle of the same acid which has been once distilled from the coarse kind, and shall beg of you to let me know what you would give a gallon for each kind, or what they would be sold for at Glasgow. I must endeavour to dispose of it for the Board of Ordnance to the best advantage I can.

Macintosh eventually took up the manufacture of his own acid, producing it at a cost of about 4d. a gallon[47]. At the government's plants the by-products crude alcohol, acetic acid and tar, were a nuisance, e.g. Parkes says[48]: 'The tar has been a great burden on the hands of those who have been largely concerned in this trade'.

A record of 1814, shows that wood distillation was well known in Scotland[49]:

> Pyroligneous, or Wood Acid, is produced by the distillation of wood in a cast-iron retort. The gas passing through a worm contained in a refrigeratory, is condensed in the same manner, as common spirits. The wood is left in a charged state in the retort, and may be used for and purpose to which charcoal is applicable. This acid is a powerful solvent of iron; and being only 4d. per gallon, is now almost universally used for making acetate of iron, or iron liquor; and acetate of alumine, a red liquor, for calico-printers and dyers. There are seven works for making pyroligneous acid in Scotland; – four at Camlachie, Tradestown, Brownfield, and Lanark, in Lanarkshire; one near Torryburn in Fifeshire; and two at Milburn and Cordale in Dumbartonshire. One ton of wood affords about 90 gallons of acid, and 10 gallons of tar. The latter comes over with the acid; but being heavier, readily subsides, and is separated.

The distillery at Millburn in the Vale of Leven was established by Turnbull and Company towards the end of the 18th century. It employed about seven hands, and consumed daily a ton of small timber, chiefly oak, 'from which the liquor, a kind of coarse vinegar', was extracted[50]:

> The process is beautifully simple. A number of iron ovens, or retorts, are placed in a row, and filled with the timber cut into small pieces. A fire of coals or charcoal is kindled in a furnace attached to each, and by its heat, forces the acid to fly off in the form of vapour. This vapour is conducted by a small tube proceeding from each retort into a refrigeratory

> or long metal pipe, on which a jet of cold water from above is continually falling. Here the acid is condensed, and runs from the end of the pipe in a considerable stream of reddish brown colour. Besides the liquor thus procured, which is employed in making colours for the calico printers, there is a considerable quantity of tar and charcoal produced during the process, the value of which is esteemed equal to the expense of fuel.

Turnbulls subsequently established works in other parts of Scotland, the principal being that at Camlachie, Glasgow, which was opened in 1808.

The foregoing information was later supplemented[51]:

> The spray of all trees not resinous may be used in the distillation of pyroligneous acid. This acid is much used in calico-printing works; and, according to Monteith, sold in 1819, in the neighbourhood of Glasgow, at from £1. 2s. to £1. 10s. per ton. The distillation is carried on in a cast or malleable iron boiler which should be from 5 to 7 feet long, 3 feet wide, and say 4 feet deep from the top of the arch, built with fire-brick. The wood is split or round, not more than three inches square in thickness, and of any length, so as to go into the boiler at the door. When full, the boiler door (b) is properly secured, to keep in the steam; then the fire is put to it in the furnace below, and the liquid comes off in the pipe above (d), which is condensed in a worm, in a stand (e) filled with cold water, by a spout (f), and empties itself, first in a gutter below (g), and from that is let into barrels, or any other vessel; and thus the liquid is prepared.
>
> One English ton weight of any wood, or refuse of oak, will make upwards of eighty gallons of the liquid. There is also a quantity of tar extracted, which may be useful in ship-building (Gard. Mag. vol. ii).

The advent of peace in 1815 doubtless rendered the isolated plants superfluous as regards charcoal for gunpowder and at that time the byproducts would scarcely command any market.

REFERENCES

1. C. E. Hart, O.U.P. (1966). For contemporary information regarding charcoal-burning, see:

   M. Schofield, 'Chemistry in The Forest of Dean', The Industrial Chemist, (Feb. 1940), pp. 65; 69.
   J. Morewood Dowsett, 'Charcoal Burning' Geographical Magazine, (Jan. 1946) pp. 387-392.
   H. L. Edlin, "Forestry and Woodland Life", (1947), p. 138.
   H. L. Edlin, "Woodland Crafts in Britain" (1949), pp. 159-165
   K. S. Woods, "Rural Crafts in England" (1949), pp. 138-140.
   L. Reynolds, Forestry Commission Forest Record No. 19 (Revised 1961), 'The Manufacture of Wood Charcoal in Great Britain.
   A. Pasmore, 'Surviving Evidence of the New Forest Charcoal Burning Industry', Jnl. of Industrial Archaeology, I (1) (May 1964), pp. 27-35½

2. Harts, "Royal Forest", 43.
3. P.R.O. E. 32/29.
4. P.R.O. C. 66, 21 Hen. III, m. 11.
5. P.R.O. E. 32/30.
6. P.R.O. S.C. 6/850/19
7. P.R.O. E. 146/1/26
8. P.R.O. E. 146/1/25
9. P.R.O. E. 32/29, 30, 332, 334.
10. P.R.O. E. 32/332.
11. P.R.O. E. 32/332, quoted in Hart, "Royal Forest", p. 44, 45.
12. P.R.O. E. 32/334, quoted in Hart, "Royal Forest", p. 44, 46.
13. P.R.O. E. 101/140/17, 18.
14. P.R.O. E. 101/140/19.
15. P.R.O. E. 101/140/20.
16. P.R.O. S.C. 6/858/15.
17. This is important as explaining 'Speech House', a derived designation.
18. P.R.O. E. 101/141/3.

19. Spring – the young growth from germination (natural regeneration from self-sown seed, or from root suckers), and sometimes that from stools after coppicing.

20. Hart, "Royal Forest" (1966), Chapters 5, 6, 7.

21. Ibid., p. 148.

22. Ibid., p. 148.

23. Ibid., p. 150.

24. Ibid., p. 168.

25. Ibid., p. 175.

26. "Sylva", Ed. 1776, p. 568.

27. Hart, "Royal Forest", p. 181.

28. T. S. Ashton, "Iron & Steel in the Industrial Revolution", 3rd Edn. (1963) p. 16, says that in 1715 charcoal sold for 28s. 6d. per dozen sacks, and in 1765 for 40s.

29. G.R.O. D. 421/T. 79.

30. Pyroligneous acid contains acetic and formic acid (and a small quantity of propionic and butyric acid), methyl alcohol, methyl acetate and acetone (allyl alcohol, methyl ethyl ketone – in very small quantities – and only traces of ethyl alcohol). In addition there are substances which are called 'disolved tar' – because when the acid is distilled these remain in the residue and insoluble tar. The water content is about 80-85%.

31. John Bellows, "A Week's Holiday in the Forest of Dean", 1880, p. 61.

32. The history of these steweries is expected to form part of a chapter in a projected book, "The Industrial Archaeology of Dean".

33. Ibid., p. 14, 24.

34. M. Schofield, op. cit.

35. In preparation for a chapter in a projected book – "The Industrial Archaeology of Dean"

36. Preserved by the Forestry Commission; the present writer has a copy of the set of photographs.

37. 'Everybody's Magazine (1940), and Brian Waters, "The Forest of Dean" (1951) pp. 136-140.

38. Part of this note may form a section of a chapter in a projected book – "The Industrial Archaeology of Dean".

39. H. W. Dickinson and E. Straker, 'Charcoal and Pyroligneous Acid Making in Sussex', Trans. Newcomen Society, vol. XVIII. 1937-38, pp. 61-66.

40. Anecdotes of the life of Richard Watson, Bishop of Llandaff. 2nd ed. 1818, vol. I. pp. 240-2

41. A Statement of facts relative to the savings which have arisen from manufacturing gunpowder at the Royal Powder Mills; and of the improvements which have been made in its strength and durability since the year 1783: 1811, p. 26.

42. Dickinson and Straker, op. cit., pp. 63, 65.

43. Arthur Young, "Agriculture of Sussex", 2nd ed. 1808, p. 432. The account does not appear in the 1st ed., 1793.

44. Dickinson and Straker, op. cit., p. 64. The two figures appeared in 1909 in 'The Rise and Progress of the British Explosives Industry", pp. 20, 21.

45. 'Charcoal Burning', Geographical Magazine, vol. VXIII (9), Jan. 1946, pp. 387-392.

46. A. and N. Clow, "The Chemical Revolution", 1952, p. 249.

47. Ibid.

48. "Chemical Essays", 1815, vol. II. p. 272.

49. Sir John Sinclair, "The General Report of the Agricultural State and Political Circumstances of Scotland", App. Vol. III. 1814, p. 308.

50. A. and N. Clow, op. cit., p. 250.

51. J. C. London, An Encyclopaedia of Agriculture, 1831, p. 657.

The Forest railways and their industrial associations

H. W. Paar

Horse-worked cast-iron tramroads were proposed for the Forest in the period 1800 to 1809. The fact that the land was owned by the Crown, and that extensive public lines were envisaged, led to opposition from Forest officials, and it was not until 1809 that two lines were authorized by Parliament, the Severn & Wye Railway from Lydney to Lydbrook, with branches, and the Bullo Pill Railway from the small port of that name to Churchway. In 1810 the Monmouth Railway, from points in the Forest east of Coleford, to Monmouth, was authorized (see Fig. 1).

Almost the whole raison d'etre of these lines was to provide an improved means of hauling coal to the rivers Wye and Severn. Benjamin Outram, in reporting to the promotors of the original Severn & Wye scheme in 1801, mentioned only two blast furnaces, at Cinderford and Parkend. He did not notice those at Bishopswood, Whitecliff, and Redbrook; possibly they were too far from the centre of the Forest, but it is more likely that they were out of use or, as Gilpin the traveller had described Bishopswood ironworks some thirty years before, "objects of little importance in themselves".

