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THE IRON INDUSTRY OF ROMAN BRITAIN

Abstract

The thesis surveys the evidence for iron smelting and iron working in Roman Britain, principally from archaeological sources. It begins with a catalogue raisonnée of sites, classified geographically into ten regions, and then analyses the distribution of these sites, in relation to the iron-ore deposits in Britain known to have been worked during the Roman period. The organization of the industry is then discussed, against the background of what is known of Roman Imperial minerals policy and administration, and the known sites are classified into five main types.

A section on the technology of Roman ironmaking deals with the basic chemistry of bloomery ironmaking, ore mining and treatment, charcoal burning, furnaces types and smelting, and steel production.

An historical outline of the industry covers the spread of ironmaking technology into Britain, the pre-Roman iron industry in Britain, and the chronological development of the Roman industry. The final section deals with the economic basis of the industry, with consideration of iron production and consumption data, markets, the export of iron from Roman Britain, and the manning requirements of the industry.

Published papers on experimental smelting in a reconstructed furnace of Roman type, the classification of bloomery furnaces, the Roman iron industry of the Weald, and some operating parameters for Roman ironworks appear as appendices.

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1 Catalogue Raisonnée of Sites 5/6

1.1 Introduction

For the purposes of this study, the Roman province of Britannia has been divided for convenience into ten regions. These are arbitrary divisions, based for the most part on modern administrative boundaries: the analysis of the distribution of these sites is contained in Chapter 2. The ten regions are as follows:

1 South-eastern counties (Kent, Surrey, Sussex, Hampshire)
2 South-western counties (Cornwall, Devon, Dorset, Somerset)
3 Western counties (Wiltshire, Gloucestershire, Herefordshire, Monmouthshire)
4 West Midlands (Cheshire, Shropshire, Staffordshire, Warwickshire, Worcestershire)
5 East Midlands (Derbyshire, Leicestershire, Lincolnshire, Nottingham hire)
6 South Midlands (Bedfordshire, Berkshire, Buckinghamshire, Hertfordshire, Northamptonshire, Oxfordshire)
7 East Anglia (Cambridgeshire, Essex, Huntingdonshire, Norfolk, Rutland, Suffolk)
8 Northern counties (Cumberland, Durham, Lancashire, Westmorland, Yorkshire)
9 Wales (excluding Monmouthshire)
10 Scotland

The catalogue gives details of sites in these groups. Within each group, sites are listed in alphabetical order according to the name of the site that has produced relevant finds. Each entry contains the following information, arranged as shown:

SITE NAME, Parish, County **National Grid Reference**
Summary account of finds
Date: type of site
Bibliographical references

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1.2 South-eastern counties

BARDOWN, Ticehurst, Sussex **TQ 663293**
Excavated 1960-68 (Cleere 1970): site covering c.3ha, divided into residential (barrack block) and working areas. Large slag bank. Ore-roasting furnaces, forging hearths, charcoal hearth. Stamped tiles of *Classis Britannica*
II-III AD: BLOOMERY (military)
Straker 1931, 28, 196
Cleere 1970
Cleere 1974, 190-1 (gives earlier references)*

BEAUPORT PARK, Battle, Sussex **TQ 786140**
Very large site (c.10ha?). Military-type bath-house excavated 1970-72. Massive slag bank removed in 19th century for road metalling. Stamped tiles of *Classis Britannica*
(I)II-III AD: BLOOMERY (military)
Straker 1931, 330-7
Cleere 1974, 191-2

BRENLEY CORNER, Kent **TR 043597**
Excavated 1962-73. Probable bloomery hearths (ore from Woolwich Beds). Possible religious site in association. Small-scale activity.
I-IV AD: BLOOMERY (civil)
Archaeol Excav 1972, 56-7; 1973, 47-8

BROADFIELDS, Crawley, Sussex **TQ 258353**
Major industrial settlement – rescue excavations 1964-73. Nearly 40 smelting
7 / 8 furnaces, ore roasting, slag dumps, etc. Domestic buildings of non-military type.
(I BC?)I-II/III AD: BLOOMERY (civil)
Cleere 1974, 192

BROOK HOUSE, Rotherfield, Sussex **TQ 506273**
Excavation in large slag heap produced sherds of Romano-British pottery.
?II/III AD: BLOOMERY (civil)
Cleere 1974, 192

BYNES FARM, Crowhurst, Sussex **TQ 752111**
Excavated 1949: slag heap, containing single and double tuyeres, much pottery. Possible satellite of Crowhurst Park.
I-II AD: BLOOMERY (military)
Cleere 1974, 192-3

CASTLE HILL, Rotherfield, Sussex **TQ 560280**
Extensive slag deposit. Radiocarbon date of mid 1st century AD.
I AD: BLOOMERY (military)
Cleere 1974, 193

CHICHESTER, Sussex
Evidence of iron working and possible melting in industrial quarter of *civitas* capital.
III-IV AD: FORGE (civil)
K M E Murray & B W Cunliffe, *Sussex Archaeol Collect* 100 (1962), 93-110

CHILGROVE, Sussex
Iron working is attested throughout the life of this settlement complex, with possible smelting in the final phase.
II-IV AD: FORGE/BLOOMERY (civil)
A Down, *Chichester Excavations* **4** (1979) 8 / 9

CHITCOMBE, Brede, Sussex **TQ 814211**
Large site, described by Rock as comparable with Beauport Park. Pottery finds suggest similar date range. Remains of masonry still visible. Finds of tile suggest existence of substantial buildings.
II-III AD: BLOOMERY (military)
Cleere 1974, 193
J Rock, *Sussex Archaeol Collect* 29 (1879), 175-80

COALPIT WOOD, Ticehurst, Sussex **TQ 652285**
Satellite of Bardown site, 1 mile to south-west and connected by slag-metalled track, lined with ore pits. Small slag deposit on side of small gill.
III AD: BLOOMERY (military)
Cleere 1974, 193

* Only the reference to Cleere 1974 is given for most of the Wealden sites: full bibliographical references and fuller descriptions are given for each site listed in the catalogue attached to that paper, which forms Appendix C to this thesis.

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CROWHURST PARK, Crowhurst, Sussex **TQ 769136**
Large bloomery (cp Beauport Park, Chitcombe), excavated 1936. Slag bank produced furnace debris, single and double tuyeres, pre-Roman and Romano-British pottery. Minepits along both sides of valley.
I BC, I-II AD: BLOOMERY (military)
E Straker and B H Lucas, *Sussex Archaeol Collect* **79** (1938), 224-9
Cleere 1974, 193
WIRG, *Wealden Iron* 1st series, **IX** (1976), 3-4

DOOZES FARM, Wadhurst, Sussex **TQ 625273**
Discovered during laying of gas pipeline 1969-70. Pit containing tap slag, cinder, and furnace debris, with two sherds of Romano-British coarse ware (East Sussex ware). Possible satellite of Bardown.
?III AD: BLOOMERY (military)
9/10 Cleere 1974, 194

FOOTLANDS, Sedlescombe, Sussex **TQ 772198**
One of the largest Wealden sites, with slag covering l.5ha. Excavated 1925 but not published. Pottery from pre-Roman Iron Age to 4th century AD. The only eastern Weald site that appears to have continued operations after the withdrawal of the *Classis Britannica* in the mid 3rd century.
?I BC, I-IV AD: BLOOMERY (military/civil)
Cleere 1974, 194

FOREWOOD, Crowhurst, Sussex
Extensive bloomery: finds included an unworked bloom of iron. No direct dating evidence, but may be satellite of Crowhurst Park.
?II/III AD: BLOOMERY (military)
Cleere 1974, 194

GREAT CANSIRON, Holtye, Sussex **TQ 448382**
Very large site, comparable with Beauport Park, Chitcombe, etc. 'Industrial area', which shows up black in ploughsoil, covers c.1.5ha. Surface collection has produced 1st and 2nd century pottery and considerable amounts of tile and other building material. Probably provided metalling for nearby London-Lewes Roman road.
I-II(-IV?) AD: BLOOMERY (civil)
Cleere 1974, 194

HOLBEANWOOD, Ticehurst, Sussex **TQ 663305**
Excavation revealed two groups of six shaft furnaces: at least one further group not excavated. No buildings, apart from shelters over furnaces. Linked with Bardown by slag-metalled road, lined with ore pits.
III AD: BLOOMERY (military)
Cleere 1974, 195 10/11

HOWBOURNE FARM, Hadlow Down, Sussex **TQ 516249**
Bloomery slag and 2nd century pottery found in association with mortared stone wall.
II AD: BLOOMERY (civil)
Cleere 1974, 195

ICKLESHAM, Sussex **TQ 8615**
Two small bloomeries, with six shaft furnaces and much slag. Nearby find of *denarius* of Hadrian.
II AD: BLOOMERY (?military)
Cleere 1974, 195

IRIDGE, Salehurst, Sussex **TQ 752277**
Large slag bank with furnace debris on bank of small stream. No direct dating evidence.
(?): BLOOMERY (?military)
WIRG, *Wealden Iron*, 1st series **IX** (1976), 3

KNOWLE FARM, Heathfield, Sussex **TQ 623241**
Small dump of tap slag, furnace debris, ore, etc, with 2nd-3rd century pottery.
II-III AD: BLOOMERY (civil)
Cleere 1974, 195

LIMNEY FARM, Rotherfield, Sussex **TQ 540271/2**
Two low mounds of bloomery slag by small stream: base of 3rd century pot found by Straker nearby.
III AD: BLOOMERY (civil)
Cleere 1974, 196

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LITTLE FARNINGHAM FARM, Sissinghurst, Kent **TQ 809358**
Substantial stone building with hypocaust, containing *Classis Britannica* stamped
11/12 tiles. No slag in building or vicinity, but a number of tuyeres found during excavation. Could be collecting point for material from bloomeries, to be transported on road to Rochester, which runs nearby.
II-III AD: ADMINISTRATIVE CENTRE (military)
Cleere 1974, 195-6

LITTLE INWOODS, Hadlow Down, Sussex **TQ 562240**
Small slag dump by stream, charcoal from which gave a 1st century BC/1st century AD date.
I BC-I AD: BLOOMERY (?civil)
Cleere 1974, 196

LUDLEY FARM, Beckley, Sussex **TQ 848208**
Large slag and refuse bank, probably disturbed for road metalling. Trial excavation produced 2nd century pottery and a sestertius of Hadrian. Ore pits nearby.
II AD: BLOOMERY (military)
Cleere 1974, 196

MAGREED FARM, Heathfield, Sussex **TQ 601229**
Small slag bank, with pottery identified as lst/2nd century.
I-II AD: BLOOMERY (civil)
Cleere 1974, 196

MINEPIT WOOD, Rotherfield, Sussex **TQ 522338**
Small slag and refuse dump alongside domed smelting furnace (Cleere's type B.1.ii). Pottery largely 1st century (at variance with radiocarbon date of 4th century).
I AD: BLOOMERY (civil)
Cleere 1974, 196-7

MORPHEWS, Buxted, Sussex **TQ 509255**
Large slag dump: trial excavation has produced 2nd century pottery.
II AD: BLOOMERY (civil)
Cleere 1974, 197

12/13

OAKENDEN FARM, Chiddingstone, Kent
Heavy spread of slag, cinder, and charcoal in ploughed field. Ore pits in the vicinity. Surface finds of 2nd century pottery.
II AD: BLOOMERY (civil)
Cleere l971, 197

OAKLANDS PARK, Sedlescombe, Sussex **TQ 785176**
Massive slag banks quarried away for road metalling in the 19th century. Only dating evidence was from coins of Hadrian. Possibly associated with small port on river Brede, now under modern buildings.
II AD: BLOOMERY (military)
Cleere 1974, 197

OCKHAM FARM, Bodiam, Sussex **TQ 782249**
Heavy concentration of bloomery slag, cinder, and roasted ore in area south-west of and above the Roman port of Bodiam.
?I-III AD: BLOOMERY (military)

OLDLANDS, Maresfield, Sussex **TQ 476268**
Major ironworking settlement, covering at least 3ha. Coins from Nero to Diocletian. Close to line of London-Lewes road, and probably provided metalling for much of this.
I-IV AD: BLOOMERY (civil)
Cleere 1974, 197-8

PEPPERINGEYE, Battle, Sussex TQ 743140
Deep layer of slag and other refuse, containing one sherd of 2nd century samian. Probably a satellite of the Crowhurst Park settlement.
II AD: BLOOMERY (military)
Cleere 1974, 198
WIRG, *Wealden Iron,* 1st series **IX** (1976), 3 13/14

PETLEY WOOD, Battle, Sussex **TQ 764176**
Iron-ore mining and pre-treatment site: minepits, roasted ore fines, and 2nd and 3rd century pottery. Almost certainly connected with the Oaklands Park settlement, 1.4km distant. A possible bloomery site has been located at TQ 769174 (G Farebrother, pers comm).
II-III AD: ORE MINING (military)
Cleere 1974, 198

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PIPPINGFORD PARK, Hartfield, Sussex **TQ 446313**

Small bloomery, with domed furnace (Cleere's type B.1.ii), a smithing hearth, a possible ore-roasting hearth, and small slag dump. Pottery Claudio-Neronian. The area has produced other sites at Pippingford East Wood (TQ 442301) and Pippingford Cow Down (TQ 452309: C F Tebbutt, *Sussex Archaeol Collect* **117** (1979), 47-56), the latter containing several B.1.ii furnaces. All three sites, and also Strickedridge Gill, seem to be connected with the Garden Hill, Hartfield, settlement (J H Money, *Sussex Archaeol Collect* **108** (1970), 39-49), which has also yielded evidence of ironworking.

I AD: BLOOMERY (civil)

Cleere 1974, 198

POUNSLEY, Framfield, Sussex **TQ 525222**

Fairly large deposit of bloomery slag along banks of small stream, containing 2nd century pottery.

II AD: BLOOMERY (civil)

Cleere 1974, 198

RENBY GRANGE, Withyham, Sussex **TQ 532332**

Large patch of soil containing much cinder, tap slag, furnace lining, etc, with Romano-British pottery.

I AD: BLOOMERY (civil)

WIRG, *Wealden Iron,* 1st series **IX** (1976), 2

14/15

RIDGE HILL, East Grinstead, Sussex **TQ 369359**

Large slag heap excavated in 1927, overlying earlier ore-roasting and charcoal hearths. Pottery certainly 2nd-3rd century, and there may be a pre-Roman phase.

(?I AD), II-III AD: BLOOMERY (civil)

Cleere 1974, 199

RICHBOROUGH, Kent

Forging slag associated with the later (Saxon Shore) phases of the military establishment.

IV AD: FORGE (military)

J P Bushe-Fox, *1st Report on the excavation of the Roman fort at Richborough Kent*. Society of Antiquaries Res Rep 6 (1926), 6

SHOYSWELL WOOD, Etchingham, Sussex **TQ 682279**

Revealed by gas pipeline trenching in 1970. Stretch c.70m long of slag and other debris, up to Im thick in places. Ore pits in the vicinity. One sherd of East Sussex ware found. The site lies c.2km from Bardown, of which it is probably a satellite.

III AD: BLOOMERY (military)

Cleere 1974, 199

STREELE FARM, Mayfield, Sussex **TQ 558268**

Small slag deposit. One sherd of East Sussex ware found when field-walked.

?II AD: BLOOMERY (?civil)

Cleere 1974, 199

STRICKEDRIDGE GILL, Hartfield, Sussex **TQ 456317**

Extensive slag bank and cutting into stream bank for iron ore. Almost certainly associated with nearby Garden Hill settlement (see Pippingford Park above).

1 AD: BLOOMERY (civil)

Cleere 1974, 199 15/16

WALESBEECH, East Grinstead, Sussex **TQ 395345**

Excavation of slag bank produced 1st and 2nd century pottery, together with tile. Large ore pits nearby.

I-II AD: BLOOMERY (civil)

Cleere 1974, 199

WEST WALK, Bere Forest, Hampshire **SU 593134**

Three small shaft furnaces, shallow but extensive slag heap. Furnaces disposed linearly, enclosed by shallow boundary ditch. Pottery 3rd-4th century.

III-IV AD: BLOOMERY (civil)

B T Schadla-Hall: pers comm

1.3 South-western counties

BATH, Somerset

Considered by Grover to have been centre for military smiths, based on Julius Vitalis inscription referring to COLLEGIVM FABRICENSIVM. No archaeological evidence to support this supposition.

?FORGE (military)

Grover 1873

BERE REGIS, Dorset
Ironworking pits were discovered in a civil settlement dated 80-350.
I-IV AD: FORGE (civil)
G S G Toms, *Proc Dorset Archaeol Nat Hist Soc* **88** (1966), 116-7

BREAN DOWN, Somerset
An ironworking pit was discovered as a feature of squatter occupation in the late 4th century on a temple site.
16 IV AD: FORGE (civil)
17 A M ApSimon, *Proc Speleol Soc* **10.3** (1964-6), 195-238

BRISLINGTON, Somerset
Iron slag was found in the paved courtyard of a corridor villa dated by coins to 265-361. A hypocausted room with corbelled flue was almost blocked with furnace debris. Appears to have been working by squatters following the abandonment of the villa in the late 4th century, although it may date to the last phase of the villa proper.
IV AD: BLOOMERY & FORGE (civil)
W R Barker, *Trans Bristol Gloucestershire Archaeol Soc* **23.2** (1900), 289-308
Vict County Hist Somerset **I**, 305

CAMERTON, Somerset
A pit over 10m in diameter and 1.5m deep was filled with slag in the mid 1st century. A great deal of slag on the whole site and a number of hearths of baked clay, with stone sides, over lm in diameter, which may represent either forging hearths or the bases of smelting furnaces (there was tap slag on the site). This complex was levelled for a hut dated to the mid 2nd century. Elsewhere on the settlement, alongside the Foss Way, a hearth nearly 3m in diameter was found, filled with soot that contained pieces of iron -probably a forging hearth.
I-?IV AD: BLOOMERY & FORGE (civil)
Wedlake 1958

CHEW STOKE, Somerset
Ironworking (slag, hearths) on villa-type establishment.
II-IV AD: FORGE (civil)
J Roman Stud **42** (1952), 98; **43** (1953), 123

DULVERTON, Somerset
17 Field-walking produced evidence of iron smelting or working from the Roman period
88 at various points on Exmoor.
L V Grinsell, *Notes Queries Somerset Dorset* **27** (1958)

EXETER, Devon
A metal-working furnace with a clay tuyere and iron slag was found in a workshop in the town: dated to 2nd century.
II AD: FORGE (civil)
J Barker, *Trans Devon Ass,* **97** (1965), 88-109

LUCCOMBE, Somerset
Roman coins (unspecified) are reported as having been found beneath refuse from hematite mines.
ORE MINING (civil?)
J C Cox, *Archaeol J,* **52** (1895), 25-42
Vict County Hist Somerset **II,** 392

LUXBOROUGH, Somerset
Roman coins from beneath refuse from hematite mining.
ORE MINING (civil?)
J C Cox, *Archaeol J*, **52** (1895), 25-42

WEMBERHAM, Somerset
Iron slag reported from villa site.
FORGE (civil)
O Davies, *Roman Mines in Europe* (1935)
Vict County Hist Somerset, **I**, 307

WHATLEY, Somerset
Iron slag reported from villa site.
FORGE (civil)
O Davies, *Roman Mines in Europe* (1935)

WHITESTAUNTON, Somerset
A possible iron-smelting site (Roman period).
?BLOOMERY (civil) 18
Vict County list Somerset, **I**, 334; **II,** 392 19

1.4 Western counties

BRAMHAM, Wiltshire
Iron slag (probably smithing) on rural occupation site: dating uncertain.
FORGE (civil)
L V Grinsell, pers comm

BREAM, West Dean, Gloucestershire **SO 605047**
The iron-ore mines (‘Scowles’), which produce limonite and goethite, have yielded Roman coins, as early as Vespasian. A pre-Roman coin of the Coriosolites was found in 1946, suggesting trade with the Bagendon area. Bream Scowles are traditionally said to be Roman in origin, and the continuous line of surface working along the outcrop of the Crease Limestone represents an early technology, but the evidence is scanty.
I AD (-IV AD?): ORE MINING (civil/military)
Fryer 1886
Hart 1967, 23
Bridgewater 1968

BRIDSTOW, Herefordshire
Large slag deposits from the Roman period are reported.
BLOOMERY (civil/military)
T Wright, *Wanderings of an Antiquary* (1854)
Bridgewater 1968
Watkin 1877

CAERWENT, Monmouthshire
Slag was found on an occupation site on Portskeweth Hill, dated to the Roman
19/20 period, suggesting that otherwise undated ironworking remains on the slopes of the
hill may be of Roman origin.
II-IV AD: FORGE (civil)
R E M Wheeler, *Prehistoric and Roman Wales* (1925), 272-3
Davies 1935

CHESTERS VILLA, Tidenham, Gloucestershire **ST 5911 ST 5913**
The villa establishment at Woolaston Pill is considered to have been occupied by a Roman ironmaster “who also indulged in farming and had connections with shipping”. It is dated from the reign of Hadrian to the end of the 4th century. Possible sites of Romano-British shaft furnaces on the banks of the river Severn near Pill House: bloomery slag at the base of the cliffs.
II-IV AD: BLOOMERY & ADMINISTRATIVE CENTRE (civil/military)
Hart 1967, 25-42
C Scott-Garrett & F H Harris, *Archaeol Cambrensis,* **93** (1938), 93-125

COLEFORD, Gloucestershire
3rd century coins reported as having been found near the Scowles.
III AD: ORE MINING (civil/military)
Grover 1873
Fryer 1886

DEVIZES, Wiltshire
Roman pottery reported as having been found amongst ancient iron slag (probably forging).
FORGE (civil)
J C Cox, *Archaeol J*, **52** (1895), 25-42

THE DOWARD, Nailbridge, Gloucestershire
Many surface workings, suggested as having supplied the furnaces in the Whitchurch
area with ore.
ORE MINING (civil/military) 20/21
Bridgewater 1968

EDGEHILL & WESTBURY BROOK, Mitcheldean, Gloucestershire
Opencast surface workings of the Roman period down the Soudley valley.
ORE MINING (civil/military)
Bridgewater 1968

GOODRICH, Herefordshire
Large cinder heaps of Roman date throughout the parish, supplied from drift mines in the Great and Little Doward Hills.
BLOOMERY (civil/military)
Watkin 1877
Grover 1873

HADNOCK, Dixton Newton, Monmouthshire **SO 5113**
Roman coins reported found in large heaps of iron slag.
BLOOMERY (civil/military)
Wilkins, *History of Monmouthshire* (1796), 67
Fryer 1886, 50

HANGERBERRY, Mitcheldean, Gloucestershire
Surface workings of the Crease Limestone: possible source of ore for smelting establishments in Ruardean area.
ORE MINING (civil/military)
Bridgewater 1968

HARTPURY, Gloucestershire **SO 772261**
Charcoal and iron slag, in association with querns, found at Buttersend Farm.
FORGE (civil)
Gloucestershire Dist Archaeol Res Group Rev, **6** (1972), 4

21/22

HENTLAND, Herefordshire
Large deposits of bloomery slag, together with Romano-British pottery. A section of the suggested Roman road from Red Rail is metalled with iron slag.
BLOOMERY (civil/military)
Bridgewater 1968

KENCHESTER, Herefordshire
Areas of very dark soil within the enclosed settlement, containing charcoal and tap slag.
BLOOMERY (civil/military)
Watkin 1877

LEINTWARDINE, Herefordshire
Slag (not further identified) was present on a settlement site.
II-III AD: ?FORGE (civil)
Trans Woolhope Nat Field Club, **12** (1921-3), 64

LITTLEDEAN, Gloucestershire **SO 683146**
Large slag deposits over the whole area. An ore-roasting furnace was discovered in the 19th century and excavations in the 1950s produced a timber-framed hut with smelting furnace bases nearby. The building was dated 2nd-4th century.
II-IV AD: BLOOMERY (civil/military)
C Scott-Garrett, *Trans Bristol Gloucestershire Archaeol Soc*, **75** (1956), 199-202
Bridgewater 1968

LLANCLOUDY, Gloucestershire
Slag deposits observed in land adjoining Hill Farm. A hoard of 2800 Roman coins was discovered in 1912 in the area.
BLOOMERY (civil/military)
Bridgewater 1968

22/23

LLANDINABO, Herefordshire
Several acres of slag deposits, known locally as ‘The Furnaces’. Dated by pottery to Roman period.
BLOOMERY (civil/military)
Bridgewater 1968

LLANGARRON, Herefordshire
Large slag deposits, dated to the Roman period, in the parish.
BLOOMERY (civil/military)
Watkin 1877
Bridgewater 1968

LYDNEY, Gloucestershire **SO 629029**
A native settlement of the 2nd and 3rd centuries produced a large amount of tap slag.
II-III AD: BLOOMERY (civil)
F Harris, *Trans Bristol Gloucestershire Archaeol Soc*, **58** (1936), 283-4; **59** (1937), 327

LYDNEY PARK, Gloucestershire **SO 616026**
A pre-Roman site was reoccupied by iron-ore miners in the 2nd and 3rd centuries. A drift mine was sealed by a later hut and bath building associated with the temple complex. The northern half of Lydney Camp Hill is honeycombed with blocked mine shafts.
Wheeler & Wheeler 1932, 22
Hart 1967, 25-42
Bridgewater 1968

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MONMOUTH — SO 5153/5156

The very large Roman slag dumps were removed in the 18th century for re-smelting. Four Roman forging hearths were discovered in Granville Street associated with 2nd
23/24 century pottery, and another site in the town produced pottery of the 2nd and 3rd centuries on iron-working hearths.

(?I AD), II-III AD, (?IV AD): BLOOMERY (military)

Grover 1873

S H Clarke, *Archaeology in Wales*, **4** (l964), 14; **5** (1965), 20; **6** (1966), 16

Bridgewater 1968

NEWENT, Gloucestershire — SO 7205

Slags containing Romano-British coins and pottery were reported in the 18th century as having been found in and around Newent.

BLOOMERY (civil/military)

S Rudder, *New History of Gloucestershire* (1779), 562

NEWLAND, Gloucestershire — SO 5707

The Clearwell Caves are reported to be Roman iron-ore mines, although no evidence seems to have been adduced for this supposition. However, Roman coins and pottery have been found at the nearby Sling Scowles.

ORE MINING (civil/military)

Ordnance Survey unpublished records

Trans Bristol Gloucestershire Archaeol Soc, **29** (1906), 11-12

PETERSTOW, Herefordshire

There are still large mounds of cinder and slag in the parish, although much was removed during the 18th century for re-smelting. The beds were in places up to 6m thick. Bloomery furnaces are reported from Peterstow Common. Many Roman coins and potsherds have been collected in the parish, with a wide date range.

I-IV AD: BLOOMERY (civil/military)

Wyrall 1877-8

Bridgewater 1968

24/25

REDBROOK, Gloucestershire

Slag of Roman date reported from the parish.

BLOOMERY (civil/military)

Grover 1873

RUARDEAN, Gloucestershire

Coins of Constantine I are reported as having been found in association with bloomery operations and ore mining.

II-III AD: BLOOMERY (civil/military)

Fryer 1886

Bridgewater 1968

ST WEONARDS, Herefordshire

Large beds of slag throughout the parish.

BLOOMERY (civil/military)

Watkin 1877

STAUNTON, Gloucestershire — SO 5510

Shallow surface workings cover the outcrop of the Crease Limestone from east of Staunton to west of Coleford. There is a possible bloomery site north of the vicarage which produced a lamp of Claudian date.

I AD (-?): BLOOMERY (civil/military)

Bridgewater 1968

M E Bagnall-Oakley, *Trans Bristol Gloucestershire Archaeol Soc.*, **6** (1881-2), 107

TIBBERTON, Gloucestershire — SO 762203

Large slag heap at Bulley Bough, with bronze brooch and leg of bronze statue.

BLOOMERY (civil/military)

Ordnance Survey unpublished records 25/26

TIDENHAM, Gloucestershire — ST 559972 ST 556932

A heavy spread of building stone and tap slag is reported in an area close to a possible Roman building.

BLOOMERY (civil/military)

Ordnance Survey unpublished records

Archaeol J, **17** (1860), 192-3

TRETIRE, Herefordshire

There are large banks of iron slag in the parish, and a probable smelting site has been located. Roman coins and pottery are frequently found in the area.

BLOOMERY (civil/military)

Watkin 1877

Bridgewater 1968

WALFORD, Herefordshire
Large banks of iron slag in the parish.
BLOOMERY (civil/military)
Watkin 1877

WANBOROUGH, Wiltshire **ST 195855**
Excavations on the western side of Ermin Street revealed buildings ‘with scattered traces of iron smelting’, dated late 1st to 4th centuries AD.
I-IV AD(?): BLOOMERY (civil)
Archaeological Excavations 1968, 20

WELSH BICKNOR, Herefordshire
Large banks of iron slag in the parish.
BLOOMERY (civil/military)
Watkin 1877

WELSH NEWTON, Herefordshire
26/27 Large slag deposits of Roman date near Gwenherrion Farm.
BLOOMERY (civil/military)
Bridgewater 1968

WESTBURY, Wiltshire
A pit from which iron ore was extracted: associated with Roman pottery.
II AD: ORE MINING
Wiltshire Archaeol Mag, **60** (1965), 136

WESTON-UNDER-PENYARD, Herefordshire
The slope on the western side of the town, known as Cinder Hill, is covered with an immense mass of slag and cinder. A number of excavations have revealed buildings dated to the 3rd and 4th centuries containing smelting furnaces; four large hollows containing six shaft furnaces dated to the 2nd half of the 2nd century, with overlying them two further furnaces and a smithing hearth and cutting into both robber trenches containing 3rd century pottery; and a posting station with an estate of c.100ha, surrounded by a belt of furnaces and smithing sites.
(?I AD), II-III AD, (?IV AD): BLOOMERY AND ADMINISTRATIVE CENTRE (civil/military)
Grover 1873
Watkin 1877
Jack 1923, 68-9
N P Bridgewater, *Trans Woolhope Nat Field Club*, **38.2** (1965), 124
Bridgewater 1968
Vict County Hist Herefordshire, **I**, 171, 187

WHITCHURCH, Herefordshire
Large slag heaps everywhere in the parish, which seems to be built upon a thick layer of iron slag. Decorated samian has been found at a depth of over 2m in these heaps.
BLOOMERY (civil/military)
Grover 1873 27/28
Watkin 1877
Wyrall 1877-8
N P Bridgewater, *Trans Woolhope Nat Field Club*, **36.2** (1959), 228; **38.1** (1964), 88
Bridgewater 1968

WIGPOOL COMMON, Mitcheldean, Gloucestershire
Roman iron-ore workings near slag-metalled road between ARICONIVM (Weston-under-Penyard) and Frogmore. Possible source of ore for the Ariconium bloomeries.
ORE MINING (civil/military)
I Cohen, *Trans Woolhope Nat Field Club*, **34** (1952-4), 161-77
Bridgewater 1968

1.5 West Midlands

CHESTER
Slag was found on part of the *vicus*
FORGE (civil)
J Newstead, *Liverpool Ann Archaeol Anthropol*, 1914, 121

DROITWICH, Worcestershire
A middle-sized house on the higher slopes of the Roman town produced some forging slag, which was also found in the fill of the ditch round the 1st century temporary camp.
I-II AD: FORGE (military: civil)
J K S St Joseph, *Trans Birmingham Archaeol Soc*, **64** (1941-2), 39-52

HERONBRIDGE, Cheshire
Iron slag was found with other metalworking residues on this industrial site, associated with the XX Legion fortress.
II-IV AD: FORGE (military)
J Roman Stud, **46** (1956), 125-6
28/29

NORTHWICH, Cheshire
Six smelting furnaces were found in an area lying outside the auxiliary fort; they were set in lean-to sheds. Low-grade ore from the nearby Cheshire Beds was being roasted in a working area adjacent to the bloomery furnace. Dated late 1st to early 2nd century.
I-II AD: BLOOMERY (military)
Archaeological Excavations 1968, 1l-2; 1972, 42-3
Short reports in *Britannia* and *J Roman Stud* 1969, 1971, and 1973

STRETTON-ON--FOSSE, Warwickshire **SP 215383**
Farmstead settlement, with iron and bronze slag in small building containing working plinth, hearth, and clay-lined water tank. Coin of 4th century.
IV AD: FORGE (civil)
P J Garner & B Haldon, *West Midlands Archaeol News Sheet*, **18** (1975), 46

TIDDINGTON, Warwickshire
This industrial site comprises a tile kiln, water cistern, washing tank, ore roasting facility, iron-smelting furnaces, and a lead-smelting cupola. The furnace was made of clay-lined stone, and set on a built-up platform. The coins cover the period 1st to 4th centuries.
I-IV AD: BLOOMERY (civil?)
Fieldhouse et al 1931
Tylecote 1962, 235

WALL, Staffordshire **SK 098066**
A metal-working furnace with much associated iron, including nails, and lead fragments, was associated with a stone building, dated to c.120. There is a considerable amount of iron slag elsewhere on the site.
29/30 II AD: FORGE (military)
J T Gould, *Trans Lichfield Staffordshire Archaeol Hist Soc*, **6** (1964-5), 1-18
A A Round, *West Midlands Archaeol News Sheet*, **18** (1975), 50-2

WHITCHURCH, Shropshire
A shaft furnace, together with smelting slag and charcoal, was found in the later phases of the civil settlement which replaced an earlier auxiliary fort.
III-IV AD: BLOOMERY (civil)
G D B Jones & P V Webster, *Archaeol J*, **125** (1968), 210-11
Kelly 1976

WORCESTER
Slag ‘from thousands of years ago’ (Yarranton l698) was used for re-smelting in the 17th and 18th centuries, mixed with slags and ores from the Forest of Dean. This was found around the walls of the Roman and medieval town, where considerable deposits have remained, to be revealed in recent excavations. The date range appears to cover most of the Roman period.
(?I AD), II-IV AD: BLOOMERY (civil)
A Yarranton, *England’s Improvement by Sea and Land* (1698)
Grover 1873
Vict County Hist Worcestershire, **I**, 203

WROXTER, Shropshire
Atkinson found charcoal and iron slag in the eastern side of the Forum, and a furnace built up against the back wall of the colonnade of the east portico. Another furnace was found in West Room I. These features all postdated the second fire, and were in prolonged use.
IV AD: FORGE (civil)
J P Bushe-Fox, *Excavations at Wroxeter* I (1912), p1 **III**, fig 11 30/31
Atkinson 1942, 9-10, 15, 108-9, 111
Tylecote 1962, 236

1.6 East Midlands

CLAXBY, Lincolnshire
Evidence of Roman working revealed by modern ore mining.
BLOOMERY (civil)
J W Key, *Mining J*, **6** June 1896, 734

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CLIPSHAM, Lincolnshire
A villa settlement, with much tap slag and forging cinder around. This appears in the latest phase of the settlement, when the villa as such had been abandoned.
IV AD: BLOOMERY (civil)
J Roman Stud, **16** (1926), 223; **19** (1929), 193; **30** (1940), 169; **45** (1955), 89
R F Tylecote, *Bull Hist Metallurgy Group*, **4** (1970), 24-7
M Todd, *The Coritani* (1973), 106-10

COADBY MARWOOD, Leicestershire
Observation of modern iron-ore open-casting mining revealed numerous shallow pits, oval in plan, containing calcined stone and slag/cinder, with much iron scrap around. Dated by coin hoard and pottery to 3rd century.
III AD: FORGE (civil)
R Abbott, *Trans Leicestershire Archaeol Hist Soc*, **32** (1956), 17-35

COLSTERWORTH, Lincolnshire
A box of hardened clay was revealed on excavation (see Chapter 4.5: The production of steel). No evidence of smelting in area investigated. Dated by pottery to late 1st
31/32 century-2nd century.
I-II AD: FORGE (civil)
Hannah 1932, 262-8
Grantham Public Library and Museum, 10th Annual Report (1931-2), 14-19

CORBY GLEN, Grantham, Lincolnshire
Large heaps of bloomery slag containing Romano-British pottery.
BLOOMERY (civil)
Bull Hist Metallurgy Group, **1.3** (1964), 9-10

DERBY
Excavations on the Racecourse Playing Fields revealed 15 hearths or furnaces of various types, both bowl-shaped and oblong. Cinder in association was from iron-working rather than smelting.
FORGE (civil)
Archaeological Excavations 1974, 39-40

MARGIDVNVM, Nottinghamshire
Iron slag was found on clay floors, associated with a series of rectangular pits, just below the south rampart. Pottery was early.
I AD: FORGE (civil)
F Oswald, *Trans Thoroton Soc*, **31** (1927), 55-84

PICKWORTH, Lincolnshire **TF 002148**
Two shaft furnaces, dated to 100-150, were found in a sand quarry. They had been built into the side of a sandpit of Roman date and had a common slag-tapping pit. They were c.1.4m high and 0.25m internal diameter. They worked on nodular ore.
II AD: BLOOMERY (civil)
J Roman Stud, **52** (1962), 173 32/33
R F Tylecote, *Bull Hist Metallurgy Group*, **4** (1970), 24-7
J B Whitwell, *Roman Lincolnshire* (1970), 113-5

SAPPERTON, Lincolnshire
Iron slag was found everywhere on the site, but no smelting furnaces. There were four hearths ‘which may relate to some form of iron processing’.
II-IV AD: FORGE (civil)
Archaeological Excavations 1974, 52

SCAWBY, Lincolnshire
A large amount of slag was found near Moor and Top Farms: it was reused in the 19th century for road-making. No furnaces were found.
BLOOMERY (civil)
Dudley 1949

THEALBY, Lincolnshire
Iron smelting furnaces of the shaft type were found with their bases dug into the bedded ironstone: the upper parts were made from large stones. They were filled with iron slag, which was very common in the area. Pottery dated the workings to the 2nd to 4th centuries.
II-IV AD: BLOOMERY (civil)
Dudley 1949, 142-3

WINTERTON, Lincolnshire **SE 911182**
The yard to the south of the main building was given over to ironworking in the late 4th century.
IV AD: FORGE (civil)
Archaeological Excavations 1973, 12
33/34

1.7 South Midlands

ABINGDON, Oxfordshire
A smithy, consisting of two rooms, one containing a hearth, was built on this agricultural settlement in the late 4th century.
IV AD: FORGE (civil)
CBA Group 9 Newsletter, **5** (1973), 39-40; **6** (1976), 64

ASTHALL, Oxfordshire
W G Hoskins describes this as a Roman ironmaking site (Making of the English Landscape), but the exact reference seems to be obscure and uncertain.