Little or no mention is made of ironworks in the various papers relating to the three tramroad concerns until the time came for the re-establishment of the Cinderford and Parkend furnaces in the 1820's, but an exception is Bishopswood; here it does appear that the ironworks was originally an important factor in inducing the Severn & Wye Company to secure powers in 1810 to extend its line northward from Lydbrook; yet in August the directors advised against building it. No doubt the furnace had ceased to function, for in 1814 bar iron was being taken thence from Lydney, suggesting that the forge alone was at work, and in 1816 the clerk seized by distress "finers metal" from the Bishops Wood Company.

It is indicative of the tramroad companies' pre-occupation with coal that the furnaces had largely to fend for themselves in bringing in the iron ore; at both Parkend and Cinderford the iron companies built tramroads privately for the purpose, and also for bringing coal from their own pits, and these continued in operation after railways were introduced, until the furnaces were closed. The public tramroads did provide one major service, however, in the rather surprising east-west ore traffic which developed via Churchway; this was due to the different characteristics of the ores obtained in the Oakwood and Cinderford districts, which produced good iron when the two were mixed in the charge.

Lest it be thought that the tramroads exercised a complete transport monopoly in the Forest, it may be mentioned that in 1847 it was stated that Cinderford ironworks had sent no traffic to Lydbrook for the last seven years, it being cheaper to forward some 1,200-1,500 tons annually (probably bar iron) from Churchway by road.

Before leaving the old tramroads, with their plodding animals hauling crude wagons with flangeless wheels, it is significant that the first great quantities of cast-iron tram-plates required for the Severn & Wye lines were imported from South Wales. Continuous replacement of plates broken by overloaded wagons and poor trackwork was necessary, but it was not until 1821 that a local firm (Pidcocks of Lydney*) secured part of the trade. A year later it was decided that the Blaenavon iron was too soft, and in 1823, it was agreed to purchase in future rails made of "foundry iron"; Samuel Hewlett of Ayleford Foundry offered these at £4 per ton, and this "sales gimmick" of free delivery where needed about the system enabled him to keep nearly all the trade for a decade. Information on the original track-work of the Bullo Pill line is lacking, but Hewlett supplied plates in the period 1827-1848.

The Bullo Pill line was replaced by a locomotive railway to Brunel's broad gauge of 7ft $0\frac{1}{4}$in. in 1854, while the Severn & Wye Railway was reconstructed as a locomotive line, and extended, in the period 1869-1875. Thus brought up to date, the railways were better able to serve the iron industry; the east-west traffic continued, Welsh coke was brought up from Lydney to Parkend furnace, while as early as 1857 the Forest of Dean branch collected as many as 30 trucks of pig iron each morning from Cinderford and Soudley furnaces.

Meanwhile, however, another economic factor was developing, which was to add to the Forest's railway map without bringing much in the way of traffic to it. By about 1850, upwards of a hundred blast furnaces were at work in South Wales, and there was a great incentive to provide a railway from the Forest to the heads of the Welsh valleys, to supply the furnaces with ore. This was the intention of the Coleford, Monmouth, Usk & Pontypool Railway, promoted largely by Crawshay Bailey and authorized in 1853. Part of the plan was, to rebuild the old Monmouth tramroad as a railway, but after reaching a point east of the Wye near Monmouth, funds ran out, and it is truly pathetic to read of the vain efforts to take the line further east. Later the GWR, disguised as the Coleford Railway Company, came forward to complete the line, and

*It is possible that the firm had moved north by this time.

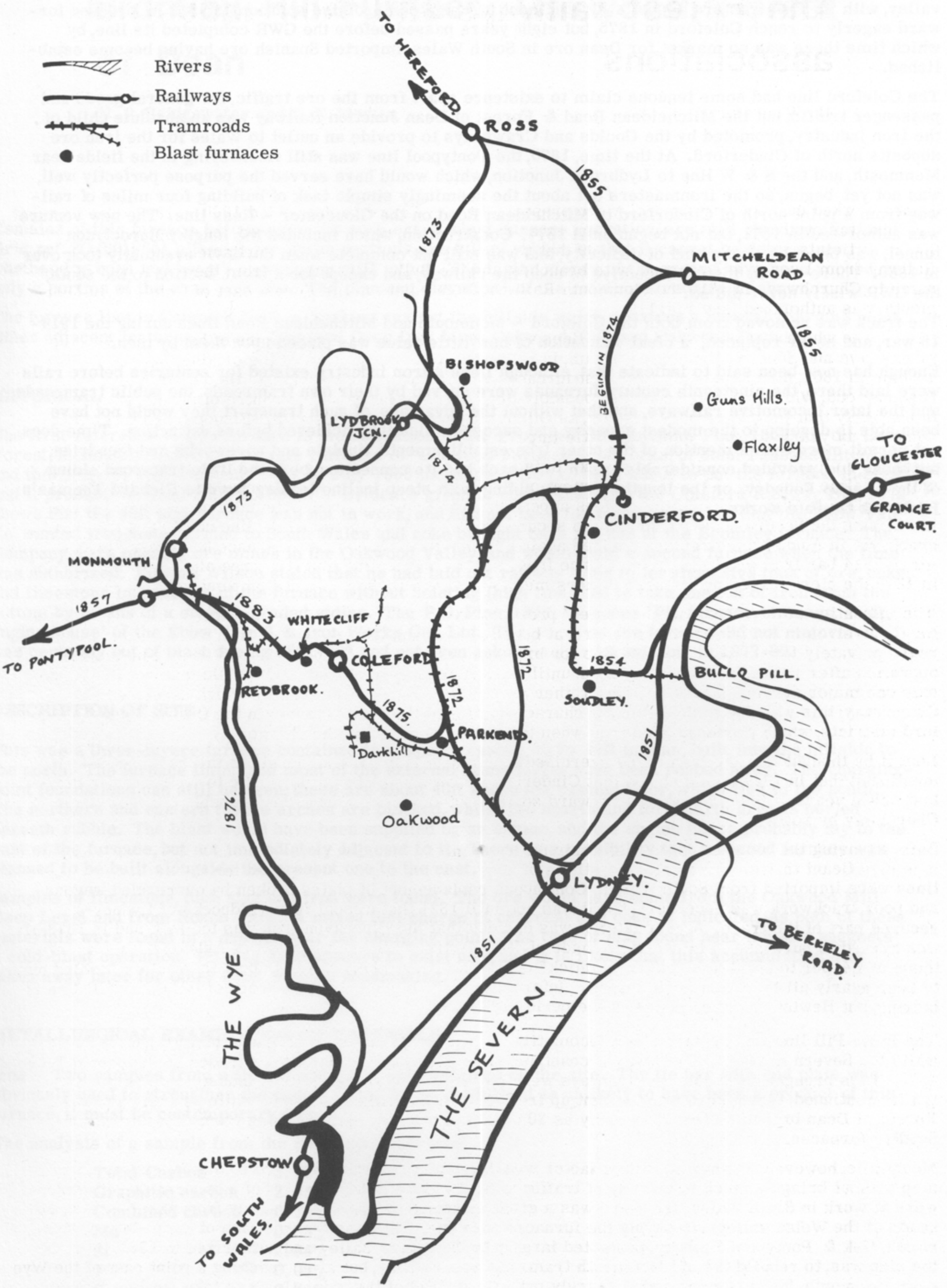

Fig. 1 – Forest railways

was soon locked in Parliamentary conflict with the S & W R, because both wanted to serve the Oakwood valley, with its rich iron ore deposits. Parliament forced a compromise solution, the S & W pressed forward eagerly to reach Coleford in 1875, but eight years passed before the GWR completed its line, by which time there was no market for Dean ore in South Wales, imported Spanish ore having become established.

The Coleford line had some tenuous claim to existence apart from the ore traffic, for general goods and passenger traffic, but the Mitcheldean Road & Forest of Dean Junction Railway was an absolute child of the iron industry, promoted by the Goolds and Crawshays to provide an outlet to Wales for the iron ore deposits north of Cinderford. At the time, 1870, the Pontypool line was still floundering in the fields near Monmouth, and the S & W line to Lydbrook Junction, which would have served the purpose perfectly well, was not yet begun, so the ironmasters set about the seemingly simple task of building four miles of railway from a point north of Cinderford to Mitcheldean Road on the Gloucester – Ross line. The new venture was authorized in 1871, but not begun until 1874. Construction, which included the lengthy Euroclydon tunnel, was beset by every kind of difficulty, and was still not complete when the GWR eventually took over in 1880. There was by then no incentive to open the railway, and except for a short section to the south, the GWR wisely never did so.

The track was removed from both the Coleford – Monmouth and Mitcheldean Road lines during the 1914-18 war, and never replaced, a clear indication of how little value was placed upon them by then.

Enough has now been said to indicate that, although Dean's iron industry existed for centuries before rails were laid there, the nineteenth century furnaces were served by their own tramroads, the public tramroads, and the later locomotive railways, and that without the advantage of such transport they would not have been able to develop to the modest capacity and success which they achieved before extinction. Time does not permit more than a mention of the other iron establishments, tinplate and wireworks and foundries, but these, too, provided considerable traffic, and each had its connection, be it the little tramroad siding of the Cannop Foundry, or the lengthy railway siding with steep incline leading down to Richard Thomas's Lydbrook tinplate works.

Bromley Hill Furnace, Oakwood, Forest of Dean

N. P. Bridgewater and G. R. Morton

Remains of this furnace, belonging to the coke era of blast-furnace operation, are still standing (National Grid ref. SO/601064), although the lower portions are full of rubble so that it cannot be determined whether the bosh and hearth system are still intact. The facing stones of the casing have been robbed, and only a portion of the shaft remains. The plan and elevation[1] of the existing structure is shown in Fig. 1.

The furnace lies in Oakwood Bottom, backing against the hillside which provides a natural charging point. Other adjacent features, include Oakwood Deep Iron Mine, Oakwood Mill, and Oakwood Foundry.

HISTORICAL

The first reference to this furnace is the indication in the Proposed Development Plan, 1852, for the Dean Forest, Monmouth Union and private railways of 'Oakwood Furnace, Ironworks, of John Passand Litchfield and the Bromley Hill Company'. By 10 July 1856 the Ebbw Vale Co. were about to put the furnace in blast[3], and it probably worked until c. 1865-70. Evidence given in connection with the Coleford Railway Bill 1872 shows that the 40ft high furnace was not in work, and had not been for many years, but that the Ebbw Vale Co. wanted ironstone carried to South Wales and coke brought back for use at the Bromley furnace. The Company were opening ore mines in the Oakwood Valley, and would build a second furnace when the time was authorized. Edward Wilson stated that he had laid out railway lines to let about five tons of ore, coke, and limestone into the top of the furnace without hoisting (high line) and to take one ton of iron from the bottom by means of a steeply-graded siding. The P.D. Plan, 1872, indicates 'Pit, furnace, chimney, shaft, engine house' of the Ebbw Vale S. & Iron Works Co., Ltd. The plans for the furnace did not mature. It was certainly out of blast during 1871-80[4] and not even acknowledged as existing in 1877-80.

DESCRIPTION OF SITE

This was a three-tuyere furnace contained in a square casing, 40 by 34ft in plan, built into the hillside to the north. The furnace lining and most of the external stone facing have been robbed away. The charging-point foundations can still be seen; these are about 40ft above the casting floor, which lies to the south. The northern and eastern tuyere arches are blocked, whilst the hearth and forehearth area is buried beneath rubble. The blast would have been supplied by an engine, and the engine house probably lay to the east of the furnace, but not immediately adjacent to it. There is a possibility that a second furnace was planned to be built alongside the present one to the east.

Samples of limestone, fuel, slag and iron were found. The ore would have come from the Oakwood Mill Deep Level and from Noxon Park. A mixed fuel charge of charcoal and coke is indicated, as both of these materials were found in a deposit near the charging point. The type of slag found near the site suggests a cold-blast operation. No slag heap appears to exist now, and it is likely that this accumulation was taken away later for other uses, such as roadmaking.

METALLURGICAL EXAMINATION OF MATERIALS

Iron Two samples from a tie bar and plate were obtained on the site. The tie bar with end plate was obviously used to strengthen the casing of the furnace; whilst it is unlikely to have been a product of this furnace, it must be contemporary with it.

The analysis of a sample from the cast-iron plate was:

Total Carbon	3.23%
Graphitic carbon	2.93%
Combined carbon	0.30%
Mn	0.23%
Si	2.34%
P	0.08%
S	0.24%

Castings of this nature would be made with the metal as tapped from the blast furnace, and the analysis also represents that of pig iron of the period. It is typical of a cold-blast iron of the early coke era, when it was not usual to balance the sulphur with manganese (Fig. 2). The sulphur is somewhat high, which suggests that the casting was made from a furnace using coke only, which supports the previous view that the casting was not made at Oakwood.

Wrought Iron Bolt This was associated with the tie bar and is likely to be contemporary with the period: the analysis was:

C	<0.005%	Si	0.14%
P	0.041%	Mn	0.14%
S	0.033%	Ni	<0.04%
Cu	<0.04%	Cr	<0.02%

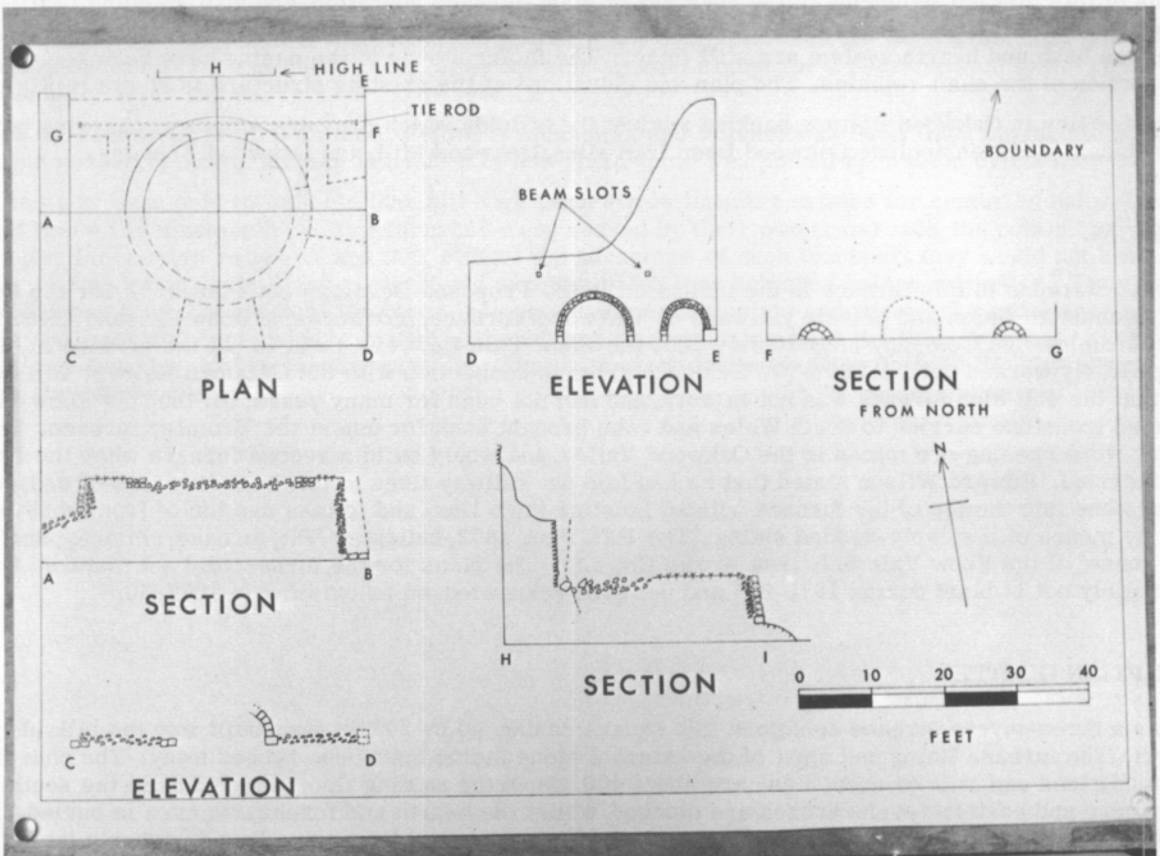

Fig. 1 – Bromley Hill Furnace

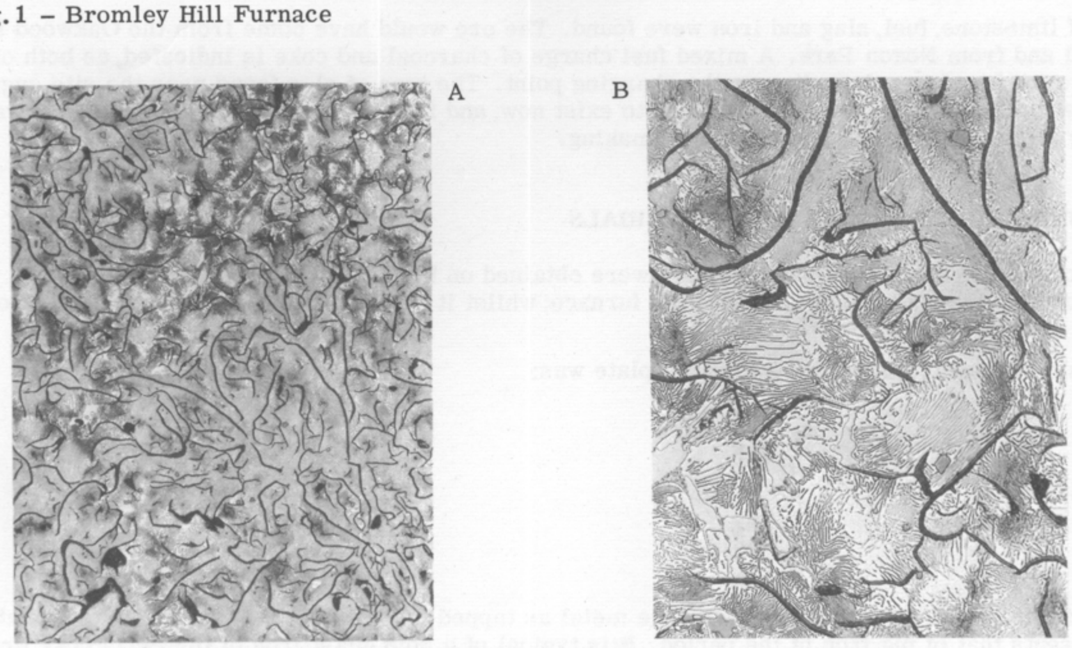

Fig. 2(A) Microsection of cast iron plate × 100 etched 4% Picral
(B) " " " " " × 400 " 4% "

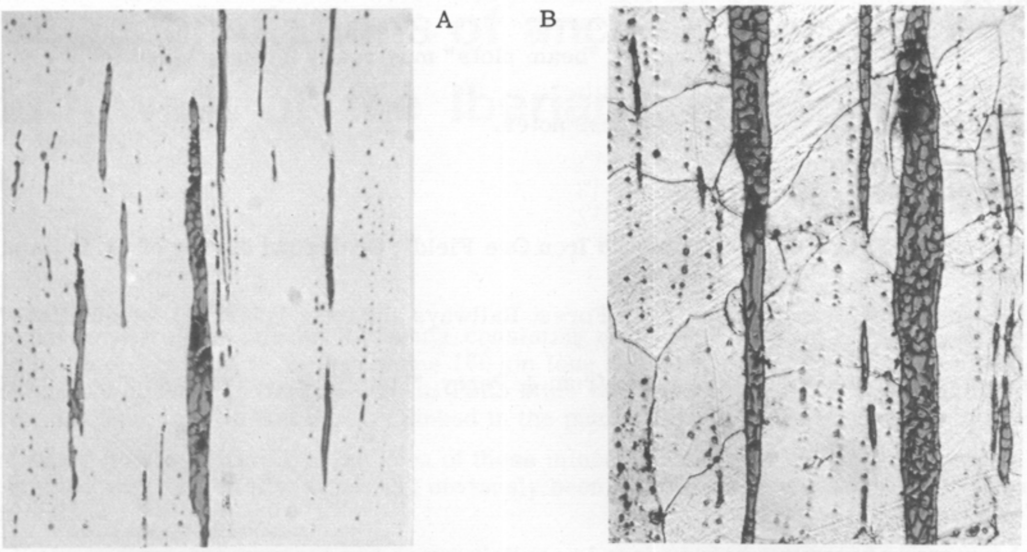

Fig. 3(A) Microsection of wrought iron bolt × 170 unetched
(B) " " " " × 170 etched 5% Nital

From the analysis and the microsection (Fig. 3) it can be seen that the iron is a very good wrought iron, which was typical of that produced in the area, and in particular typical of what would be the "tough" iron made in the charcoal era from Forest ores.