BARNACK, Northamptonshire
Iron-smelting furnaces are recorded.
BLOOMERY (civil)
W G Simpson in C Thomas (ed), *Rural settlement in Roman Britain* (1966), 15-25

BULWICK, Northamptonshire **SP 9293**
Six smelting furnaces (Cleere's type B.1.i – see Appendix B) were found on two sites, associated with much slag and opencast pits for nodular ore.
I-III AD: BLOOMERY (civil)
D A Jackson, *Northamptonshire Archaeol*, **14** (1979), 31-7

COLLEYWESTON, Northamptonshire
A floor for ore roasting or iron working was found, with a good deal of slag. Dated to 2nd-3rd centuries.
II-III AD: FORGE (civil)
G M Knocker, *Archaeol J*, **122** (1965), 52-72

GEDDINGTON, Northamptonshire **SP 871824**
34/35 Observation of area being scraped in advance of iron-ore extraction revealed one smelting furnace (probably type B.1.i) and ditches and pits containing 1st century pottery.
I AD: BLOOMERY (civil)
Northamptonshire Archaeol, **9** (1974), 89

GREAT MISSENDEN, Buckinghamshire
A Roman bloomery is recorded.
BLOOMERY (civil)
J F Head, *Rec Buckinghamshire*, **17.4** (1964), 228-31

GREAT WELDON, Northamptonshire
Ironmaking (possible furnace base, slag) in latest phase of villa.
IV AD: BLOOMERY (civil)
J Roman Stud, **44** (1954), 93-5

GRETTON, Northamptonshire **SP 909945 & SP 876922**
One site revealed a scatter of Roman pottery with much iron slag and the other a shaft furnace.
BLOOMERY (civil)
D A Jackson, *Northamptonshire Archaeol*, **14** (1979), 31-7

KINGSCLIFFE, Northamptonshire
Bloomery furnaces were revealed during iron ore mining that were 'possibly Roman'.
BLOOMERY (civil)
Vict County Hist Northants, **I**, 206

LAXTON, Northamptonshire
Possibly Roman bloomery furnaces.
BLOOMERY (civil)
Vict County Hist Northants, **I,** 206 35/36

MAXEY, Northamptonshire
Iron slag on occupation site.
?BLOOMERY (civil)
W G Simpson in C Thomas (ed), *Rural settlement in Roman Britain* (1966), 15-25

OUNDLE, Northamptonshire
Possibly Roman bloomery furnaces.
BLOOMERY (civil)
Vict County Hist Northants, **I**, 206

ROCKINGHAM, Northamptonshire
Possibly Roman bloomery furnaces.
BLOOMERY (civil)
Vict County Hist Northants, **I**, 206

SOUTHORPE, Northamptonshire **TF 073036**
Iron slag associated with pottery of mid 2nd to late 4th centuries.
II-IV AD: ?FORGE (civil)
Northamptonshire Archaeol, **9** (1971), 96

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STANTONBURY, Buckinghamshire
Round house of mid 3rd century with keyhole-shaped hearth in the middle, containing an iron bar.
II AD: FORGE (civil)
CBA Group 9 Newsletter **6** (1976), 41-4, fig 10

THORNHAUGH, Sacrewell, Northamptonshire **TF 077005**
Winged villa of mid 2nd to late 4th century date was converted to industrial use in its final phase. Eight furnaces included at least one certain bloomery furnace (type B.1.i) and a possible ore-roasting hearth.
36/37 IV AD: BLOOMERY (civil)
Northamptonshire Archaeol, **9** (1974), 96-7

WAKERLEY, Northamptonshire **SP 9498**
Ironmaking appears to have begun in the pre-Roman period and to have continued until at least the 3rd century. A number of furnaces, mostly type B.1.i, were found during excavations.
I-III AD: BLOOMERY (civil)
D A Jackson, *Britannia*, **9** (1978), 151-66

WAPPENHAM, Northamptonshire
Possibly Roman bloomery furnaces.
BLOOMERY (civil)
Vict County Hist Northants, **I**, 221

1.8 East Anglia

ASHWICKEN, Norfolk
Series of shaft furnaces built in excavated iron-ore pit, which was later filled with slag and other industrial refuse. The furnaces were built into a bank of sand in the pit. Pottery suggests 2nd century date.
II AD: BLOOMERY (civil)
Tylecote & Owles 1960
R F Tylecote, *J Iron Steel Inst*, **200** (1962), 19-22

BEDFORD PURLIEUS, Huntingdonshire **TF 048997**
Ore-roasting furnaces cut into rock on edge of quarry: filled with burnt stone, ash, charcoal, and slag. Associated pottery late 2nd-early 3rd century.
II-III AD: ORE PREPARATION (civil)
J Roman Stud, **56** (1966), 207
G F Dakin, *Bull Hist Metallurgy Group*, **2** (1968), ii, 66-7

BEESTON REGIS, Norfolk
Pits sunk into greensand for iron ore: Roman material associated. 37/38
ORE MINING (civil)
J Spurrell, *Archaeol J*, **40** (1883), 281
Davies 1935
Vict County Hist Norfolk, **I**, 313

BRAMPTON, Norfolk **TG 220234**
Extensive ironworking debris associated with industrial area to west of Roman town. It seems to be linked with a house of the 3rd/4th centuries.
III-IV AD: FORGE (civil)
Britannia, **1** (1970), 290
Archaeological Excavations 1974, 59

GODMANCHESTER, Huntingdonshire **TL 246705**
A number of iron-working furnaces have been discovered, and also a group of four shaft furnaces (c 0.45m internal diameter), together with a smithing hearth, in a timber-framed strip house alongside Ermine Street. Dating 2nd and 3rd centuries.
II-III AD: BLOOMERY (civil)
J Roman Stud, **55** (1965), 209
Archaeological Excavations 1972, 55
Britannia, **4** (1973), 289

GREAT CASTERTON, Rutland
Excavation of an area adjacent to Ermine Street in the centre of the Roman town produced considerable evidence of iron smelting (tap slag, furnace debris) in association with Roman pottery.
BLOOMERY (civil)
P Corder, *The Roman Town and Villa at Great Casterton, Rutland* (1950)
J Roman Stud, **47** (1957), 212
Archaeological Excavations 1973, 55-6 38/39

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HACHESTON, Suffolk **TM 313567**

This was ‘a discontinuous rural industrial settlement’. A probable smelting furnace was associated with 3rd century grey wares on one part of the settlement, and large pits filled with iron slag and late 3rd/4th century pottery in another area.

III-IV AD: BLOOMERY (civil)

Archaeological Excavations 1974, 63-4

Britannia, **5** (1974), 439

HEYBRIDGE, Essex **TL 850082**

Industrial waste, including ash, charcoal, iron slag, and furnace fragments, was used to level a 2nd century wharf area.

II/III AD: ?BLOOMERY (civil)

MUCKING, Essex

Working hollows contained hearths and forging slag.

?II-III AD: FORGE (civil)

Archaeological Excavations 1966

1.9 Northern counties

BINCHESTER, County Durham

A metal working area for iron and copper alloys was found in the later phase of the fort.

III/IV AD: FORGE (military)

Archaeological Excavations 1971, 54

Britannia, **3** (1972), 309

CHESTERHOLM, Northumberland

A military smithing establishment associated with the fort.

II-IV AD: FORGE (military)

39/40 *Britannia*, **4** (1973), 275

CHESTER-LE-STREET, County Durham

A military smithing establishment associated with the fort.

IV AD: FORGE (military)

J Roman Stud, **54** (1964), 156

CORBRIDGE, Northumberland

The metal-working workshop excavated in this fort contained a special heating furnace used for the construction of the composite blooms used in bath-houses.

II-IV AD: FORGE (military)

B H Forster & W H Knowles, *Archaeol Aeliana*, ser 3, **6** (1910), 1-43

H Bell, *J Iron Steel Inst*, **89** (1912), 117-28

Tylecote 1962, 237-40

DONCASTER, Yorkshire

The Roman industrial settlement at Cantley contained principally pottery kilns, but one iron-smelting furnace of type B.1.i was found, built of small stones set in clay.

II-III AD: BLOOMERY (civil)

S M Cregeen, *Yorkshire Archaeol J*, **153** (1956), 32-47

ESKMEALS, Cumberland

A 4th century occupation site in the sand dunes had considerable ironmaking debris scattered over it, including slag, hematite ore, cinder, and charcoal. There were also some possible smelting furnaces.

IV AD: BLOOMERY (civil)

J Cherry, *Trans Cumberland Westmorland Archaeol Soc*, **66** (1966), 44-56

HALTON, Northumberland

A military smithing establishment associated with the fort.

II-IV AD: FORGE (military) 40/41

J Roman Stud, **49** (1959), 106

HOUSESTEADS, Northumberland

A military smithing establishment attached to the fort.

II-IV AD: FORGE (military)

R C Bosanquet, *Archaeol Aeliana*, **25** (1904), 241

LANCHESTER, County Durham

Possible smelting establishment to supply iron to troops on Wall. Description suggests that two shaft-type furnaces were found.

III-IV AD: BLOOMERY (military)

Grover 1873, 123

J Collingwood Bruce, *The Roman Wall* 11th ed, 432-4

LEVISHAM, Yorkshire **SE 830922**
Domed furnace (type B.1.ii), built of clay, slag, and stones and overlying remains of earlier furnaces. Centrally sited in round Iron-Age type hut. Using nodular ore, available locally. Small quantity of Iron-Age pottery
(c.60-90); Roman material in adjacent sites.
I AD: BLOOMERY (civil)
Bull Hist Metallurgy Group, **4** (1970), 79

MANCHESTER, Lancashire
Extensive excavation of *vicus* of Roman fort of MANVCIVM in 1972-3 produced over 30 furnaces. Most are forging hearths, but excavator claims that three were used for smelting. This is difficult to substantiate from the evidence presented, especially since no tap slag was identified. However, one of the structures appears to be a box-like furnace of the Colsterworth type. Four types of smithing hearth were classified: P.1 – an irregular clay area with random perforations; P.2 – irregular with elongated channel or trough; P.3 – circular, with perforations around bowl; P.4 – circular with
41 perforations around and within bowl.
42 II-III AD: FORGE (civil)
Jones & Grealey 1974, 67-75, 143-57

PAPCASTLE, Cumberland
A building outside the wall of the Roman fort contained two areas of intensive burning, associated with a large amount of iron slag.
II-IV AD: FORGE (military)
CBA Group 3 Archaeol Newsbulletin, **14** (1976)

TEMPLEBOROUGH, Yorkshire
Military smithy inside fort, large quantities of iron slag. Water tanks lined with sandstone and sandstone anvil block. Descriptions of structure suggest smelting as well as forging.
I-II AD: BLOOMERY (military)
T May, *The Roman Forts of Templeborough near Rotherham* (1922), 55 ff.
D Greene, *The Roman Roads in the Don Valley. The Roman fort Templeborough – the western approach* (n.d.), 14

WATERCROOK, Cumberland
'Debris from ironworking' on Roman fort.
II-IV AD: FORGE (military)
Archaeological Excavations 1974, 38-9

WILDERSPOOL, Warrington, Lancashire
A major industrial settlement, with pottery manufacture and iron smelting and working. Several types of furnace, including bloomeries and forging hearths. Evidence of dating somewhat sketchy, and no indication of military involvement.
II-III AD: BLOOMERY (?civil) 42
May 1904, 18 ff. 43
Tylecote 1962, 234-6

YORK
Specimens of slag from the south corner tower of the legionary fortress were identified as forging cinders: debris from legionary workshops? The city has also produced a tombstone, now in the Yorkshire Museum, with an effigy in relief of a smith with his tools (hammer, tongs, etc).
II-IV AD: FORGE (military)
J H Wright, pers comm

1.10 Wales

ABERFFRAW, Anglesey
Forging hearths and slag on auxiliary fort.
II-IV AD: FORGE (military)
R White, pers comm

BOLSTON GAER, Glamorgan
A considerable amount of slag is recorded as having been dug out from the site of this civil settlement in the mid 18th century for re-smelting: an Antonine coin and much Roman pottery was found in the process.
II AD: ?FORGE (civil)
Wheeler 1925, 272-3

BRAICH-Y-DDINAS, Caernarvonshire
Excavations on a native hillfort produced much slag, high-grade hematite ore, and an iron bloom.
I-IV AD: BLOOMKRY (civil)
H Hughes, *Archaeol Cambrensis*, **68** (1913), 353-66
H Hughes, ibid **78** (1923), 243-68 43
44

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BRYN-Y-GEFEILIAU, Caernarvonshire
Forging slag on auxiliary fort.
II-IV AD: FORGE (military)
J P Hall, *Caer Llugwy* (1923), 16-18

CAE'R MYNYDD, Caernarvonshire
A forging hearth with much slag found in native homestead.
II-IV AD: FORGE (civil)
W E Griffiths, *Antiq J*, **39** (1959), 33-60

CAERAU, Caernarvonshire
A native homestead settlement, with a small building enclosing a forging hearth surrounded by slag and charcoal.
II-IV AD: FORGE (civil)
B H St J O'Neil, *Antiq J*, **16** (1936), 295-320

CARDIFF, Glamorgan
Much slag recorded in fort and *vicus* where main roads were slag-metalled. Slag appears to have been mostly from forging rather than smelting, but some possible smelting residues have resulted from recent (1979) excavations.
I-IV AD: FORGE (military, civil)
Wheeler 1922
Wheeler 1925, 272-3
Davies 1935
P V Webster, pers comm.

CEFN GRAENOG, Caernarvonshire
Forging and smelting operations being carried out in the earlier phases of occupation of a native homestead.
I-II AD: BLOONERY (civil)
A H A Hogg, *Trans Caernarvonshire Hist Soc*, **30** (1969), 8-20

44/45

COED NEWYDD, Anglesey
A smithy on a native settlement, defined by stones, which may form the footings for a timber-framed wall. Floor covered with deep layer of coal dust and slag, with two iron bars. A coal bunker in one corner, but no identifiable hearth.
?II-IV AD: FORGE (civil)
E N Baynes, *Archaeol Cambrensis*, **75** (1920), 91-8

COED UCHAF, Caernarvonshire
Forging hearth and slag in a hut on a native homestead site.
I-III AD: FORGE (civil)
RCAHM *Caernarvonshire* **I** (1956), 148

COED-Y-BRAIN, Caernarvonshire
Smelting and forging slags found in association with a hearth in a small building on a native homestead settlement.
I-IV AD: BLOOMERY (civil)
H Williams, *Archaeol Cambrensis*, **78** (1923), 291-302

DIN LLIGWY, Anglesey
Seven huts on a low cliff, built of dry stone with rubble filling, contained a variety of materials and structures associated with ironmaking and metal working (including silver and lead). Several smelting furnaces (type B.1.i or B.1.ii) of 0.30-0.50m diameter were found in one of the huts, on or below the final floor level.
III-IV AD: BLOOMERY (civil)
E N Baynes, *Archaeol Cambrensis*, **63** (1908), 183-210
E N Baynes, ibid **85** (1930), 375-93

DINAS EMRYS, Caernarvonshire
Native homestead with considerable ore and slag refuse, a possible shaft furnace, and a smithing hearth. 45/46
IV-V AD: BLOOMERY (civil)
H N Savory, *Archaeol Cambrensis*, **109** (1960), 13-77

DINORBEN, Denbighshire
Slag and a high-grade bloom of highly carburized iron were found on a native hillfort.
I BC-V AD: FORGE (civil)
Davies 1935
W Gardner & H N Savory, *Dinorben* (1964), 108-9
H N Savory, *Trans Denbighshire Hist Soc*, **20** (1971), 9-30

DYSERTH CASTLE, Flintshire
Slag found on native settlement.
IV AD: FORGE (civil)
T A Glenn, *Archaeol Cambrensis*, **70** (1915), 74
E Davies, *The Prehistoric and Roman remains of Flintshire* (1949), 109-17

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ELY, Glamorgan
Excavation of a villa, dating from the early 2nd century, produced abundant evidence of iron working and probably also smelting. A small hearth of c.0.20m diameter was surrounded by slag, 'clinker', and iron ore (Rhwbina and Wenvoe hematite); there was also a 'casting floor' of sand (which seems more likely to have been a forging hearth). Much of the open space was paved with iron slag. A small dump of manganese ore was identified as coming from Spain. The excavator's opinion was that this villa establishment was based on ironmaking.
II-IV AD:BLOOMERY (civil)
J Storrie, *Cardiff Nat Soc Rep Trans*, **26.2** (1893-4), 125-8, 129-33
Wheeler 1922

46/47

FORDEN GAER, Montgomeryshire
Forging hearths and slag on an auxiliary fort.
II-IV AD: FORGE (military)
F N & T D Pryce, *Montgomeryshire Collect*, **40** (1929), 193
O Davies, ibid **45** (1938), 156-7
Kelly 1976

HAFOTY WERN LAS, Caernarvonshire
Smithing establishment, comprising hearth in small building, with much slag and charcoal, on native homestead site.
II-IV AD: FORGE (civil)
H Williams, *Archaeol Cambrensis*, **78** (1923), 87-113
Kelly 1976

HOLT, Denbighshire
Iron slag was found in the workshops of the XX Legion, and also some possible forging hearths.
I-III AD: FORGE (military)
W F Grimes, *Y Cymmrodor*, **41** (1930), 129
Kelly 1976

LLANHARRY, Glamorgan
Roman pottery was found in the refuse from hematite ore workings at Ty-isaf and Llechau.
ORE MINING (civil?)
Wheeler 1925, 272-3

MOEL HIRADDUG, Flintshire
A Roman bronze shield and helmet were found in opencast hematite workings.
ORE MINING (military?)
Bromehead 1947, 362
E Davies, *The Prehistoric and Roman remains of Flintshire* (1949), 100 47/48
Mem Geol Survey, *Special Reports on the Mineral Resources of Great Britain*, **9** (1919), 16
Kelly 1976

MURIAU'R DREF, Caernarvonshire
Slag and charcoal found in a native hut settlement.
I-IV AD: FORGE (civil)
G C Chambers, *Archaeol Cambrensis*, **58** (1903), 282-4
RCAHM *Caernarvonshire,* **II**, lix, 27

PARC SALMON, Anglesey
Forging slag on native hut settlement.
II-IV AD: FORGE (civil)
RCAHM *Anglesey* (1937), 135
Kelly 1976

PARCIAU, Anglesey
Slag on hillfort.
II-IV AD: FORGE (civil)
RCAHM *Anglesey* (1937), 63

PEN LLYSTYN, Caernarvonshire
A substantial quantity of slag was found up against the north-eastern rampart of the auxiliary fort.
II-IV AD: FORGE (military)
A H A Hogg, *Archaeol J*, **125** (1968), 122

PEN-Y-BONC, Anglesey
Slag, forging hearth, and tuyere on occupation site (native).
II-IV AD: FORGE (civil)
W O Stanley, *Archaeol J*, **27** (1870), 147

PEN-Y-GROES, Caernarvonshire
48/49 Forging slag on occupation site.
FORGE (civil)
H Williams, *Archaeol Cambrensis*, **77** (1922), 335
Davies 1935

RHOSTRYFAN, Caernarvonshire
Forging slag on occupation site.
FORGE (civil)
Davies 1935
H Williams, *Archaeol Cambrensis*, **77** (1922), 335; **78** (1923), 87-113; 291-302

TREFEGLWYS, Montgomeryshire
Roman coins found in association with slag.
I-II AD: FORGE (civil)
RCAHM *Montgomeryshire* (1911), l74-5
Davies 1935, 58

TREGARTH, Caernarvonshire
Slag on occupation site.
FORGE (civil)
Davies 1935

TY MAWR, Caernarvonshire
Slag, tuyeres, and iron ore found near hut settlement, together with small forging hearth.
II-IV AD: ?BLOOMERY (civil)
W O Stanley, *Archaeol J*, **26** (1869), 310-11; **27** (1870), 147-64
B H St J O'Neil, *Archaeol Cambrensis*, **95** (1940), 65-74

Y BREIDDIN, Montgomeryshire
A hearth or furnace base, with ore and slag around it, was found in the area outside a
49/50 hut dated to the Romano-British period located in this hillfort.
I-IV AD: BLOOMERY (civil)
B H St J O'Neil, *Montgomeryshire Collect*, **43** (1934), 104-6, 166-7
B H St J O'Neil, *Archaeol Cambrensis*, **92** (1937), 111-12

1.11 Scotland

BAR HILL, Lanarkshire
Forging slag on Antonine Wall fort.
II AD: FORGE (military)
Davies 1935

CARPOW, Perthshire
Filling of ditch on north side of fort contained a layer of slag and furnace bottoms c.0.15m deep; also a single tuyere built into part of a section of furnace wall.
III AD: ?BLOOMERY (military)
Bull Hist Metallurgy Group, **4** (1970), 3
J Roman Stud, **58** (1968), 177

CASTLELAW, Midlothian
A defended native site on the south-east slopes of the Pentland Hills included an earthen house with an attached beehive hut, containing two hearths. One may be base of bloomery furnace, containing much slag and charcoal; there was an iron bloom opposite the entrance in the floor rubbish.
II AD: BLOOMERY (civil)
V G Childe, *Proc Soc Antiq Scotland*, **67** (1932-3), 362-88
V G Childe, *The Prehistory of Scotland* (1935), 226

CONSTANTINE'S CAVE, East Fife
A walled cave contained in its thick occupation layer much slag and charcoal,
together with 2nd century samian and amphora sherds. A stone lined depression in 50/51
the middle of the cave showed signs of heavy burning and was surrounded by iron slag. Many fragments of burnt clay represent remains of the superstructure.
II AD: BLOOMERY (civil)
Wace & Jehu 1914-l5, 233-55

CROY HILL, Dunbartonshire
Slag in Antonine Wall fort.
II AD: FORGE (military)
Davies 1935

INCHTUTHILL, Perthshire

About seven tons of iron nails, all unused, were found in a pit dug into the floor of the legionary workshops and sealed with a layer of sand before demolition. One small hearth was found inside the ramparts, probably for forging.

I AD: FORGE (military)

N S Angus, G T Brown, & H F Cleere, *J Iron Steel Inst*, **200** (1962), 956-68

H F Cleere, unpublished report

RUDH' AN DUNAIN, Skye

An Early Bronze-Age settlement, reoccupied in the Roman period, produced the remains of a stone-built smelting furnace, set into peaty soil. There was bloomery slag and some ore.

?I AD: BLOOMERY (civil)

Scott 1933-4, 200-23

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51/52 2 Geographical Distribution of the Industry

2.1 Iron ores in Britain

Iron is the second most common metal on the earth's surface, but it does not always occur in a form that is readily reducible so as to produce pure metal. The iron sands, high in silica and often also in titanium, that occur widely are still not economically workable. Other forms of iron ore vary from the black magnetite, containing 70% and more of iron, to the clay ironstones of central England, with an iron content as low as 22%.

The western provinces of the Roman Empire were well endowed with rich iron ores. The most famous in antiquity was that from Noricum, where the celebrated Erzberg was being mined in pre-Roman times. Norican iron, *ferrum Noricum* made from the manganiferous spathic (carbonate) ore of the region, was hard yet ductile; it was, in fact, a natural iron-manganese alloy, comparable in mechanical properties with modern steel, arid was greatly in demand throughout the Empire. Other major deposits worked by the Romans were those of Asturias in northern Spain and the ores of Lorraine on which the modern French iron and steel industry was founded. These were the major deposits worked by the Romans, but they were not the only ones; wherever iron ore was discovered in a readily workable form it was mined and smelted, usually to meet local requirements.

Britain is remarkably rich in iron ore, and it was this fact, combined with the other great mineral wealth in the form of coal, which was responsible in no small measure for England's role in initiating the Industrial Revolution. However, the British ores are for the most part not rich ones; they cannot compare with the magnetites of Lapland or the Carinthian ores. They range from the Cumberland and South Wales hematites containing 50-80% iron to the lean Jurassic ores of Lincolnshire and Northamptonshire, with no more than 20-30% iron.

Virtually no iron ore is now being mined in Britain. Until recently it was still
52/53 being exploited on an industrial scale on the Jurassic belt, from Oxfordshire to Lincolnshire, in the Cleveland hills, and in Cumberland. The report of the Imperial Mineral Resources Bureau on iron ore in the United Kingdom (1922) lists iron ore in no fewer than twenty-seven of the historic English counties – Cornwall, Cumberland, Derbyshire, Devon, Durham, Gloucestershire, Hampshire, Herefordshire, Kent, Lancashire, Leicestershire, Lincolnshire, Northamptonshire, Nottinghamshire, Oxfordshire, Rutland, Shropshire, Somerset, Staffordshire, Surrey, Sussex, Warwickshire, Wiltshire, Worcestershire, Yorkshire, and the Isle of Wight – as well as North and South Wales, Scotland, and the Isle of Man. It will be seen that very few regions of Britain are far from a source, however small, of iron ore that is reducible in a simple bloomery furnace of the primitive type. In addition, there were doubtless many deposits of bog ore in antiquity, widely distributed over Britain, which were totally mined away or which were too small to warrant notice in the IMRB report.

2.1.a Types of iron ore

The four principal sources of iron available in nature are magnetite, hematite, hydrated, and carbonate ores; these consist of varying quantities of iron oxides and carbonates. In addition, there are sulphide minerals (pyrites and marcasite) and compounds of iron and titanium such as ilmenite. These are difficult to reduce to produce iron and were almost certainly not used in early ironmaking practice. However, recent indications from the Butser Ancient Farm Project (P J Reynolds, pers comm) suggest that de-sulphurized marcasite nodules, which occur quite plentifully in certain Chalk areas and have been shown to be highly reducible minerals (F Fitzgerald, pers comm) may have served as burden materials for domestic-scale ironmaking operations in the pre-Roman Iron Age, and even possibly in the Roman period.

Magnetite is the richest source of iron. It is a black magnetic mineral containing very high proportions of ferroso-ferric oxide (Fe_3O_4). It is usually found in contact with or included in igneous or metamorphic rocks. The only deposit known in Britain appears to be a small lode at Haytor in Cornwall. It was not worked during the Roman
period. 53/54
Hematite is principally ferric oxide (Fe_2O_3); when it is pure the iron content is 60-70%. In colour it is mainly reddish-brown, and its colour gives rise to its name (from the Greek word for blood). The iron content of hematite deposits varies widely. The pure form is comparatively rare in Britain; the best deposits are those in Cumberland, the Furness area of Lancashire, and parts of South Wales, all of which average about 50% Fe. Pure hematite (eg the kidney ores of Cumberland) is somewhat difficult to reduce with the temperature and reducing conditions that could be achieved in the bloomery smelting furnaces of the type used in antiquity.

Hydrated ores cover a number of minerals containing large proportions of hydrated ferric oxide, the principal ones being limonite ($2FE_2O_3.3H_2O$) and geothite ($Fe_2O_3.H_2O$). These ores usually occur as bedded masses; the so-called 'bog ores' are of this type. They are relatively easy to reduce in bloomery furnaces.

Carbonate ores cover those important deposits containing iron carbonate ($FeCO_3$); they are variously known as chalybite, siderite, and spathic ore. The iron content of the pure ore is high, but pure ore is very rare indeed; the carboniferous clayband and blackband ores of Britain generally contain about 30% Fe and that from the Wadhurst Clay in the Wealden series around 40%.

It should be borne in mind that iron ore does not occur in compact homogeneous deposits, and that various different types of iron ore may be mixed in the same deposit. This is due to the manner of formation of the ore and to its subsequent geological history. Thus, both hematite and carbonate lodes may be affected by exposure and weathering. The compact hematite becomes hydrated to form limonite or geothite, whilst the carbonate is oxidized to form ferric oxide, almost invariably in

hydrated form. The most normal form of iron ore deposit will therefore consist of a core of relatively pure hematite or carbonate ores, the upper surface of which has been transformed to ‘the hydrated ferric oxide form to varying depths. In the following classification of British iron ore sources, the deposits are classified according to the
54/55 main constituent of the lode.

2.1.b Iron ore deposits in Britain

In the following survey the ores are classified under three main headings – hematite, hydrated ore, and carbonate ore. It should be stressed that the ore deposits are those that have been examined in the last century to assess their economic value to the modern industry. Almost all have been worked until comparatively recent times, with the exception of the Wealden deposits, which do not appear to have been worked since the 18th century (apart from a very short-lived attempt to mine ore at Snape, near Wadhurst, in the mid-19th century, which closed down after less than one year’s operation).

The survey does not take into account very small isolated pockets of ferruginous material that are known to exist, or whose former existence may be postulated, in areas not mentioned in the survey, and which may well have been large enough to justify exploitation for purely local or-domestic purposes in Roman times. The best example is probably that of Norfolk, which supplied the shaft furnaces at Ashwicken, near King’s Lynn. This ore source does not earn a mention in either Kendall (1893) or the report of the Imperial Mineral Resources Bureau (1922), the two main sources of this chapter.

Hematite

West Cumberland and Lancashire

Deposits of low-phosphorus hematite containing an average of 60-65% Fe occur in the Carboniferous Limestone along the coast of Cumberland and Lancashire between Whitehaven and Ulverston in a belt about 8km wide. In addition there are small lodes of the ore in the central Lake District.

The ore occurs chiefly in compact masses of brownish or purple to bluish-grey; there are also deposits where ‘kidney ore’, which takes its name from the characteristic shape, is mined. Another form of hematite, the bright specular ore, was at one time mined in this area. This, like the attractive kidney ore, must have been especially conspicuous from the point of view of the primitive prospector, but it would have been difficult to smelt.

55/56

South Wales

Hematite deposits have been found in many parts of the Carboniferous Limestone in South Wales, bordering on the South Wales coalfield. The largest ore bodies lie to the south-east of the coalfield, in the so-called Taff’s Well-Llanharry orefield, between Cardiff and Bridgend. In the orefield itself the main lodes lie on the top of the Main Limestone. There is an admixture of hydrated ore (geothite), but the bulk is hematite, which occurs in large well defined masses. The average iron content is 50-55%.

Cornwall and South Devon

Small deposits of hematite occur in the granite at Brixham, Newton Abbott, St Austell, and Launceston. The iron content is about 55%, and the ore is found as massive lumps of reddish material or in the specular form.

A more mixed deposit is the Great Perran lode near Newquay, which includes hematite, limonite, and carbonate ore.

North Wales

Small pockets of hematite appear in the Carboniferous Limestone of North Wales, chiefly in the northern part of Flintshire (eg Moel Hiraddug) and adjacent counties. The iron content of the ore appears to be between 45% and 57%.

Derbyshire

Hematite again occurs in the Carboniferous Limestone in parts of Derbyshire, particularly near Hartington and Newhaven. It is reported that pockets of the ore occur very close to the surface.

Bristol, West Somerset, and North Devon

A number of places in this region have small pockets of hematite, some of it hydrated to limonite or goethite. It occurs in the Carboniferous Limestone and also in the Dolomitic Conglomerate of the Triassic. Among the locations of the ore are Westbury, Clifton, Winford, Blagdon, Wells, Wookey, Long Ashton, Banwell, Yatton, Radstock,
Minehead, Exmoor, North Molton, Barnstaple, Ilfracombe, and the Brendon and Eisen 56/57
Hills. The ores appear to have an average iron content of about 27-34%.

Hydrated Ores

Forest of Dean

Iron ores are found in the Forest of Dean region in both the Carboniferous Limestone and in the Drybrook Sandstone, which lie on the rim of the coalfield basin. They occur chiefly in narrow deposits, but these occasionally open up to form large pockets. The ore bodies vary greatly in shape and in distribution; however, the majority are concentrated along the top of the Crease Limestone.

The major constituent is limonite, although there is some admixture of hematite. Three grades are recognized: brush ore (a hard dark brownish-purple cellular limonite), smith ore (a powdery or gravelly limonite), and grey ore (a mixture of brush ore and dolomite). The smith ore represents about two-thirds of the whole, and the separate grades are difficult to keep distinct in mining. The average iron content of the mixed ore is about 30-35%.

South Wales

The Taff's Well-Llanharry orefield also produces a considerable amount of limonite, but it is largely distinct from the hematite mentioned earlier. In form it is very similar to the Forest of Dean ore, although there is a proportion of softer ore, brownish-yellow in colour. The iron content varies between 30% and 45%.

Kent

The only other deposit of hydrated ore of any interest is the brown sandy ironstone in the Oldhaven Beds (Tertiary) in East Kent. It occurs between Faversham and Canterbury, at Broughton-under-Blean and Harbledown. It appears to be fairly high in iron, but no accurate analyses are available.

Carbonate Ores

Jurassic ores

The Jurassic strata in Britain outcrop between the Yorkshire and Dorset coasts; they
57/58 consist of clays, sands, and limestones, bedded almost horizontally. There are a number of ironstone deposits, but they do not form continuous beds.

The ironstones occur in four horizons – the Corallian Beds, the lower part of the Inferior Oolite, the upper part of the Middle Lias, and the middle part of the Lower Lias. With the exception of the first-named group, which is a very small one, all these ores were worked on a very large scale until very recently in Northamptonshire, Rutland, Lincolnshire, and the Cleveland Hills.

There are two main outcrops of the ore bed in the **Upper Corallian** – at Westbury (Wilts) and at Dover. As in all the Jurassic deposits, the ore is iron carbonate, but oxidized on its upper surface to hydrated hematite. At Dover the process of oxidation has gone so far that there is almost no carbonate left. The iron content is about 30% and that of silica between 8% and 15%; the lime content is variable, between 4% and 11%. The silica/lime ratio is such that the ore is not 'self-fluxing', ie the gangue material cannot be separated from the reduced metal without addition of extra lime or loss of iron in the slag.

The **Inferior Oolite** covers a considerable area of Northamptonshire and Rutland, and consists of a carbonate ore in oolitic form. The upper portion is largely oxidized to hydrated hematite; in addition there are pockets of spathic ore. Naturally, over such a large area the composition of the ore varies greatly. However, the average iron content is about 32.5%, with around 14.5% silica and 3% lime. It will be seen that this ore too is not self-fluxing, and in modern practice it is generally mixed with a more calcareous ore before being fed to the blast furnace.

Like the ore of Northamptonshire and Rutland, the **Middle Lias** ore of south Lincolnshire, Leicestershire, Oxfordshire, and Cleveland is a ferriferous oolitic limestone, oxidized on its upper surface to hydrated hematite. The oxidation is more thorough in Cleveland, where the iron content is correspondingly higher. There are
three main divisions, and their compositions show distinct differences: 58/59

	Average Fe %	**SiO_2 %**	**CaO %**
Cleveland	28.1	14.7	2.7
S Lincs, Leics	25.2	10.9	9.6
Oxfordshire	24.0	10.2	12.2

The silica/lime ratio in the Oxfordshire ore is almost sufficient to make it self-fluxing, but the Cleveland stone is very siliceous.