DOLOMITIC ROCK AND SLAG

It is necessary to consider these two materials together for a complete appreciation of the furnace reactions.

Large heaps of red Dolomitic rock were to be seen south of the furnace. This material consisted largely of magnesian limestone, but was interlaced with veins of iron ore. There is not much doubt that the source of this rock was Noxon Park, where samples can still be obtained from surface debris. It is known that both old surface workings and deeper shafts were worked there[5]. This rock, however, cannot be regarded as the only source of ore for the furnace; probably a mixed charge was used with the ore from the Crease Limestone to be found in the Oakwood Mill Deep Mine, and it is known that ores from different parts of the Forest were sometimes mixed[6]. The analysis of these materials were as follows:

	Ore[7]	Red Rock	Slag
SiO_2	2.14	14.50%	39.00%
Fe_2O_3	89.80	5.57%	–
FeO		–	1.80%
Al_2O_3	0.98	1.33%	16.20%
MnO	0.04	0.20%	0.30%
CaO	0.51	24.60%	25.56%
MgO	0.40	16.42%	14.04%
P_2O_5	0.13	0.82%	0.46%
CaS	Trace	–	2.88%
Loss on Ignition	7.05	36.65(CO_2)	–
Total	101.05	100.09%	100.24%
S		Less than 0.01%	1.28%
P		0.36%	0.20%
Fe	62.86	3.90%	1.40%

From the above it will be seen that the MgO content of the slag is much higher than would be expected from the ore. This suggests that the red rock was mainly used as a flux, as the MgO would considerably increase the fluidity of the slag and make sulphur removal easier and more efficient.

REFERENCES

1. Mr W. K. V. Gale has suggested that the "beam slots" may really be weep holed for the drainage of surplus moisture.

2. We are indebted to Dr C. E. Hart for these notes.

3. Severn and Wye minute book.

4. Insole & c. p. 88.

5. "Geology of the Forest of Dean Coal and Iron Ore Field", Geological Survey of Gt. Britain, H.M.S.O., 1942.

6. H.M.G. Annual Conference Paper "The Forest Railways and their Industrial Associations" by H. W. Paar (this issue).

7. No ore was found; the analysis is taken from J. Percy, "Metallurgy — Iron and Steel", 1864, p. 207.

The accumulations of ancient slag in the south-west of the Iberian Peninsula

John C. Allan

In the south-western corner of the Iberian Peninsula, consisting of the western part of the Spanish province of Huelva and the south of Portugal in an area some 160 km long and 30km wide, are found a series of pyritic masses. The best known of these is the famous Rio Tinto Mine which, with numerous other similar occurrences in the area, has been for the last century linked in the public mind with the production of copper.

The discovery of much Roman material in the area of these mines and this association with copper, lead to the assumption that the earlier activity, which had obviously been very great, had been directed towards the winning of this metal.

Associated with these various occurrences are accumulations of ancient slag estimated to amount to not less than 25,000,000 tons, of which by far the largest tonnages are found at Rio Tinto. Pyritic ores of this nature are subject to atmospheric influences which in time produce profound modifications in the parts of the orebodies affected by them. In a copper orebody the copper is oxidized, dissolved, and reprecipitated at greater depth to form a zone of enrichment. With the techniques available to them the Romans required a grade of about 8%Cu in order to operate, and it was to ores of this content that they directed their attention throughout the field. Datable evidence suggests that Roman interest in copper mining in the area began in the last half of the 1st century B.C., and continued for some 200 years; while operations continued on a much reduced scale for a further 300 years, it is clear that had the 25,000,000 tons been the result of smelting for copper, at the grade of ore indicated above, the resultant copper would have been far in excess of the market requirements of the epoch. Even as late as the 19th century, the total world production of copper for the whole of the first decade was but 91,000 tons.

It therefore seems reasonable to doubt whether the vast bulk of the accumulated slag is indeed the result of smelting for copper. While it is not possible to distinguish it by eye from the bulk of the slag, sampling and assay has demonstrated the existence of only about 1,000,000 tons of ancient copper slag at Rio Tinto, much of which has been resmelted, so that this tonnage now averages between 0.3 and over 1% Cu, 2 to 15g of silver per 1,000kg, and a trace of gold.

The surface oxidation and the leaching processes referred to above, which in turn lead to a zone of copper-enriched pyrite, leave behind them in the capping of the mass a mantle of ironstone known as "gossan" of varying thickness which at Rio Tinto can be up to 100 feet thick, carrying only a trace of copper. Typical analyses of the gossan are:

Cu	Tr	Tr to 0.04%
Fe	57.75%	55%
As	1%	1.04%
Pb	nil	2% as $PbSO_4$
Sb	0.05%	n.d.
Si	4.64%	n.d.
Au	3 g/1000kg	3.2 g/1000kg
Ag	48 " "	49 " " "

The silver content of the underlying pyrite is remarkably constant, and shows no relation to the copper content even in the case of the enriched ore, as the following characteristic analyses of pyritic ores show:

Mineral	% Cu	Ag(g/1000kg)	Au(g/1000kg)
Underlying pyrite	0.13	30.0	0.4
	0.39	41.4	0.35
	0.56	52.6	0.65
	0.60	35.5	0.4
	1.11	36.6	0.55
	1.57	41.1	0.5
Overlying secondary ore	16.5	62.0	0.8
Modern flotation concentrates	13.0	51.0	0.4

As the higher copper contents of the secondary ore are derived from the original overlying low-copper pyrite comparable to the first examples, it will be seen that there is an important amount of silver to be accounted for which is missing from the secondary enriched zone.

At the turn of the present century, the extremely low copper values in the bulk of the slag began to call attention to the fact that slags of this grade could not have been produced from the high-grade copper ore that the successful application of the Roman smelting techniques demanded.

Cumulative study of the slag dumps at Rio Tinto established that over 15,000,000 tons were obviously derived from a raw material distinct from that used to produce the 1,000,000 tons of copper slag mentioned above. This tonnage averages between 0.03% and 0.2% Cu, 0.3 – 0.8 g Au, and 30 – 200 g Ag per 1,000 kg. Some of the very ancient slags contain much more silver. This copper value is so low that it could only have been the result of smelting an ore initially very low in this metal. Even with modern smelting, due to entrained values, it is not possible to produce slags with less than 0.35 – 0.4% copper.

Although the slag heaps may contain as an exception some slag from iron smelting, for with heaps of this size anything is possible, slag from iron smelting had made no appreciable contribution to the whole. There is no record of any modern exploitation of the gossan for iron on account of the arsenic content[1].

While there is historical evidence as to the Roman production of copper from the zone of secondary enrichment underlying up to 100ft of ironstone gossan, the same cannot be said for mining that might have taken place at higher levels in the capping of these lodes, and it is reasonable to assume that primitive mining started on ores that were distinguishable as "grass roots". Unfortunately to-day much of the surface evidence that might have been available, when modern large-scale mining for copper and its associated iron pyrites started, has been dispersed owing to the removal of very large tonnages of overburden to permit the winning of this ore by opencast, so that any evidence of earlier surface work has been destroyed. However, a number of writers of the middle of the last century refer to large depressions along the line of the lodes, and it is considered that these represent what was left of the type of workings from which the bulk of these large tonnages of silver-bearing slag was produced.

This material was the product of the same oxidation processes that released the copper for transportation and deposition in the zone of secondary enrichment below the gossan. In other words, the silver originally present in the primary lean sulphides which unlike the copper was not transported and reprecipitated in the underlying enriched pyrite.

It therefore becomes necessary to devise a viable theory as to how these large tonnages of silver-bearing slag came to be produced.

One unquestionable source of this silver slag has been disclosed by modern mining. At the base of the gossan over the North Lode, there occurs a narrow band from a few inches to a few feet thick which has been classified as jarositic earth[2]. Finds of Roman mining material establish that this band was worked by them, and Roman debris in the upper layers of some of the slag dumps complete the evidence that this material was mined and smelted by them. Little was left by the early operators so that only some 30,000 tons remained to be recovered by modern operations.