The Frodingham ore from the **Lower Lias** in the Scunthorpe district of north Lincolnshire is once again a ferriferous limestone, with a distinct oolitic structure. It shows the familiar pattern of a basically carbonate ore oxidized to hydrated hematite on its upper surface. However, there is one significant difference between this and the other Jurassic ores, in that it is calcareous (except for a thin siliceous capping), which makes it strongly self-fluxing. The average composition is 22.7% Fe, 8.1% SiO_2, 18.2% CaO. It is, however, a very sticky ore, which causes mechanical problems in modern ironmaking plants, but should have presented no difficulties for early bloomery operators.

Carboniferous Clayband and Blackband Ores

The British iron and steel industry of the early modern period was largely based on these ores, which occur in the coalfields. Once Abraham Darby III had learned how to make pig iron with coke in 1709, these ores assumed a new importance, since the coalfields thus produced both the raw materials needed for successful coke ironmaking. The distribution of Roman ironmaking sites shows that their potential was realized equally at that period.

The blackband ironstones are argillaceous carbonates containing sufficient carbonaceous material to support combustion, and can be calcined without the use of additional fuel. The clayband ores differ only in that their carbonaceous content is much smaller. Both types occur as nodules and thin beds in the Coal Measures. Their silica content is lower than that of the Jurassic ores, but the alumina content is much
higher, and so they are not easily reducible without using limestone additions (or by 59/60
sacrificing iron yield). The iron content is generally not high, averaging about 35%.

The main areas are as follows, in every case in association with existing or former coalfields:

1	Northumberland and Durham	Hareshaw, Redesdale. Haltwhistle, Nenthead, Haydon Bridge, Shotley Bridge, Consett
2	Yorkshire	Along the outcrop of the coalfield between Leeds and Bradford
3	Derby and Nottingham	Sheffield (Thorncliffe) to Ripley (especially Dronfield and Chesterfield)
4	Warwickshire	Tamworth to Coventry
5	South Staffordshire and Worcestershire	Dudley, Netherton
6	North Staffordshire	The Potteries, Cheadle
7	Shropshire	Coalbrookdale, Bridgnorth
8	North Wales	Flint, Denbigh
9	Cumberland	Workington, Maryport
10	Gloucestershire and Somerset	The Bristol district
11	South Wales and Monmouthshire	Llanfabon, Risca, Pontypool

Miscellaneous deposits

In **North Wales** there are small deposits of carbonate ore, of the Ordovician period, at Llandegai, near Bangor, and at Aber, near Llanfairfechan. The iron content varies between 27% and 37%. However, their silica content is in places as high as 50%, which makes them virtually impossible to smelt alone, or without considerable fluxing (when the volume of slag produced becomes enormous).

A patch of ferruginous sandstone emerges from the Chalk near Kirkby Underdale in east **Yorkshire** The iron content is about 30%. There is also some tabular ironstone at Goodmanham, near Market Weighton, which is of very high quality (50%
60 Fe).

61 In addition to the Jurassic ores of Frodingham and south **Lincolnsh**ire, there is an outcrop of ironstone at Claxby, in the Cretaceous; it has an iron content of 26-30%.

At Seend, near Devizes, in **Wiltshire** there is a deposit of brown ferruginous sand, which is an outlier of the Lower Greensand, with an iron content of about 40%.

The famous Wealden iron ore of **Sussex and Kent** occurs chiefly as nodules and thin beds in the Wadhurst Clay, one of the Wealden series. Iron is also present in other rocks of the Wealden series, including the Fairlight Clays, the Ashdown Sand, and the Weald Clay, but the distribution of Roman ironworks in the Weald suggests that only the first-named was worked in addition to the ore in the Wadhurst Clay. The ore is siderite, hard and light grey-green; some of it has been oxidized to limonite and is soft and brown, and in-other cases this process was only partial, producing the characteristic 'box-stone', with a core of carbonate enclosed in a coherent shell of limonite.

In addition to the Wealden ore, there is a thick band of iron sand near the base of the Sandgate Beds, to the north of Midhurst. It is made up of polished flakes and grains of brown ore, containing about 23% Fe. This ore has also been reported from Petersfield and from Albury (Surrey).

Nodules of clay ironstone have been found in the Hamstead Beds on the **Isle of Wight** between Hamstead and Yarmouth Lodge. Layers of tabular carbonate ironstone have been revealed at Hengistbury Head, **Hampshire** and were worked about a century ago for a short time. 61

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2.2 Distribution of sites

A comparison of the information on the occurrence of iron ores given in the preceding section with the general distribution map (Figure 1) gives a clear indication of the main concentrations of ironmaking establishments in Roman Britain in relation to iron ore sources. There is a heavy concentration of sites in the Weald and another in the Forest of Dean, with a further clear grouping in the East Midlands on the Jurassic Ridge. There are lesser groupings in North Wales and in the south-west.

It is proposed therefore to discuss the Weald, Forest of Dean, and Jurassic Ridge sites in separate sections, and covering other discrete areas in a final section. The significance of the more isolated sites is discussed in Chapter 3 in the section on 'Types of site' (3.3).

2.3 The Weald

Schubert (1957, 36-7), following Straker (1931), but with some characteristic looseness of interpretation, lists no fewer than eighteen sites of the Roman period from the Weald. Some of these were only tentatively identified by Straker as Roman, using phrases such as 'Slag of a Roman type was found'. In other cases, the presence of a bloomery was assumed from slag metalling on a Roman road, but this does not necessarily imply the existence of an iron-smelting site in the immediate vicinity. The present author has discussed 36 sites which have been proved by excavation or by stray finds of pottery and coins to be Roman (Cleere 1974 – Appendix C to this thesis). These are shown on the map in Figure 2 (from Cleere 1974). This also shows stretches of Roman road metalled with iron slag, where as yet undiscovered sites may be postulated.

Geographically, the sites may be said to fall into two main groups: (a) the coastal sites, such as Beauport Park, Chitcombe, Crowhurst Park, Footlands, Icklesham, Oaklands Park etc, and (b) the High Weald sites, such as Bardown, Great Cansiron, Knowle Farm, Minepit Wood, Oldlands, Ridge Hill etc, with an extreme westerly 62
outlier at Broadfields. The former group is concentrated in a relatively small area 66
measuring some l6 × 10 km, whilst the remainder spread across about 50km of the High Weald.

Figure 3 (from Cleere 1974) is a chronological chart for the 36 sites; it indicates

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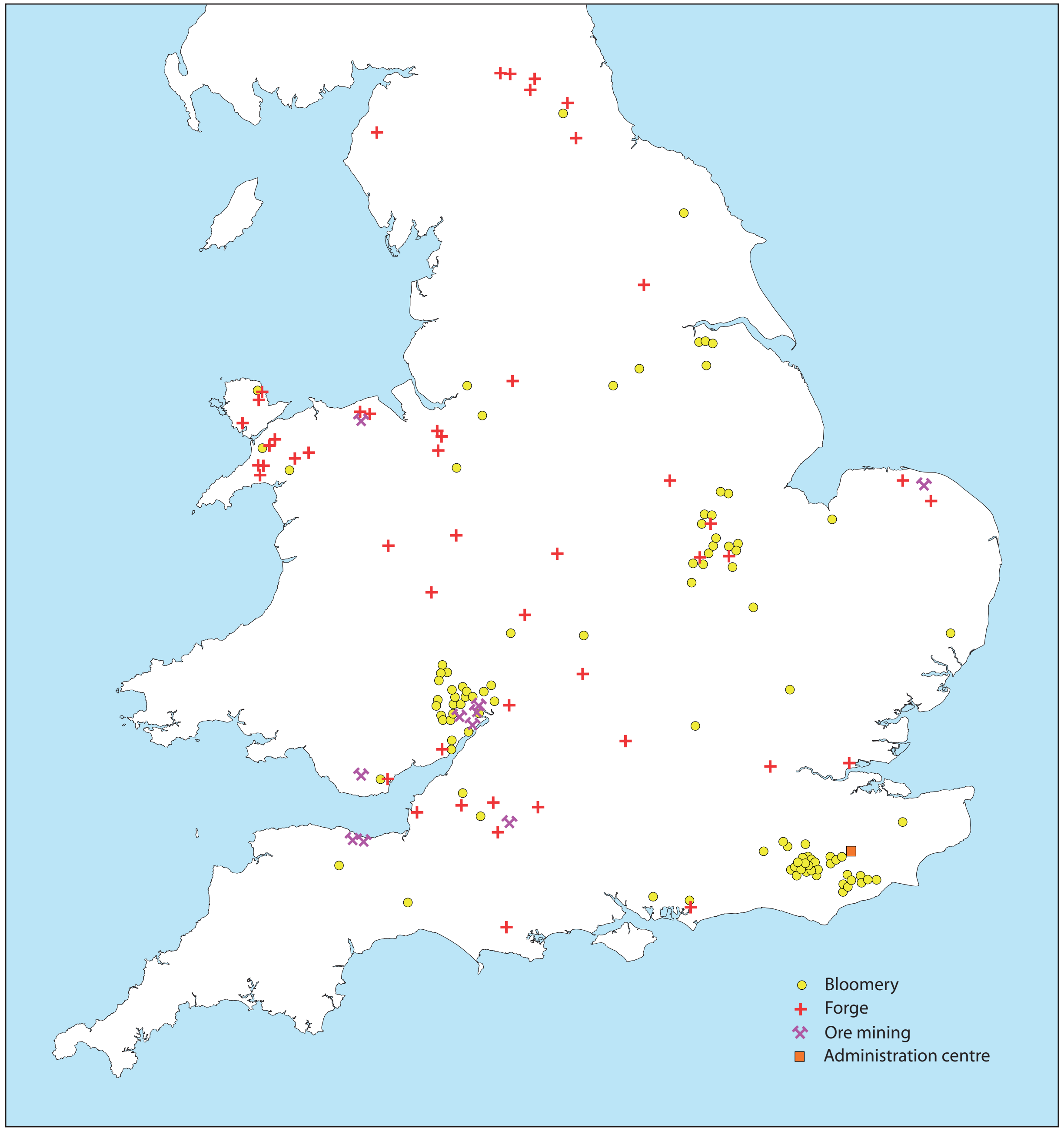

Figure 1: Distribution of ironmaking and ironworking sites in Roman Britain

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that, by the end of the 1st century, ironmaking was in progress at most of the coastal sites and at the High Weald sites of Broadfields, Oldlands, Ridge Hill, and Walesbeech, and in all probability at Great Cansiron. By the mid 2nd century, operations had started at a number of other sites in both areas, including Bardown, Chitcombe, Petley Wood, etc.

Fifty years later, at the beginning of the 3rd century, the picture is beginning to change. Operations at the main Bardown settlement had ceased, although the site was still occupied, but the satellite site at Holbeanwood, about 1.5km away, had started working, and other satellites, such as Coalpit Wood and Shoyswell Wood, were probably also operating at this time. Holbeanwood is the only one of the Bardown satellites to have been excavated; there are several others, all like Holbeanwood, apparently linked to Bardown by small slag-metalled roads. A similar situation may well have obtained at Crowhurst Park, where the main settlement seems to be ringed by subsidiary sites such as Bynes Farm, Forewood, and Pepperingeye, whilst there are also indications that Oaklands Park and Beauport Park may also have had satellite working sites. Most of the other early 2nd century ‘sites seem to have continued in operation.

The next important stage comes in the mid 3rd century. Operations ceased for certain at the Bardown-Holbeanwood complex and Beauport Park, and there are strong indications that many other sites stopped around the same time – Chitcombe, the Crowhurst Park complex, Knowle Farm, Oaklands Park, Ridge Hill, and Walesbeech, for example, have produced no late 3rd or 4th century material. By the end of the 3rd century iron appears to have been manufactured only at Footlands in the east and Oldlands and Broadfields in the west. The great flowering of the Roman iron industry in the Weald, which left such dramatic remains as the enormous 66
67
slag and refuse tips at Bardown, Beauport Park, Chitcombe, Oaklands Park, and elsewhere, seems to have been between the latter part of the 1st century and the middle of the 3rd century: a period of less than 200 years.

The decline of this industry, which must have been one of the largest concentrations in the Roman Empire, may be attributable to over-exploitation. The excellent siderite ore of the Wadhurst Clay occurs in fairly small deposits which are quickly exhausted; the multitude of pits and ponds around major sites such as Bardown are evidence of the tireless search for ore. However, the geology of the Weald is complex, with much faulting and discontinuity, and it is likely that the more easily won deposits, identified by Cattell (1970) as lying at the junction of the Wadhurst Clay and the Ashdown Sand, eventually ran out.

So far as fuel was concerned, this was a prodigal industry in terms of deforestation; at least two parts of charcoal would be needed for every part of metal produced. The present author has studied the likely deforestation rate in this region (Cleere 1976 – Appendix D to this thesis).

It is certainly for these reasons that ironmaking operations ceased at the central Bardown settlement around AD 200, after half a century of activity. The amount of labour expended in bringing supplies of ore and charcoal to the central working site from increasingly far distant ore-pits and stands of timber must have been seen to be uneconomic, and so small working sites were set up on the perimeter of the cleared area.

The map in Figure 2 shows that the pattern of Roman penetration into and through the great forest of the Weald is not identical as between the western and eastern sections of the region. This is primarily reflected by the road system. All the Roman

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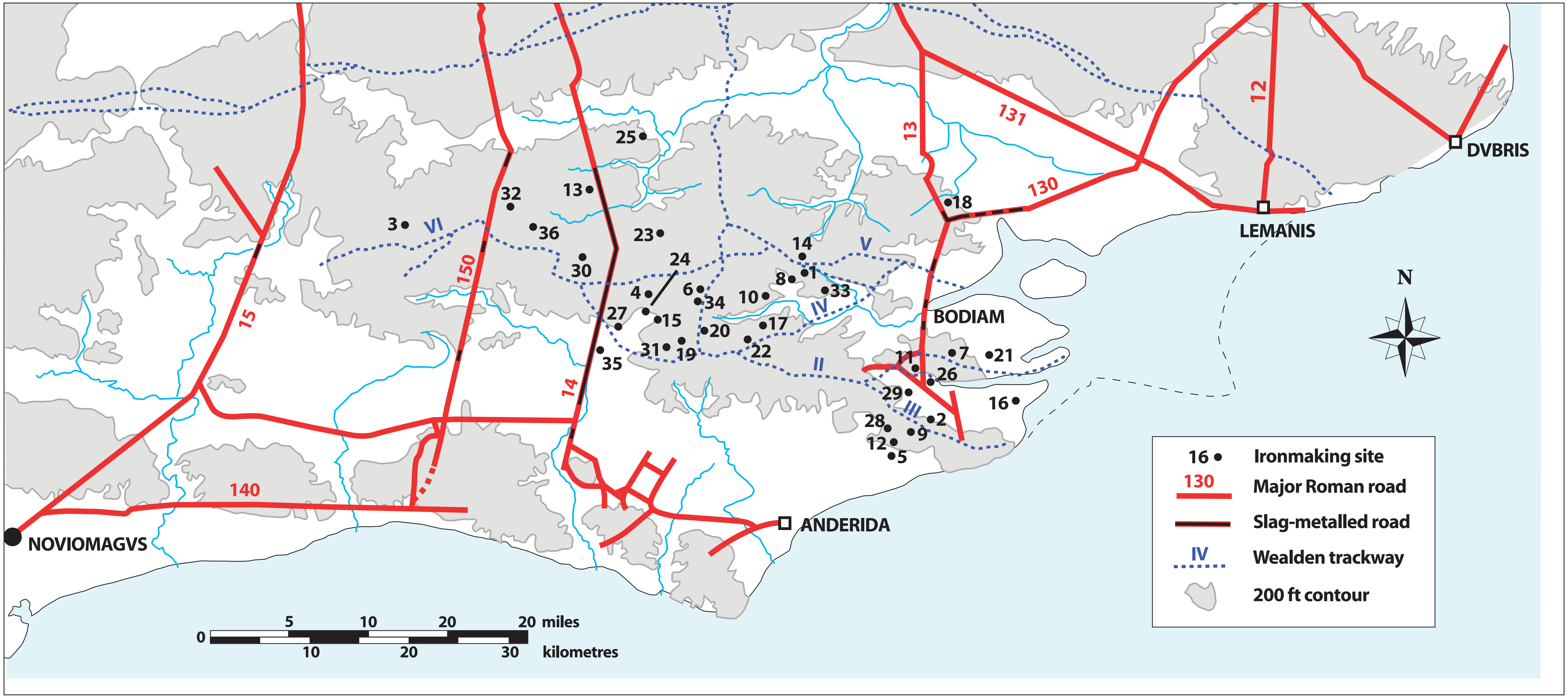

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1. Bardown
2. Beauport Park
3. Broadfields
4. Brook House
5. Bynes Farm
6. Castle Hill
7. Chitcombe
8. Coalpit Wood
9. Crowhurst Park
10. Doozes Farm
11. Footlands
12. Forewood
13. Great Cansiron
14. Holbeanwood
15. Howbourne Farm
16. Icklesham
17. Knowle Farm
18. Little Farningham
19. Limney Farm
20. Little Inwoods
21. Ludley Farm
22. Magreed Farm
23. Minepit Wood
24. Morphews
25. Oakenden
26. Oaklands Park
27. Oldlands
28. Pepperingeye
29. Petley Wood
30. Pippingford
31. Pounsley
32. Ridge Hill
33. Shoyswell
34. Streele Farm
35. Strickedridge
36. Walesbeech

Figure 2: Distribution of Roman ironmaking sites in the Weald (Cleere 1975)

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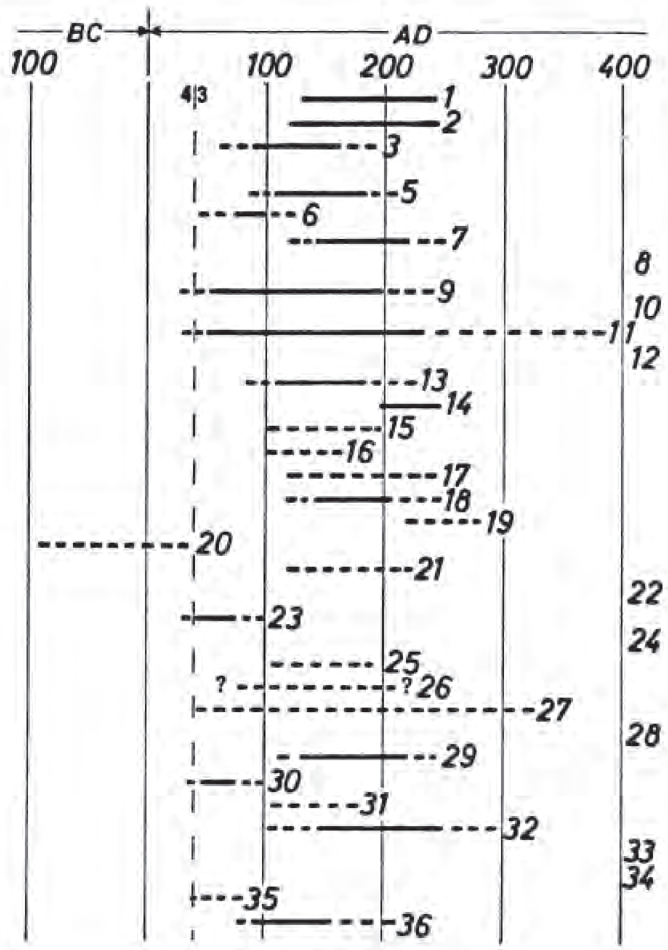

1. Bardown
2. Beauport Park
3. Broadfields
4. Brook House
5. Bynes Farm
6. Castle Hill
7. Chitcombe
8. Coalpit Wood
9. Crowhurst Park
10. Doozes Farm
11. Footlands
12. Forewood
13. Great Cansiron
14. Holbeanwood
15. Howbourne Farm
16. Icklesham
17. Knowle Farm
18. Little Farningham
19. Limney Farm
20. Little Inwoods
21. Ludley Farm
22. Magreed Farm
23. Minepit Wood
24. Morphews
25. Oakenden
26. Oaklands Park
27. Oldlands
28. Pepperingeye
29. Petley Wood
30. Pippingford
31. Pounsley
32. Ridge Hill
33. Shoyswell
34. Streele Farm
35. Strickedridge
36. Walesbeech

Figure 3: Approximate time spans of Roman ironmaking sites in the Weald (from Cleere 1975)

sites lie within 3.5km of a known Roman road, either a major arterial road such as the London-Brighton and London-Lewes highways or one of the minor roads and ridgeways. For example, the Ridge Hill/Walesbeech group lie close to the London-Brighton road (Margary's Route 150); Broadfields is near Margary's track VI (Margary 67/68 1965) and equidistant from Stane Street (Route 15) and the London-Brighton road (150); Oldlands and Great Cansiron lie on the London-Lewes road (14); Bardown and Holbeanwood straddle Margary's track V (the Mark Cross-Sandhurst ridgeway); Magreed Farm and Knowle Farm are on his track IV (the Heathfield-Hurst Green ridgeway); and the coastal group lie near or on the complex of minor roads in the south-east corner of Sussex, linked to Watling Street at Rochester by Route 13. This suggests an alternative classification of the sites, based on their relationship to their communications by both land and sea and on their possible markets.

This alternative classification, which is believed to be more representative of the organization of the industry, distinguishes two groups of sites: the western group, orientated on the major highways running north-south, and the eastern group, with a primary outlet by sea from the estuaries of the small rivers Rother and Brede.

It is postulated that the western group of sites, such as Broadfields, Great Cansiron, Oldlands, and Ridge Hill, may have been set up to exploit ore bodies discovered during road-building operations. Of this group of sites, only that at Ridge Hill had been excavated until recently (Straker 1928). Straker suggested that this, the farthest north of the Roman sites that he had found, probably had its market outlet in London. This comment probably provides the key to this group of sites. Routes 15 and 150 connected the prosperous and densely populated agricultural areas of the South Downs, with their fine villas and centuriation, to the mercantile centre of the province; they were roads along which goods of great value would have passed. Both ends of the roads would be potential markets for iron in large quantities. During the 1st and 2nd centuries, and well into the 3rd, there were hardly any military establishments in the south and only the Cripplegate fort in London, and so it can be safely assumed that this was essentially a civilian operation. It is not inconceivable that the large works, such as Great Cansiron and Oldlands, with their relatively long periods of operation, were set up by entrepreneurs, either individuals or corporate 68/69 groups similar to the *collegium fabrorum* of Chichester. Limited companies or guilds of this type could have ensured a steady revenue from relatively modest ironmaking activities along the main highways, supplying markets at their two ends. There is a strong presumption, therefore, that the operations of this western group of sites were in the hands of civilians and based on land transport of their products. Serving as they did markets in the most settled part Of the province, they were not exposed to military or economic pressures, and probably continued to operate well into the 4th century.

In the eastern group the earliest sites are those in the Battle-Sedlescornbe area: Beauport Park, Chitcome, Crowhurst Park, Footlands, and Oaklands Park; Footlands and Crowhurst Park may well have been in existence at the time of the conquest in AD 43. The later sites, which seem to have started up in the first half of the 2nd century, Bardown, Knowle Farm, Little Farningham Farm, Magreed Farm, lie further north, in the High Weald. There appears to have been a northward shift some time between AD 120 and 140, and at the same time satellite sites, such as Bynes Farm, Forewood, and Pepperingeye, may have been set up around Crowhurst Park. Such evidence as there is implies that a number of the early sites in the eastern group began producing on a very large scale in the mid 1st century. There is no evidence as to who was responsible for the operation of these works. The apparent increase in the degree of organization bespeaks a government-administered undertaking rather than a native industry. This was essentially a sea-based operation, at least at the beginning. Margary claimed a relatively early date for his Route 13, though not so early as for the major arterial Routes 14 and 150. He does, however, imply that Routes 130 and 131 are later, largely because of the imperfection of their alignments. One should not, therefore, see these roads as the primary outlets for the products of the eastern group sites, at least in their earlier phase.

The important roads for this early period are those which appear to wander
69/70 somewhat purposelessly around the Hastings-Battle-Sedlescombe-Staplecross-Udimore area. If these are studied carefully, it will be seen that they link the five early sites quite efficiently. Margary (1947) proposed three stages of development in this area. In the first, products from the works were shipped by sea from the south coast in the Hastings area and the Brede estuary. Later, the ironmaking activity moved further inland, local roadways and ridgeways being built to serve the new settlements. These led to ports on the Brede and Rother estuaries for shipment out to sea. Finally, in the third stage road communications were established with East Kent and with London via Rochester.

During the first stage, which Margary suggests lasted from the conquest to AD 140-150, material could have been moved from Beauport Park along Track III through Ore to a possible harbour near Fairlight. This is an attractive proposition in view of Peacock's recent identification of the Fairlight Clays as the source of CL BR stamped tiles found on Wealden sites (Peacock 1977). However, as yet no Roman settlement has been found in this area, and Fairlight would in fact not have been a very secure haven. One is tempted therefore to conceive of iron being moved north-east to the more sheltered Brede estuary near Sedlescombe. The Oaklands Park site lies on the edge of Sedlescombe, and foundation digging in the Pestalozzi Village located there has revealed a slag-metalled road surface of Roman date. Footlands is only a short distance from Sedlescombe and is linked with it by a well proved Roman road. Chitcombe is situated to the north of the Brede estuary, but it is connected by road to Cripps Corner, only a couple of miles from Sedlescombe. The nodal point of all these communications would therefore appear to be the head of the Brede estuary, and it would seem to be justifiable to postulate a port installation somewhere in that area.

In Margary's second period, which from evidence at Bardown and Little Farningham Farm seems to have begun around AD 140, or perhaps a decade before, there was a drive into the High Weald. The focal point of the new road system also appears to have shifted north. The Bardown-Holbeanwood complex
is served by a road running directly along the Limden valley to join Track IV near 70/71
Hurst Green; it appears to disregard Track V (the Mark Cross-Sandhurst ridgeway, claimed as pre-Roman by Margary), which is crossed by the track joining Bardown and Holbeanwood. The contour road to Hurst Green is clearly marked and has been observed from the air by the author.

The Magreed Farm and Knowle Farm sites lie along Track IV, which joins Route 13 at Sandhurst. Little Farningham Farm is just to the east of Route 13 itself, about 8km north of Sandhurst. From here, Route 13 continues southwards to cross what would have at that time been the mouth of the Rother estuary at Bodiam.

It is suggested that Bodiam superseded the hypothetical Brede estuary port some time in the mid 2nd century. The site lying on the south bank of the river (Lemmon and Hill 1966) showed occupation from the 1st century, but its main occupation levels certainly date from the 2nd century and go through to the early 3rd century.* Until the Brede estuary port can be located and excavated so as to give more precise dating evidence for the first stage, it is not permissible to assume that it was replaced by Bodiam; it is quite conceivable that both ports continued in operation. However, it will be seen from Figure 2 that the Rother estuary port was located at a point virtually equidistant from all the main centres of iron production. It was, moreover, connected by road with both Sandhurst road junction and that in the neighbourhood of Cripps Corner. Silting has been proceeding steadily on this part of the coast for many centuries, and so it is conceivable that this process led to the transfer of the main port from the Brede estuary to that of the Rother.

Margary's third stage, which is not easy to date accurately but which may have begun in the early 3rd century, involves the construction of the two major roads, Route 13 to Rochester and Route 130 to Canterbury. These roads must have been built before the industry in this part of the Weald had virtually ceased in the mid
3rd century, otherwise they would have served no apparent purpose, there being 71/72
no settlements other than ironworks in the region. The excavations at Bodiam show a marked decline at the beginning of the 3rd century, and so the date for the construction of Route 13 from Sissinghurst northwards and Route 130 from St Michael's eastwards may be set some time in the second or third decade of the 3rd century.

Why was it necessary for these roads to be built? There are two possible reasons, which are not necessarily mutually exclusive. First, it is likely that, as has been suggested above, the estuaries were silting up rapidly, and that navigation across what is now Romney Marsh was becoming increasingly hazardous, so that it became desirable to switch from seaborne to land-borne transportation. Secondly, it is possible that a change in ownership led to the need to open up new markets. By

* The recent (March 1977) discovery of a bloomery site with Roman pottery about 400m from the main site reinforces the connexion between the hypothetical Bodiam port and the iron industry.

about AD 250 most of the major sites were no longer functioning; however, Footlands continued into the 4th century'-and could clearly have benefited from these new roads.

Another possible explanation that might be considered concerns the relative vulnerability of the sea lanes to attack by pirates and raiders, especially from the beginning of the 3rd century onwards. Road transport would doubtless have been somewhat safer and would have prevented heavy losses of a valuable raw material, with obvious military potential. However, the whole subject of the situation in the Channel in the years preceding the establishment of the Saxon Shore forts is one in which reliable data are conspicuously missing, and so this can only be offered very tentatively to explain the construction of Routes 13 and 130.

Brodribb (1969) has catalogued all the finds of stamped tiles of the *Classis Britannica* known up to the end of 1968: 'the presence of stamped tiles in quantity is likely to reflect naval activity' (Cunliffe 1968, 257). The idea of tiles being manufactured by contractors for the fleet stamped with the CL BR emblem is possible, but it cannot be paralleled elsewhere. A direct connexion may be assumed between the fleet an the sites that have so far produced specimens of these tiles. So far, stamped tiles have been found at the following sites associated with the
72/73 Roman iron industry: Bardown (28 examples), Beauport Park (over 1,000), and Little Farningham (over 50). They have also appeared in a late 2nd century context at Bodiam. Of the Bardown tiles, all the stratified examples were found in a late 2nd/ early 3rd century context. The Little Farningham Farm specimens all come from a late 2nd century context. Those from Beauport Park come preponderantly from the roof and floors of a bath-house that was probably built in the mid 2nd century and was rebuilt and enlarged at least twice before its final abandonment in the mid 3rd century. It can, therefore, be claimed incontrovertibly that the *Classis Britannica* was controlling these sites and the port at Bodiam in the period between the mid 2nd century and the early 3rd century.

Of this group of sites, only Bardown has been excavated in any detail (the bath-house alone at Beauport Park has been fully excavated). It is clear from Bardown that there is no break between the 'pre-stamped tile' occupation and the unquestionable fleet control period. Little Farningham Farm, like Bardown, appears to have been set up in the mid 2nd century and also exhibits a 'pre-stamped tile' phase, but again without any discontinuity of occupation, and the same is true of Bodiam, where occupation began in the 1st century. In default of any evidence to suggest a change of ownership during the latter half of the 2nd century, one is inclined therefore to accept Cunliffe's view that the practice of stamping tiles was not introduced by the *Classis Britannica* until the end of the 2nd century.

This evidence leads to the assumption that the second phase of the eastern group of Wealden ironmaking sites was operated under the direct control of the *Classis Britannica* At present there is no evidence of a positive nature to confirm fleet control during the first phase, when the large works in the Battle-Sedlescombe area were in operation and sending their products out through the hypothetical port in the Brede estuary. However, the large scale of operations at this time, combined with the continuity of such sites as Beauport Park, makes centralized control seem most probable. A pre-Roman industry existed, but on only a very limited scale and lacking the resources that would permit it to expand to meet the requirements of the army. It 73/74
would seem logical, therefore, for the fleet to have taken over. This involvement of the fleet is discussed further in Chapter 3.

2.4 The Forest of Dean

The importance of the Forest of Dean as an iron-producing centre in the Roman period is frequently asserted in standard works on Roman Britain, but the evidence is much slighter than that from the Wealden industry. One of the earliest accounts is that of Wyrall (1877-8), who gives a summary description of extensive slag deposits in the Forest. Cinder heaps containing Roman coins, brooches, and other material are quoted from the neighbourhood of Whitchurch, Peterstow, and the Ross-Hereford road.

Fryer (1886) concentrates on the well known Bream Scowles, where coins of Vespasian had been found, and refers to other coin finds at Coleford (Gallienus, Victorinus, Tetricus) and Ruardean (Constantine). Military forges are mentioned at Monmouth (Blestium) and Hadnock. The northern part of the Forest is covered in an early article on Roman Herefordshire (Watkin 1877), which deals in some detail with finds from Kenchester and Weston-under-Penyard (Ariconium), where large beds of slag were known. In a more general description of the ironworking area of south Herefordshire, a large area of Monmouthshire, and part of Gloucestershire, the author states that the following parishes 'abound' in large beds of slag and cinder: St Weonards, Peterstow, Bridstow, Llangarron, Goodrich, Ganarew, Hentland, Tretire, Weston-under-Penyard, Walford, Welsh Bicknor, and Whitchurch. He talks of 'hand bloomeries' having been found on Peterstow Common and of beds of cinders in places 3.5-6m thick.

The only recent survey of the archaeology of the Forest of Dean (Hart 1967) draws attention to the finding of a Coriosolite coin at the Bream Scowles in 1946. and suggests that in the pre-conquest period trade was probably orientated to the east – the Dobunni in the Bagendon area -rather than westward with the Silures; 74/75
this is not entirely suppositious, since two Dobunnic coins are also recorded from 1867. However, Hart rather upsets his case by explaining that the Silures used iron currency bars rather than coins: one is tempted to ask where they obtained their iron from, since there is no evidence of ironmaking in the Silurian area in the pre-Roman period, even though there were reasonable deposits of iron ore available.

Hart goes on to discuss the iron industry in the Roman period, but gives only sketchy information about its extent. He concentrates on the settlements within the historic Forest rather than on the ironmaking sites – the Chesters villa at Woolaston ('probably occupied by a Roman ironmaster who also indulged in farming and had connections with shipping'), which dates from the early 2nd to the 4th century, and the Lydney Park complex, where iron was mined and worked in the 2nd and 3rd centuries. He also comments on the north-south 'Dean Road', running between Ariconium and Lydney, to which he attributes a commercial use, connected with the iron industry.

The major problems in studying the Roman iron industry in the Forest of Dean stem from later iron ore mining and smelting. Iron was being made in Dean within living memory, and Roman workings were disturbed and often obliterated by later mining and slag dumping activities. Moreover, the slags, rich in iron owing to the nature of the early process, which had attracted Wyrall's attention were seen by early blast-furnace ironmakers as a handy source of feed stock for their furnaces: they were quarried away and re-smelted from the 16th century onwards, not only by Dean ironmasters but also by those of Shropshire. This process was much more comprehensive that it was in the Weald, where only a few sites, such as Beauport Park and Oaklands Park, served as quarries for road metalling; many thousands of tons of Roman iron slag were taken up the Severn in barges to the blast furnaces of Worcestershire and Shropshire during the 16th and 17th centuries. It is hardly surprising, therefore, that so little detailed evidence on the industry in Roman times is available; however, the widespread distribution f the remains of these slag dumps and their rich yield of blast-furnace feed for so many years testifies to the size of the
75 industry.

76 The sketch-map of the Forest of Dean ironmaking sites (Figure 4) confirms that Blestium, Striguil, and Glevum were on the fringes of the ironmaking area. Ariconium, however, though lying outside the historic Forest, is the focus for a group of sites (Llandinabo, St Weonards, Tretire, Peterstow, Whitchurch, Ganarew, Llancloudy, The Doward, Goodrich, and Welsh Bicknor to the west, Ruardean and the Littledean and Mitcheldean sites to the south). It is connected by road, moreover, with the other towns in the region, a branch road leaving the Dean Road near Mitcheldean in the direction of Glevum.

A second discrete group of sites lies to the east of Blestium (where slag and furnace bases have been found); these include Hadnock, Staunton, Redbrook, Clearwell, St Briavels, Newland, and Coleford. The Bream Scowles lie between this group and the two Lydney sites, which are in their turn linked with the Chesters villa at Woolaston and the small group of sites in the parish of Tidenham by the road from Ariconium to Striguil and Venta Silurum. There are only two outlying sites that cannot be attributed to one of these three groups, both north-west of Glevum at Newent and Tibberton.