Unfortunately the only record that has survived of this activity is five samples of jarositic earth found in the Mine Museum which on assay yielded the following results:

Colour	Black	Black	Grey	Grey Green	Yellow	Nearly White	An Analysis 1911
Cu, %	Nil	0.06	Nil	Nil	0.02	Nil	0.07
SiO_2, %	58.80	36.43	91.07	53.96	63.95	89.77	22.05
Fe, %	6.01	11.30	2.18	7.05	14.50	0.39	8.79
Pb, %	0.06	0.11	Nil	1.09	2.66	0.08	34.37
As, %	0.02	36.28	0.11	2.03	0.77	0.08	0.66
S, %	N.D.	2.28	N.D.	1.24	N.D.	0.16	8.92
Sb, %	N.D.	4.44	0.07	2.99	N.D.	N.D.	1.41
Bi, %	N.D.	1.01	N.D.	0.08	N.D.	N.D.	0.16
Ag, g/1000kg	2804	3110	595	616	166	2296	1440
Au, g/1000kg	1.5	62	2	2	31	20	40

Note the relatively high silica content and no low iron. The assays do not bring it out, but the silver is there as cerargyrite and argento-jarosite, the amounts of which minerals are present in such small quantities that it is only for convenience one is justified in using the term jarositic. However, about 50% of the silver in the gossan is found to be insoluble in cyanide which makes it reasonable to suppose that it is there as argento-jarosite, and that jarosite has been a major factor in anchoring the silver in the capping of the mass.

Unless one visualises the arrival on the scene of prospectors with sufficient mining and metallurgical experience of similar occurrences elsewhere, it is reasonable to assume that at grass roots there existed pockets of material similar to the grey and light grey material whose assays are shown above. At surface there would be a tendency for there to be even less iron, so that simple heating of the material would produce beads of silver.

The Elder Pliny in his "Natural History", without specifically mentioning Rio Tinto, described the location and appearance of silver ore in such terms as to leave no doubt that he was describing the Roman operations on this band. This is of particular interest because he was obviously aware of earlier silver workings, since he comments that in "ancient days" the silver workings stopped on reaching a certain horizon. This comment is even more significant because he goes on to say that a recent discovery of copper below the old silver workings had created much enthusiasm.

It has been estimated that the maximum possible tonnage of ore that could have been won from the narrow band underlying the gossan was of the order of 1,000,000 tons, so that it could not possibly have been the source of the whole tonnage of low-copper slag. However, it is not possible to distinguish either by eye or assay between slag from dumps in which the discovery of Roman material establishes their date and dumps in which this material is absent. It therefore seems reasonable to suppose that the earlier slag was made from comparable material. As has been explained above, however, a combination of extensive ancient mining and massive modern overburden removal has so modified the original capping of the lodes that no positive evidence remains as to the original situation encountered by the first prospectors. From other pyritic masses in other parts of the world jarosite is known to be an oxidation product left in the capping. Variations in the composition of the pyrite and differences in the climatic conditions, however, have produced variable results. In Cyprus, massive jarosite amounting to about one-third of the underlying pyrite shows the relative importance that this phenomenon can assume. In this field, however, the jarosite rarely carries precious metals owing to a difference in association of the precious metals in the original pyrite.

At the Matagente Mine in Peru, large pockets of argentiferous jarositic material up to 40m deep occur, the richest of which have long since been worked out by the Indians. Jarosite also occurs at the United Verde Mine in the United States and at the Mount Lyall Mine in Australia, but there is no regular pattern.

Nevertheless, these examples serve to show that material comparable to that won from the narrow band at the base of the gossan can occur in important amounts at or near the surface of the cappings of these pyritic masses. The silver would be retained either as cerargyrite or argento-jarosite, and the older deposits near the surface would be high in silica and low in iron and lead, the percentage of which would increase with depth. Highly siliceous friable silver-bearing material at or near the surface would favour the primitive prospector, and it can hardly be a coincidence that as far as Peru a primitive people faced with a similar situation independently developed the art of recovering silver from this type of material.

The primitive bowl furnace consisting of a hollow in the ground lined with clay would serve for the simplest ores, but as the iron content increased with increasing depth, greater heat would be required.

The earliest slag so far discovered has recently been found associated with the foundations of dwellings and pottery, which have been classified as similar to early Cypriot and dated c. 800 B.C. The slag is badly fused and contains much free silica particles. The lead had separated extremely well from the slag, but recovery of silver was low, for one sample contained 575g Ag and 0.84% Pb. With increasing iron content greater heat would be necessary which could be obtained by raising a wall round the bowl, so that more fuel could be employed.

This produced a better fused slag, of which important quantities were visible on the surface prior to the removal of overburden from the North Lode. It could be distinguished by its brown colour. As the silica content was insufficient to satisfy the iron, surface oxidation of this over the centuries imparted the brown colour. Little of this slag is visible to-day at Rio Tinto, but much of it appears to be porous and badly fused and contains up to 200g of silver.

Improving technique led to the discovery that higher furnace temperatures and a better silica iron ratio resulted in a more fluid slag and a better silver recovery. This in turn led to the development of a shaft furnace comparable to those later used by the Romans, for they produced characteristically the same type of slag. These later appear to have been some 7ft high and 30in. in diameter, and remained in use until late in the Middle Ages. These furnaces produced a black vitreous slag of which the bulk of the 15,000,000 tons at Rio Tinto, and at least 5,000,000 tons at other mines is composed.

As indicated above, there is now firm evidence that active smelting was in progress in the Rio Tinto area as far back as 800 B.C.

It has been shown that the same processes that resulted in the formation of the copper ores that in modern times made the district famous would have released large amounts of silver, and a suggestion has been put forward as to how this silver could have provided the raw material for the production of the large tonnages of low-copper silver-bearing slag found in the district. There are numerous references in the writings of the earliest historians to the wealth and prosperity of a fabled kingdom of Tartessus occupying the same area as that in which these pyritic masses are found. Unfortunately, however, archaeological research has so far not thrown any real light on the existence of the conditions obtaining in the legendary Tartessus, and these large accumulations of slag are a striking confirmation of intensive mining and smelting activity from the end of the 2nd millennium B.C.

With the advent of the Carthaginians in the middle of the 1st millennium B.C. a striking change took place, for in order to obtain the silver that was such an important factor in their economy, they appear to have ignored the mines of the south-west responsible for the prosperity of Tartessus and the profitable trade of their earlier kinsmen, the Phoenicians, out of Gades and turned their attention to an entirely different type of mineral occurrence, that of argentiferous galena. These they actively exploited, being followed by the Roman successors.

It seems likely therefore, that after centuries of active exploitation the silver mines, on which the fame of Tartessus rested, were exhausted by the middle of the last millennium B.C., and that it fell to the Romans to encounter and mine the narrow band of silver-bearing material at the base of the gossan, and later in the last half of the 1st century A.D. contact the underlying copper on which the modern fame of the district has rested.

Pliny the Elder refers to the 'recent' discovery of copper under the ancient silver workings. The Roman smelting technique like that of mediaeval Europe, required for a sulphide ore a copper content of about 8%. This was found in zones in the mass of secondary-enriched pyrite, which they followed. It is estimated that at Rio Tinto during the period of Roman activity some 750,000 tons of copper slag were made, with a resultant production of 60,000 to 70,000 tons of copper metal.

NOTES

1. The presence of arsenic is interesting; it may explain some of the high arsenic levels of some early medieval irons which appear to have been used for soldering or welding (Editor).

2. Jarosite is strictly a hydrated basic sulphate of iron and potassium with the potassium subject to substitution by varying amounts of other metals, as in plumbo-jarosite, argento-jarosite etc.

   D. Williams in his "Gossanised Breccia, Ores, Jarosites, and Jaspers at Rio Tinto, Spain" (Trans. I.M.M. Sept. 1950) talks about these complex ferric hydroxides as being a stage in the alteration of massive pyrite into the more stable ferric hydroxides.

   Following the example of others, the term "jarosite" has been used rather loosely to cover material carrying even small amounts of true jarosite which has served as an anchor for the silver. Recent study of a particular gossan has shown that only 40-45% of the silver is soluble in cyanide, and that the rest is associated with plumbo-jarosite. The term "jarositic earth" is used to describe the siliceous material covered by the assays quoted.

Reports on work in progress

The composition of 26 Roman Imperial silver and bronze coins minted between A.D. 206 and 360

Lawrence H. Cope and Harry N. Billingham

Since the publication of the chemical analyses of 35 Roman bronze coins in the last issue of the Bulletin[1], another 26 Roman silver and bronze coin analyses have been completed. The results are listed in Tables I and II, into which the silver denominations and the succeeding bronze issues are separated, although it is now evident that during the last three or four decades of the third century A.D. a general class of argentiferous bronze alloys was used for the coinage of both series.

The metallurgical features of the early 4th century bronze coinage revealed by the previous work, and their numismatic implications, have necessitated the confirmation of some of the earlier observations and the inclusion of other pieces for which complete analyses have never been recorded. The evidence which has been collated recently for the existence of Roman Imperial silver coinage alloy standards[2] – from at least as early as the 2nd century A.D., to the mid-3rd century – has stimulated the examination, also, of the compositions of the core alloys of a number of the much-debased and occasionally surface-silvered issues of the later 3rd century silver coinage which anteceded the argentiferous bronze denominations.

The limited space available for this report precludes any detailed discussion of the accumulated results, which will, in any case, be more significant when further analyses become available for other coins of the period from a wider range of Imperial mints. A few points of some numismatic importance, arising out of the present work, do merit brief mention.

First, it is apparent that the Romans minted their early contemporary antoniniani and denarii in Cu-Ag alloys having identical fineness standards, and these alloys could be made to a remarkably high degree of purity. Secondly, it is evident that, despite the number and severity of the debasements which took place in the middle of the 3rd century, the Romans persisted throughout with their metallurgical tradition of minting the silver coinage in alloys having definite standards of fineness, until the most severe debasement, under Gallienus, in the years A.D. 266-268, reduced the silver coinage to one which contained only 6 scruples of silver per libra of bronze base. Similar argentiferous bronzes, having this and slightly higher fineness standards, can now be discerned clearly as the alloys of the 'silver' issues of the succeeding Emperors, and in the subsequent aes coinage of Diocletian and his colleagues. In consequence, it is now possible to distinguish a 'proto-reform' coinage alloy of Aurelian, and to interpret the enigmatic XX and XXI exergual marks of Aurelian's eventual reformed 'silver' coinage, with some certainty, as having the identical meaning as the XXI mark on the large Diocletianic folles of about a quarter of a century later, and as indicating the addition of 20 half-scruples of silver to each libra of bronze, in the preparation of the coinage alloy.