Dating evidence from the 'Ariconium' groups of sites is slight and somewhat unreliable. Ariconium itself has produced a 1st century brooch from a small excavation, but this appears to have been a survival, since it lay on a working surface securely dated to the 2nd century. Pottery and coin evidence from this and other

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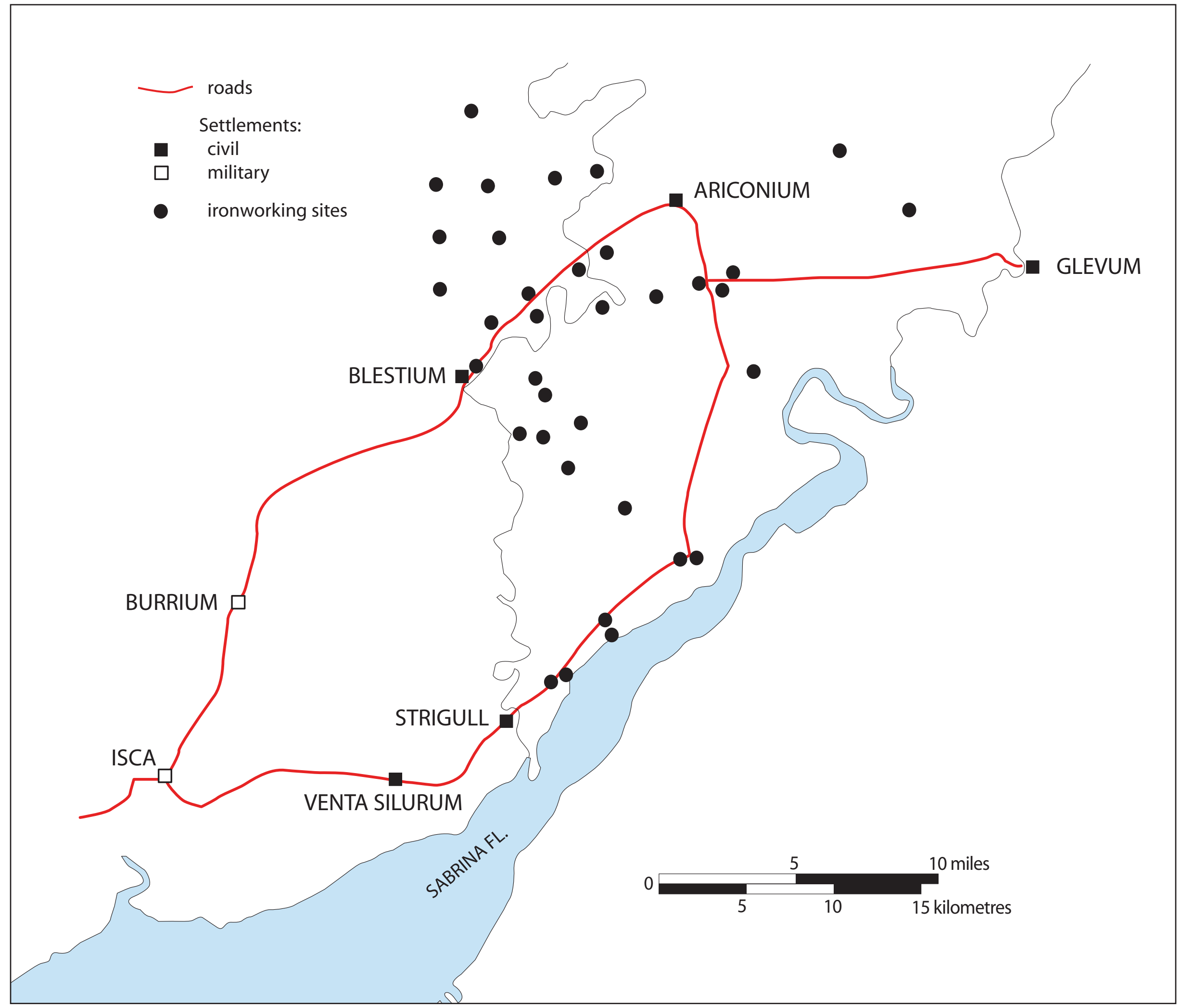

Figure 4: Sketchmap showing distribution of Roman ironworking sites in the Forest of Dean. 77

excavations on and around the immense spread of ironmaking refuse on Cinder Hill, at the western end of the Roman settlement, give clear and abundant proof of iron working from the mid 2nd century continuously to the end of the Roman period. However, Jack (1923) suggests that the period of most intensive occupation was from the early 3rd century to the mid 4th century. Whitchurch seems to be 2nd century at least, but the very large slag heaps in the parish – the whole village appears to lie on a thick bed of slag – suggest a longer period of occupation and ironmaking activity. A coin of Constantine I was found in association with ore working at Ruardean. The only site of this group (with the exception of Ariconium itself) where excavations have been carried out, at Pope's Hill in the parish of Littledean, has a date range similar to 76
that proposed for Ariconium. It would appear that the ironmaking here was based on 78
the ores from the Scowles on the nearby Cinderford ridge.

Evidence from the 'Blestium' group is equally scanty. The town itself was occupied from the 1st century onwards, but the ironworking areas so far investigated by excavation suggest that this form of industrial activity did not begin until the 2nd century. There was possibly 1st century working at Staunton, where 'a lamp of Claudian date' is recorded from a 19th century excavation. At Coleford 3rd century coins have been found in the Scowles in the area.

The 'coastal' group is better dated: both Lydney sites were clearly working in the 2nd and 3rd centuries, but that at Lydney Park had ceased ironmaking activities by the end of the 3rd century. The Bream Scowles appear to have been in use in the 1st century: a coin of Vespasian has been found, as well as the Coriosolites potin coin referred to above. The Chesters villa was founded in Hadrianic times and continued in use to the end of the Roman period.

This evidence is admittedly meagre, but a positive picture does emerge. There was a little ironmaking at the time of the Roman incursion into the area, probably centring on Bream and with an outlet to the sea at Lydney, where pre-Roman occupation is attested. The industry was on a modest scale until the middle of the 2nd century, when it appears to have expanded greatly in a short time: this is comparable with the process of development in the Weald at least a century earlier. The centre of the industry was most likely Ariconium, connected to the Bristol Channel at Lydney and to the important towns to east and west (Blestium, yenta; Glevum) by road. The industry appears to have continued without interruption until the end of the Roman period (and in all probability well into the 5th century). Mining activity was intense, with deep opencast mining at Coleford, Staunton, Newland, Ruardean, Mitcheldean,
78 The Doward, Bream, and Lydney.

79 The organization and control of the industry cannot be judged from the few securely attributable finds. However, the absence of urban settlement in most of the region and the apparently nodal location of Ariconium raise the possibility that this was an Imperial estate: this hypothesis is discussed in detail in Chapter 3.

The markets of the Forest of Dean industry are not difficult to deduce. Glevum was almost certainly a major mercantile centre in the Roman province, serving markets in the west (Cleere 1978). Forest of Dean iron would have travelled, most probably in the form of semi-finished products (worked blooms), by road from the Ariconium group and perhaps by sea from the coastal group to the markets in Glevum, whence it could be traded in the west Midlands up the Severn by boat or barge and in the settled areas to the west and south-west by both road and water. The markets for Dean iron probably encountered those of the Weald in the Salisbury Plain area and those of the Northamptonshire ironworks to the west of Ratae. In addition, there was doubtless trade westwards along the coast of south Wales. The relationship of the Forest of Dean iron industry with the army in Wales and in the north-west is not known, but it is conceivable that military supplies for this region could have been derived from Dean, leaving the Weald establishments to supply the Wall from its eastern terminal, the York-based legion, and the garrisons of the forts in the north-east, plus also a considerable export across the Channel to the armies on the lower Rhine.

2.5 The Jurassic Ridge (Oxfordshire, Northamptonshire, Lincolnshire)

The Jurassic belt sweeps from Somerset in a north-easterly direction to the Wash in north Lincolnshire. As described above (Chapter 2.1), iron ore occurs in considerable quantities at three points along its length: in north Oxfordshire, Northamptonshire, and north Lincolnshire. The ores are carbonates, weathered to hydrated hematite on their upper surfaces, and are relatively lean (low in iron), with an average iron content ranging from 23% in the Frodingham ores of north, Lincolnshire to about 33% in the Inferior Oolite of Northamptonshire. However, their low iron content is offset by their 79
good reducibility: the Frodingham ores in particular have a high lime content, making 80
them strongly self-fluxing (ie they readily form a fusible slag without significant sacrifice of iron).

Figure 5 shows the distribution of Roman ironmaking sites in the area under discussion. It will be seen that there is no concentration of sites in Oxfordshire: at the three sites indicated (Abingdon, Stanton Low, Asthall), all on the Thames Gravels, the metallurgical activity seems to have been iron working rather than smelting, and it was on a very small scale -essentially a domestic industry. This is perhaps not surprising, since the main ore deposits here are relatively deep; indeed, they were not commercially exploited in any great quantity during the heyday of the Jurassic ores between 1920 and 1970, largely because their low iron content and heavy overburden made exploitation only marginally economic. However, in view of the manifest skill of Roman ore prospectors it is perhaps surprising that the rare outcrops were not apparently worked during the Roman period. It may be that the abundance of easily won ore nearby in Northamptonshire and Rutland, which was apparently being worked on a large scale, made this unnecessary in economic terms.

At the other end of the Jurassic Ridge, the Frodingham ores were certainly discovered and worked during the Roman period. Unfortunately, all too little fieldwork has been done in this area. The small group of sites lying to the north of Scunthorpe, however, may be the only survivors of a considerably larger number. The Frodingham ore has been mined opencast for about a century. Dudley was able to record only two or three of the ironmaking sites which were, according to officials of the company responsible for the opencast mining in the area, frequent finds: one of these officials estimated that a major 'ancient' ironmaking site was discovered on average every two years (T P Lloyd, pers comm). The judgement of Whitwell (1970, 113) that 'the present known scale of ironworking in Lincolnshire in Roman times does not suggest anything more than a local industry, supplying local needs' may be open to question, in view of this information. A similar situation obtained in Northamptonshire, where 80
iron ore was mined opencast from the 1920s until the present day; until intensive 82

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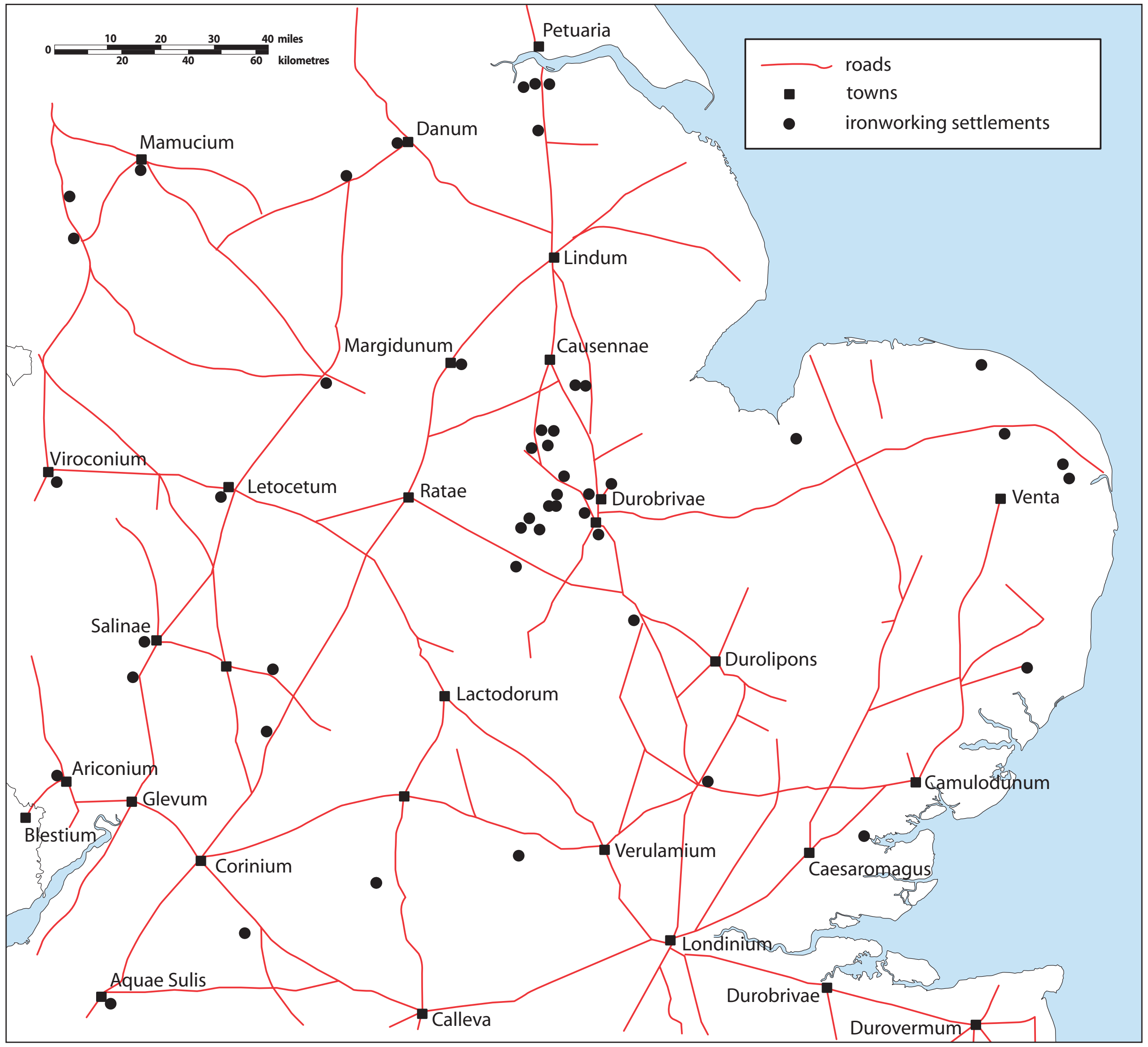

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Figure 5: Distribution of Roman ironmaking and ironworking sites on the Jurassic Ridge.

fieldwork in advance of overburden stripping was carried out by D A Jackson in the past two decades, only a handful of ironmaking sites was known, and a similar reaction from officials of the steel company concerned was forthcoming on questioning to that obtained in Lincolnshire.

Smelting furnaces of indeterminate type (in all probability B.1.i in Cleere's 1970 classification) were recorded by Dudley (1949, 142-3) at Thealby. These were associated with coins and pottery of the 2nd to 4th centuries. The Scawby remains were more substantial, but no dating evidence is recorded. At the Winterton villa the yard to the south of the main building was given over to ironworking in the 4th century, but this would appear to be another example of the phenomenon observed elsewhere in Roman Britain of domestic-scale ironworking in associated with villa establishments in the latter half of the 4th century.

The main concentration of known ironmaking sites on the Jurassic Ridge during the Roman period lies to the north and west of Durobrivae (Water Newton) on the Inferior Oolite. This ore lies relatively close to the surface and is still being mined opencast, though in considerably smaller quantities than it was up to five years ago. The work of D A Jackson has ensured that some at least of the sites that can be destroyed instantaneously by one of the giant walking draglines of the steel company are recorded summarily, with occasional opportunities for limited excavation.

There are indications that ironmaking had begun in this area before the Roman invasion. At Wakerley this is incontrovertible: slag and furnaces of an early type were found in association with circular huts inside a double-ditched enclosure. At Geddington, also, smelting slag was found in association with late Belgic pottery. Early Roman pottery from Bulwick and Colsterworth suggests a mid 1st century start for ironmaking operations.

By the 2nd century ironmaking had spread to other parts of the region: it is attested 82
at this period at Bedford Purlieus, Colleyweston, Pickworth, Sapperton, Sacrewell, 83
and Southorpe. The scale of operations is somewhat difficult to evaluate from published reports: no giant slag heaps of the type known from the Weald are referred to, though there are indications that at Bedford Purlieus, Pickworth, and Sapperton at least slag was much in evidence. At Wakerley there were five furnaces in a group lying just outside the main enclosure (site 4), a modest group in Wealden terms.

Most of the sites already mentioned continued operations during the 3rd century. To them should be added the Coadby Marwood settlement, observed during overburden stripping and dated by a coin hoard to the 3rd century. By the 4th century, however, the scale of operations appears to have diminished. Only at Clipsham, Sacrewell, Sapperton, and Southorpe is there clear evidence of 4th century iron production, and at both Clipsham and Sacrewell the picture seems to be similar to that at Winterton – domestic iron production at villas at a period when the main industrial settlements had ceased activities. At Clipsham, however, ironmaking seems to have been on a large scale and to have continued well into the 5th century.

Smelting furnaces are attested from a number of these sites, notably Barnack, Bedford Purlieus, Bulwick, Pickworth, Sacrewell, and Wakerley. Most would appear to be shaft furnaces of the standard B.1.i type by the 2nd century, but Wakerley provided examples of the non-slagging types Al and A2 from pre-Roman and early Roman contexts. In addition, ore-roasting furnaces are known from Bedford Purlieus, Bulwick, Sacrewell, and Wakerley (the Jurassic carbonate ores, like those from the Weald, form better bloomery feed materials if roasted before being charged to the smelting furnace), those from the last-named site being similar to the pit furnaces observed at Bardown. Forging hearths are recorded from many sites in the region, including those just mentioned.

The organization of iron-ore mining and iron production in this region is obscure. The very large establishments of the Weald or the Forest of Dean are on present 83
84

evidence lacking. The picture seems to be one of operations continuing on a relatively modest scale (eg Wakerley) over a long period – somewhat akin to the situation in the western part of the Weald, though not so clearly centralized on large establishments such as Great Cansiron or Oldlands. The central town for the region is clearly Durobrivae: all the sites discussed in the Northamptonshire-Rutland region lie within 50km of this town, which was clearly a major industrial centre, producing pottery in enormous quantities.

In terms of communications, Durobrivae is well situated as a marketing centre. It lies athwart the main road north from London to Lincoln and York (Ermine Street) and so could supply iron to consumers in these three major centres: its ceramic products are, of course, widely distributed throughout the province, so a marketing network was clearly in existence. It also has east-west links with East Anglia and the west Midlands, where there were also a number of secondary concentrations of population. The best explanation of the growth of this industry is probably that it was set up to exploit the easily won and worked ore of the central Jurassic Ridge and supply civilian markets within a 100-150km radius – say to Lincoln in the north, Venta Icenorum in the east, perhaps Verulamium in the south, and Ratae Coritanorum and beyond to the west. Iron from this region is unlikely to have penetrated the London market significantly, since this would have been supplied by the western Weald establishments, whilst the Forest of Dean iron would have saturated the Severn basin and the south-west. The scale of operations at individual works suggests independent entrepreneurial establishments rather than the military control of the eastern Weald or the centralized Imperial estate postulated for the Forest of Dean.

2.6 Other areas

2.6.a South-western Britain

84/85 The only major settlement in this area is that at Camerton (Wedlake 1958), where ironmaking seems to have been carried on in the earlier Roman period on an organized basis in one area. The fairly widespread use of slag for metalling may indicate that there were later bloomeries or forges in operation after the 2nd century, when the area excavated was levelled to form the foundation of a hut not associated with ironmaking. It is not improbable that this settlement, on the edge of the metalliferous Mendip Hills, produced iron for purely local distribution, but that its markets were taken away in the mid 2nd century, when the Forest of Dean industry began to expand its commercial activities.

Ironworking and possibly smelting does occur in the 4th century on a number of settlements, notably the Brislington villa and the Brean Down temple site, illustrating a general tendency towards the end of the Roman period for normal distribution networks to break down and for small-scale industrial operations to be set up to supply local or even domestic requirements.

2.6.b Wales

The iron industry in Roman Wales was not highly developed. A number of hillforts (Braich-y-Dinas, Dinorben, Parciau, Y Breiddin) and other native homesteads (Cae'r Mynydd, Caerau, Cefn Graenog, Coed Newydd, Coed Uchaf, Coed-y-Brain, Dinas Emrys, Hafoty Wern Las, Muriau'r Dref, Parc Salmon, Pen-y-Groes, Rhostryfan, Tregarth, Ty Mawr) have produced iron slag, some of which results from smelting rather than ironworking, but these were all very small-scale operations, doubtless producing iron only for domestic needs. Only at Din Lligwy was a more substantial operation evidenced, perhaps distributing iron and artefacts over a wider area, such as the Isle of Anglesey. This may well have been a long-standing tradition, predating the Roman occupation, which continued throughout the Roman period, partly owing to an inadequate communications and marketing network.

Most of the evidence for civilian iron production in Wales comes from the northern part of the principality: this is to some extent an accident of modern administrative procedure, 85/86 in that the work of the Royal Commission on Ancient and Historic Monuments in Wales has been preponderantly in central and north Wales. Their work, and that published in Welsh archaeological journals, formed the basis of the survey of metal working generally in north Wales by Kelly (1976). However, it can be said with some confidence that the other main ore-producing area of Wales, in Glamorgan, appears not to have been extensively worked in the Roman period, as a study of excavation reports for that area has shown. The only major operation was that on the villa found on the Ely Racecourse, Cardiff (Wheeler 1922), which appears to have been based solely on iron production. It is difficult to see how this fits into the overall pattern of production and distribution of iron: the major industry of the Forest of Dean lay close at hand, and the military establishments would presumably have been supplied, at least until the mid 3rd century, from the Weald. Indeed, the existence of a villa so far west is itself anomalous: this region is not one in which a villa-based economy would be expected. It may be that the interpretation of this establishment, excavated in the late 1890s and only reported upon by Wheeler, is incorrect, and that it may be a military foundation, analogous to the Holt base of the XX Legion and connected either with the legionary fortress at Caerleon or the Cardiff fort.

There is no evidence of any military iron smelting in Wales, although the finding of military equipment at the Moel Hiraddug hematite mine in Flintshire raises some questions that could be answered by proper excavation at the site. On the other hand, most of the military establishments in Wales have produced evidence of forging operations being carried out by the military smiths: some examples are the forts at Aberffraw, Bryn-y-Gefeiliau, Cardiff (where it seems to have been on a considerable scale), Forden Gaer, and Penllystyn.

2.6.c Northern Britain

The picture on northern Britain (including Scotland) is very similar to that in Wales.

There was considerable iron working carried out at military establishments – the legionary fortresses at Inchtuthil, Chester, and York, for examples, Wall forts such as Chesterholm, Cambridge, and Housecleans and Bar Hill and Cory Hill, and other forts like Chester-le-Street, Manchester, and Templeborough. Although it was claimed by the excavators that iron was being smelted P in the *vicus* of the Manchester fort, this is not borne out by a close study of the evidence. At Templeborough, however, excavated during World War I in advance of the construction of a modern steelworks, the structures described seem to be bloomery furnaces, no doubt using the rich iron ores of the Rotherham area.

Again as in Wales, there were some small establishments producing iron for purely local requirements, notably Levisham and Eskmeals. In addition, the Cantley (Doncaster) and Wilderspool (Warrington) industrial settlements are reminiscent of Durobrivae, producing a variety of products for a relatively restricted local market, though considerably more ‘romanized’ than the native type of settlement represented by, say, Levisham or Din Lligwy; both are, of course, on the southern limits of the ‘civil zone’ of Roman Britain and may represent outposts of industrialization. It must also be borne in mind that neither is far distant from a legionary fortress, and so there may be links with the II and XX Legions at Chester and York respectively; however, the existence of known workshops of the XX Legion at Holt and Heronbridge, coupled with the absence of any clearly identifiable military material, makes a civilian origin 87
more probable. 88

87/88

3 Organization of the Industry

3.1 Imperial minerals policy and administration

It is generally accepted that the state owned the mineral rights in all provinces during the early Empire; in practice this meant that they were vested in the Imperial *patrimonium* and thereby made an important contribution to the *fiscus*. Davies (1935, 3) summarizes the position as follows: “In the provinces the Roman state usually took over those mines which had been crown-property at the time of the conquest, and perhaps all others known to exist, so that *de facto* it was normally the precarious as well as the absolute owner of minerals.” However, this is nowhere explicitly stated, and a study of the development of mining administration in the more important provinces from the point of view of mineral resources suggests that imperial assertion of mineral rights was more of a convention that evolved piecemeal rather than an established and legitimate prerogative. However, the importance to the *fiscus* of firm control over mineral resources was obvious, although it was not until the reign of Vespasian that this policy was confirmed by the establishment of an extensive network of Imperial estates, which included the major metal-producing regions, and of powerful bureaucratic machinery (Rostovtzeff 1957, 110).

Generally speaking, the state – viz the *patrimonium* – was the largest direct owner and exploiter of mines; however, a varied pattern developed, based partly on the circumstances of the accession of individual provinces to the Empire and on the relative importance of the mineral resources. This pattern was modified for political and/or economic reasons, during the first two centuries of Imperial control. It is proposed to examine the situation in the major metals-producing provinces (Spain, Noricum, Dalmatia, and Gaul), where the epigraphic record is more varied and less enigmatic than in Britain, in an attempt to draw certain conclusions that may be considered relevant to the British situation.

The Iberian peninsula was the major metals-producing region of the ancient
88/89 world. Its resources of gold, silver, copper, tin, lead, mercury, and iron were immense and had. been recognized and exploited from early times. With the advent of Roman dominion, production increased enormously. The great mining areas of the Sierra Morena, Carthago Nova, Rio Tinto, Cantabria, Asturias, Murcia, and Galicia have been exploited almost continuously since the Roman period and so detailed archaeological evidence of operations is sparse. However, these regions are rich in epigraphic evidence, which has been extensively studied; it is perhaps inevitable that this very wealth of evidence has resulted in a diversity of interpretation. Thus, Torres (1962, 332-41) asserts unequivocally that in the early Empire mineral rights were vested in private proprietors, although confiscations and purchases led eventually to large-scale State ownership. Sutherland (1939, 57 ff) has it that ownership of certain gold and silver mines was vested directly in the State, but that most copper, lead, and iron mines were leased to individuals or companies, who paid royalties based on their outputs, which would appear to imply State ownership of mineral rights. The existence of such companies is attested epigraphically at Mazarrón (CIL. XV.7916) and Almade (CIL.X.3964). Rostovtzeff (1957, 340-3) states that there was no State monopoly of mines under the early Empire, but is somewhat equivocal in his references to Spain: thus, in discussing the position in Noricum (op cit, 233), he claims that the mines were largely State-owned, and compares this with the situation in Dalmatia and Spain, but omits reference to Spain in a later passage (op cit, 341) where he describes those provinces where State ownership predominated.

There is classical authority (Strabo, III, 2.10) for State ownership of the gold mines of Cantabria and Asturias, and it seems clear that the great silver mines of Carthago Nova, which according to Polybius employed 40,000 men and produced an almost unbelievable 25,000 drachmae of silver daily, were under direct State supervision. The pattern elsewhere is less clear. The general picture seems to be of leasing mining rights in the pre-Flavian period in a somewhat haphazard way. Concessions were handled by *publicanes* on a tax-farming basis (with attendant abuses), and were
granted to both individuals and collectives, with little surveillance or supervision. 89/90

However, a general statute for the control of mining *(lex metallis dicta*) appears to have been introduced towards the end of the 1st century, and specific mining districts were defined and placed under the control of Imperial *procuratores* (usually *equites* assisted by staffs of *tabularii, commentarienses*, etc). These districts had their own detailed regulations, as evidenced by the famous *Aljustrel* tablets (CIL. II.5181=ILS.6891), which preserves the majority of the *lex metalli Vipascensis* the statutes of the Vipasca mining district. The bronze tablets originally adorned the base of a statue of an unknown *procurator metallorum* (also described as *vicarius rationalium*) erected by the *coloni* or small concessionnaires of the *metallum Vipascense* an unrecorded decline or disaster is suggested by the additional title *restitutor metallorum* accorded to the *procurator*.

It is clear that with the enactment of the *lex metallis dicta* State ownership was extended to all mining operations in Spain, and that they were subject to rigorous procuratorial control and surveillance. Leases were granted conditional upon acceptance of procuratorial administration of both the mines and the mining settlements. Moreover, it would appear that in a period when Latin rights were being extended to the whole of the Iberian peninsula Vipasca remained a non-urban (extra-territorial) and unprivileged community, presumably an Imperial estate, and it would seem not unreasonable to assume that the same conditions applied in other mining districts. There are indications to this effect from Rio Tinto (CIL.II.956), the Sierra Morena (CIL.II.1179), and the Galician *metallum Albocolense* (CIL.II.2598).

Study of the Aljustrel tablets shows, however, that there were certain benefits deriving from Imperial administration. The social welfare of the mining communities was safeguarded by regulations defining the responsibilities of the operators of communal baths, by the close surveillance of tradesmen providing essential services,

such as barbers, cobblers, and laundrymen, and by the exemption of schoolmaster
90/91 from taxation.

The situation in Spain would appear to have been the replacement of a ‘mixed economy! with direct State exploitation of gold mines and the larger silver mines alongside nominal State control of other mines by means of taxation in the form of royalties, by a more integrated, and comprehensive assertion of Imperial control of mining rights and the strict supervision of designated Imperial mining estates by *procuratores metallorum*

Noricum was the major producer of iron in the Roman Empire. The great iron-ore deposits of northern Carinthia and Upper Styria were being exploited on a large scale in the second and first centuries BC. The economic life of the kingdom of Noricum was largely based on its iron production, and the Magdalensberg was a great commercial centre, exporting iron and importing a variety of products from Italy. The merchants of Aquileia recognized the importance of the Magdalensberg as an entrepôt, and a Roman mercantile settlement was in existence on its lower slopes by about 100 BC; indeed, it is probably no exaggeration to say that Aquileia owed much of its importance as a mercantile centre to its links with the Magdalensberg.

The Roman annexation of Noricum, proceded as it was by commercial penetration, is reminiscent of British imperial expansion during the 19th century. Ownership of the iron mines was almost certainly vested in the Norican monarchy, and was ‘inherited’ by Augustus, passing thus directly into the *patrimonium* (Alföldy 1974, 43-4). The Magdalensberg, not surprisingly, became the site of the first Roman administration of the new province, and it would appear that initially franchises were granted to Aquileian mercantile houses to work the mines, with which they had long-standing contacts. However, direct Imperial control seems to have been introduced fairly soon (Alföldy 1974, 113 ff), the mines being managed by Imperial slaves (CIL.III.4808, 4807, 4822 from Hohenstein; III.4912 from Tiffen). A presidial *procurator* is attested from the reign of Claudius, apparently responsible for the economic administration of the entire province, which meant in effect the iron industry. This change may date
91/92 from the reign of Tiberius, if there is a direct analogy with events in Narbonensis, where mines at Villefranche-de-flouergue reverted to Imperial control under a *vilicus* (CIL.XIII.1550).

However, around the beginning of the 2nd century, the epigraphic records begin to yield evidence of a new system; for about half a century the direct exploitation of the Norican iron mines around the Ossiachersee (Tiffen, Feldkirchen, Hohenstein, etc) and in the Görtschitztal (Hüttenberg, Lölling, etc) was in the hands of rich entrepreneurs, the *conductores ferrariarum Noricarum* as they proudly styled themselves. These magnates, whose connexions with Aquileia are recorded (eg CIL.V.810: Ti Claudius Macro; CIL.III.4788: M Trebius Alfius), leased large tracts of mines on the Imperial estates (which, like those in Spain, were not urbanized). Their holdings were so large that they required *procuratores ferrariarum* of their own to administer them (eg CIL.III.4809=ILS.1467 (from Hohenstein): Q Septueius Clemens; CIL.III. 5036 (from Friesach): Q Calpurnius Phoebianus). There is no record of the direct involvement of the presidial *procurator* in the iron industry at this period, but official participation in the administration of the mines was maintained by the *assessores ferrariarum* who were responsible for the administration of the law in the mining districts.

This system was to be short-lived, however; by the reign of Antoninus Pius control had reverted to the Imperial *procuratores*. The reason for this is not clear, but it may have some connexion with the barbarian pressures on the Danube frontier in the mid 2nd century. There was certainly a considerable growth in iron-ore exploitation after the Marcomannic wars; it was at this time that the first large-scale mining of the Styrian Erzberg began. Iron production from Noricum continued at a high rate throughout the early Empire, and indeed the output of the province was still being quoted in the early 5th century (Rutilius Namatianus, I.351 ff).’ It would appear from the epigraphic record to have remained firmly under direct procuratorial control from 92/93
the mid 2nd century.

What is interesting is the apparently different policies in operation in the Iberian provinces and Naricum during the 1st and 2nd centuries. In Spain direct procuratorial control was introduced during the Flavian period: Imperial mining estates were designated and franchises seem to have been granted thereafter mostly to smaller concessionaires (*coloni*). In Noricum, however, up to the time of the Flavian reforms the iron-ore mines were exploited directly; then concessions were granted to rich entrepreneurs, but these withdrawn within half-a-century, to be replaced by a resumption of direct Imperial exploitation (or perhaps by concessions to groups of *coloni* the epigraphic evidence for this is, however, lacking). The reasons for this change of policy invite speculation. Several possibilities suggest themselves. For example, the exploitation by the Aquileian *conductores* may have been so ruthless, without any capital investment, as to run an industry producing essential military material down to a point when ‘nationalization’ was the only solution (the parallel with the coal industry in Britain after World War II is irresistible). It could be that the royalties demanded by the State made commercial exploitation unprofitable: after all, these royalties were as high as 50% in Spanish silver mines at the time. Another possibility is that barbarian pressure on the Danube frontier required an exponential increase in output and capital investment on a scale beyond the means of private interests. Or it may simply have been an act of deliberate Imperial policy to buy out or expropriate the interests of the entrepreneurs in order to safeguard the production of this paramount strategic and commercial material.

The third province that will be examined is Dalmatia, recently the subject of a major work in English (Wilkes 1969). The territory of the Iapodes in the valley of the river Sana was rich in iron ore, which was worked quite extensively before the region became part of the Roman Empire. As in other provinces, metal production increased greatly with the coming of the Romans; there is conclusive evidence of this in the
increase in the number of settlements in the region from seven in the immediate 93/94

93/94 pre-Roman period to twenty-eight, clearly the result of a substantial growth in iron production, no doubt encouraged actively by the State (Sergejovski 1963; Wilkes 1969, 351). That the Dalmatian provinces produced a notable iron mining and working tradition is witnessed by the transfer of Pirustae to work the Dacian mines in the early 2nd century (*vicus Pirustar*(*um*) in CIL.III.944).

Epigraphic evidence from the Iapydian mining region is sparse. However, there is a valuable series of seven altars dedicated to Terra Mater, patron deity of miners, from the Briševo-Ljubija region, set up by successive *procuratores ferrararium* of the district and their *villici officinae ferrariae* dating from 201 to the reign of Gallienus (Sergejevski 1963; Wilkes 1969, 267-8). It is worthy of comment that on only the first of these is reference made to a conductor the procurator was evidently in full control by 209, the date of the second altar in the series.

It seems probable that the Sana valley iron mines formed an Imperial estate, similar to those in Spain and Noricum. Wilkes comments (1969, 193) that the growth of towns in certain areas (including that of the Iapodes) was inhibited by the system of working mineral deposits under the close control of Imperial officials, who were also responsible for the civil administration in these regions (cp the *lex metalli Vipascensis*) Another echo of the Aljustrel tablets comes from the lead/silver mining centre of Domavia, where the elaborate baths were rim by a *conductor*, who was no doubt subject to the same severe official surveillance as that prescribed in the *lex metalli Vipascensis* (Wilkes 1969,378).

In Dalmatia a similar picture emerges of iron mining in nonurban Imperial estates, controlled by Imperial *procuratores* There is evidence of the granting of concessions as late as the first decade of the 3rd century, somewhat later than in Noricum, but reflecting the same process of concentrating the exploitation of mineral resources directly under the control of Imperial officials.

94/95 Another mining region in this part of the Empire where metals were produced on a relatively large scale is the Kosmaj valley, near Belgrade. It is not certain whether these mines were located in Dalmatia or Upper Moesia. Veličković (1956-57), on the basis of certain inscriptions favours the latter, despite the lead pigs found with the stamp M(etalla) D(almatiae). The mines produced galena ore, which produced a high-silver lead. However, the principal interest for a study of the iron industry of Roman Britain of the Kosmaj valley is the finding, in 1912, of a brick stamped CLASSIS. Veličković sees this as a direct link with the Classis Moesica, based at Vimatium or Margum. It represents the only link outside the Weald between a metal-producing industry and a provincial Roman fleet. As yet no direct functional relationship has been revealed by epigraphic studies between the Moesian fleet and the *procurator metallorum Pannoniarum et Dalmatiarum* at Domavia, or with the Guberevad mines, where an inscription (CIL.IIIS.8163) implies direct Imperial ownership during the reign of Marcus Aurelius.