Thirdly, the analyses of the large folles of A.D. 294-306, and of the succeeding issues, are revealing the chronological changes in the deliberate proportions of silver present in the alloys of the majority of the bronze coinage minted to at least the middle of the 4th century.

Finally, microscopical examinations of the structures of 30 of the larger coins listed in this and the previous report[2], spanning the entire period of one and a half centuries of coin fabrication in a variety of alloys, reveal mainly fine-grained and fairly homogeneous recrystallized mechanically deformed structures characteristic of tin-bronzes which have been reheated and hot-worked. In no case has a completely cast and unstruck coin been observed, even amongst the forgeries, and no coin has yet been found to contain the residual internal strain markings which are indicative of cold-striking as the final minting operation. Although it is not possible to distinguish completely between structures which have been hot-worked and those which have been cold-worked and recrystallized by subsequent reheating, it might be concluded on the basis of the overall metallographic evidence, and since there is no good reason why all the coin varieties should have been cold-struck and then softened by re-heating, that they were minted by hot-striking (in one blow) either cast or pre-formed blanks which had been reheated, possibly to a dull-red heat.

Coining by hot-striking appears, therefore, to have been the conventional Roman minting practice of the period, for both silver and bronze, despite the apparent unsuitability of some of the more highly-leaded bronze alloys for such a process. We can observe that, in this inflationary period, hot-striking undoubtedly facilitated the mass-production of coins by the manual coining methods that had to be used, and that the techniques could have been intended also to allow a much longer average die life than would have been possible with cold-striking. In these matters the 3rd and 4th century Romans appear to have combined sound economic sense with considerable metallurgical knowledge and skill.

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Mr A. Gunstone, City of Birmingham Museum & Art Gallery	(" " 'B.')
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REFERENCES

1. L. H. Cope and H. N. Billingham, "The compositions of 35 Roman bronze coins of the period A.D. 284-363". Bulletin of the Historical Metallurgy Group Vol. 1 – No. 9, 1967.
2. L. H Cope, "Roman Imperial Silver Coinage Alloy Standards; the evidence". Numismatic Chronicle, 1967. (To be published).

TABLE I **ANALYSES OF THIRD-CENTURY ROMAN IMPERIAL COINS IN THE SILVER SERIES**

No.	Code No.	Emperor	Date of issue (A.D.)	Weight (grams)	Reverse type	Mint	CHEMICAL ANALYSIS (weight per cent.)										Sample	Coin Reference
							Silver	Copper	Lead	Tin	Iron	Nickel	Cobalt	Zinc	Gold	TOTAL		
1	Bromwich 1	Caracalla	206-210	2.47	VOTA SVS/CEPTA X	Rome	50.85	48.20	trace	0.010	0.080	0.072	0.110	0.044	0.22	99.586	1	RIC, 179
2	Bromwich 2	Elagabalus	218	4.50	PMTRP COS PP	Rome	42.75	56.50	trace	0.010	0.090	0.036	0.070	0.015	0.22	99.691	1	RIC, 1; Cohen, 125
3	Bromwich 3	Elagabalus	219	3.70	LAETITIA PVBL	Rome	44.20	53.78	1.62	0.57	0.03	0.06	0.09	0.04	not determined	100.39	1	RIC, 95
4	M.1	Valerian	c.253	2.30	FELICITAS AVGG	Rome	17.60	78.46	0.89	3.14	0.05	0.05	0.02	0.01	"	100.22	1	RIC, V, 87
5	Ls.2	Valerian	254-255	4.78	PROVIDENTIA AVGG	Rome	16.18 16.32 16.25	80.57 81.01 80.79	0.76 0.64 0.70	2.59 2.44 2.52	0.04 0.01 0.03	0.02 0.04 0.03	0.03 0.04 0.04	0.03 0.02 0.03	"	100.22 100.52 100.39	1 2 Av	RIC, V, 112
6	M.2	Gallienus	257-258	2.65	VICT GERMANICA	Cologne	18.38	79.11	1.14	0.83	0.09	0.02	0.01	0.01	"	99.59	1	RIC, V, 45
7	W.11	Gallienus	264	3.30	FORTVNA REDVX	Rome	0.62 0.50 0.56	79.69 79.01 79.35	11.39 11.47 11.43	6.53 6.64 6.59	0.06 0.04 0.05	0.01 0.03 0.02	0.03 0.01 0.02	0.03 0.01 0.02	"	98.36 97.71 98.04	1 2 Av	RIC, V, 193
8	W.8	Salonina	c.266?	2.80	FECUNDITAS AVG	Rome	5.39	84.42	2.37	7.92	0.01	0.03	0.01	0.01	"	100.16	1	RIC, V, 5
9	B.106	Gallienus	266-268	3.63	APOLLINI CONS AVG	Rome	2.41 2 36 2.39	87.67 87.80 87.74	2.26 2.20 2.23	7.22 7.18 7.20	0.03 0.03 0.03	0.02 0.02 0.02	0.02 0.04 0.03	0.01 0.03 0.02	"	99.64 99.66 99.66	1 2 Av	RIC, V, 163
10	B.M.68	Aurelian	c.272-274	2.93	FORTVNA REDVX	Milan	2.93 2.20 2.57	91.09 90.92 91.01	2.62 3.48 3.05	3.10 3.08 3.09	0.06 0.07 0.07	0.01 0.01 0.01	0.03 0.05 0.04	0.02 0.03 0.03	"	99.86 99.84 99.87	1 2 Av	RIC, V, 128
11	B.M.69	Aurelian	c.272-274	3.37	CONCORDIA MILITVM	Siscia	2.97 2.45 2.71	93.98 93.00 93.49	1.67 2.32 2.00	1.11 1.03 1.07	0.03 0.04 0.04	0.03 0.03 0.03	0.01 0.04 0.03	0.01 0.03 0.02	"	99.81 98.94 99.39	1 2 Av	RIC:V, 216
12	B.M.70	Aurelian	c.274-275	2.78	ORIENS AVG (PXXT)	Ticinum	3.77 4.00 3.89	93.88 93.50 93.69	0.26 0.21 0.24	1.88 2.38 2.13	0.03 0.02 0.03	0.04 0.04 0.04	0.03 0.04 0.04	0.01 0.02 0.02	"	99.90 100.21 100.08	1 2 Av	RIC, V, 151
13	B.M.71	Aurelian	c.274-275	2.63	ORIENS AVG (XXI)	Rome	4.51 4.20 4.36	92.95 92.50 92.73	Nil Nil Nil	2.60 2.80 2.70	0.05 0.04 0.05	0.02 0.03 0.03	0.04 0.06 0.05	0.03 0.05 0.04	"	100.20 99.68 99.96	1 2 Av	RIC, V, 62
14	B.M.72	Aurelian	c.274-275	3.09	ORIENS AVG (XXI)	Rome	3.81 3.40 3.61	93.16 93.86 93.51	0.65 0.64 0.65	2.68 2.26 2.47	0.02 0.02 0.02	0.04 0.04 0.05	0.01 0.02 0.02	0.01 0.01 0.01	"	100.38 100.26 100.34	1 2 Av	RIC, V, 62

Note: (i) Nos. 1 and 3 (Bromwich 1 and 3) are denarii, the remainder are antoniniani.
(ii) Nos. 1 and 2 (Bromwich 1 and 2) were analysed by Alfred H. Knight, Assayers, Liverpool, the remainder (in this Table and in Table II) by H. N. Billingham.
(iii Duplicate analyses were made if possible, single analyses are recorded when the material available for analysis and microspecimens was more limited.
(iv) Nos. 1 to 9, inclusive, are also reported, with more numismatic details, in The Numismatic Chronicle 1967 (Reference 1).