Our knowledge of the administration of the iron industry in Gaul is even more scanty. Davies (1935, 80, 86-91) lists the regions where iron was produced in the Roman period – the eastern Pyrenees, central Aquitania, the Loire valley, the Côte d'Or, and Provence – but no coherent picture emerges, unlike the provinces already discussed. There are a number of significant inscriptions: Ti Iunius Fadianus, *conductor ferrariarum ripae dextrae* (CIL.XII.4398 – Nîmes, 2nd century); Primio, *ferrariarum servus* (CIL.XII.3336 Nîmes, 2nd century); *procurator ferrariarum* (CIL.XIII.1797 – Lyon, 3rd century*); tabularius rationis ferrariarum* and *mancipes splendidissimi vectigalis massae ferrariarum* (CIL.XIII.1811=ILS.8641 – Lyon, mid 2nd century); *fabrica ferraria* (CIL.XIII.2036 – Lyon, 2nd century); *fabri ferrarii* (CIL. XIII.5474 – Dijon, 2nd century). From these and others it may be deduced that there was Imperial, control of mineral rights, at least in Provence and Lugdunensis, with *procuratores ferrariarum* based at Nîmes and Lyon by the 3rd century. Concessions seem to have been granted to major entrepreneurs (*conductores*) in Narbonensis at any rate, in the 2nd century; the later franchise system is not known, although one of 95/96
the inscriptions from Lyon (CIL.XIII.1811) does additionally make reference to *socii ferrariarum*, which suggests some form of co-operative or limited company, perhaps analogous to the *coloni* in Spain. Evidence for Imperial estates is also slight: the regions round Nîmes and Lyon where iron is likely to have been worked do not reveal the lack of urbanization that characterizes the Sierra Morena, the Styrian Erzberg, or the Sana valley; however, Grenier (1934. 859-67) draws attention to the absence of villas in Lorraine on what prove on examination to be iron ore deposits, and suggests that the native settlements that replace them indicate the existence of an Imperial estate.

To summarize, it can be said that most Roman provinces exhibit several phenomena in common, so far as their respective iron industries are concerned:

1 Massive increases in mining and ironmaking activities following absorption into the Roman Empire.

2 The assertion of nominal State control over mineral resources, which manifests itself in the earliest period in the form of direct exploitation of gold and the larger silver deposits and the granting of franchises for other types of mining.

3 A period of exploitation by rich entrepreneurs, lasting until the end of the 1st century in Spain, the mid 2nd century in Noricum, and the end of the 2nd century or the early 3rd century in Gaul and Dalmatia.

4 Assumption of direct responsibility for mining and ironmaking operations by Imperial officials (*procuratores ferrariarum*) most probably working through small concessionnaires (*coloni*) or managers (*vilici*).

5 The establishment of Imperial estates with no citizenship rights, a low level of urbanization, but considerable social protection for the inhabitants.

It appears, furthermore, that 4 and 5 above were probably contemporaneous, although the outlines of the Imperial estates may have been laid down at an earlier 96/97
stage. The process of absorption wholly into the *patrimonium* represented by these steps does not seem to have occurred simultaneously throughout the Empire. In

Spain, for example, it was part of the Flavian reforms, which established the model for the application of this process, possibly under military pressure, in the Antonine period in Noricum and the Severan in Gaul and Dalmatia.

This supports the view of Rostovtzeff (1957, 340-3) that the general trend was towards the elimination of large capitalists and concentration of the exploitation of mineral resources into the hands of Imperial officials. He further points out that a policy developed from the time of Hadrian of giving preference to small contractors. He goes on to claim that this system later gave way to direct exploitation by the use of criminals (*damnati in metallum*) or slaves under military supervision. However, there is little evidence (with the exception of gold mining, always a special case) of this practice, and none in the iron industry, at least before the 5th century, and so this development, the general application of which is open to challenge, will be disregarded in the present study.

In view of its limited application to Britain, it is also not intended to deal with the administrative structure of the later 4th century, beyond noting that there is evidence that Imperial control of the mining regions appears to have remained absolute. The rights of 'free mining' were ostensibly granted to all, but at the same time a swingeing rate of royalty levies was imposed (Codex Theodosianus, X.19.3). There was also a change in nomenclature, comparable with that in the army and other branches of administration. The earlier *procuratores* were replaced, in some regions at any rate, by *comites* eg the *comes sacrarum largitionum* who was in charge of the Dalmatian iron-producing region (Wilkes 1969, 424) and the *comes metallorum per Illyricum*
97/98 who figures in the *Notitia Dignitatum* (12: Torres 1962, 329).

3.2 The organization of the iron industry in Roman Britain

3.2.a Introduction

In the preceding section it has been possible to produce a conspectus of the administration of the iron industries in certain Roman provinces and to deduce from this some general ideas about Imperial policy for the industry as a whole. This has been based principally on the epigraphic evidence, which is relatively abundant and informative, though not so rich as to permit sure conclusions to be drawn. The archaeological record, at least so far as specific studies of the remains of Roman working are concerned, is less rich and can only be considered as secondary and corroborative to the epigraphic evidence. There have been no surveys within the *limes* (with the possible exception of the work in progress in the Burgenland (Pannonia) under the leadership of Ohrenberger and Polartschek, little of which has yet been published) devoted to the systematic exploration of a region with the aim of delimiting its extent and quantifying its iron output.

The converse situation applies in Britain. The epigraphic record is effectively non-existent: only one inscription is known from a major iron-producing site, Beauport Park, and this is tantalizingly incomplete. A systematic study of one important iron-producing region, the Weald, has been in progress under the aegis of the Wealden Iron Research Group for more than a decade, and individual workers have been responsible for the collection and collation of information and for fieldwork in two other key areas the Forest of Dean (N P Bridgewater) and the Northamptonshire ironstone region (D A Jackson) – over a similar period. The problem in attempting to evaluate the likely organization and administration of the iron industry in Roman Britain is therefore one of interpreting relatively abundant archaeological data in the light of the system postulated for the Empire as a whole.

3.2.b Imperial Estates

There is no direct evidence for the existence of Imperial estates in Britain. However,
the existence of such estates in the settled southern part of the province has been 98/99
postulated in the past: their existence has been deduced primarily from the non-territorial organization implicit in the settlement pattern in certain areas. A large tract of country with no early villas and at some distance from any large towns or *civitas* capitals has been taken to imply the existence of a different form of land ownership from the normal, and Imperial estates have suggested themselves. The best known examples are probably those of Cranborne Chase and the Fenland, where the criteria laid down above seem to be complied with (Rivet 1964, 102-3, 117; Frere 1974, 312-3).

The case for the Fenland as an Imperial estate is made effectively by Salway (1970, 10-11). The conditions set out above are clearly complied with, but in addition there is the evidence of major public works, for drainage, carried out by what is ostensibly a completely rural population, without the benefit of wealthy municipal authorities. The expenditure involved must have been considerable, involving large injections of capital. The most obvious source of this finance would surely have been the State (or the Emperor), and this view is lent some support by a fragmentary inscription from Sawtry (Phillips 1970, 181; *Antiq J,* **20** (1950), 504-6) a square stone base inscribed PVBLIC(… Of slightly less value, but none the less interesting, is an amphora handle dated to AD 208-11 which derives from one of the properties sequestered by Septimus Severus in Spain (Phillips op cit, 238). Imperial involvement, under the general supervision of a *procurator saltus* responsible to the *procurator provinciae* as suggested by Salway (1970, 10), is thus indicated, and can be parallelled from similar regions elsewhere in the Empire.

A study of the Ordnance Survey *Map of Roman Britain* reveals another possible Imperial estate in the Weald of Sussex and Kent. The traditional interpretation of the sparse Roman occupation of this region has always been based on the impenetrable nature of the forest cover on the wet claylands of the Weald which, it is argued,
prevented its being deforested and ploughed until the advent of the Saxons with their 99/100
improved ploughs and cultivation techniques (eg Brandon 1974. 71; Wilson 1976, 7). However, the most recent account of Anglo-Saxon agricultural methods challenges the widely held view that the Anglo-Saxons introduced the heavy plough, and

suggests that this implement was already in use during the Roman period (Fowler 1976, 27-8). Moreover, the traditional view of the impenetrable Wealden forest has been seriously challenged by recent intensive fieldwork on Ashdown Forest (Tebbutt l974), which has revealed very widespread penetration and settlement from the mesolithic period onwards. Such sites as Saxonbury (Winbolt 1930) and High Rocks (Money 1968) are evidence that systematic settlement of the Weald from the north had begun in the pre-Roman Iron Age, a view confirmed by the discovery of Iron Age pottery on ironmaking sites in the Hastings area, such as Crowhurst Park and Footlands, and further north at Pippingford and Minepit Wood.

It would therefore seem permissible to seek another explanation for this lack of Roman urban or villa settlement in the Weald. The clue would seem to lie in the pre-Roman iron-working in the Hastings area and the reference in Caesar to iron production in the maritime region of Britain (*nascitur ibi … in maritimis regionibus ferrum* BG.V.12). This would seem to indicate a pre-existing iron-mining region which was absorbed into the Imperial *patrimonium* at the conquest; the parallels with Dalmatia and Noricum would make the foundation of an Imperial estate likely. The possibility of acquisition by inheritance, as occurred in Noricum, should not be overlooked. It has been suggested (Cleere 1974) that the Chichester inscription referring to a *collegium fabrorum* (RIB.I.91) might represent a link with the iron-mining in the Hastings area. If so, it is conceivable that this would have been under licence from the king, and that the Wealden iron industry did not come under direct Roman rule until the death of Cogidubnus around AD 80-90 (Cunliffe 1971, 14; see also Cunliffe 1973, 124).

If the Weald did become an Imperial estate towards the end of the 1st century,
100/101 it appears to have been exploited in two ways direct State working (by the *Classis Britannica* in the eastern part and leasing, perhaps to *conductores* or *collegii* although no epigraphic evidence has survived, in the western half. This is discussed fully in a paper by the present author (Cleere 1974), summarized in section 2.1 above and given in full as Appendix C.

The involvement of the *Classis Britannica* in the iron industry of the Weald is amply attested by inscriptions from four sites connected with ironmaking (Brodribb 1969; Cleere 1974, 186-90). The most recent survey of the *Classis Britannica* (Cleere 1917) links the expansion of the fleet from its invasion base at Richborough to Dover and the iron-mining area with the erection of the Great Foundation at Richborough c. AD 85; the earliest stamped tiles from ironmaking establishments appear at the beginning of the 2nd century. This may lend support to the hypothesis advanced above, that the Weald remained part of Cogidubnus's *patrimonium* as client-king until being bequeathed to the Emperor on his death. However, this may be purely coincidental; the creation of the suggested Imperial estate may be more properly linked with the reforms begun by Vespasian.

The case for the existence of an Imperial estate based on the ironworks of the Weald appears to be a strong one. There is evidence of direct State participation (at least until the mid 3rd century) in the eastern region, there are no towns within the Weald itself, and villa settlement is confined to the peripheral Greensand and Chalk. The differences in road pattern between the eastern and western parts of the Weald tend to confirm the existence of different modes of exploitation, those in the west driving through the forest and linking the sites with London to the north and Chichester and the villas of the South Downs to the south, whilst those in the eastern region converge on the estuarine ports, one of which, Bodiam, has fleet connexions (Lemmon & Hill 1966). A conservative view might be to consider the putative Imperial estate to be confined to the eastern region. However, it is clear that 'free miners' were operating on Imperial estates in other provinces, and more thorough exploration of mining areas in Noricum and Spain, in particular, might produce parallels for the
'mixed economy' postulated for the Weald. 101/102

There is one further link between the *Classis Britannica* and the imperial administration that should be taken into account. Under Antoninus Pius, M Maenius Agrippa L Tusidius combined the posts of *praefectus 'Classis Britannicae* and *procurator provinciae Britanniae* (CIL.XI.5632; Pflaum 1960-1, No 120). At this time the fleet was well established as responsible for iron production in the eastern Weald, a major source of iron for Britain and also, perhaps, for the north-western provinces (Cleere 1974, 189; Cleere 1977). There would seem to be some logic in the combination of the command of the fleet with the provincial procuratorship. Support for this view comes from the unpublished Beauport Park' inscription; this so far undated dedication (which is hardly likely to have been much later than the end of the 3rd century) relates to the rebuilding of the bath-house under the supervision of a *vilicus* named as Bassus or Bassianus. This is suggestively reminiscent of the series of dedications by the *procurator ferrariarum* and his *vilicus officinae ferrariae* from the Briševo-Ljubija region of Dalmatia (Wilkes 1969, 267-8). The pluralism implied in the Maenius Agrippa inscription may have been reproduced at the ironworks: ie whilst control of the mining operations were vested in a civilian (the *vilicus*) support services, especially transport and materiel (including tiles), were the responsibility of the fleet and its personnel. This might help to explain the apparent heavy involvement of a military unit in industrial operation, which has no parallels in other fleets of the Roman world.

The Weald is the only iron-producing region where a strong case can be made out for the existence of an Imperial estate. Another possible candidate, though on more slender evidence, is the Forest of Dean. In his 'political' map of Roman Britain Rivet (1964, fig 9) uses the same shading for 'mining districts and areas under military government'. The areas so marked on this map cover the northern military area, most of Wales, the Weald, the Mendips, and the Forest of Dean. Frere (1974, 321-4) discusses the somewhat sketchy evidence from Mendip; he postulates an initial
period under direct military control, followed by leasing to *conductores* and *societates* 102/103
for which stamped pigs of lead provide the evidence. It would seem likely that this area (perhaps along with other lead/silver-producing areas such as Flintshire and Derbyshire) formed an Imperial estate until the later 2nd century, to which period the

Margin numbering in red refers to the original page numbers of the thesis

latest inscribed ingots are attributable. Thereafter the growth of villas in the Mendip area may be taken to imply the sale of parts of the estate to private individuals; as Frere points out in an earlier passage (1974, 312-3), ‘land held by the Emperor… was not inalienable, and could be transferred by gift or sale; thus, the pattern of Imperial ownership was ever liable to change’. The evidence from Mendip is, admittedly, circumstantial, and the most recent study of the lead industry in the region (Elkington 1976) fails to draw any conclusions about it.

The inscribed pigs provide some tangible evidence, albeit slight, about the control of the Mendip lead industry; the case for the Forest of Dean is considerably more circumstantial and founded on analogy. The scale of the Dean industry is discussed in section 2.2 above; it was clearly extensive, from Lydney on the Severn to Llandinabo in the north and from Redbrook in the west to Cinderford in the east. In addition, towns lying outside the traditional forest – Monmouth (Blestium), Chepstow (Striguil), Weston-under-Penyard (Ariconium), and Gloucester (Glevum) – show that there was considerable metal working (as opposed to smelting) being carried out in and around them. Unfortunately the volume of production during the Roman period is less easy to calculate than it is in the Weald, owing to subsequent iron mining and smelting in the same area and the removal of many thousands of tons of Roman iron slag for re-smelting in blast furnaces higher up the Severn in later centuries. This fact, combined with the less systematic study that has been made of Roman iron sites in Dean, also makes it difficult to date the industry as securely as that of the Weald. For the present discussion, however, it will suffice to accept that the number of sites in the Dean and the still considerable slag heaps suggest that the region was second
103 only to the Weald in terms of iron production in Roman Britain.

104 Reference again to the *Map of Roman Britain* shows that within the historic Forest of Dean, as delineated in the early Middle Ages (Hart 1967, Map V), there were no major towns, a situation that has persisted to the present day. The larger Roman urban settlements listed above all lay outside the Forest proper. With the exception of the late Roman temple complex at Lydney Park (Wheeler & Wheeler 1932), itself built on the site of a Roman iron-mining settlement of the earlier period, there is only one site in Dean, the Chesters villa at Woolaston (Harris & Scott-Garrett 1938), on the south-western fringe of the Forest, that has produced evidence of any type of Roman occupation other than industrial. It may be significant that this establishment possessed two bath-houses and a ‘light guideline, for guiding Severn craft through the Guscar rocks to its shore’ (Hart 1967, 25). The generous provision of bathing facilities is reminiscent of the *lex metallum Vipascense* and also of the substantial bath-house at Beauport Park in the Weald. This prompted one Dean archaeologist (Hart 1967, 25) to speculate that ‘possibly it was occupied by a Roman ironmaster who also indulged in farming and had connections with shipping.’ An equally valid speculation might be that this was the residence of the *vilicus* of the Imperial estate.

The Woolaston villa dates from the reign of Hadrian until the end of the Roman period, being rebuilt after destruction at the beginning of the)4th century. The foundation date may be of interest in that it seems to correspond with a considerable expansion of the Wealden industry. Of particular interest is the navigational aid for shipping: this may be linked with the seaborne transport of iron products, either across the Severn or coastwise to settlements and garrisons on the coasts of Wales and north-western Britain.

The Lydney Park site provides the only evidence of any possible connexion between the Forest of Dean and the Fleet. The mosaic dedication by Flavius Senilis, who describes himself as *praepositus reliquationis classis* (Bathurst 1879, quoted in Wheeler & Wheeler 1932) may be merely coincidental; in any case the interpretation 104
of the mosaic, which is no longer extant, is debatable. However, the disappearance of 105
the *Classis Britannica* from the south-east in the mid 3rd century may be explained by its being transferred to the western approaches, partly perhaps to exploit the iron-ore deposits more fully, those in the Weald being more difficult to win by that time (Cleere 1974), and partly to protect a coastline at that period more exposed to barbarian raids than the south east.

Based on continental models, and with reference to the suggested situation in the Weald, it is thus defensible to put forward the hypothesis that the Forest of Dean was established as an Imperial estate at the time of (or very soon after) the Conquest, conceivably by confiscation from its Dobunnic suzerain. Initially, Imperial control was probably exercised with a light hand, the small-scale ironmaking operations being permitted in return for simple taxation. However, in the first half of the 2nd century, the scale of operations was increased enormously, and a metal-producing centre (reminiscent of, for example, Domavia) was established at Ariconium. At the same time a port establishment was set up on the coast, connected by road with Ariconium. The impetus for this increase in production can only be conjectured; however, it is tempting to link it with the building of the two northern *limites* in the 2nd century. The amount of iron needed in Roman civil engineering and building works was enormous, as Schindler (1976) has recently demonstrated, and the output of the Weald ironworks was probably inadequate to meet the demand.

A possible relationship with the *Classis Britannica* from the early 2nd century, contemporaneous with that unit’s operations in the eastern Weald, cannot be ruled out, although the absence of stamped ‘tiles, so frequent in the Weald, militates against this theory. A fleet ‘takeover’ in the 3rd century is perhaps a little more justifiable. There is no evidence as to the later history of the region, although ironmaking appears to have continued on a sizeable scale until the end’ of the
Roman period. 105

The only other possible candidate for consideration as an Imperial estate based 106
on iron mining and production lies in Northamptonshire, where a number of sites have been found on the ironstones of the Jurassic Ridge (see Section 2.3 above). However, the settlement pattern, with towns at Godmanchester, Irchester, Water New-ton, and elsewhere and the relatively greater number of villas by comparison with the Weald or the Forest of Dean, coupled with the relatively modest scale of

operations at the sites so far investigated, tend to rule out so formal an organization in this region. It would appear more likely that this was a case where mining rights were leased to small operators against royalty payments.

3.3 Types of site

The main problem in attempting a classification of iron making and iron working sites in Roman Britain is the fragmentary nature of the evidence available. Very few excavations have been carried out on sites devoted exclusively to iron, and most of these have concentrated on the industrial aspects, without a search being made for the related settlements (eg Ashwicken, Minepit Wood). This tends to be the pattern elsewhere in Europe as well: excavators have studied industrial technology in isolation from the economic and social background to the sites. There is, of course, another extreme, represented by excavations on settlements where furnaces and other evidence of iron technology have been discovered, but where little or no attempt has been made to relate these to the excavated occupation areas.

On the evidence available, it would appear to be possible to classify the sites listed in the catalogue into five main groups:

a Major industrial settlements
b Minor industrial settlements
c Military ironmaking sites
d Urban ironmaking sites
106 e Ironmaking on villas
107

3.3.a Major industrial settlements

The criteria for this type of site are that it should be devoted preponderantly to iron production, that it should have been in operation for a substantial period (not less than 50 years), and that it should cover a minimum of 1ha.

Sites of this group are to be found principally in the primary iron-producing areas – the Weald, the Forest of Dean, and the Jurassic Ridge – although isolated sites such as Ashwicken and Tiddington may well also belong in this category. In the Weald the following may be identified with confidence as major sites: Bardown, Beauport Park, Broadfields, Chitcombe, Crowhurst Park, Footlands, Great Cansiron, Oaklands Park, Oldlands, and the East Grinstead group of Ridge Hill and Walesbeech. The situation in the Forest of Dean is less clear, owing to the lack of detailed survey and excavation. However, the scanty evidence suggests that major settlements existed at Ariconium (but see 3.3.d below), Bream, Goodrich, Hentlands, Littledean, Llandinabo, Monmouth, Peterstow, Tretire, and Whitchurch. The Jurassic Ridge is even less informative, but candidates for inclusion in this category are Bedford Purlieus, Bulwick, Scawby, and Wakerley.

Of these sites, only Bardown has been investigated in a relatively comprehensive way, with the intention of locating both the industrial and the residential areas. However, an intensive ground survey has been carried out at Beauport Park, and long-term excavations were conducted, albeit on a rescue basis, at Broadfields. It seems clear from the evidence from these three sites that the settlements were divided into distinct working and living zones, at Bardown delimited by a central roadway running through the site, with the residential zone lying to the south-east of the industrial and thereby largely sheltered from atmospheric pollution carried by the prevailing south-westerly winds. A similar layout appears to have existed at Beauport Park; at Broadfields the areas excavated were devoted exclusively to industrial operations, with no apparent intermingling of purely residential buildings. 107

This physical separation of dwellings and working areas would appear to bespeak 108
a degree of central organization and planning from a superior authority. Ironmaking at these establishments was not a ‘cottage industry’, in contrast with, for example, 18th century Sheffield, where cutlers worked as individual craftsmen and carried on their work in the same buildings in which they lived, or the 17th and 18th century wool villages in the West Riding of Yorkshire, where weaving was carried on in the upper storeys of dwelling houses. The major Roman iron settlements may be assumed to have operated on a different basis, judged on the archaeological evidence. It is unfortunate that two at least of the three settlements under discussion were operated under State control, and that all three are located in a putative Imperial estate. It is difficult on this evidence to put this layout and organization forward as a norm for the whole province; however, certain of the other sites have been shown to contain concentrations of furnaces (eg Bulwick, Ariconium), and the slag dumps at most of these sites are large and concentrated in one place, which implies centralized administration rather than ‘cottage industry’ operation.

The size of these sites is difficult to determine in most cases, since only the slag dumps have been identified and the extent of the settlement itself is unknown. Moreover, the terms used to describe the extent of these dumps is usually imprecise and unquantified. Again, the Wealden sites are best known. At Bardown the total area of the settlement is about 3.25ha, of which the slag dump represents only 0.4ha: here at least a factor of 8 applies between slag dump and total settlement. The Beauport Park dump probably covered an area twice as large, which implies a total settlement area on this basis of some 6.5ha; in fact, fieldwork there suggests that it was somewhat larger – perhaps up to 8ha in extent, giving a factor of 10. The topography of individual settlements varies, of course: most of the Wealden sites are located in fairly steep-sided valleys, into the bottom on which the slag was usually tipped, and this resulted in a deeper but less scattered dump. On flatter sites, such as those on 108
the Jurassic Ridge, or hilltop sites, as many of the Forest of Dean sites appear to 109
have been, the spread of refuse would have been considerably greater, and so it is perhaps advisable to adopt a factor of no more than 5 for these sites.

The Wealden sites listed above each cover between 2 and 8ha; however, it should not be overlooked that several of these probably had ‘satellite’ workplaces of the

Holbeanwood type. The Forest of Dean settlements were probably equivalent in size range, if not larger: Bridgewater (1968) writes of 'several acres' of slag deposits at Llandinabo, which might put this settlement at over 8ha, whilst at Whitchurch the whole present-day village is apparently built on a bed of slag, which implies a very large scale of operations and settlements. There are no data available on the extent of the Jurassic Ridge settlement slag dumps, unfortunately, but the impression derived from reading short reports is that they were smaller than those in the Weald or the Forest of Dean – probably normally 1-2ha in extent.

The size and organization of this group of sites are considered to justify the view that they represent entrepreneurial operation on a large scale. The eastern group of Wealden sites was, as indicated in 2.2 above, under State control, either by the Fleet or by the procurator's department in association with the Fleet. The western group appear to have been independent, though they would have been operated under licence if this area formed part of the Imperial estate postulated for the Weald. The organizational framework in the Forest of Dean is unknown, owing to the absence of any epigraphic evidence, although a case can be made for an Imperial estate here as well (see 3.2.b above). The large size of many of the sites, however, suggests entrepreneurial control. On the Jurassic Ridge the evidence is too slender to do more than suggest that the concentrations of furnaces may imply a measure of centralized control.

The nature of the non-State enterprises responsible for operations in the Weald
109 and the Forest of Dean can only be a matter for speculation, since there is only the
110 Chichester dedication to, hint at the existence of *collegii fabrorum* in Roman Britain,
and no reference has yet been found in the province to a *conductor*.

3.3.b Minor industrial settlements

Most of the other ironmaking settlements in Britain must be consigned to this somewhat vague group, in view of the very limited information available about most of them. These are the sites of relatively short duration (under 50 years) and small extent (under 1ha).

The Weald produces two examples, both early in date – Minepit Wood and Pippingford Park. Both were operated for a short period in the mid 1st century and were based on single smelting furnaces. They are small in extent and have only modest slag dumps, measurable in tens of tonnes rather than thousands. Neither has produced any evidence of living accommodation (although in neither case was the search very thorough); the timber structure at Minepit Wood was almost certainly used for an industrial purpose. A caveat has to be entered here, however: it is not unlikely that these sites were both 'satellites' of late Iron Age settlements that continued into the Roman period – Saxonbury (Winbolt 1930) in the case of Minepit Wood and Garden Hill (Money 1977) in the case of Pippingford Park. The recently discovered Pippingford Cowpark site, with three furnaces, was also probably operated by ironmakers based at Garden Hill.

The Wakerley site in Northamptonshire is a good example of this type of small-scale operation. The settlement appears to have originated in the pre-Roman Iron Age, based on agriculture. However, the potential of the local ironstone was recognized, and iron began to be smelted, using small non-slag-tapping furnaces. A more developed type of furnace was introduced later, but still of the non-slag-tapping group. Production appears to have been increased, perhaps towards the end of the 1st century, with the introduction of the slag-tapping shaft furnace that became
standard in most of Britain during the Roman period. However, it seems not unlikely 110
that ironmaking was not the sole basis of the settlement: pottery was certainly made 111
for a time, and agriculture probably continued throughout the Roman period.

More typical of settlements in this group, perhaps, are the sites in Wales, such as Braich-y-Ddinas, Caer Mynnydd, Caerau, Cefn Graenog, etc, where iron ore was smelted and iron objects were produced in 'native' settlements for a purely local market, and the 3rd and]4th century sites in England, where a limited amount of smelting was carried out in periods when the commercial life of the province had collapsed and iron was produced for local markets, or even solely for use on the settlement itself. Examples of the latter are to be found throughout the province – in East Anglia (Brampton, Hacheston), the west (Brean Down, Bere Regis), and the north (Eskmeals).

Very few conclusions can be drawn from the disparate and incomplete data at our disposal. Three main groups of small-scale operations may perhaps be identified:

i Late Iron Age settlements (Weald and also probably elsewhere – eg Levisham), superseded in the late 1st and early 2nd centuries, when iron production was concentrated in three major regions

ii Native settlements in Wales (and also possibly the southwest – eg Dulverton), producing iron to meet the requirements of the immediately surrounding area

iii Ironmaking operations on settlements throughout the province, again producing iron for local needs in periods when normal commercial activities had been interrupted or had ceased completely (see also 3.3.e below).

3.3.c Military ironmaking sites

The versatility of Roman soldiers is well attested: clearly, military smiths – and indeed all Roman smiths, military or civilian – were capable of smelting iron ores if
necessary as well as forging weapons, armour, tools, and constructional items. It 111
seems not unlikely, for example, that some at least of the one million iron nails from 112
Inchtuthil were produced from iron smelted in the vicinity of the fortress, since one possible smelting furnace base and a small amount of tap slag were found there (I A Richmond, pers comm: material examined by HC).

Almost every fortress and fort has produced evidence of ironworking – in Wales (Aberffraw, Forden Gaer, Pen Llystyn), the northern military zone (Binchester, Papcastle, Templeborough, Watercrook, York), Hadrian's Wall (Corbridge, Housesteads), and the Antonine Wall (Bar Hill, Croy Hill). In addition to Inchtuthil, there is evidence of smelting having been carried out at some of the forts: at Northwich, for example, six smelting furnaces were found outside the auxiliary fort which were apparently in use during the late 1st and early 2nd centuries, and bloomery slag was used for metalling within the fort at Cardiff. It is possible that ore was being smelted at Margidunum in the conquest period, and there may also have been some smelting at Lanchester; a tuyere from Carpow may be interpreted as being associated with smelting, although smithing would seem more likely.

Tylecote's statement (1962, 217) that '… military authorities did not bother to smelt their own material on (military) sites' seems to be borne out by these observations: smelting seems to have been carried out by army *fabri* only during the early phases of occupation or on campaign to meet urgent needs. However, he goes on to suggest that they 'bought it from the natives', an assertion that needs some modification in the light of work subsequent to the appearance of his standard work establishing a strong link between the iron industry of the eastern Weald and the *Classis Britannica* (Cleere l974). The needs of the British garrison were clearly filled by the eastern Weald ironworks from the end of the 1st century to the middle of the 3rd century, and thereafter it is not unlikely that the Forest of Dean works took over this role.

There remains only one other settlement that requires some consideration in this
112/113 section. Excavations at Wilderspool have so far revealed only slight evidence of a military connexion, in the form of a single stamped tile of the XX Legion (May 1904, 4). This would suggest that the original settlement here was military, but it would appear to have been short-lived. Iron was unquestionably smelted at Wilderspool, but so far as can be judged from the report on the furnaces this was in the 2nd century at the earliest. It is possible that iron was produced here for military use, but the probability is that Wilderspool was a civilian industrial settlement producing a variety of manufactures for civilian markets, like Doncaster, where iron was also smelted but where the main industry was pottery manufacture.

3.3.d Urban ironmaking sites

As with the military settlements, almost every Roman town *colonia*, *civitas* capital, or *vicus* – has produced evidence of smithing activities. Some of these have also yielded some specimens of tap slag, suggesting short-lived and ad hoc smelting being carried out during periods of shortage. For the most part, however, urban smiths seem to have confined themselves to forging operations, producing artefacts for the local market from imported iron semi-products.

These operations were usually carried on outside the walled settlement area. The best studied settlement of this kind so far is perhaps Manchester, where Professor Jones's excavations revealed a large industrial settlement in the *vicus* of the fort, in operation from c.AD 77-78 to the late 3rd century. The metallurgical structures found all appear to have been forging hearths or melting furnaces for non-ferrous metals; three are claimed to be iron-smelting furnaces, but the specialist report (Bestwick & Cleland 1974) is less than specific in its ascription. This was clearly a metalworking section of the *vicus,* comprising a number of small jobbing workshops: the layout does, not imply a larger-scale operation centrally directed. A similar arrangements seems to have existed at, inter alia, Caerwent, Droitwich, and Derby. 113/114

There is, however, a small group of urban iron-working settlements where smelting was apparently carried out as a matter of course. Aribonium was exceptional, in that it appears to have been a small town devoted exclusively to iron. It is debatable whether this was an urban settlement *proprio dictu* or whether it was the largest 'major industrial settlement' in the Forest of Dean; another possibility is that it was the *chef-lieu* of a putative Imperial estate in Dean, comparable with, say, Domavia.

A town where iron smelting was carried out on a large scale outside the walls and where there is no major iron-producing region in the vicinity is Worcester. At the end of the 17th century, Yarranton (1698) reported that many thousands of tonnes of Roman slag were quarried from outside the city walls of Worcester and taken further up the Severn for re-smelting in the blast furnaces of Shropshire, and evidence of this activity in Roman Worcester was found in a recent rescue excavation (Barker 1977). Camerton seems to have been another small town where iron making and working were major industrial activities, and Wilderspool and Doncester were mentioned in the preceding section.

Finally, two small towns on the Jurassic Ridge – Godmanchester and Great Casterton – have yielded evidence of iron smelting as well as iron working. The apparent pattern of smaller settlements and ownership spread over a large number of small entrepreneurs (*coloni*?) in this region makes this type of operation in two of the small towns more comprehensible: against this ownership background, and with the widespread distribution of iron ore in the region, it is reasonable to postulate a commercial situation that would make it possible for an enterprising smith in an urban industrial sector to secure the rights to a small pocket of ore and maximize his profits by carrying out the full range of operations from mining to artefact production.

Other finds connected with metal working rather than smelting are not uncommon
within the enceintes of certain towns during the closing years of the Roman period. 114/115
The best example of this is probably Wroxeter, where hearths were built in the ruins of the forum after the second fire. This situation is paralleled throughout the province in many villas (see 3.3.e below).

3.3.e Ironmaking on villas

It is now generally accepted that villa economies could be based on activities other than agriculture. In his recent study, Percival (1976, 616-3) discusses the possibility of villas being founded to exploit iron ore, and quotes those at Anthée and Chastres-lès-Walcourt in Gallia Belgica, where 'the surrounding land is not particularly fertile, there are numerous ironworking sites in the area, and a nearby Roman road is paved with iron slag'. The situation is strongly reminiscent of the romanized Iron Age settlement at Garden Hill in the Weald., with at least two bloomery sites nearby (Pippingford Park and Cowpark): Garden Hill unfortunately failed to live up to its pretensions and closed down in the 2nd century, instead of expanding, like Anthe. Another region where iron may have formed the basis of a villa economy was Périgord (Percival 1976, 71), and there is a suggestion that some Breton villas were connected with iron (Percival 1976, 74).

A study of British villas provides only one example of an establishment that was almost certainly based on iron production. This was the Ely (Cardiff) villa, which seems to have been in use in the 1st and 2nd centuries. Stocks of local iron ores (and a manganese ore, allegedly from Spain, for the presence of which no plausible explanation has yet been put forward) were found in association with a small shaft furnace and large quantities of iron slag, used for metalling open space in and around the villa. Lead and bronze working are also attested on the site. Wheeler (1922) was emphatic that the main activity at Ely was ironworking.

It is possible that tile Ashwicken ironworks, where no buildings were discovered, was connected with the Gayton Thorpe villa (Tylecote 1962, 217), but the villa lies
115/116 some 5km distant, which is somewhat further than 'satellite' workplaces in the Weald. The Great Weldon villa also has some connexions with iron smelting, but only in so far as large blocks of slag weighing up to 30kg were found in its foundations: there was no continuous ironworking activity at the villa during its life.

It would appear that villas based on ironworking do not form part of the overall picture in Britain. The Ely villa is an exception, of course, but it is a somewhat anomalous establishment in any case. It lies farther west than any other villa north of the Bristol Channel, on the very edge of the civilian area – indeed, it needed to be equipped with a defensive ditch, a somewhat rare feature in British villas. Its date range suggests a lone enterprise that went out of business with the expansion of the Forest of Dean industry.

Most villa reports, of course, refer to metal-working activities, but these represent no more than the normal work of the estate smith, concerned solely with forging iron and making simple non-ferrous metal castings. However, a number of villas have provided evidence of ironworking activities being carried out in the main buildings in the 4th century. These are to be found widely scattered – the Jurassic Ridge (Clipsham, Great Weldon, Thornhaugh, Winterton), Somerset (Brislington, Wemberham, Whatley), the edge of the Weald (Chilgrove), and the Thames Valley (Sutton Courtney). At Clipsham iron ore was demonstrably being smelted as well, and the same may be true of Brislington. This phenomenon can only be interpreted, like the ironworking in the Wroxeter forum, as symptomatic of the breakdown of Roman society in Britain during the later 4th century. 116/117

116/117 # 4 The Technology of Roman Ironmaking

4.1 The basic chemistry of bloomery ironmaking

4.1.a Theory of the reduction of iron ore

The extraction of metallic iron from its ore is a reduction process, ie the removal of the oxygen atom or atoms from the oxide molecule, liberating atoms of iron. The oxides of iron are stable compounds; they represent the usual form in which iron is found in nature, since iron has a great affinity for oxygen and readily forms oxides. Free or native iron is almost never found naturally; the only form known on the surface of the earth is meteoric in origin, and is often alloyed with a considerable proportion of nickel. The nickel confers great resistance to corrosion on the iron (cp stainless steel), but also makes it very difficult to work. Analysis has shown a number of the earliest iron objects (from Mesopotamia and Egypt) to be made from meteoric iron, but the extreme rarity of this material must rule it out as a significant factor in the development and spread of iron metallurgy in antiquity.

Because of the strength of the bonds formed between iron and oxygen atoms in the oxide molecules, considerable energy is needed to dissociate them. Energy is most commonly available in the form of heat, and so the reduction of iron ores requires high temperatures, maintained over considerable periods of time; the reaction must be an endothermic one, ie one requiring heat to be contributed to bring about its completion.