TABLE II **ANALYSES OF LATE THIRD- AND EARLY FOURTH-CENTURY ROMAN IMPERIAL BRONZE COINS**

No.	Code No.	Emperor	Date of issue (A.D.)	Weight (grams)	Reverse Type	Mint	Chemical Analysis – weight per cent									Sample	Coin Reference
							Copper	Tin	Silver	Lead	Iron	Nickel	Cobalt	Zinc	Total		
1	N.M.W.11	Galerius	c.298-299	10.18	GENIO POPVLI ROMANI (Follis)	probably Thessalonica	94.54 93.90 94.22	1.73 1.87 1.80	2.62 2.82 2.72	1.13 1.04 1.11	0.02 0.03 0.03	0.01 0.02 0.02	0.03 0.03 0.03	0.02 0.01 0.02	100.10 99.72 99.95	1 2 Av.	probably RIC, VI, Thessalonica 20b.
2	N.M.W.3	Diocletian	c.299	7.26	GENIO POPVLI ROMANI (Follis)	Rome	91.71 91.60 91.66	3.23 3.20 3.22	2.18 2.24 2.21	1.42 1.48 1.45	0.02 0.01 0.02	0.04 0.04 0.04	0.02 0.03 0.03	0.01 0.01 0.01	98.63 98.61 98.64	1 2 Av.	RIC, VI, Rome 94a.
3	B.M.49	Diocletian	300-301	10.14	M·SACRA AVGG ET CAESS NN (Follis)	Trier	91.08 91.20 91.14	3.75 3.70 3.73	1.20 1.32 1.26	3.02 3.00 3.01	0.06 0.08 0.07	0.10 0.06 0.08	0.03 0.05 0.04	0.01 0.02 0.02	99.25 99.43 99.35	1 2 Av.	RIC, VI, Trier 474
4	B.M.52	Maxentius	307	6.37	CONSERV/VRB SVAE (Reduced follis)	Rome	87.00 87.21 87.11	5.44 5.70 5.57	0.35 0.30 0.33	5.65 5.64 5.65	0.16 0.18 0.17	0.05 0.07 0.06	0.01 0.02 0.02	0.04 0.03 0.04	98.70 99.05 98.95	1 2 Av.	RIC, VI, Rome 163
5	N.M.W.12	Maximinus Daza	308-311	6.15	GENIO CA/ESARIS* (Reduced follis)	Antioch	91.83 91.40 91.62	2.61 2.53 2.57	1.06 1.08 1.07	3.73 4.12 3.93	Nil Nil Nil	0.20 0.18 0.19	0.11 0.08 0.10	0.02 0.01 0.02	99.56 99.40 99.50	1 2 Av.	RIC, VI, Antioch 87a.
6	B.M.55	Maximinus Daza	early 311	6.29	GENIO IMP/ERATORIS (Reduced follis)	Alexandria	92.45 92.18 92.32	2.27 2.56 2.42	0.98 1.01 1.00	4.07 3.80 3.94	0.02 0.04 0.03	0.04 0.02 0.03	0.01 0.03 0.02	Nil Nil Nil	99.84 99.64 99.76	1 2 Av.	RIC, VI, Alexandria 124
7	B.55	Constantine II	317	3.27	PROVIDENTIAE CAESS	Heraclea Thracica	93.87	2.71	2.22	1.51	0.06	0.04	0.03	0.08	100.52	1	RIC, VII, Heraclea 20
8	B.M.2	Constantine I	326-327	3.13	PROVIDEN/TIAE AVGG	Cyzicus	86.09	4.56	1.45	8.66	0.07	0.02	0.03	0.02	100.90	1	LRBC, I, 1179 RIC VII. Cyzicus 44
9	B.M.3	Constantine I	330-333	2.44	GLOR/IA EXERC/ITVS (Two standards)	Constantinople	93.24	1.98	1.17	3.29	0.02	0.20	0.14	0.03	100.07	1	RIC VII Constanti-nople 59 LRBC, I, 1005
10	B.M.24	Constantine II	335-337	1.61	GLOR/IA EXERC/ITVS (One standard)	Alexandria	91.15	3.85	2.09	3.08	0.03	0.11	0.01	0.07	100.39	1	RIC, VII, Alexandria 66 LRBC, I, 1436
11	B.M.35	Magnentius	350-351	5.36	FELICITAS/REIPVBLICE (2)	Trier	81.57 81.70 81.64	2.19 2.23 2.21	2.52 2.50 2.51	12.94 13.08 13.01	0.09 0.07 0.08	0.08 0.06 0.07	0.06 0.09 0.08	0.04 0.04 0.04	99.49 99.77 99.64	1 2 Av.	LRBC, II, 51
12	B.M.43	Constantius II	355-360	1.89	SPES REI PVBLICE	Arles	83.60 83.46 83.53	0.15 0.20 0.18	0.09 0.10 0.10	14.51 14.86 14.69	0.04 0.07 0.06	0.08 0.07 0.08	0.08 0.05 0.07	0.09 0.04 0.07	98.64 98.85 98.78	1 2 Av.	LRBC, II, 460

MUNCASTER HEAD BLOOMERY

R. F. Tylecote

During the last two weeks of July 1967, an excavation was carried out on the site of a bloomery at Muncaster Head, Eskdale, Cumberland (Nat. Grid Ref. SD/141989). As a result, it is certain that this is the site of a bloomery mentioned in an agreement dated 1636. The civil engineering was of a very high order, and water power was supplied from the Esk via a channel about 10ft wide operating undershot or low breast wheels. Remains of a wheel were found, and these suggest a diameter of about 12ft. Large deposits of hematite ore and charcoal had been left, together with very large 'furnace bottoms' consisting of slag and charcoal. The rest of the slag was in the form of small pieces of tap slag. As much as 3lb of iron were found adhering to the top of one of the 'furnace bottoms', which weighed 48lb. It is certain that this metal was left over after the bloom had been detached. No furnaces were located, but it is hoped to do a small excavation in another part of the site at Easter 1968.

Compared with the civil engineering, the metallurgical level seems to have been somewhat primitive. Attempts had been made to tap the slag from the furnaces, but it is clear that not much left the furnace in the liquid state. The greater part was removed in the form of a furnace bottom, which was the method used in pre-Roman and Dark Age times. This means that there was not much room left in the furnace for the development of a very large bloom, and that the bloom size was probably no more than 30lb. Furthermore, severe damage is done to the furnace when the slag has to be removed in the solid state, which is avoided when it is removed in the liquid state. All this may have resulted from the difficulty of smelting the hematite ore. No signs of any other ore were found.

PANNINGRIDGE FURNACE, SUSSEX

D. W. Crossley

During the second season of excavations in August 1967 at Panningridge Furnace, Sussex (Nat. Grid Ref. TQ/687175), work was carried out for two weeks, and two areas were examined in the copse on the downstream side of the dam, continuing the search for the blast furnace of 1542 begun in the 1964 excavation.

Near the eastern end of the dam, a north-south trench was dug across the level ground east of the present stream and bounded on its south-east side by a slight bank. This bank was apparently designed to protect the area from water which collects at the foot of the hillside to the east of the site; it consisted of earth and stones and was prevented from collapsing into swampy ground by a stone revetment on its south-east edge. The bank was constructed over layers of soil containing scatterings of slag, and was thus a secondary feature, post-dating the building of a blast furnace. Glass which came from beneath the bank was of a quality typical of the 1560's or later, which emphasizes the possibility that this feature was built late in the life of the furnace or after it went out of use in the 1570's.

No structures were found in this cutting, but one further test trench will be necessary.

After a dry summer the western side of the copse was rather less waterlogged than in previous years, and it was possible to open test trenches immediately east of a prominent spur which runs 40ft southwards from the dam some 20ft from its western end.

This spur separates the level ground below the dam where the soil is thickly stained with charcoal from a swampy depression at the bottom of the hillside to the west. The swamp may indicate the foot of an overflow from the dam, in a layout reminiscent of Sheffield Park furnace, Sussex. This depression must originally have been dug out from the hillside, for the spur proved to be surviving natural clay and sandstone, very sharply scarped-off by excavation on both its eastern and western margins. The eastern side of the spur was covered by quantities of stone and tiles, and a substantial foundation trench was located on its top, 15ft from the dam. Contemporary practice, attested by the work of Flemish artists, suggests that this spur, placed as it is at the end of the dam closest to the ore-pits in Pannelridge Wood, would be used as a charging-ramp for supplying the top of an adjacent furnace with charcoal and ore. It was common for such a ramp to have a storehouse built upon it, and this season's excavation suggested such an arrangement.

A cutting along the foot of the eastern slope of the spur produced quantities of charcoal and ore among rubble from the storehouse. Ore and slag have been sent for examination and analysis, together with runners of cast iron from the demolition layers. It is hoped that comparison of these materials from the upper levels may indicate the efficiency of extraction late in the life of the furnace. Any results will be circulated.

Test cuttings to the east of the spur established that a 60ft square was free from the slag dumps that cover most of the copse. This area lies in the angle between the dam and the spur, and from it a well-cambered track built of crushed slag runs south-eastwards towards the present road to Bunce's Farm. Within this area significant traces of structures were seen in test cuttings. A robber trench was traced running for 20ft north and south along the eastern foot of the spur, and 15ft to the east substantial coursed and faced masonry was exposed, enclosing a floor of hard slag. There are slight surface indications of a tail-race running southwards from this area; there are, however, no traces of a pen-stock on the dam itself, and it must be assumed that water was fed over the dam-top in a trough to a wheel some distance away.

Future Work It is highly probable that the masonry seen this year is part of the foundation of a furnace; the combination of features of this size and the character of the debris found in test cuttings is most encouraging, and next season stripping can be confined to a well-defined area. There will be considerable problems of drainage, but mere comprehensive pumping arrangements should ensure working conditions less waterlogged than during this past season.

It is proposed to work for 3-4 weeks in July and August 1968, stripping an area 60ft square on the basis of the test cuttings made in 1967.

Acknowledgements I should like to thank all the volunteers who worked on the site and achieved such encouraging results, often in most unpleasant conditions. I am grateful to Mr J. Wills, owner of the Beech Estate, and Messrs. W. & G. Rudman, tenants of Rocks Farm, for permission to excavate, to Messrs. Bush, Morse & Welling, the agents for the estate, for their co-operation, and to Mrs D. I. Martin, Hon. Secretary of the Robertsbridge and District Archaeological Society, for valuable help in locating local volunteers. The main costs of the excavation were borne by the Knoop Fund of the University of Sheffield, with a donation from the Sussex Archaeological Society; I am most grateful to these bodies for their support.

BARDOWN ROMAN BLOOMERY, SUSSEX

H. F. Cleere

Excavations were resumed during August 1967 at the Roman bloomery site at Bardown, Wadhurst, Sussex (Nat. Grid Ref. TQ/663294). Two areas were examined, in the "industrial" and "residential" areas of the site.

In the industrial area, a feature revealed by magnetic and resistivity surveying was excavated. This was a heavy deposit of hard-packed layers of iron slag, about 8ft wide and 1ft thick, overlying a layer of large sandstone boulders. It started from an area of hard-burnt natural soil and was cleared for a distance of about 20ft; it ran downhill, and was oriented towards the massive slag and rubbish tip on the south bank of the River Limden.