Heat alone, however, is inadequate to break down the oxides; a reducing agent is also required. This is a substance with a strong affinity for oxygen that can capture the oxygen atoms liberated by the heat and sweep them away. In the absence of such an agent, the oxygen would promptly recombine with the iron atoms as fast as they were dissociated.

The two requisites of a heat source (fuel) and reducing agent are combined for the
117/118 reduction of iron ores in one material – carbon. Carbon combines readily with oxygen: in doing so it produces heat (ie it burns – an exothermic reaction). At the same time, under appropriate conditions, it produces a strong reducing agent in the form of the incompletely oxidized carbon (carbon monoxide – CO). In a hot state, carbon monoxide combines with the oxygen atoms in the iron oxide molecule to form the fully oxidized compound carbon dioxide (CO_2).

In chemical terms, the reactions involved in reducing iron oxide are simple. First, a carbon fuel is burnt in a controlled atmosphere of oxygen to produce carbon monoxide:

$$2C + O_2 \rightarrow 2CO$$

In practice, the oxygen is atmospheric, derived from a flow of air entering the reaction chamber, and so it is diluted with nitrogen in the proportion of about four parts of nitrogen to one of oxygen. The composition of the gas resulting from the combustion of carbon in air is therefore about 35% CO and 65% N_2. However, since nitrogen is effectively inert, it plays no part in the reduction process and so can be disregarded.

The highly reducing CO gas, hot because the reaction shown above by means of which it is produced is strongly exothermic, then sweeps upwards through the particles of iron oxide in the reaction chamber. Its action is to remove oxygen atoms in three stages:

$$\begin{array}{lllllll} 3Fe_2O_3 & + & CO & \rightarrow & 2Fe_3O_4 & + CO_2 & \ldots\ldots\ldots (1) \\ Fe_3O_4 & + & CO & \rightarrow & 3FeO & + CO_2 & \ldots\ldots\ldots (2) \\ FeO & + & CO & \rightarrow & Fe & + CO_2 & \ldots\ldots\ldots (3) \end{array}$$

Thus, first the oxygen-rich ferric oxide (Fe_2O_3) loses part of its oxygen, to form ferroso-ferric oxide ($Fe_3O_4 = Fe_2O_3 + FeO$). This is then in its turn reduced by further evolving CO, to form ferrous oxide (FeO), in which individual iron atoms are each bonded to a single oxygen atom. Finally, this oxygen atom is removed by a further molecule of carbon monoxide. 118/119

It follows from the above that the material to be reduced must be situated immediately above the source of heat and reducing agent, since carbon monoxide, being a gas that is lighter than air, will naturally rise. The iron-smelting process in fact operates on a counter-current principle, the gas moving upwards and the liberated iron dropping slowly downwards under the influence of gravitational force. The process and its chemical reactions can be represented diagrammatically, as shown in Figure 6 (from Pleiner 1958).

The reactions given above give only a simplified picture of the extremely complex series that take place in practice in any form of iron-ore smelting furnace; modern authorities (Brandt 1953; Newton 1959) are not in full agreement, for example about the exact sequence of reactions that take place within a modern blast furnace, the principle of which is identical with that of primitive furnaces so far as reduction is concerned. However, this simplified picture gives the essential features of the process.

The end-products of the process are thus basically metallic iron and carbon dioxide gas. However, as will be discussed later, this result would be possible only when using pure carbon as a fuel in an atmosphere of pure oxygen to smelt pure ferrous oxide, conditions that can only be obtained in the laboratory. There are in practice considerable residues and by-products from any iron-smelting operation, and these are of considerable value in the reconstruction of early metallurgical processes, although they create many problems in identification and analysis.

4.1.b Practical application of iron-ore reduction and its problems

The discussion of the chemical basis for the reduction of iron ores given in the preceding section would suggest that the process is a simple one, since the reactions involved are not ostensibly complex. However, there are a number of factors that
119/121 make the practical application of the process extremely difficult, and these help to explain why iron, though one of the commonest metals in the earth's crust, was not the first to be reduced from its ores and used by man.

The successful reduction of iron ores is only possible if close attention is given to certain aspects of the process. The conditions of operating must be controlled so as to lie within certain relatively close limits, otherwise metallic iron does not result. Even if it does, it may even then not be in a form that can readily be utilized by primitive metal-workers.

i Air supply

It will have been seen from the previous section that, for the oxide ore to be broken down, the hot gases resulting from the combustion of the carbon fuel must be preponderantly reducing, ie composed of carbon monoxide (CO). However, CO will only preponderate if roughly equal proportions of carbon and oxygen are brought together.

If there is an excess of oxygen, the carbon is completely oxidized to form carbon dioxide (CO_2), which is inert in this connexion; a stream of hot CO_2 will have no reducing action on the ore.* The physical energy of the heat resulting from the exothermic reaction

$$C + O_2 \rightarrow CO_2$$

would have some effect in dissociating the iron and oxygen atoms, but the affinity of iron for oxygen would immediately ensure their continuous recombination (re-oxidation) in the presence of surplus air; this phenomenon has been observed by those who have carried out experiments on reconstructed furnaces of the early type
121/122 (Tylecote et al 1971; Cleere 1971 – Appendix A to this thesis).

An insufficient supply of air is equally disadvantageous from a theoretical point of view. Combustion is slow, the amount of carbon monoxide formed is diminished, and an inadequate amount of heat is produced by the reaction to help in the dissociation of the oxide.

Thus, to achieve reduction of iron ore, the amount of air (oxygen) available for the process should be sufficient for each oxygen atom present to combine with a single carbon atom so as to form carbon monoxide, but not so great as to produce too high a proportion of carbon dioxide. In practical terms, the air flow is variable, dependent on the size of the reaction chamber, the size grading of the charge materials, and other parameters.

ii Temperature

It has already been shown that inadequate heat in the process inhibits the reducing action of the carbon monoxide. The temperature needed for complete reduction of the oxide is between 750° and 800°C. As will be seen below, this theoretical temperature for the reduction of iron oxides is inadequate for the formation of a free-running slag, in order to separate off the stony portion of the ore.

Too high a temperature, on the other hand, initiates a further phenomenon, of great importance in modern iron and steel making, but one that would have proved a source of embarrassment to primitive ironmakers.

At the temperature of reduction, the pure metallic iron resulting from the reduction reaction, initially in the form of single atoms of metal, tends to agglomerate slowly into small particles. These coalesce further and percolate slowly downwards under gravitational forces, and as the bulk of the material below them diminishes as a result of combustion and reduction. As they move downwards, they become. hotter as they approach the combustion zone, and at about 1100-1150°C they begin to flow together, forming a viscous, porous mass which eventually settles into the 122/123
combustion zone itself. It should be emphasized that at this temperature the iron is not liquid; there is a wide transitional zone of temperature over which the plasticity of the metal increases but during which its properties are not those of a liquid phase. In this condition the iron will tend to entrain with it particles of unreduced ore and fuel.

If, however, the temperature of the metal is raised further up to its melting point just over 1500°C, it develops a new property. This is the ability to take carbon and other elements rapidly into solution, a process of alloying. The most important of these elements is carbon, which begins to go into solution around 1000°C (Elliot & Bond 1959) but is not taken up significantly until much higher temperatures are reached. The effect of carbon in solution is to lower the melting point of the metal, forming from 3%C onwards what is known as cast iron. This is a very hard, brittle, crystalline material, which can only be worked mechanically after extensive refining operations designed to lower the carbon content. Early ironmakers were unable to deal with cast iron, which was occasionally produced, and appears to have been discarded, as at Tiddington (Fieldhouse et al 1931). Only in China was this property of iron to absorb carbon exploited in antiquity; cast iron seems to date back to at least the 5th century BC there, and the process was not adopted in western Europe until the Middle Ages.

Too high a smelting temperature is therefore disadvantageous from the point of view of the so-called direct reduction process, ie that in which relatively pure iron is produced directly from the ore without any intermediate refining (the process used in antiquity). It is, however, the basis of modern ironmaking practice, since the productivity of the modern high-temperature blast-furnace, which operates on the principle of indirect reduction (ie the production of low-carbon iron or steel from the

* Carbon dioxide cannot exist above 1000°C in the presence of free carbon (Newton 1959, 305), but forms carbon monoxide ($C + CO_2 \rightarrow 2CO$), which is then available for reduction. However, temperatures of this order are only likely to be achieved outside the combustion zone in modern blast-furnaces, and so this reaction need not be considered apart from the $2C + O_2 \rightarrow 2CO$ reaction in early furnaces.

Margin numbering in red refers to the original page numbers of the thesis

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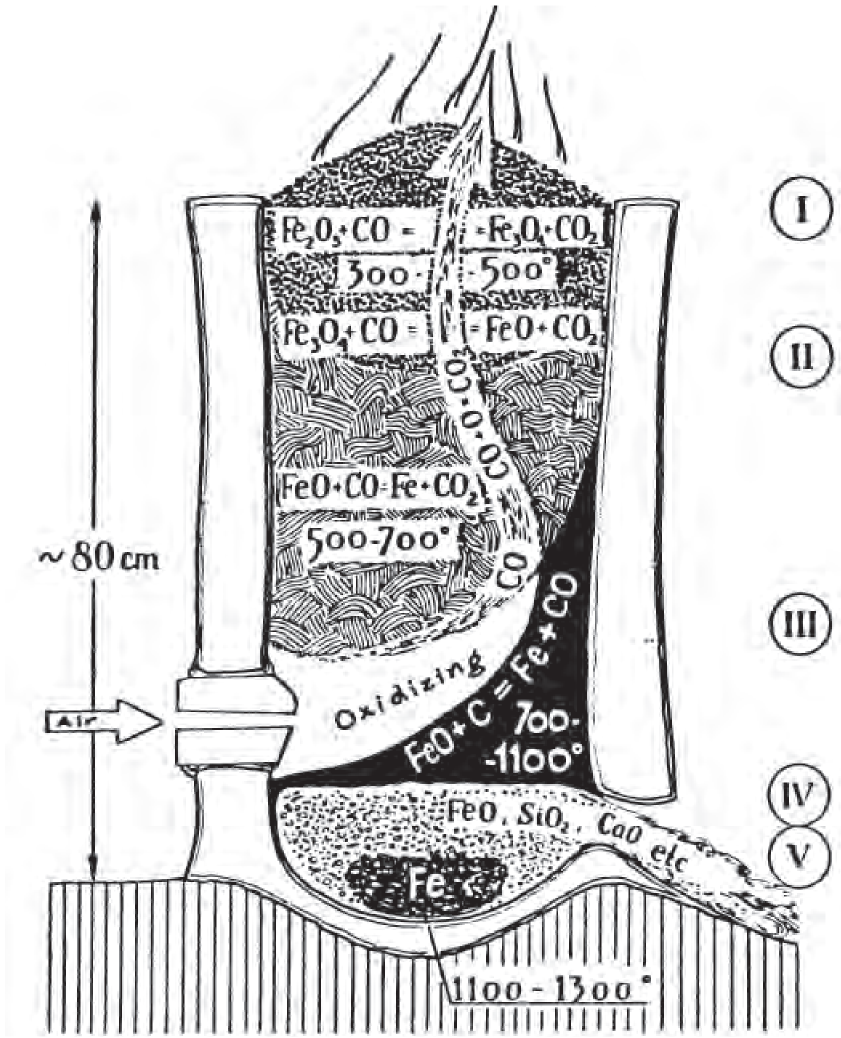


I Roasting zone
II Indirect reduction zone
III Oxidation zone
IV Direct reduction in hearth
V Slag bath and outlet

Figure 6: Schematic of bloomery shaft furnace, showing temperatures and reactions (Pleiner 1958, fig 44).

120

ore in two stages), is much greater because of the high temperatures at which it works.

This means that the comments in the preceding sub-section about the amount of air needed for direct reduction need some qualification. The temperature of the 123/124 process must be high enough to produce sufficient carbon monoxide for reduction of the ore and to enable the free metal to become pasty and sink down the furnace, but it must not be too high so as to allow the metal to become liquid, in which phase it will take carbon into solution, producing a metal that the early ironmaker was not technically competent to process further.

In specific terms, the temperature of the gases in contact with the ore must be at least 800°C in order to reduce it, and temperatures of above 1100°C but not exceeding 1350°C must be available in the lower part of the reduction chamber.

Paradoxically, a small excess of air in the lower part of the reduction chamber can have a beneficial effect. Prolonged holding of hot metal in contact with carbon will inevitably lead to a certain amount of diffusion by the latter into the reduced metal particles; this is evidenced by micro-structural examination of iron blooms, which usually contain small areas of relatively high carbon content (up to 1%). This diffusion process is, however, counteracted by the oxidizing effect of excess oxygen, which will ensure that carburization does not lead to a risk of cast iron being produced. It seems likely, indeed, that all the iron that is produced becomes carburized as it travels down the furnace and remains in the combustion zone, and that this diffused carbon is effectively burnt out. It in only the last reduced iron particles that retain this carbon, since they are not exposed to the oxidizing conditions for a significant period. The simple picture of direct reduction presented above is thus likely to be something of an over-simplification; the sequence is more probably reduction → carburization → oxidation. However, this view is still somewhat speculative and its confirmation awaits further experimental work.

iii Fuel

Carbon has been cited as the best fuel for the reduction of iron ores, because it can supply adequate heat and a good reducing medium. However, pure carbon does not 124/125 occur naturally in a form that can readily be utilized for industrial purposes.

Modern carbon fuels include gas, oil, coal, coke, and wood. Natural gas (usually methane – CH_4) has always been available, but it requires considerable technological skill to utilize it effectively, and its use was not known in antiquity. The same considerations apply to the hydrocarbon oils used as fuels today; they are difficult to exploit and require great technological skill in handling.

Coal has been known for millennia, and its valuable properties as a fuel have been recognized for almost as long. It is high in carbon, and so might be considered to constitute an excellent fuel for the reduction of iron ores. However, it has one serious disadvantage: it is by no means pure carbon, but contains varying proportions of other elements, the most significant of which are sulphur and phosphorus so far as

iron smelting is concerned. These elements have a very deleterious effect on the properties of cast iron; they induce brittleness and porosity and render the resulting metal useless without elaborate refining. Phosphorus begins to be 0 taken into solution in iron at about 1200ºC, but sulphur is taken up at much lower temperatures. Coal is therefore obviously a very difficult fuel to use in the indirect process, which operates at higher temperatures. However, the effect in the direct process is almost negligible; moreover, any sulphur taken up immediately after reduction is likely to be burnt out during prolonged heating in the oxidizing zone. Thus the use of coal by ironmakers in antiquity may be considered to be perfectly feasible, contrary to the view generally held. Both cannel and ordinary coal were found at Wilderspool (May 1904), along with charcoal. Coal is also recorded at Camerton (Wedlake 1958, 94-5) and Wroxeter (Atkinson 1942). Its use in Roman Britain was probably restricted not for metallurgical reasons but because the abundance of timber for charcoal burning made it unnecessary to exploit the outcrops. Certainly the combustible properties of coal were acknowledged, as evidenced by the familiar reference to the burning of
125 coal at Aquae Sulis.

126 Coke is an infinitely superior fuel to coal for metallurgical purposes, because in the coking process the bulk of the sulphur and other volatile materials is driven off, leaving a relatively pure form of carbon. However, the process of coking was not discovered until the 17th century, long after the indirect process had established itself at the expense of the direct process.

The fifth source of carbon mentioned above, wood, is not a good fuel for metallurgical purposes. Fresh wood contains 40-50% moisture, and even after lengthy air-drying this does not come down to much less than 15-25%. Furthermore, its calorific value is only 5000-6000 Btu/lb, compared with about 15,000 Btu/lb for coal. However, the moisture and volatiles in wood can be driven off by means of a distillation process operating at a relatively low temperature and with a carefully controlled access of air. The resulting material, known as charcoal, is a very pure carbon fuel, containing no sulphur and with a very low ash content. It has a calorific value of about 11,000 Btu/lb, nearly double that of the original wood.

From the point of view of the primitive metalworker, the best fuel available for the smelting of iron ore was charcoal, which offers the following advantages:

1 High carbon content
2 No sulphur
3 High calorific value
4 Readily available
5 Easy to produce

Mention should be made of one other possible fuel, peat. The use of peat in early ironmaking has been postulated by several writers on the subject (eg Maréchal 1963; 1973; Morton 1965). Maréchal examined a large number of objects with a largely north-western French provenance, and noticed in them the presence of needles of iron nitride. In his opinion these can only be explained by the use of a high-nitrogen 126
fuel, such as green wood or peat. He argues for peat, because, as noted above, 127
green wood has too low a calorific value. In support, he quotes the fact that bog iron ores, which appear to have been exploited in early times in Britanny, occur in association with peat and in areas where there is little or no tree cover.

Although the calorific value of peat is lower (c.10,000 Btu/lb) than that of charcoal, it would certainly be possible to operate a furnace with this as fuel, and it seems likely that it was used for some of the furnaces located in rather unlikely sites, such as Constantine's Cave (Wace & Jehu 1914-I5). However, nitride needles have not been observed in many Roman artefacts from Britain, and so it may be considered to be a secondary material.

iv Slag

In the foregoing, it has been assumed that the ore was pure iron oxide. In practice, however, ores always contain larger or smaller proportions of siliceous and/or aluminous material, the presence of which makes the successful reduction of the metalliferous mineral much more difficult. This stony portion of the ore is generally known as *gangue*. With the exception of rich magnetite ores such as those from Lapland, the Fe content of which is over 90%, most iron ores contain 40-60% gangue. In some cases, such as the clay ironstones of Lincolnshire, the Fe content may be as low as 22-28%.

The principal gangue constituents in iron ores are silica (SiO_2) and alumina (Al_2O_3). These materials have very high melting points – over 2500°C; indeed, both are commonly used nowadays as high-temperature refractory lining materials in various types of furnace. It will be appreciated, therefore, that these materials are not easy to dispose of in a furnace, especially when they represent the major proportion of the ore's composition.

The structure of most iron ores is such that the iron oxide and the gangue are 127
intimately combined. It would thus be impracticable to expect to be able to reduce 128
all the iron ore present and to leave the silica or alumina matrix intact. In any case, this would mean that the furnace would quickly become choked with stone. It is necessary to devise some method whereby the gangue can be separated from the reduced iron.

Several successful methods of dealing with this problem have been devised in modern blast-furnace practice. The iron content of the ore can be increased by various concentration techniques, involving crushing followed by the separation of part of the nonmetallic fraction by magnetic methods or by flotation. However, such techniques are relatively modern; so-called 'burden preparation' has only been studied and applied seriously in the past few decades. Before that, 'run-of-mine' iron ore was charged to blast-furnaces and the gangue was separated out by means of a *flux*.

The effect of a flux is to combine with the silica and alumina to form various combinations of double and triple oxides whose melting point is very much lower than that of the individual components. This induced combination of oxides, which is in effect an artificial mineral, is known as a *slag*.

In modern blast-furnace practice the flux commonly used is limestone ($CaCO_3$), although a range of other oxides are suitable. The primitive use of deliberately added fluxes is a subject of some controversy. Schubert (1958) claims that limestone was used on two sites in Roman Britain, but Coghlan (1956), quoting May (1904), expressed surprise that lime was not in fact added at, for example, Warrington. Study of all the available evidence on ironmaking in Roman Britain has produced no evidence of the regular use of fluxes in the Roman period. No site has produced any substantial quantity of limestone in association with furnaces or other ironmaking remains.

However, the site at Minepit Wood in the Weald (Money 1974) and that at Rudh' an
128 Dunain, Skye (Scott I933-4) have both yielded a type of glassy slag, the lime content
129 of which is higher than might be expected from the composition of the ore (which in the case of Minepit Wood does contain a small percentage of CaO). This has been adduced as evidence of fluxing during the Roman period. However, in the Weald the nodular carbonate ores occur in association with a ferruginous shelly (*Cyrene*) limestone, which is almost entirely $CaCO_3$, though with a sufficient iron oxide content to make it similar in colour to the ore. This material was deliberately discarded at other Wealden sites such as Bardown (Cleere 1970), where it was used only for constructional purposes. At Minepit Wood, however, a less fastidious ironmaster appears to have fed this material to his furnaces, and in doing so to have achieved unwittingly a more efficient process and a higher yield. However, the significance of this technological advance was not appreciated by the ironmakers, since the glassy slag is very uncommon on the site. The same applied to Rudh' an Dunain, where the slag is assumed to have resulted from the use of fragments of limestone in the make-up of the furnace.

Analysis and petrographic examination of Roman iron slags reveals that limestone was never used to flux off the gangue. Every study shows that the slags consist principally of fayalite ($2FeO.SiO_2$), an iron silicate which corresponds to the double oxide mentioned above but using ferrous oxide in place of lime. Fayalite is formed at about 800°c (Baldwin 1954) and melts at 1150-1200°C, a temperature low enough for the metal itself not to become molten or for too much carbon to be taken into solution.

The only source of this ferrous oxide is, of course, the ore itself. Thus it is only possible for the gangue to be removed by sacrificing a substantial fraction of the iron. In many ways, therefore, primitive iron smelting in the bloomery furnace using the direct process is a wasteful and uneconomic one. However, the use of the word 'wasteful' in this context is in the nature of an arrière pensée, since by primitive standards it was efficient enough. Materials were easily accessible and productivity
129 was not the touchstone of success.
130 To sum up the foregoing discussion of smelting and slag-forming succinctly, one cannot do better than quote the model of Holewinski et al (1960):

$$\begin{array}{c} Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO \rightarrow Fe \text{ (metal)} \\ \downarrow \\ 2FeO.\ SiO_2 \\ \downarrow \\ \text{high-Fe} \\ \text{fluid slag} \end{array}$$

4.1.c The reduction chamber

It will be clear from the foregoing sections that, since the reducing agent for smelting iron ores is carbon monoxide, which is a gas, it is important that the ore should be situated above the fuel, the source of heat, and the reducing agent. The gas is formed in the combustion zone and rises, passing through the mass of ore.

The simplest form of reduction should thus appear to consist of a charcoal fire, with ore heaped above it. However, this would be inefficient, for two reasons. First, the oxygen in the air would have ready access to the exposed ore and to the freshly reduced metal, and re-oxidation would take place. Secondly, and conversely, the fuel, being screened by ore, would probably not derive sufficient oxygen to maintain the desired level of combustion, and so the gas passing through the ore would be too cool to effect the desired reduction. Furthermore, any carbon monoxide that penetrated the ore surrounding the charcoal fire would immediately be converted to carbon dioxide as it came in contact with the air circulating around the outside of the mass.

Equilibrium between these two extremes, which might be attainable with very careful control, could result in the production of metallic iron. However, the tolerance in terms of temperature and oxygen access would be very fine and could only be
achieved using sophisticated instruments; iron production by any process of this kind 130
in antiquity must be considered to be out of the question. 131

Coghlan (1956, 45) discusses the frequently repeated hypothesis that iron was first smelted accidentally in a camp fire, but rejects it decisively; his own experiments (Coghlan 1941) reveal the extremely fine limits that are involved.

This means that the ore and fuel must be enclosed in some way, so as to prevent the access of unwanted atmospheric oxygen; a reaction chamber has to be formed. However, it must not be totally enclosed, otherwise there is insufficient oxygen available for producing the reducing gas. The most important factor is to ensure that the air is allowed into the chamber only at that point where it can be of use in the reaction, namely at the combustion zone. The picture is thus that of an enclosed structure, with a hole opening to the atmosphere only at the bottom.

However, this is still an incomplete picture. The ultimate product of the process (in addition to metal) is carbon dioxide (CO_2), which is formed after the carbon monoxide has liberated the oxygen atom from the iron oxide molecule. This gas will collect in the top of a totally enclosed chamber. As it accumulates it will gradually slow down and ultimately stop the reducing reaction. There must therefore be some form of gas exit at the top of the chamber through which the carbon dioxide can escape.

The provision of an aperture at the top of the furnace also serves another important function. As the gases pass upwards and escape to the atmosphere, their place is taken by fresh oxygen drawn in through the aperture at the bottom near the combustion zone. A draught is created, drawing in oxygen that is available to combine with the carbon of the fuel thereby sustaining and increasing the speed of combustion.

The final picture of the idealized reaction chamber is therefore that of an enclosed structure, with apertures at top and bottom. It will be appreciated that the size of
131 these apertures is critical to the process. If the lower air inlet is too large, too much
132 oxygen is made available, and the gas resulting from the combustion of carbon contains too high a proportion of carbon dioxide; if the aperture is too small, there is insufficient draught, and so inadequate heat is generated.

There is one further parameter of importance in relation to the design of the reaction chamber: its height. It will be appreciated that the deeper the bed of ore through which the carbon monoxide passes, the more chance it will have to reduce the ore. There is obviously a limiting factor in this respect, related to the heat that can be generated at the base, but so long as the gases do not escape from the top of the chamber at a temperature at which they are still capable of reducing the oxide ore, the furnace will be an efficient unit. Too short a column means that reducing gas is still escaping without doing its job and that material at the top may be reduced, only to become oxidized again upon contact with the surrounding air.

4.2 Ore mining and treatment

4.2.a Mining technology

Evidence for iron-ore mining in Roman Britain is sparse. Latter-day exploitation of the ore deposits has destroyed traces of Roman working in many places; current mining operations often bring to light traces of earlier activity, but much evidence must have been destroyed in earlier times. Elsewhere, agricultural operations will have masked the evidence, by levelling spoil heaps and filling excavations.

The available evidence suggests that most mining of iron ore in Britain was opencast. The deposits worked in the Roman period were generally either in the form of shallowly stratified pockets of nodular ore, accessible from the surface, as in the Weald, or bedded ores outcropping to the surface, as in the Forest of Dean or the Jurassic Belt. Only at Lydney Park (Wheeler & Wheeler 1932) does there appear to have been a determined attempt to follow an orebody underground; nevertheless, it is well established, by the evidence of the Neolithic flint mines, that underground mining
132 techniques were known in Britain in antiquity, and so it is reasonable to surmise that
133 the Lydney Park mine was not unique.

Davies (1935) has shown that Roman mining methods were by no means primitive. The mines of Greece and Spain were often highly developed complexes of shafts, galleries, and adits. The galleries were generally regular in section (square or trapezoidal) and comparatively well lit; niches for oil lamps occur at regular intervals in mines in Spain and Austria. Elaborate drainage and ventilation systems were provided, and water was removed from the workings by various means. These included simple baling, using baskets made waterproof by being smeared with pitch, water-wheels, and Archimedean screws (*cochlea*) Davies gives examples of all these methods, including some in which both types of machine were used together in series at different levels.

This type of operation would have been economically justifiable only for the rarer and more valuable metals – gold, silver, lead, copper, mercury. Here the capital and operating costs would have been higher but this would have been offset by the greater revenue from the end product. At the present time, the large capital investment in the iron and steel industry is only economic in relation to the immense outputs obtained; at an earlier stage in the development of the industry, mining and extraction methods were of the simplest. Before the creation of a mass market for iron and steel products, there was little incentive for any elaboration of technological methods, which is one explanation for the slow progress in the industry between the Roman period and the Industrial Revolution.

It should also not be overlooked that iron ores are very common in Britain. Their abundance was such that, when extraction became too difficult, it would have been simpler to move to another site where it was easier to mine. The Lydney example seems to represent the comparatively rare case. where ore outcrops were not common in the immediate vicinity of the settlement. 133

134 Pits from which iron ore has been extracted are common in certain areas. The Ashwicken furnaces (Tylecote & Owles 1960) were constructed inside what was almost certainly an ore pit, and there are many examples in the Weald. The Bardown settlement (Cleere 1970) is surrounded by scores of pits, many now filled with water, located alongside tracks leading into the main settlement. The high-grade nodular ore was simply dug out and transported to the smelting area. In the Weald, this ore occurs as lenses in a continuous ferruginous stratum. When a lens was exhausted, it would appear that trial bores were made until the next lens of high-grade ore was located, when the whole process was repeated.

This technique is described as ‘grubbing’ by Schubert (1957), who discusses Straker’s theory (Straker 1931) that, in the Weald at least, a more refined technique, known as ‘bell-pitting’, was in use. The bell-pit-was one which widened out from the mouth; it was designed to conserve labour in removing the non-ore-bearing overburden. This technique was certainly in use in the Middle Ages (Agricola 1555), but there is no direct evidence that it was used in the Roman period and, as Schubert (following Lemmon 1951-2) rightly points out, it would not have been a practicable technique in the Hastings Beds or the Wealden Clays. However, Worssam (1964) has shown examples of unmistakable bell-pits outlined in the sections of quarries dug into the Weald Clay (but these have not yet been dated). Examination of a number of supposed Roman pits in the Weald bears out Schubert's contention that mining there was by simple grubbing.

At Bardown (Cleere 1970), the ore body appears to have been located first where it had been laid bare on the north bank of the small river Limden, which has cut a deep valley or 'gill' through the soft Wadhurst Clay along a geological fault. Deep scoops were cut into the bank, the overburden being used to build up a massive causeway to link the pits with the smelting site on the south bank. As these lenses petered out, pits were dug higher up the slope. It would appear that the overburden
134 from these later pits was spread around them or dumped into adjacent stream beds.

135 A number or pits in the Bardown area show a characteristic 'keyhole' plan. Access to the pits was probably down a sloping ramp overlying a non-ore-bearing portion of the stratum. These ramps are in several cases clearly orientated towards the slag-metalled roads leading into the main smelting area.

A development of the simple pit is that quoted by Bromehead (1947). After the main ore body had been removed by grubbing from the main pit, ore veins were sometimes followed by digging small galleries. The mine at Coleford consisted of a pit 20-30m in diameter, with small galleries running a short distance into the sides of the pit. A similar example is quoted from Great Doward.

It is not clear from the information available at the present time whether it was customary to grade and pre-treat the ore at the mine or at the bloomery site as a general rule. The pits at Oaklands Park and Bardown do not appear to have any large spoil heaps or other features in association with them, but it should be borne in mind that they are within 200m of large bloomery sites. At Petley Wood, however (Lemmon 1951-2), there is no doubt that the grading and roasting processes were carried out at the pit-head. There is, moreover, no evidence for any smelting operations having been carried out on this site. It may be postulated therefore that at some sites ore was mined, sorted, graded, and roasted at the pithead, the resulting high-grade furnace burden material being transported some distance to the bloomery site. At others, the ore was simply dug out and separated from the overburden before being transported in the as-mined state to the bloomery site close at hand.

At Bardown, however, another phenomenon is observable. As the distance between new pits and the central smelting site increased, transportation became a problem – not only for ore but also for charcoal, as the surrounding forest cover was used up. Thus a series of satellite sites, of which one, Holbeanwood (Cleere 1970)
135 has been completely excavated, were set up, roughly 2km from the main settlement.
136 At these the ore was treated and smelted in close proximity to the ore sources, the resulting iron being transported back to the main settlement for further working. These satellite sites were solely workplaces: no trace of habitation was found at Holbeanwood.

Once the ore had been completely extracted, the pits were generally left open, to fill in with silt and rainwater, and operations were transferred to another location. At Ashwicken, however, where the smelting operations were carried out very close to the site of the mining, the pits were first used as smelting areas, sheltered from the biting east winds of north Norfolk, and were ultimately filled in with rubbish. Some 350 tonnes of slag and other industrial refuse from nearby smelting operations had to be removed to reach the furnaces at the bottom of the pit excavated. This was not called for at Bardown, where there was a more convenient dump nearer to hand, in the river Limden. At Oaklands Park the labour of carting slag and other refuse up the hill to the minepits was excessive, and so the spoil from the smelting operations was tipped in great heaps, remnants of which are still visible.

In locations where bedded ores outcropped, the general practice appears to have been to dig out the ore until the pit grew too deep or until the seam disappeared underground. The examples at Coleford and Great Doward quoted by Bromehead (1947) represent an effort to follow the seams in a half-hearted way. They seem to indicate that the miners of this area did not have at their disposal the knowledge of mining technique of their contemporaries in Spain or Greece. More common in the Forest of Dean area are the so-called 'scowles', deep clefts from which outcropping ores have been removed until the labour of hauling it to the surface became excessive or the conditions at the bottom became too hazardous. Since the iron-bearing strata in the Forest of Dean are inclined, this would be the area for true shaft mining, similar to that practised elsewhere in the Roman Empire (Davies
1935, passim; Coghlan 1956, 21). However, apart from the examples quoted by 136
Bromehead, which are in fact merely developments of the grubbing method, nothing 137
comparable has been observed, with the exception of the sloping shaft from Lydney Park (Wheeler & Wheeler 1932).

The Lydney Park mine consists of a passage c.1m. wide cut into the rock to a depth of about 1.7m. It extended, sloping downwards, for a distance of about 6m. At this point a shaft begins, cut into the rock. It is claimed to be an exploratory cutting, following a band of ferruginous marl in the hope that it would lead to a body of iron ore. However, the mine appears to have been abortive and its entrance was ultimately filled in, to enable a hut to be built over it at a later date.

Wheeler says of this mine that it goes some way to prove that other mining shafts found throughout the Forest of Dean justify their ascription to the Roman period. However, the evidence is very slight, especially when it is borne in mind that the same mining technique has been used for iron ore in the area until comparatively recently. This can, of course, be looked at from another standpoint: it may be that mines of Roman origin have been destroyed by continuous working since the Middle Ages, which was certainly the case at Noricum (Alföldy 1974). The Lydney Park mine nevertheless proves that underground mining for iron ore as well as gold and silver ores, which is well proven at, for example Dolaucothi (Lewis & Jones 1969), was practised in the Roman period. However, the evidence is proportionally very meagre in comparison with that for opencast working. Moreover, the economic structure of the iron industry in Roman Britain (see below, Chapter 6) would seem to militate against the use of such a costly technique.

The Jurassic ores are bedded, like those in the Forest of Dean, and it would be reasonable to expect to find evidence of underground mining in Lincolnshire or Northamptonshire. Roman workings come to light at intervals during the modern 137/138 exploitation of these ores, but so far the workings discovered have all been of the pit type. Where the bedded ore outcrops or comes near to the surface, a pit was sunk and ore was removed opencast until, as in the scowles of the Forest of Dean, it became too laborious or dangerous to haul the ore to the surface. At Thealby (Dudley 1949, 142-3) the mine was a long narrow excavation sloping downwards; it was, however, completely opencast. The working was abandoned when the pit became too deep and no attempt was made to follow the ore underground.

It is fair, in the present very imperfect state of knowledge of the subject, to summarize the above as follows. In Roman Britain, opencast mining was the predominant technique. Ore was won by grubbing out pits and on rare occasions the ore body was followed underground for a short distance. The mines were generally very simple, nowhere approaching the complexity and degree of organization of mines elsewhere in the Roman Empire at the same time or that of gold and silver/lead mines elsewhere in Britain.

4.2.b Ore mining tools and practices

The tools used for iron-ore mining in Roman Britain can only be inferred by analogy with those in use elsewhere in the Roman Empire. Very few implements have been found in Britain in association with mining operations.

One of the most important advances made in prehistoric times in the development of mining techniques was that of fire-setting the heating up of a hard rock by lighting a fire up against it and then throwing water over it, causing it to spall off and fragment. There is no direct evidence for the use of fire-setting in Roman Britain. However, its use may be inferred from the type of ore worked in the province. The hematite ores worked in Cumberland and South Wales are very hard and would have been difficult to dislodge using the relatively soft hand tools of the time. It is by no means 138/139 improbable that fire-setting was in use.

For the most part, however, the iron ores of Britain were not of the type that would have made fire-setting essential. The nodular clay ironstones and the bedded Jurassic ores are relatively soft and can easily be detached using hand tools. Two main techniques can be identified: the pick method and the gad and maul method.

The pick method was used chiefly for the softer rocks. The miner's pick has not changed significantly over two thousand years. A good example was found at Lydney Park (Wheeler & Wheeler 1932): a two-bladed tool of iron, hafted with wood. The marks on the inside of the tunnel at Lydney Park show how it was used: one blade was forced into the rock and it was levered off by pressure on the handle of the pick.

In addition to the double-bladed pick, a single-bladed implement was also widely used in the Roman period. However, no example is known from an iron-mining context in Roman Britain. So far as can be judged, there was no distinction between the use made of the two types; the choice seems to have been determined solely by local tradition.

Hafts of picks do not commonly survive; however, the few specimens known (from Spain and Greece) have generally been short, not more than 0.50m. The utility of a short haft is obvious; although it reduces the amount of leverage that can be applied, it is more practicable and safer in the restricted environment of a mine shaft or at the bottom of an ore pit.

The pattern left by picks on the inside of a shaft or the sides of a pit are easily recognized. The somewhat irregular distribution of the striations contrasts with the regular pattern resulting from the use of a gad and maul.

For harder rocks, the pick (especially the relatively soft tool of the Roman period) would have been ineffectual, and so for these a gad and maul would have been used. The heavy wedge-shaped gad would have been forced into the rock by means of blows from the maul (or heavy hammer). Roman hammers were frequently of iron, 139/140 but it is certain that some stone implements were still in use. Coghlan (1945-7) has discussed hammers and mauls in some detail, and states that stone mauls were associated with mining at this period. The most characteristic type was the grooved stone maul, a simple ovoid with a groove cut round its middle to receive the thongs used for fastening it to its haft. The average weight of such tools was 2-3kg, but specimens of up to 14kg have been found.

Other tools used for detaching and breaking rock would no doubt have included crowbars of iron and wood and smaller hammers of iron and stone.

The sequence of operations would have been for the ore to be detached from the face or bed by means of picks or gads. The detached material would then be broken into lumps convenient for handling with hammers.

The next stage would be the transportation of the ore from the working face to the surface. Shovels would be needed for picking up the ore. These appear in general in Roman Britain to have been of wood; they are well attested in contexts outside mining (eg Wheeler 1925). The edge of the blade was frequently shod with iron, to prolong its life. There are also a few examples of shovel blades made of iron (eg Cleere 1958, 66), and a complete example has been found at Bardown. The latter was in fact found on a smelting site and not in association with ore mining. It is exactly the same length and general proportions as the modern shovels used on the excavation itself.

To remove the ore from the workings, it seems likely that some sort of man-hauled receptacle was used. Davies (1935) quotes the following as have been found at Roman mining sites: leather bags, bronze bowls, wooden trays, wooden buckets, baskets. No examples of these have been found on Ran sites in Britain, because of the unfavourable environmental conditions. 140/141

140/141 The receptacles would no doubt have been hauled to the surface using a windlass of some sort. This equipment has, once again, not survived in Britain, but its use would be difficult to deny. The windlass was well known to Roman engineers, and this application is an obvious one.

In underground mining there is evidence in Europe that sledges were used to transport material to the surface. Davies (1935) quotes examples from Lorraine. In other cases, bags or sacks would simply have been dragged along the floor of the galleries.

The only other equipment of the mines that requires comment is that connected with the access of the workers to the mines. Again, there are no remains from Romano-British iron-mining sites, but Davies gives a number of analogous examples. Notched trunks were found in Hungary and Spain, and would appear to have been more common than runged ladders. For the small pits in Britain, a simple rope would have been used, or even steps cut into the side of the pit, whilst the keyhole-shaped pits of the Weald could be reached simply by walking down the ramp.

4.2.c Ore preparation

After being mined, the ore was transferred to the smelting site. At most establishments, this would appear to have been near at hand; this was the pattern at Ashwicken, Bardown, Bynes Farm, Minepit Wood, Oaklands Park, Thealby, and Wakerley, which are among the few sites at which the source of ore can be identified with any certainty. In these cases the means of transport would not have needed to be very elaborate. The ore could have been manhandled, using baskets, sacks, trays, etc, the short distance involved, which does not exceed 200m on any of the sites mentioned.

At other sites, notably Petley Wood, the location of the bloomery site has not been established, and it is possible that the ore may have been transported some
141/142 distance for smelting. The same may well apply to the legionary fortress at Inchtuthil (Richmond pers comm), where iron-smelting slags have been found, but where the nearest ore deposit may have been at least 30km away. For these longer hauls pack animals were probably used; there is monumental evidence for the use of horses and oxen as pack animals in the Roman period (cf Trajan's Column). Thanks to the work of Margary, a well-developed system of minor roads has been shown to exist in the Weald, connecting the ironmaking sites with one another and with the main roads (Margary 1947). It is reasonable to assume that this was also the case elsewhere in those regions where iron was worked, especially in the Forest of Dean and on the Jurassic deposits.

At some of the larger establishments, especially those in north Somerset, local ore stocks may have been exhausted fairly quickly, but the bloomery sites appear to have been large industrial units (eg Brislington). In these cases, even longer hauls may have become necessary to keep the furnaces in operation. Heavier forms of transport might have been more economical, such as horse- or ox-drawn wagons. Too little is known about general methods of transportation in the early Roman Empire for categorical statements to be made on this subject; it is only possible to postulate that some means of freight carriage was necessary at those sites where the ore used was not mined in the immediate vicinity of the furnaces.

It is necessary, however, to enter a caveat at this point. Vestiges of iron smelting have been found on a number of sites not located on known existing ore deposits. To explain these operations, excavators have postulated the movement of ore over long distances: for example, it has been suggested that the ore used at Ramsbury (Wilts) came from Seend, some 40km distant. Since the scale of operations on many of these sites is very small indeed, there would appear to be no justification for such hypotheses. What might be termed the 'microgeology' of many parts of Britain is scarcely known except to local geologists. No reference is made on geological maps or in Geological Survey Memoirs to very small patches of usable ore, often bog ore. However, these may well have been noticed by Roman smiths who would have
had the expertise needed to enable them to produce a few kilograms of metal. For 142/143
these modest establishments, an ore source must be sought close at hand. It is only for major operations such as that at the Brislington villa or the Inchtuthil legionary fortress that it is valid to consider long hauls of ore. The evidence of the major industry in the Weald underlines this view.

Before being charged to the iron-smelting furnaces, the ore was often pre-treated in a variety of ways. The processes used included grading, crushing, sieving (screening), and roasting. It has been suggested by some writers that the ore was also occasionally washed, but the evidence is flimsy. Generally speaking, washing of carbonate ore confers very little benefit, unlike magnetite or many non-ferrous minerals. The notion of washing iron ore is probably due to a misinterpretation of water channels occasionally found on bloomery sites, which are more probably associated with the work of the smith rather than that of the iron smelter.

Grading of ore is a matter of commonsense; it simply involves hand picking of the as-mined material, so as to separate out material that is not iron-bearing. The piles of coal found at Wilderspool (May 1904) and elsewhere that are discussed above (Chapter 1.b) may represent this process of grading. The Blackband ore would have been picked over and pieces of mineral coal rejected. At Bardown the shelly limestone found closely associated with the nodular carbonate ore in the Wadhurst Clay was carefully removed, large lumps often being used for structural purposes.

The amount of such material would no doubt have been small, since the small scale of the mining operations would have ensured that the material dug out would consist chiefly of ore. Only when thin seams were being worked might there have been some admixture of non-metalliferous stone. The grading operations would almost certainly have been carried out principally at the mine; however, a conscientious bloomery operator would no doubt have made a final check on his burden (charge material) before feeding it to his furnaces – and there is evidence of less good practice at Minepit Wood (see above, Chapter 4.1.a.iv). 143/144

143/144 **Crushing of ore** is evident from the abundance of ore fines on iron-smelting sites. Excavations at Bardown have revealed the presence of large deposits of fine ore particles in the waste heaps. The pit at Ashwicken in which smelting was carried out was later filled with rubbish and slag; the interstices between the larger lumps of slag were filled with a red ochreish dust. Reports of excavations at a number of Wealden sites usually refer to the same material (eg Beauport Park, Crowhurst Park, Ridge Hill), which is variously described in excavation reports.

The presence of this material in the rubbish tips was by no means fortuitous. The Roman ironmakers were fully aware that the presence of finely divided ore in the furnaces was undesirable and prejudicial to the success of the smelting process. It tended to clog the air passages between the lumps of ore in the furnace and reduce the permeability of the burden. The draught would be reduced, which would lower the heat of the process and prevent completion of the reduction reaction and the formation of free-flowing slag.

Crushing was certainly carried out manually; the use of water power to operate a hammer or mill does not appear to have been known to the Roman ironmakers. Davies (1935) states that stone hammers, querns, and mortars (from Dacia) and hand mills (France, Spain, and Greece) were all used for the purpose of reducing the ore particles to the size thought most appropriate for charging to furnaces.

No record of similar equipment can be found on Romano-British iron sites. The many fragments of Niedermendig lava quern from Bardown cannot be connected directly with the ironmaking operations in view of the proportion of domestic rubbish found in association with them on the tip. In addition, such querns could only have been used for the production of material with a small grain size, whilst it has already been observed that the optimum size of ore for charging to the furnaces
144/145 was around 20mm cube. A number of large pebbles, some with battered surfaces, were also found on the tip, but none could be assigned confidently to this function. Nevertheless, some form of crushing must have been employed, especially for harder, denser ores.

For ores with a fairly high moisture content, direct crushing of this type would not have been essential, since the effect of the roasting operation (see below) would have been to break up the larger lumps by the simple mechanical process of the vaporization of the included water causing expansion and consequent fragmentation. This process also produces a large proportion of fines, larger than would result from simple mechanical crushing. Experiments in roasting Wealden carbonate ores (Cleere 1971) have demonstrated the considerable degree of size degradation that results from roasting.

The maximum size grade in the fine material, at Bardown at least, appears to have been about 5mm cube. Ore fragments entrapped in tap slags appear in general to be larger than this size; the largest fragments found at Bardown and Ashwicken do not exceed around) 40mm cube, which would be a very suitable size for reduction, creating excellent permeability of the burden.

Screening or sieving must have been used on most sites to separate out the fine fraction of the ore. Hand picking might have sufficed at smaller establishments, but it would doubtless have been too slow and laborious for use at the larger units. Davies (1935) describes a sieve of hazel twigs found in Austria, and this seems to have been the most likely form of equipment. Metal sieves would have been cumbersome and would probably wear or deform quickly, in view of the softness of iron at that period. Wooden sieves would be easy to make and replace, but unfortunately they do not survive on most sites. None are known from British sites.

At both Ashwicken and Bardown the ore fines were bright red in colour and had certainly been roasted: it was, indeed, impossible to identify any considerable amounts of ore fines that had unquestionably not been roasted. There are two 145/146
possible explanations for this: first, there may have been a preliminary screening at the mine, or, secondly, the ore may have been so wet and sticky as-mined as to yield virtually no fines before roasting. Probably both factors made a contribution. The material selected at the mine may have been transported before it dried out significantly, the fine material adhering to the lumps and only being detached upon being roasted.

Roasting was probably carried out primarily to break up the large as-mined lumps or nodules. However, the process conferred other advantages. For example, the water of association in limonite ($2Fe_2O_3.3H_2O$) would be driven off, leaving a more readily reducible hematite ore (Fe_2O_3) for charging to the furnace. The carbonate ores would also benefit from roasting. Heating in an oxidizing atmosphere would first drive off the carbon dioxide and then produce a carbonate ore:

$$FeCO_3 + \text{heat} \rightarrow FeO + CO_2$$
$$4FeO + O_2 \rightarrow 2Fe_2O_3$$

In this way, a preliminary stage of reaction is taken out of the smelting furnace proper. It is better for this process to be performed outside the bloomery furnace. The danger from clogging resulting from the breakup of the structure of the original carbonate ore during the first stage of heating is reduced and, moreover, roasting, being a relatively low-temperature process (not exceeding 400-500°C), can be performed using green rather than charked wood, which is inevitably more expensive as a result of its higher technological content.

Ore-roasting hearths of varying degrees of sophistication have been found on several Roman sites in Britain. Large areas of burnt clay or natural soil have been found on several Wealden sites. These have been interpreted more than once as smelting furnaces – the so-called ‘bonfire furnaces. This type of furnace has received the approval of Davies (1935) and of Straker (1931) amongst others, although the former made some reservations; he felt that the furnaces at Ridge Hill and Cinder Mead. were more likely to have been reheating furnaces. 146/147

The extent of these ‘furnaces’ makes it extremely unlikely that they could have been the bases of smelting furnaces. Those at Ridge Hill, for example, measured nearly 3m in diameter, and the comparable structure from Great Casterton (Gillam 1957) is even larger. The difficulty of creating an adequate draught in such furnaces rules out these interpretations. Another explanation must therefore be sought.

The most likely explanation is that these were ore-roasting bases. Reference to later writers such as Agricola (1555) shows that in the Middle Ages ore was stacked up on a clay base, covered with a thick layer of charcoal. The whole was sometimes coated with clay, although this was not altogether necessary, and the charcoal was then ignited. The construction was different from that of a charcoal-burning kiln, since oxidizing rather than reducing conditions were necessary; an excess of oxygen was desirable. When combustion of the charcoal was complete, the ore was allowed to cool, screened, and stored under cover until required for charging to the smelting furnace.

A larger and more elaborate structure for ore roasting was found at Petley Wood. A flor over 6m in diameter was found, under a rubbish tip containing pottery of the 2nd and early 3rd centuries AD. The floor consisted of large pieces of ore grouted with clay burnt red. The site also yielded a large amount of charcoal (chiefly of oak). More conclusive still in the firm identification of this as a roasting hearth was the discovery of a flat heap of roasted ore, 4m square and 0.70m thick. This, combined with the complete absence of iron slag from the site, confirms the identification. The area is surprisingly large; however, it may owe its large extent to the fact that roasting was carried out here for a considerable period, with a consequent tendency to enlarge the working area.

This example is unique in that it is the only one of an ore-roasting hearth in the vicinity of an ore source: the Petley Wood site produced a number of ‘pudding basin’
147/148 shaped pits up to 20m across by 5m deep. The other comparable remains all occur on iron-smelting sites, and the small amount of iron slag resulting from localized reducing conditions found on the bases of these hearths has resulted in incorrect interpretations as smelting furnaces. The more general arrangement, however, would seem to be for the ore to be roasted at the iron-smelting site. This must remain hypothetical until more ironmaking sites have been fully excavated; the exact relationship of mines and smelting establishments is not yet fully understood.

Two other supposed ore-roasting hearths were identified by May at Wilderspool (1904) and Tiddington (Fieldhouse et al 1931). Ore-roasting oven I at Wilderspool is described as a basin-shaped cavity 0.5m in diameter by 0.2m deep, with a fan-shaped flue on one side, sloping down to a square hearth paved with bricks cracked and whitened by hot ashes raked from the furnace. There is no diagram of this structure in the report, and it is hard to visualize it from the description. Unfortunately, no dimensions are given for the square hearth, which seems to have been subjected to very great heat, more than would be expected from rapidly cooling ashes. From the description the square hearth would appear to be the more likely ore-roasting hearth; the dimensions of the ‘basin-shaped’ cavity suggest that it was the base of a smelting furnace, the ‘flue’ corresponding to the slag runner and the square hearth to the slag-collecting bowl.

May also refers to two further ore-roasting ovens at Wilderspool, but in even less detail. They are described as a pair of oval hearths and are illustrated by a characteristically uninformative diagram. Again, the more likely interpretation-is that these were twin smelting furnaces, tapping their slag into a common bed. It is perhaps significant that they were overlaid by what appears to be a later smelting furnace. The only reason for describing them as ore-roasting hearths was the presence in them of a mass of hematite ore; however, this is not an ore that would be significantly improved by roasting, since its moisture content is low. 148/149

The so-called ore-roasting hearth at Tiddington is equally open to doubt. It is described as being built of limestone bricks, compacted with red loam; the furnace is merely a recess in a wall of rough limestone blocks measuring 0.70m long by 0.45m wide. The size and shape of the structure do not seem to support the ascription to ore roasting; it is more likely that this was a reheating furnace of some description, or possibly a forge. May’s interpretations are all based on his belief that Roman ironmakers worked the indirect process of reduction, with cast iron as the primary product, later refined by puddling. This fundamental misconception led him to seek certain features in smelting furnaces. When these were missing, another explanation had to be sought, with the result that a heterogeneous collection of remains were grouped under the category ‘ore-roasting furnaces’.

The smelting furnaces so described by Straker (1928) after excavation at Ridge Hill, East Grinstead, clearly fall into the category of ore-roasting hearths. Schubert (1957) disputes the excavator’s interpretation, pointing to the absence of a cavity in the 2-3m diameter hearth. To this point should be added the dimensions, which are manifestly too large for a smelting furnace. At this site there were a series of hearths superimposed, with alternate layers of red burnt sand, charcoal dust, and slag. The presence of slag is not remarkable, since, unlike Petley Wood, this was a bloomery site; a slag heap measuring 150m by 60m was found nearby. On bloomery sites slag is omnipresent; it finds its way all over the site, partly by accident and partly deliberately, in the form of hard standing. The mere presence of slag on a hearth does not make the latter automatically a smelting furnace, in the way that its marked absence at Petley Wood confirms that this was a roasting hearth. The Ridge Hill structures can confidently be described as roasting hearths.

The most elaborate strictures used for ore roasting were those found at Bardown (Cleere 1970). These furnaces, of which two have been discovered, consisted of pits approximately 2.50m long by 0.80m wide, dug into the natural sandy clay soil to 149/150
a depth of about 0.2m. They were lined with stones along the sides; two courses of stones survived, but there were indications that there had originally been two higher courses at least, giving a total depth of 0.4-0.5m. The stone walls and the bottom of the trench were carefully and liberally coated with puddled clay. The furnace was open at one of its narrow ends. Similar structures, though lacking the stone lining,

were found at Wakerley (Northants).

It was suggested at the time of the discovery of the second of these furnaces that they had been filled with alternate layers of crushed and sized ore and charcoal, the lowest layer of charcoal being ignited and the whole mass being allowed to burn itself out. Subsequently, a deep layer of ore fines, in the roasted condition, was found very close to the second furnace. On excavation, this produced several large flagon necks, the handles of which had been trimmed off and which had been exposed to a certain amount of heat. This suggested that there might have been some blowing of the mass with bellows, the flagon necks serving as rough tuyeres, to shield the nozzles, which were in all probability made of wood. Certainly the presence of the concentration of fine material confirmed that there must have been a screening process after roasting.

To test these hypotheses, a facsimile ore roasting furnace of this type was built at Horam in association with the reconstructed smelting furnace (see Section 4.4 below and Appendix A). Pre-packing and ignition proved to be adequate to promote even roasting of the ore, which had previously been broken with hammers and screened. However, it was a very slow process and so, in view of the timetable imposed upon the experiments, it was decided to use a bellows. This was located at the open end of the furnace. Roasting proceeded very rapidly, and at times the temperatures and atmospheric conditions achieved were such as to effect partial reduction of the ore. It was also found necessary to rake fresh material continuously to the hot zone in front of the bellows. The process also proved to be a somewhat hazardous one; the fragmentation of the ore was at times explosive, and it became necessary, in
150 the interests of safety, to keep the furnace covered with a sheet of corrugated iron.
151 It is interesting to speculate on how this might have been achieved by the Roman ironmaker. To use, for example, a layer of turves would have been a possibility; however, this might have led to considerable pre-reduction in advance of the smelting furnace. It may be that some proportion of the considerable quantities of burnt clay found on Roman sites, especially those without any adherent slag, could have originated from this sort of cover. However, there was very little burnt clay around the two furnaces at Bardown. It would seem more likely that the iron workers were protected from flying particles of red-hot ore by a cover of green branches laid over the top of the furnace.

The experimental roasting was worked on a continuous basis after the first non-blown trial, partly because of the exigencies of the smelting programme. In cases where there was less pressure of this kind, the batch process, without blowing, would appear to be more economical, and this is believed to have been the more likely Roman practice. The prepared charge would then have been allowed to burn itself out and the roasted ore would then have been raked out at the open end for screening; No 2 ore furnace at Bardown had a considerable area of reddened clay around the open end, suggesting that hot ore had been allowed to rest on it. The rather more leisurely batch process would also seem to be more consonant with the cyclical working that is believed to have been customary at the larger Wealden sites (Cleere 1971a).

For the experimental roastings, charcoal was used as the fuel. It would be feasible, however, for this process to have been carried out with uncharked wood. Temperatures of 300-400ºC can be achieved in open wood fires using dried materials, and these could obviously be increased by the introduction of a forced draught by means of bellows. It is thus possible that the flagon necks from Bardown may indicate the use of green wood for some at least of the roasting operations
carried out in the furnaces there. 151
The Bardown furnaces are the most advanced types of these pit roasting 152
furnaces, and were the first to be identified as such. There are suggestions, however, that similar structures found during earlier excavations on other sites (such as Margidunum (Oswald 1927, 66) and Camerton (Wedlake 1958)) should be interpreted in this way.

4.3 Charcoal burning

As mentioned above (Chapter 4.1.b.iii), charcoal was the most suitable fuel for the bloomery process. The type of wood used has been the subject of some speculation in earlier works, and there is a generally accepted view that in Britain the hardwoods, and particularly oak, were especially favoured. This is based on a misconception of the process, coupled with inadequate study of charcoal found on smelting sites.

The later bloomeries, such as the Stücköfen and the early charcoal-fired blast furnaces, were large structures. A woodcut of a *Stücköfen* in Agricola (1555) shows a shaft over 3m high, and charcoal blast furnaces had stacks that may often have exceeded 6m in height. The weight of the burden in such shafts would have been large, and for this purpose it would have been necessary to have a charcoal that possessed a considerable strength, otherwise it would have been crushed as it moved down the furnace and as a consequence the permeability of the burden would have been impaired. A dense wood such as oak would have been the best fuel for this purpose; softwood charcoals would not have possessed the strength to withstand the weight. In the Weald in the early modern period hornbeam was planted extensively by ironmasters, to provide a rapid-growing source of strong charcoal. However, the small shafts of Roman furnaces, which did not exceed lm in height, would not have imposed this additional requirement on their fuels.

This fact is borne out by the fact that furnaces in Bohemia were found to have been run exclusively on conifer charcoal in the early Slav period (Pleiner pers comm).
Furthermore, study of charcoal from the Bardown site revealed that the timbers 152
utilized for charcoal included all the species that would have been growing around the 153
site at the time -oak, ash, beech, hornbeam, birch, hazel, hawthorn, and elder were all identified.

The process of charking has been described frequently in the literature (eg Percy

1861). However, little is known about the exact process used in Roman Britain. The Bardown site produced one area nearly 3m in diameter where the natural sandy clay soil had been raised to a high temperature: the surface gave the impression of ceramic when cleared. There was a considerable depth of charcoal fines overlying this surface, and it has been identified as the base of a permanent charcoal heap. However, there were no signs of any central structure to provide the flue that is a common feature of most descriptions of recent charcoal burning operations and which might have been expected to have left traces in the form of post-holes. The area was, however, defined clearly by a series of stones, which could well have been used in connexion with the access of air from the outside to the base of the heap.

One can thus only infer that the process in Roman times was in general terms similar to that still practised in parts of England at the present day. The heap was built up around some kind of central structure of uprights, though these appear not to have been bedded in the ground. A cover of turves was laid over the top, with holes around the circumference at the base, which could be controlled by the charcoal burner to accelerate or slow down the process. Once the process had completed its course, the charcoal would be dug out, to be screened and stocked. Both the latter were represented close to the Bardown structure; there was a clearly defined charcoal stocking area, delimited by stones, about lm, away, and a layer of charcoal fines alongside it. Many tons of charcoal fines can be found on the refuse bank some 30m distant.

The yield in terms of weight from this classical heap-burning process was the subject of considerable study in the 19th century. Percy (1861) attempts to evaluate
153 the rather disparate results of earlier workers. The decisive factor is the speed of the
154 process: rapid charking leads to the consumption of part of the carbon skeleton of the wood. Careful control of the process can result in a yield of about 25% of the weight of the original wood, but this will drop to 14-17% if it is too precipitate.

Another important factor is the condition of the wood when it is charked. Green wood will obviously yield less, since it contains a higher proportion of water. It is well established that charking is more effective if the wood is allowed to dry for some months before being charged to the heaps. It is also advantageous to cut the wood during the winter, when the sap content is lowest. These factors will be considered further in connexion with cyclical working.

Screening is well attested for charcoal. The reject size has not been established accurately; most of the material on the refuse bank is less than 10mm cube, but most of the lumps found in association with smelting furnaces are at least 20mm cube. The minimum acceptable size for Roman furnaces would appear to lie somewhere between these two limits.

Charcoal was probably held in stock at the major works for some time before the smelting campaign. It is interesting to note that Percy (1861) reports that charcoal undergoes a maturing process, increasing in strength and calorific value if kept for a few weeks before use. This will be discussed later in relation to Roman working.

4.4 Furnace types and smelting

4.4.a Furnace types

There have been a number of theories about the origin of iron smelting. The ‘camp fire’ was favoured by earlier writers such as Beck (1884), Percy (1864), and others, and has been repeated recently by Forbes (1950; 1956). However, the experiments of Coghlan (1956) render it unlikely that this was the source of the earliest smelted
iron. By the time iron was first being smelted there was a metalworking tradition that 154
was already many hundreds of years old (Coghlan 1956). Man was capable by then 155
of achieving very high temperatures and had evolved furnaces for smelting copper that fulfilled the conditions laid down in Section 4.1.c above. It would seem to be far more likely, therefore, that the first iron ore was smelted in a copper-smelting furnace.

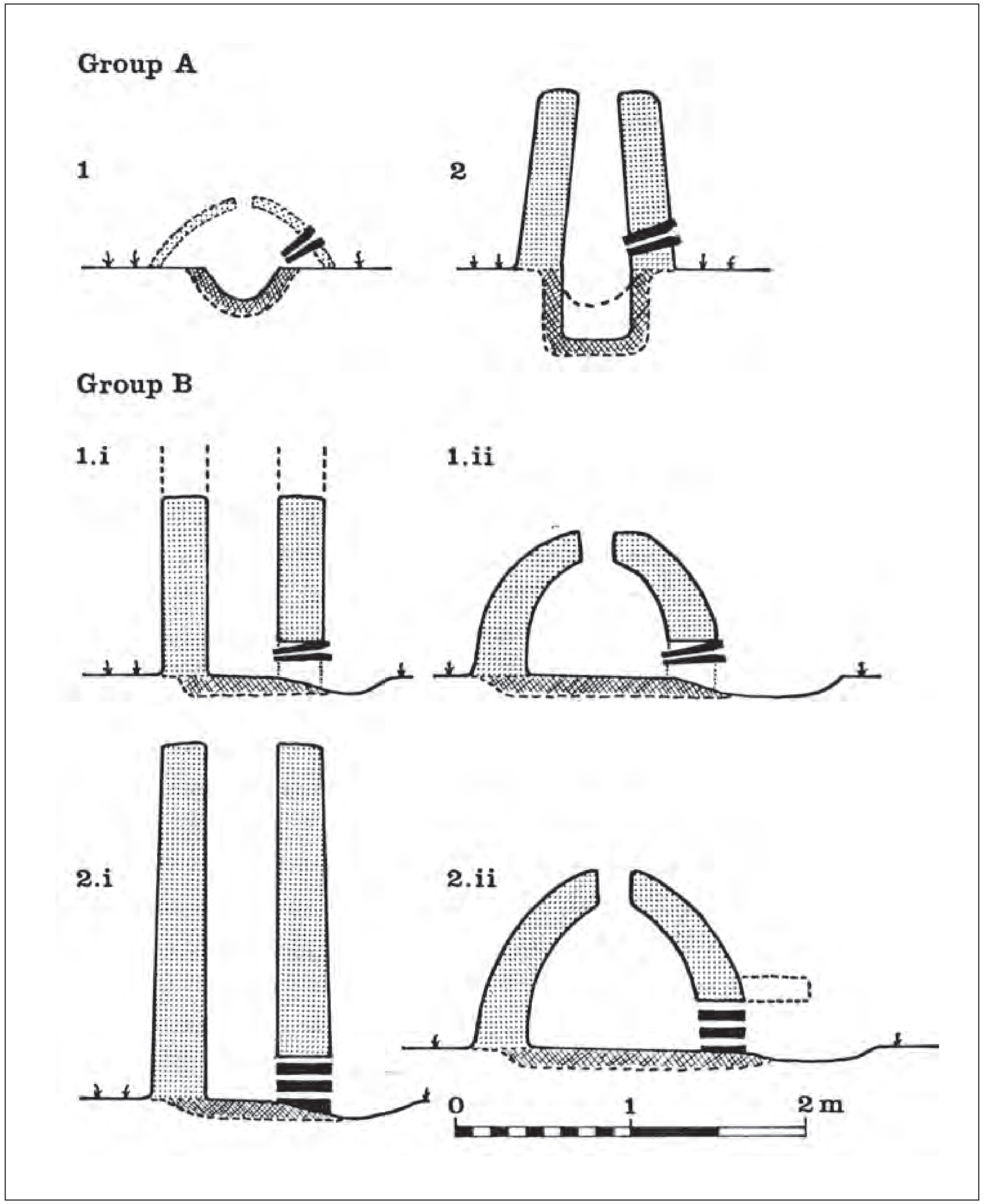
By the time the Roman imperial power had spread to Britain there were several different types of furnace in use in northern Europe for the reduction of iron ores. These have been classified in various ways, notably by Coghlan (1956), Schubert (1957), Tylecote (1962), Pelet (1979), and Martens (1978); Weiershausen (1939) and Gilles (1936) described a number of furnaces from Germany and Pleiner (1958) dealt very comprehensively with examples from Bohemia and Moravia, but none of these European writers attempted a general classification. The present author (Cleere 1972) offered a broader classification which is slowly gaining acceptance in published work (see Appendix B).

In 1956 Coghlan pointed out that the number of furnaces that had been excavated was very small and that there was “little point in trying to work out an elaborate series of furnace types which can only be based upon vague and often unreliable theories and reconstruction”. In the intervening twenty years, a long series of excavations, notably in Poland (Bielenin 1974), Scandinavia (Voss 1964; Martens 1977; Serning 1979), and Britain have provided a much larger sample, which permitted the 1972 classification.

This classification is based not on the morphology of the furnace structure, as in the case of earlier classifications, but on whether or not provision is made for the removal of liquid slag during the smelting process. Subdivisions are introduced based on the shape of the furnace superstructure and/or the method of supplying the air
blast. The classes of furnace are shown graphically in Figure 7 (Cleere 1972, fig 11). 155
The European origins of the furnace types found in Britain during the pre-Roman 157
Iron Age and the Roman period are discussed in Section 5.1 below. Only Cleere’s types B.1.i and B.1.ii need discussion in this section; it is considered that type A.1 (the ‘bowl furnace’ referred to so often in the literature) was technologically non-viable and that all the so-called bowl furnaces may be properly interpreted as the hearths of shaft furnaces of the general B.1 type.

All the smelting furnaces known from Roman Britain appear to have been made of clay or of stone coated inside (and often outside) with clay. Shaft furnaces of the B.1.i type were generally set into a bank of clay or sand, as at Ashwicken (Tylecote

156



156 *Figure 7: Classification of early iron-smelting (bloomery) furnaces (from Cleere 1972)*

& Owles 1960), Holbeanwood (Cleere 1970), Pickworth, and elsewhere, or built in a small pit, as at Wakerley, but it seems possible that they were occasionally free-standing. At Broadfields there were furnaces of this type that seem to have been free-standing alongside others set into a clay bank. Domed furnaces of the B.1.ii type, as at Minepit Wood or Pippingford Park, were apparently always free-standing, although the lower part was sometimes set into the side of a pit.

Careful examination of the Ashwicken and Holbeanwood furnaces suggests that an appropriately sized cylindrical or semi-cylindrical hole was made into a clay bank and that the main furnace lining was built up of puddled clay, perhaps with grog added, using a technique analogous to that of the coil building of pottery. Experiments with a free-standing version of the Holbeanwood type of furnace (Cleere 1971 – Appendix A) showed that it was necessary to dry the furnace out, first in air and then using relatively low temperatures derived from green wood burning. The cracks that developed during this process-had then to be fettled with a slurry of clay, to make the furnace air-tight. During the smelting operation further cracks developed. These could be sealed from the outside with slurry, but after one or two smelts they became sealed on the inside very effectively by adherent iron slag, and so further fettling was necessary only for the purpose of ensuring structural strength. 157

The internal symmetry and regularity of the Ashwicken furnaces in particular 158
suggested that they were built up around a former of some kind. The obvious method of doing this would be to use a section of tree-trunk, though the difficulties of removing this from the interior, either when the clay was wet or when it had dried out, should not be minimized. It is not inconceivable that a lighter framework of withies could have been used.

This certainly appears to have been the technique used for forming the superstructures of the domed type B.1.ii furnaces. Meticulous excavation at Minepit Wood and Pippingford Cow Down revealed a circle of small stake holes within the furnace, and these can have served no other purpose than to support a dome of plaited withies, in the form of an inverted basket, on to which the clay would have been daubed or coiled. There would have been no necessity to provide for this to be removed, since it could be left in situ, to burn out when the drying process began. Any traces of this former in the remains of the lining would have been removed by fettling during the heating and drying sequence and by the slag coating, although faint impressions have been visible through the slag coatings on some lining fragments.

The Minepit Wood furnace is interesting for another reason. Its superstructure consists of stone heavily coated on both sides with clay for at least half its height. This feature was not observed on the Pippingford example, and the explanation is not clear. There was abundant highly refractory clay in the Minepit Wood area and so it can only be assumed that the stone was used to give greater strength and rigidity to the structure. The use of stone is common in stony areas, and there are innumerable examples from continental Europe, as at Lölling (Weiershausen 1939, Abb. 44), the Bernese Jura (Beck 1888), and elsewhere, where the acute shortage of good clay

made this essential, but the incorporation of stone for structural reasons rather than
158/159 necessity is attested only at Minepit Wood.

It was necessary to prepare the clay not only for the superstructure but also for the hearth. The many ‘bowl furnaces’ in the literature are almost invariably described as consisting of carefully puddled clay lining a hollow in the natural soil. The effect of great heat on any soil, even natural clay, is to make it porous and friable. These would result in not only loss of air-tightness but also structural instability, which might result in disastrous collapse of the whole structure in the case of a free-standing furnace or of the front wall in an embedded furnace. The hearth therefore had to be prepared as carefully as the superstructure, with which it in effect formed a single build. The furnace bases at Holbeanwood (Cleere 1970) were all sectioned and showed very meticulous preparation; the patching of cracks that developed during smelting was clearly visible.

The final part of the furnaces that required especial care in construction were the front apertures used for blowing and slag tapping. Smelting experiments with the Holbeanwood furnace facsimile (Cleere 1971) demonstrated that this was the weakest part of the structure. Cracks developed, originating from the crown of the arch and extending radially towards the top. Fettling helped to close them, but they were found to have spread further at the end of each smelt. It was clear that they would ultimately lead to the collapse of the whole front of the furnace. It is, indeed, very rare to find this part of a furnace in situ; most of those illustrated show the whole front section missing, and it is easy to understand why. Of the twelve furnaces found at Holbeanwood, only one had its arch intact, and this had been preserved only because a slab of sandstone had been incorporated in the clay superstructure as a kind of lintel. It is surprising that this feature has not been observed elsewhere, since it would obviously help to prolong the life of a furnace.

Collapse of the front seems to have been the almost invariable reason for furnace failure. In some cases, such as Ashwicken, it appears that collapsed furnaces were
159/160 not rebuilt; they were abandoned and new furnaces were constructed alongside. At
Holbeanwood, however, it appears to have been the regular practice to construct a new furnace by inserting a new lining within the existing cavity, but without removing the existing back wall. A series of overlapping crescents was visible in plan on several of the Holbeanwood furnaces, and sectioning (Cleere 1970, fig 7) showed at least three relines of this kind. However, so far this practice has only been observed at Wakerley, in the pit-built furnaces. At one of the Wakerley sites (No 1), the excavators suggest that only the front of the furnace was rebuilt – ‘grafted onto the rear of an earlier shaft’. It is obviously more relevant to furnaces of the embedded type; there would be little advantage to be derived from inserting a new lining into a free-standing furnace in this way. However, the build-up of hearth layers at the Minepit Wood furnace suggests that the existing base had been re-utilized more than once.

4.4.b The smelting process

Once the furnace had been built and dried out satisfactorily, it was possible for the smelting process to begin. This involved the closing off of the tapping arch and the insertion of a tuyere to enable the blast to be applied and the high temperature needed for smelting to be attained.

A number of assumptions are made in the literature about the closing off of the arch. The most common (eg Tylecote 1962) is that it was sealed off with clay, which could then be dismantled quickly for slag tapping. However, practical experience (Cleere 1971) proved that a clay seal was extremely difficult to dismantle quickly; on the first experimental smelt the furnace heat was lost while the clay stopping was prised out with crowbars and the smelt had to be abandoned.

Several Wealden sites have produced wedge-shaped lumps of clay, about 200mm long and vitrified at one end, indicating that they have been raised to a high temperature in the presence of an alkali. These conditions would obtain inside the tapping arch, the alkali deriving from the charcoal, and so these lumps have
been interpreted as components in the stopping of the tapping arches. The use of 160/161
such lumps made the removal of the stopping much easier in the experiments, but heat was still lost. The most successful experiment involved the use of fired lumps together with a turf at the base of the arch. This was found to burn away as the molten slag built up inside the furnace, and slag started to run out naturally; it proved unnecessary to remove the lumps at all for tapping, since the slag ran continuously, and the stopping only had to be dismantled at the conclusion of the experiment, in order to remove the bloom.