The feature had been interpreted as a track for taking slag tapped from furnaces down to the tip. The natural soil is a silty sand, and is rapidly turned to glutinous mud; some form of metalling would have been essential if carts or sledges were to be run down to the tip. The slag mass was composed of successive overlapping spreads, each probably representing a barrow load, separated by thin layers of surface accumulation; the surface was no doubt renewed by tipping a load when required. Find in this area confirmed the previous dating range of c. A.D. 140-220/230. The "residential" area lies to the S.E. of the industrial area, further up the valley slope. Excavation revelaed traces of two buildings in an area which appears from air photographs to include a rectilinear range of buildings. The earlier building, which was timber-framed, with wattle and daub walls, had been destroyed by fire and not rebuilt. The later building was also probably burnt; it appeared to have been of more impressive construction, with floors cobbled with stone and slag. Finds included two stones used for sharpening blades; both had marks indicating that they had also been used for pointing needles and perhaps nails. A preliminary study of the finds suggests that the earlier building was burnt down by about A.D. 180.

A special study was made of the considerable amount of charcoal collected in both areas. The charcoal from the industrial area, which would have been used in furnaces proved to include a wide range of woods, principally oak, ash, and hazel. Charred beams from the domestic area were all of oak.

Field work around the site earlier in the year established the existence of another road, inferred from air photographs, running southwards towards the River Rother at Witherenden. This road was metalled with bloomery slag, and links three large ore-pits with the Bardown site.

Excavations will be resumed in August 1968, when an intensive excavation of the "industrial"area is planned.

THE WEALDEN IRON RESEARCH GROUP

In the later Iron Age and the early Roman period and again in the middle ages and the early modern period, the Weald of Kent and Sussex was the major iron-producing region in the British Isles. There is abundant evidence of this fact on the ground – slag heaps, hammerponds and bays – and from maps in the form of place names such as Furnace Farm, Forge Field, Cinder Mead etc. This is complementary to information and from the study of the records of the old works, such as accounts, contracts, etc.

The only major study of the industrial past of the Weald was that of Ernest Straker, who published the results of a lifetime's work in 1931 in his book "Wealden Iron". Straker's book, which is recognised as a classic of its kind, has been out of print for many years. Since its publication, a good deal of additional exploration and excavation has been carried out, and some of Straker's judgments require re-interpretation in the light of modern knowledge. The need for a revised "Wealden Iron" is very pressing.

To assist in the preparation of a new survey of the Wealden iron industry, a Wealden Iron Research Group has been set up, with the support of The Iron and Steel Institute and the Historical Metallurgy Group. The joint convenors of the Group are Mr H. F. Cleere FSA (General Assistant Secretary, The Iron and Steel Institute) and Mr D. W. Crossley (Lecturer in Economic History, University of Sheffield).

The first objective of the Group will be to review all the known ironworking sites and to evaluate them in the light of modern knowledge. At the same time, it is hoped to obtain information about sites as yet unknown, by systematic field work.

The second phase will be devoted to the excavation of selected sites. Excavations are already in progress at the 2nd century Roman site at Bardown near Wadhurst, and the 16th century Panningridge works near Robertsbridge (see above). At least three further excavations are contemplated, one of them at a site to be submerged when the Bewl Valley reservoir is completed.

It is hoped to be able in due course to publish a complete gazetteer of sites, accompanied by a technological and economic history of the industry, to replace "Wealden Iron".

Those wishing to take part in the work of the Group should write to Mr H. F. Cleere at 4 Grosvenor Gardens, London, S.W.1., or at Little Bardown, Stonegate, Wadhurst. The joint convenors would be glad to hear from anyone interested in the subject, since the projected work will require a wide range of skills and interests.

Abstracts

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

British Isles

Sussex firebacks – History of an early application of cast iron P.J. Browne (Found. Trade J. 1967, **123**, 27 July, 109-111) The evolution of the craft from the 14th to the late 18th century is described with illustrations.

Monastic mining and metallurgy in the British Isles H. O'Neill (Met. Mat., 1967. **1**, June, 182-190) The influence of the monasteries on the early development of mining and metallurgy is described.

Richard Reynolds and the first iron rails M. Schofield (Steel Times 1967. **194**, June 16, 694-695) A description of the production of cast-iron rails up to 4in wide and $1\frac{1}{4}$in wide and $1\frac{1}{4}$in in depth in 1767.

Faraday and the first alloy steels M. Schofield (Iron Steel. 1967, **40**, Aug., 357-358) The author discusses the early work of Faraday who died 100 years ago, and described in particular Faraday's metallurgical work on, for example, improving steel by the addition of alloying elements and the preparation of 'rustless' steel. Early experiments carried out by Faraday at the Royal Institution and by the cutler James Stodart working under Faraday's direction at Sheffield are mentioned. The article suggests that Faraday's work in metallurgy cannot entirely be dismissed as of little importance as the experiments of Faraday and Stodart were significant since they paved the way for other workers. (e.g. Mushet and Hadfield) in the field of alloy steels.

J.C. Fischer's visit to London between 1794 and 1851 W.O. Henderson (Tradition 1967, **12**, (3), June 416-426) [In Ger.] Outstanding events, societies visited, and individuals encountered by the Swiss metallurgist are described. Among these are the Royal Institution, Michael Faraday, W. T. Brande, the Apothecaries Company, Woolwich Arsenal, the Patent Office, the British Museum and the Great Exhibition.

Europe

From bloomery iron to high strength malleable cast iron – 400 years of Eisenwerke Schönheiderhammer G. Pistol (Giessereitechnik, 1967, 13, (7), 193-197) [In Ger.] The story of the works from 1566 to the present day, illustrated by woodcuts and drawings.

History of the iron and steel industry in the Northern Eifel W. Günther (Rhein. Viertelj. Bl., 1965, **30**, (1-4), 309-333, reprint) [In Ger.] A detailed historical survey of the region covering mainly the period between the 15th and 19th Centuries.

Early iron mining and its traces in the northern Alpine region of S. Bavaria H. Frei (Münchner Geogr. Hefte., 1966, **29**, pp. 93). [In Ger.] A detailed study with a topographical list of ca. 15,000 pits and shafts, dating from 8th-11th Cent. A.D., in the neighbourhood of Augsberg and between the rivers Danube and Inn. Two types of iron ore working methods have been found, shallow conically-shaped circular pits and deeper shafts of a four-cornered, timbered type.

The beginnings of la Compagnie des Houillères, Fonderies et Forges de l'Aveyron (Decazeville) B. Gille (Rev. Histoire Sidér. 1967., **8**, (2), 113-141) [In Fr.] The proceedings of meetings of this company are reproduced for the years 1826-9.

The development of the water wheel drive in the Hungarian iron and steel industry G. Heckenast (Rev. Histoire Sidér., 1967, **8**, (2). 73-94) [in Fr.] The development, particularly in the period 1250-1400 under German influence, of water power in iron and steel industries in Hungary, is reviewed.

Metallurgical Investigations

The fatigue strength of wrought iron after weathering in service M. S. G. Cullimore (Struct. Eng., 1967. **45**, May, 193-199) Wrought iron was taken from Brunel's tubular bridge at Chepstow during its demolition in 1962, after 110 years of service. Direct stress fatigue tests at zero mean stress and in fluctuating tension are described, together with tests on deliberately notched specimens and severely corroded material. There had been little, if any deterioration in the basic tensile strength, even of the severely corroded material, although in these parts there was a marked reduction in overall ductility. A normal value was obtained for the fatigue strength ratio at low mean stresses, but there was an unexpectedly rapid falling off as the mean stress increased. Factors affecting the assessment of the strength of wrought iron structures are discussed, and the possible effects of the combined action of corrosion and stress are suggested.

Metallographic criteria in the comparative analysis of iron objects J. Piaskowski (Archeol. Polski, 1966, **11**, (2), 290-306 [In Pol.] Metallographic studies of numerous early iron objects found in Poland have suggested that some objects of similar shape may have been produced in various production centres. Tables are presented which classify fibulae by shape and give data for sites, production methods and chemical compositions.

The determination of the origin of ancient objects by analysis of their features J. Piaskowski (Kwart. Hist. Nauki Techn, **12**, (1), 61-97) [In Pol.] A discussion of methods of dating and placing the centres of production.

Metallographic examination of iron objects from Miezany and Sudata J. Piaskowski (Lithuanian SSR) (Wiad. Archaeol., 1965, **31**, 4, 363-379.) [In Pol.] A study of 24 objects dated 4th-8th century A.D. found in barrows. The majority are of high-phosphorus iron (0.15-0.60%).

Metallographic examinations of iron objects and bloomery slag from sites at Dalewice and Wolka Lasiecka J. Piaskowski (Spraw. Archaeol., **18**, 356-374.) [In Pol.] A study of 11 items from the late La Tène and Roman periods found in these districts of Poland.

Metallographic examination of iron objects from an early medieval site at Lazy J. Piaskowski (Spraw. Archaeol., 1966, **18**, 375-386.) [In Pol.] Deductions on processes and the skills of the local smiths are drawn.

Metallurgical research on iron objects found in the vicinity of the rivers Pyrpic, Dniester and Bug J. Piaskowski (Materialow. Archeol., 1967, 7, 197-214.) [In Pol.] The analysis is reported of 24 objects, some of which are believed to be of the la Tène period.

Some implications of the metallographic investigation of ancient materials O. Schaaber (Radex Rundschau, 1967, **3/4**, 547-554) [In Ger.] After an introduction dealing with the need to avoid narrow specialization, the paper demonstrates with several examples of metallographic examination and electron-beam microanalysis how the investigation of metal objects from antiquity can provide valuable suggestions for the improvement of research techniques for use with modern materials.

Miscellaneous

Visit to the Iron Museum A. France-Lanord (Rev. Histoire Sidér., 1967. **8**, 10-50) [In Fr.] A detailed description is given of the Musée du Fer Nancy, including its main divisions and exhibits.