Another possibility is that the tapping arch was stopped up with sand, perhaps loosely held together with a clay slurry binder. This is the practice among contemporary Indian primitive ironmakers (Cleere 1963); it proved a simple matter to clear the arch to enable the liquid slag to run, and re-stopping was equally rapid. Such a technique may have been used in Roman Britain, though there is as yet no evidence for it on sites that have been thoroughly excavated. The clay lump stopping, perhaps combined with a ‘running taphole’, on the other hand, does seem to be corroborated to some extent.

Tuyeres (clay nozzles inserted into the tapping arch to receive the nozzle of the bellows and protect it from burning or clogging) are well attested from Roman ironmaking sites in Britain. Tylecote (1962, fig 47) illustrates various examples from Iron Age, Roman, and Dark Age sites. Two basic types can be identified single and double.

The single tuyere consisted of a tapering cylinder of clay with a central hole 30-50mm in diameter, flaring out at the larger end of the cylinder. A variant, from Glastonbury Lake Village (Tylecote 1962, fig 47a, after Bulleid & Gray 1911), is oval in cross-section (although the hole is round), and is considered by Tylecote to have been designed to receive the nozzles of two bellows.

Double tuyeres are known only from the Weald, at Bardown, Beauport Park, 161/162

Margin numbering in red refers to the original page numbers of the thesis

161/162 Chitcombe, Crowhurst Park, and Little Farningham Farm. The present author discussed their form and use in a short note (Cleere 1963). Two variants have been identified – a simple rectangular slab of clay, pierced by two diverging holes c.25mm in diameter, and a trumpet-shaped object, also pierced by diverging holes and with a flared mouth. Examination of the examples from Bardown showed that slag had encrusted the end of the tuyeres where the holes diverged and not that at which they converged. The latter case might have been expected, since it would have directed the air blast from two apertures to a single point in the heart of the furnace. However, the relatively small diameter of the hearth (0.30-0.35m) would have offered a greater advantage from diverging jets, since considerable turbulence would have been created in the whole hearth area and the temperature would have been higher over the reduction zone.

In the type B.1.i furnaces, only one tuyere (single or double) was used, inserted into the packing of the tapping arch. Examination of fragments suggests that the tuyeres were not fired in advance of use, but were inserted in the leather-hard state, and this proved to give satisfactory results in experimental smelting (Cleere 1971). The exact position of insertion is not clear, since none have been found in situ on furnaces of this type. However, it is obvious that they should be sited well above the molten slag zone, to prevent their being clogged with slag, and it is most likely that they would have been inserted at the top of the aperture, ie about 0.15-0.20m above the hearth level. Further corroboration may be derived from the fact that ‘furnace bottoms’ are common finds on ironmaking sites. These are fused masses of slag, containing much ore and even charcoal, circular in shape and 50-100mm thick. They represent the first-formed slag during the process, which settled down in the relatively cool zone below the tuyere and solidified. Their thickness gives an indication of the minimum height of the tuyere above hearth level.

For the type B.1.ii furnaces, there is evidence from the Minepit Wood furnace that at least three, and probably four, tuyeres were used. Two were found in situ
162/163 when the furnace was excavated (Money 1974), one in the wall immediately facing the tapping arch (which had collapsed) arid one it the side to the left of the arch. A third can confidently be postulated to the right of the arch, since a massive tree root had gained entry to the interior of the furnace at the appropriate point. There is no indication as to whether there had been a fourth tuyere in the filling of the arch itself, but this would seem to be highly likely. The two tuyeres found in situ were of the single type. It is interesting that there appears, in the Weald at any rate, to be a direct correlation between single tuyeres and type B.1.ii furnaces and between double tuyeres and type B.1.i furnaces; this is discussed further in Chapter 5.

The in situ tuyeres on the Minepit Wood furnace were an integral part of the furnace structure; no provision was made for removing them. It is interesting to record that they were higher than would be expected from observations on type B.1.i furnaces – c.300mm. This would tend to support the view that there had been a fourth tuyere in the tapping arch at a lower level. This might well have been used in the initial stages of the smelting, the others, at 900 intervals around the circumference of the furnace, being brought into play as the temperature built up. A similar arrangement has been observed in the furnaces (of type A.2) from the Holy Cross Mountains in Poland (Bielenin 1974).

There is no evidence available about the method of manufacture of tuyeres. As mentioned above, they appear not to have been fired before use. Examination of the interior of the holes suggests that they were probably made around a wooden former. The inner surfaces are usually fired very hard, probably as a result of the escape of hot gases when the blast was taken off temporarily, and they often appear to have a burnished finish. However, examination of the tuyeres used in the experimental smelting (Cleere 1971), which had been made around a wooden former but not burnished in any way, showed that they exhibited the same finish. This must therefore probably be attributed to a combination of the removal of the former at a green-hard stage and the effect of continuous air blasting from the bellows. 163/164

Experimental experience and observations of modern primitive ironmaking (Cleere 1963) suggest that more than one tuyere was used for each smelting. Breaking down the tapping arch fill, whether this was of clay or of sand, tended to result in the fracture of the tuyere, and the Indian ironworkers kept several unused tuyeres alongside the furnace for use as replacements.

Little is known about the type of *bellows* used by ironmakers in Roman Britain. Davies (1935) refers to bellows consisting of ‘skins with a hole closed by the heel and a cord to inflate them’ (a type still in use in India (Cleere 1963) and Rhodesia (Hodges 1970, fig 135)) as having been in use in Egypt, and asserts that the ‘modern type with boards and a valve is not established for Roman times’. He goes on to state that ‘… neither the Catalan trompe nor bellows driven by a water-wheel were known to the Romans’. The latter statement is difficult to dispute, but his statement about the valve bellows may be challenged. A Greek bowl of about 400 BC illustrated by Hodges (1970, figs 160, 161) shows a smith using a bellows which can best be explained as a valve type, and Anacharsis the Scythian seems to have been responsible for the invention of the clapper valve around the same time (Hodges 1970, 160). The lack of any remains that may be confidently described as forming parts of bellows on Roman sites in Britain would imply that these were made of organic materials (leather and wood). The use of tuyeres suggests further that the nozzles of the bellows were made of wood and so required protection against molten slag and charcoal.

In discussing the double tuyere from Crowhurst Park, Tylecote (1962, 200) follows Straker (1931) in claiming that this type of tuyere (which he characterizes as ‘probably more primitive’) implies the use of bellows ‘of the most primitive type without valves’. It is suggested that the two bellows were operated alternately, which seems unexceptional and in accordance with modern primitive practice, ‘the air being sucked into the bellows through an opening around the poorly fitting bellows-tube’. It is difficult to understand the reasoning behind this statement; there seems to be 164/165

164/165 no reason why this type of double tuyere would not have worked equally efficiently with valved bellows. Indeed, there is no evidence from double tuyeres alone that twin bellows were used. The flared openings of the double tuyeres of the type found at Crowhurst Park are roughly round in section, unlike those from Glastonbury, and therefore might be considered to be better adapted to receive a single bellows nozzle. The diverging holes, contrary to Tylecote's view that they are more primitive than the single type, might well be interpreted as representing a technological development, in that they produce better blast distribution and more even heat throughout the hearth and reduction zone.

Obviously, the use of a single bellows reduces the effectiveness of the blast, which becomes intermittent rather than continuous. An indication of one possible way in which twin bellows were linked with a double tuyere comes from the Little Farningham Farm site. The purpose of this settlement is not clear, since it produced both tuyeres and stamped tiles of the *Classis Britannica* but no iron slag; it is discussed in more detail in Chapters 2 and 5. Its interest in relation to the blowing of furnaces stems from a very unusual pottery vessel discovered there.

This pot is gourd-shaped, with a bulbous body and tapering neck, starting above a pronounced groove; there are three holes in the body at 90º intervals. It is postulated that the nozzles of two bellows were luted into two of these holes with clay or resin, an exit nozzle being attached to the third. The top would have been sealed by a membrane, probably of leather, secured by a thong running in the groove below the neck. The two bellows, operating alternately, would have fed blast into the rot, which would have served as a form of pressure equalizer, directing a constant and continuous blast through the exit nozzle into the tuyere. It is possible that leather clapper valves might have been attached to the interior of the pot over the holes, but
165/166 there is no indication of how they might have been secured.

Smelting would have begun with the furnace interior hot as a result of preheating but not yet at a temperature suitable for reduction to begin. It is suggested (and this has been borne out by experiments) that the initial charges would have been of charcoal alone, to enable reduction temperatures to be achieved. There is no indication of how this point was determined. Thermocouples have been used in most experimental work, but no temperature measuring device was known at the Roman period. The Indian ironmakers (Cleere 1963) used an empirical method, based on the appearance of the flame at the top of the furnace, and it would seem likely that the Roman ironmakers worked in the same way; as in recent steelmaking practice, the ironmaker developed a remarkable ability to judge temperatures by eye with great accuracy.

The addition of roasted and sized ore would have begun at this stage. For practical reasons, these additions would need to be small: too large an addition would lead to cooling within the reaction chamber. In most recent experiments (eg Cleere 1971; Tylecote et al 1971; Straube et al 1964) the ore additions have been of the order of 0.5-1.0kg. Simultaneous additions of charcoal were necessary, to speed up the thorough heating of the ore and initiate reduction. Most experimenters have found that a 1:1 ore/charcoal ratio gave the best results.

The temperature gradient through the furnace and the reactions are shown in Figure 6 (based on Pleiner 1958, fig 44). Combustion of charcoal produced a temperature of 300-500°C in the upper part of the furnace and a continuous stream of hot reducing gas (CO). This would drive off any remaining water in the ore and initiate the reduction process, the ferric oxide (Fe_2O_3) being reduced successively to the ferrosoferric (Fe_3O_4) and ferrous (FeO) forms. Under the influence of gravitational forces and as the charcoal lower down the stack was consumed, the partially reduced ore would descend the stack, into the hotter mid-zone, with temperatures of 500-800°C. Here the final reduction of the ferrous oxide would take place, yielding metallic iron, initially in the form of microscopic particles, which would gradually coalesce into larger lumps. 166/167

At the same time, slag formation would take place. Part of the ferrous oxide resulting from the primary reduction would fuse with the predominantly silica gangue to form fayalite ($2FeO.SiO_2$), as described in Section 4.i.b.iv above. As this material descended the furnace, it would enter the hottest zone immediately above the tuyere (800-1200ºC) where it would melt and collect in a liquid pool at the base, to await tapping as it built up (or perhaps to run out continuously through a running taphole). The material formed first and lying below tuyere level would probably solidify, coating the relatively cooler furnace base to form a 'furnace bottom'. The structure of such of these as have been examined suggests that they were not completely solid, but became plastic at least on their upper surfaces under the influence of the molten slag above them, cooling off rapidly as the slag ran out.

The formation of metallic iron was slow. The coalescence increased gradually as the iron descended the stack, and the raw spongy bloom built up above the furnace bottom. Doubtless a certain amount of metallic iron was swept out with the slag during the early stages of smelting, and small 'prills' of metal can often be found when slag is broken up with a hammer. However, it appears from the observations of Tylecote and others that a stable bloom would start to build up, attached to the furnace bottom and the lining, probably in the cooler part below the tuyere. Indeed, it would seem essential to allow a furnace bottom to build up, to provide an anchoring point for the growing bloom.

Because of its slow piecemeal method of buildup, the raw bloom was not homogeneous; it consisted essentially of a sponge-like iron mass, its interstices filled with slag. Since the iron was never melted during the process, it was impossible to consolidate or homogenize the bloom within the smelting furnace.

The capacity of the process was limited by the dimensions of the furnace itself, The predominant Holy Cross Mountains furnace (Bielenin 1974) was of Cleere's type A.2, without any provision for slag tapping, and so it was necessary to demolish 167/168
the entire furnace superstructure to remove the bloom. The only limitation in this case was the provision of space for receiving the slag formed during the process at

the base of the furnace. Raw blooms weighing 150-200kg have been produced in experimental work on facsimiles of these furnaces. However, for the type B.1.i and B.1.ii furnaces known from Romano-British sites, the constraint lay in the size of the apertures available for the removal of the bloom without damaging the superstructure, ie the tapping arch and, to a lesser extent, the furnace top. Experimental work suggests that the tapping arch was the more convenient, since the bloom tended to be fully as wide as the furnace internal diameter and so almost impossible to extricate from above without causing severe damage to the lining of the stack. The heat of the furnace lining also made with method of removal both unpleasant and hazardous. It proved relatively simple to remove the bloom from the arch, a crowbar being used from above to detach it from the inner walls of the furnace.

It is uncertain how the Roman ironmakers judged the completion of a smelting operation. It would seem likely that this was judged on the basis of the amount of material fed into the furnace. With a relatively stable operating practice the yield would not vary markedly from smelt to smelt, and it would have been possible to derive empirically a suitable charge weight for a given size of furnace that would produce a raw bloom that could be handled without too much difficulty or damage to the structure.

To reduce the amount of slag entrapped in the spongy iron bloom, it would obviously be desirable to maintain the blowing for a short period after the last additions of iron ore. It was found from experimental work that blowing with continuing additions of charcoal for up to an hour after the last ore charge enabled reduction to proceed to completion and the maximum amount of slag to be tapped off. This end, point can probably best be identified when the molten slag ceases to
168 run.

169 All the Romano-British furnaces that have been properly studied have a depression immediately in front of the tapping arch into which the molten slag was allowed to run. An early engraving of a furnace from Durobrivae illustrates this admirably: here, as at Ashwicken (Tylecote & Owles 1960), the solidified slag cakes were found still in situ. These large cakes, either entire, as at Ahrweiler (O Kleeman, pers comm) or broken into pieces, as on most Romano-British sites, are very common finds and are essential diagnostic features in identifying an iron-smelting site, as opposed to one where only iron-working was practised.

It is evident that, for the type B.1.i furnaces, with only one tuyere inserted into the tapping arch, the bellows could not have been located within the slag-tapping pit immediately in front of the furnace during tapping. This fact might explain the twin tapping pits at Ashwicken and Durobrivae: the bellows would have been located on the higher area between the two runners, so as to avoid the necessity of removing it (or them). A temporary clay weir would have been built just outside the furnace, the slag being distributed to each pit in turn. When one had filled, slag would be diverted into the other; meanwhile, the slag in the first would have cooled sufficiently for the cake to be removed bodily and discarded. This hypothesis is supported by the finding of a larger number of complete slag cakes at Ashwicken than elsewhere.

At the Bardown/Holbeanwood complex, only one slag-tapping pit has been observed on any of the furnaces excavated. It is interesting, however, that there is a small posthole offset to one side of the tapping arch on most of the Holbeanwood furnaces (a similar posthole was observed n at least two of the Ashwicken furnaces). It could well be that these represent the base of some kind of gantry structure that supported the bellows above the molten slag as it emerged from the furnace. One of the Ahrweiler furnaces has a roughly built stone platform in a similar position, and this may represent an alternative solution. The relatively small size of the slag cake fragments at both Bardown and Holbeanwood is taken to be an indication that the tapped slag was removed rapidly from the tapping pits; the presence of 169
some proportion of very small chips could indicate rapid cooling and fragmentation 170
with water, to permit it to be handled easily when still in a relatively hot state. The likelihood of slag being handled when still hot is reinforced by the finding of a slag-metalled road within the Bardown settlement, running from the ironworking area to the dump, where the slag appears to have been dumped at a temperature high enough for some fusion to have taken place in situ. Moreover, several pieces of pottery have been found at Bardown firmly embedded into solidified slag. That the material thrown on the heap was very hot is shown by the large number of sherds of normally black ware that had changed colour to pale beige as a result of being reheated in reducing conditions.

At the end of the process, there were therefore three products – two waste products (tap slag and furnace bottom) and the raw bloom. The tap slag was disposed of continuously and the furnace bottom was most likely prised out and discarded once the bloom had been removed. All that would be needed for the process to recommence would be any patching required on the exterior or interior of the furnace superstructure and the re-blocking of the tapping arch with a new tuyere inserted. The clay superstructure retains its heat for a considerable time, and the charcoal consumption in heating up would be reduced considerably by starting the cycle again immediately the bloom and furnace bottom had been removed. However, unless there was a form of shift-working, it is unlikely that the ironmakers would be ready to operate the furnaces continuously for periods of twelve hours and more, and so it is more probable that the furnaces would have been sealed up, with a charge of charcoal inside, overnight. In one experimental operation (Cleere 1971), the tapping arch was roughly sealed with clay and the top covered with a steel sheet overnight. It was found that the temperature 12h later was still 350-400°C inside the furnace, which meant that ore charging could start within half an hour of putting the blast on again.

On being removed from the furnace, the raw bloom consisted of a sponge of iron with its interstices filled with slag. A number of these have been produced experimentally (eg Tylecote et al 1971); they show that the slag inclusions vary from 170
less than 1mm to 50mm across. It is necessary to expel this slag and to weld up the 171

metal into a coherent mass. This requires a process of repeated heating and forging.

The raw bloom must be heated to a high temperature, in the region of 1200°C. At this temperature the entrapped slag will be in a molten condition but also, and more important, the iron will be at a temperature at which it will weld together effectively. The process is a simple, if laborious one: the bloom is heated in a small forging hearth, fired with charcoal or even coal (eg Wilderspool), of the type found on many smelting sites (eg Minepit Wood) and then hammered on a nearby anvil at which heat. Slag is expelled violently and takes up a characteristic plate-like shape; these platelets are composed of entrapped fayalite slag together with the oxidized scale resulting from heating of the iron in the bloom in the forging hearth. Tylecote (1962, table 84) publishes analyses of three such hammer-scales, showing them to consist of varying proportions of Fe_2O_3 (from the smelting slag) and Fe_3O_4 (the forging scale).

The success of the ironmaker in consolidating his bloom has been shown by metallographic examination of blooms and iron artefacts to vary considerably. The Inchtuthil nails (Angus et al 1962), for example, show the long stringers of included slag characteristic of bloomery iron, but in some cases these were remarkably large: one nail in the author's possession has a large void in its side where a slag inclusion has been torn away. Obviously, it was very important to maintain a high temperature, in order to keep the slag fluid and to enable the iron to weld up. If the temperature during forging dropped below the welding temperature a viscous thin layer of slag would remain between individual iron pieces and this would be very difficult to dislodge in subsequent forging.

The end-product of the process was the worked bloom. Very few of these have been found and only a handful have been examined. That from Little Farningham
171 Farm (Brown 1964) was about 165mm long by 20mm square and weighed about 2kg.
172 Obviously it represented only part of the average make of iron from a single smelt in a shaft furnace of the Wealden B.1.i type. Other blooms, such as that from Nanny's Croft, Arundel (Smythe 1936-7), were less regular in shape; the blooms which made up the composite blooms used in bath-houses (Wacher 1971) were also less regular, and indeed appear to have varied in size; however, this may be due to the fact that the composite blooms were fabricated on or near the smelting site and did not rely on bought-in blooms.

4.5 Production of steel

Steel is defined by Tylecote (1962, 315) as 'an alloy of iron and carbon in which the carbon content does not exceed about 1.8%.' Varying carbon contents and small amounts of other elements, such as chromium, manganese, and molybdenum, can produce a seemingly infinite range of properties in steel – hardness, ductility, stress resistance, corrosion resistance, etc – and these can be further modified by heat treatments such as annealing, tempering, and normalizing.

Modern steel is produced from pig (or cast) iron, an alloy of iron with 2% and more of carbon made in the blast furnace by the indirect process. The excess carbon is oxidized: effectively, it is burnt out of the molten pig iron. However, this process of making steel was not known in Europe until the Middle Ages: prior to the introduction of the blast furnace the end-product of smelting by the direct process had been pure iron, a very ductile, malleable material but one that lacked hardness and strength. This metal was inferior to the tin-bronzes of the Late Bronze Age in everything except availability: it could not be cast and it was less suitable for making weapons and edge tools.

As discussed above (4.1.b.ii), the slow progress of iron-ore reduction in the bloomery furnace resulted in the reduced iron ore particles being exposed at high temperature to the carbon in the fuel, with the result that they became heavily
carburized by diffusion – in effect, they were converted to steel. However, the 172
prolonged holding of these particles lower down the furnace, as the bloom coalesced, 173
in a stream of air caused most of the carbon to be burnt out, so that it was only the last-reduced part of the bloom that contained steel. The effect of the consolidating process (see 4.4.b above) was to distribute this steel in a random way throughout the semi-product, as the mass of slag and iron was worked this way and that to expel the slag. This random distribution is well illustrated by the Inchtuthil nails (Angus et al 1962, figs 6, 8, 11, 13), where sectioning revealed areas of high-carbon material (0.35-1.35% C) in the cross-section, especially in the larger sizes of nails. The metallographers who studied these nails thought that this represented deliberate selection of steel for use in the heads of the larger nails at first, but as more nails were sectioned it became clear that high-carbon material could appear in any part of all the sizes of nails, arid that in fact it was absent from most of those examined.

Forbes (1956, 56-7) was of the opinion that the higher temperatures obtainable in the shaft furnace would have facilitated the production of high-carbon material, and implied that such was in fact the role of this type of furnace, pure iron being produced in the bowl furnace. However, this view is hardly borne out by the evidence: in the Roman period virtually all iron was made in the larger shaft or domed furnaces, whether slag-tapping (type B.1) or non-slag tapping (type A.2), which would lead one to expect very widespread use of steel at that time. However, metallographic studies of iron artefacts from this period show that the great majority of the metal used was pure bloomery iron, with a random admixture of high-carbon material, consistent with a non-specialized smelting practice.

It is certainly possible to produce a considerable quantity of steel by the direct method in a bloomery furnace. Pleiner (1958) claims that his Podbaba type of furnace, with a chamber behind and below the main hearth, was designed for this
purpose: reduced iron collected here in a zone protected from the oxidizing blast. 173
Straube et al (1964) produced a raw bloom containing a considerable amount of 174
steel in a reconstructed domed furnace of Norican type. However, the metallographic examination of artefacts seems to argue against deliberate and consistent direct steel production in Europe during the Roman period: if the process had been as

straightforward as the Austrian experiment suggested, there would surely have been very widespread use of steel for artefact manufacture, but the metallographic evidence is against this.

The suggestion about deliberate selection of high-carbon material was put forward rather hesitantly by the authors of the report on the Inchtuthil nails, and their subsequent work convinced them that this hypothesis was not supported by the evidence. However, Tylecote (1962, 53-4) flatly asserts in this connexion that suitable blooms or parts of blooms were selected for use in the heads of the larger nails. It is difficult to envisage how the high-carbon material would have been identified and then separated from the normal heterogeneous raw bloom, however; examination of experimental blooms shows that the high-carbon areas are by no means uniformly distributed. It is possible, of course, that small amounts of steel could have been made by stopping the process shortly after the bloom began to build up in the furnace, but in this case the distribution of the steel in the heads of the larger nails could be expected to be more consistent, and apparent anomalies such as large nails with soft iron heads and steel tips or small nails made entirely of steel would not have been observed.

It is undeniable that high-carbon material did result from smelting, as mentioned above. The worked bloom from Little Farningham Farm (Brown 1964) had an average carbon content of 1.16-1.46%: its microstructure was a remarkable one, showing that the bloom had been repeatedly heated and quenched. The metallurgist who examined it told the author that if it had been subjected to much more of this type of treatment it would have begun to disintegrate. The Nanny's Croft bloom
174/175 (Smythe 1936-7) was also high in carbon (up to 1.6% C in places), but it also contained low-carbon areas. It may be significant that these are among the handful of blooms that have survived: this survival may be attributable to the fact that they were rejects, rather than marketable products that had been accidentally lost. Ironmakers certainly discarded accidentally produced cast iron (as at Tiddington and Wilderspool), since they were unable to work it and could not recycle such material; it is possible that blooms that had proved somewhat intractable in forging, owing to the hardness of their steel components, were also rejected as unsuitable for further use. The metallurgist concerned suggested to the author that the repeated heating and quenching might have represented a misguided attempt to restore ductibility and malleability to the Little Farningham Farm bloom.

Neither of these blooms was, of course, found at a smelting site, and this may perhaps represent some kind of 'quality control' by distributors or users. The overall structures of both blooms suggest that they resulted either from a shortened smelting operation or from the working up of the last reduced part of the raw bloom. Deliberate production of steel in the bloomery cannot be substantiated on the basis of these two finds alone, and the question of whether this was in fact common practice must be left open.

However, there are other methods of producing steel. Prolonged heating of pure iron in contact with carbonaceous material and in a reducing atmosphere results in carbon diffusing into the metal to form a surface layer of steel. This process is identical with that which takes place in the upper layers of the bloomery furnace, but in the latter case the small size of the newly reduced particles results in complete carburization. With a larger piece of metal, diffusion of iron is a protracted process, and is, moreover, dependent on fairly precise maintenance of atmospheric and temperature conditions: Tylecote (1962, 250) says that it would take 14h at 1100°C to carburize a solid iron sword in thick, and even then there would be a pronounced reduction in carbon content towards the centre. 175/175a

For swords and certain tools such, as axes, such a condition is a dangerous one, since the implement would be liable to shatter on impact. However, many tools, such as knives and sickles, which are not subjected to the arduous duties of swords and axes, benefit from the formation of such a thin hardened layer. The desirable qualities of the steel at high temperature can be retained by quenching it in water from the carburizing temperature; these would disappear owing to a reorientation of the grain structure if the steel were left to cool in air. This technique, known as quench-hardening, is still widely used today.

Examples of case-hardened objects from antiquity are not common, but this is probably due to the fact that iron objects from excavations are usually corroded, and it is precisely the region of the object that is worst corroded that would have constituted the original thin case of steel. However, this is not properly a method of steel production, but rather a means of imparting a steel surface layer to iron objects.

There is one process that utilizes the property of carbon diffusing into hot iron that may be deemed steelmaking proper, that of cementation. This process consists of packing small pieces of bloomery iron along with carbonaceous material into closed vessels arid heating them to high temperatures for long periods. As a result the iron becomes completely converted to steel by diffusion of carbon throughout its structure; these particles of steel also tend to fuse together – indeed, if the temperature is high enough they melt and the structure becomes completely homogeneous.

This process is known from India from a very early period; here the iron fragments were packed into sealed crucibles with leaves and the crucibles were heated for periods of several days (Rao 1970). Forbes (1956, 57), quoting Richardson (1934), states that steel made in this way in the Hyderabad region was imported into the Roman Empire as *ferrum sericum* (Chinese iron), possibly via Abyssinia. It appears to have been traded in the form of round cakes weighing about 1kg. This material, later 175a/176
known as wootz steel, was imported into Europe via Damascus in the Middle Ages and provided the raw material for the renowned Damascene swords.

There is no direct evidence for the production of steel by this process in Britain, or indeed anywhere in the Roman Empire. However, there is one metallurgical structure from Britain which may be associated with steel production using a form of cementation. This is the 'blast furnace', as the excavator described it in his report, from Colsterworth in Lincolnshire (Hannah 1932).

The Colsterworth structure consists of a clay box measuring 0.95m × 0.60m × 0.35-0.40m deep. The sides were c.120mm thick, with an opening in each, interpreted as tuyeres, and the ends appeared to be open; the top was slightly arched and pierced by a number of small holes. A number of bars of baked clay were found near the structure and others on top of it; most of the holes in the top were covered with potsherds. When found, during the course of iron-ore mining, the structure, which was built in a shallow pit, was found to contain much charcoal and ash and a piece of partly reduced ironstone. There was a small piece of bloomery iron inside and another came to light nearby; the latter was described as having 'been cut off on an anvil and curled in the process'. The base and lower part of the walls had been exposed to very high temperatures, as had the walls of the pit in which it was located. The upper parts of the walls were only lightly fired, but the excavator was of the opinion that these had been rebuilt and not fired seriously subsequent to the rebuilding. There was slag and charcoal in the vicinity; the pit was cut into the natural ironstone.

This unusual structure has been the subject of much discussion and speculation. Coghlan (1956, 47) points to its affinities with a pottery kiln, and adduces it to support the view that the development of iron smelting may be associated with ceramic technology; he does not dispute the excavator's view that the structure was used
176/177 for iron smelting. Tylecote (1962, 130-1) says that 'it is very doubtful whether such a furnace would have produced iron', and suggests that it may have been 'a potter's attempt at an iron smelting furnace', although he concedes that 'it is just possible that this furnace was used for the production of steel by carburizing pure iron'.

The use of this structure for smelting seems highly unlikely. The presence of the partly reduced ironstone inside seems to have worried those attempting to interpret the structure; however, since it is built into the ironstone, it would not be surprising if a lump fell inside from time to time, and in the conditions that prevailed inside it is certain that any lump would become partially reduced. Tylecote tries to explain how it might have been used for smelting, but the impossibility of adding more charcoal once smelting had begun present insuperable difficulties – whether the ironmaker was a professional or a potter trying his hand at another technology. In this connexion the dating of the site – lst/2nd century – seems to militate against this latter explanation, which would sound more plausible if the associated pottery were late 4th century in date.

It seems much more likely that this was indeed a cementation furnace for steel production. One way in which it might have been operated would have been as follows. Small fragments of bloomery iron, cut up on an anvil to increase their surface area for diffusion of carbon, were mixed up with some carbonaceous material – leaves or cow dung would be suitable – and sealed into rough balls or packs made of puddled clay: pieces of 'shapeless clay with deep thumb and finger marks' were recorded by the excavator. These packs were placed inside the chamber with a great deal of charcoal around them, and the charcoal was then ignited and raised to a high temperature by the use of bellows through the holes in the sides. Once the desired temperature had been reached, it is conceivable that the gaps between the walls of the structure and the sides of the pit were filled in, to increase the blanket of fuel all round. The combustion of the charcoal within the structure was controlled by adjusting the potsherd covers over the vents in the roof. When the charcoal had all been consumed, the clay lumps would be broken open, to reveal small lumps of iron 177/178
that had been completely carburized by combustion of the carbonaceous material in the reducing conditions inside the clay packs.

This is probably the most efficacious method of operation, but it is possible that steel could have been produced without the use of clay packing. Small pieces of iron buried in a large mass of charcoal would also be carburized: however, in this case a greater degree of atmosphere control would be needed, to ensure that the conditions inside the structure remained reducing. The presence of so many holes in the roof of the structure may lend some support to this interpretation, since they would have helped to ensure more even temperature distribution and reducing conditions, and their number would have permitted more delicate regulation.

Whether this interpretation of the Colsterworth structure is the correct one could only be proved or disproved by experiment, as Tylecote (1962, 131) rightly says. On the evidence, however, it seems to be the most plausible of the suggestions made. Moreover, steel was in use in Roman Britain and if it was needed in any quantities a process of this kind would produce the right material.

It is not proposed to deal with the fabrication of iron objects. The iron industry proper in Roman Britain was concerned solely with the manufacture of semi-products: blooms or bars of iron which were circulated as objects of trade. These would then be worked up by craftsmen such as blacksmiths and armourers into artefacts for use. Whilst ironmakers were clearly capable of working the metal they produced – they forged up the blooms which they sold – and in cases of expediency blacksmiths appear to have been able to smelt iron ore (as in the 4th century towns and villas), a considerable degree of specialization appears to have developed in Roman Britain. There is little evidence from any of the ironmaking settlements in the three major iron-producing regions that finished products were being manufactured.

However, it is perhaps relevant, in surveying steel production, to mention its use in the finishing industries. There is evidence of small cutting edges being welded on 178/179
implements such as chisels (eg Pearson & Smythe 1938). Strips of steel were also welded together with strips of soft bloomery iron in a piled structure in the process known as 'pattern welding', which is well illustrated by the South Shields swords, dating from AD 197-205 Tylecote 1962, 250). It is possible that some of this steel came from the primary iron-producing centres in the form of blooms or bars, but the more likely source would be the workshop of the individual smith or armourer: by an extension of the case-hardening referred to above, it would be possible for thin strips of iron to be converted to steel in an ordinary forging hearth without undue difficulty. If there was indeed a steel trade, it was probably a small and specialized one. 179/180

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5 Historical Outline

5.1 Spread of ironmaking technology into Britain

The diffusion of knowledge of iron metallurgy across Europe from a presumptive Near Eastern origin is still imperfectly understood. The distribution map prepared by Pleiner (1965), however, suggests that two discrete ironmaking technological traditions can be observed, distinguished by the type of smelting process used.

The eastern route, using non-slag-tapping furnaces of type A.2 (Cleere 1972), is found in Austria (Ohrenberger & Bielenin 1969; Bielenin 1977), Hungary (Nóváki 1966; Gömöri 1977), Bohemia (Pleiner 1958, passim), southern Poland (Bielenin l974), northern Germany, Schleswig-Holstein (Hingst 1952), and Denmark (Voss l964). There is no evidence that this technology reached Britain before or during the Roman period. There are in fact, only three finds that suggest that this process was ever worked in Britain. A large slag cake in the Castle Museum, Norwich, probably from an Anglo-Saxon context, and a similar object from an early Anglo-Saxon ditch fill at Mucking (M U Jones, pers comm) may be identified as *Schlackenklotze* of the type familiar in the Holy Cross Mountains of southern Poland and in southern Denmark, and there is evidence that a furnace from St Peter's Street, Northampton (Williams 1979, 278-9) from a Middle Saxon horizon was of the A.2 type, although the only other iron-smelting furnace attributed to the Anglo-Saxon period in Britain, at Ramsbury, Wilts (J Haslam, unpublished), is clearly of the slag-tapping type B.1.i.

It is clear, therefore, that ironmaking metallurgy did not reach pre-Roman Britain by this route. Attention must therefore be focused on the western route. Unfortunately, archaeological research into iron metallurgy has been less systematic in the western countries than it has been in Czechoslovakia, Poland, and Denmark, and the route is more fragmentarily recorded in the literature.

The starting point seems to have been established in the non~ classical world
180/181 by the Austro-Polish work in the Burgenland, where Bielenin, Polartschek, and Ohrenberger have found and excavated a number of early La Then sites on which both slag-tapping (B.1.ii) and non-slag-tapping (A.2) furnaces occur (Ohrenberger & Bielenin 1969). As described, above, the A.2 tradition moved northwards, whilst the slag-tapping technology appears to have spread westwards (although there are early B.1.i/ii furnaces in Bohemia, illustrated by Pleiner (1958)). Unfortunately, subsequent iron-ore mining has obliterated almost all the vestiges of the renowned Norican iron industry in the Styrian Erzberg region. The scattered remains that have been discovered (eg Schmid 1932; Straube et al 1964) have all been of the slag-tapping (B.1.ii) type.

From this region there appears to have been a general diffusion of iron metallurgy based on the slag-tapping furnace. These are summarized for Germany by Weiershausen (1939); Gilles (1936, 1960, etc) deals especially with the Siegerland, where there was evidently a major industry from the 4th century BC until Merovingian times, and the industry in the Eifel has been studied sporadically (Freise 1908; Kleeman 1959; von Petrikovits 1958). Switzerland has been dealt with rather patchily: the early emphasis was on the Bernese Jura (Quiquerez 1871; Pelet 1960/61), but there has been more work in other cantons in recent years (Guyan 1956; 1977).

Data from France and Belgium are even more sketchy. Davies (1935) records large slag dumps in several regions, notably the Massif Central and the Côte d'Or, but no furnaces appear to have been discovered (or recognized). Again, Davies is still the only definitive source for information about modern Belgium; he reports that the enormous slag dumps of southern Belgium were used, like those in the Forest of Dean, to supply feed for blast-furnaces of the early modern period, but no furnaces appear to have been identified. There is still an unfortunate spatial gap between the furnaces of the Siegerland, the Eifel, and the Jura and the earliest furnace types in Britain.

The absence of any detailed survey of ironmaking in Gaul is especially
unfortunate. The only site that appears to have been examined scientifically in recent 181/182
years is Les Martys (Aude), excavated by the Centre de Recherche Archéologique of the University of Toulouse-Mirail in 1972-5 (Domergue et al 1975). Fourteen other sites have been identified. in the Montagne Noire area. However, this region lies in Provence and its relevance to the introduction of iron into Britain is slight. The absence of good information on the ironmaking industry in the region between the Rhine and the Channel makes any study of the industry in Britain very conjectural. In particular an intensive study of the Burgundy (Côte d'Or) and Lorraine regions is greatly to be desired, whilst some knowledge of the technology of ironmaking in the major ironmaking region south of the Alps, on Elba and the mainland facing it, might well be of crucial importance in identifying the source of the 'Roman' B.1.i furnace in Britain. It is not inconceivable that there might be a direct route Elba-Provence northern Gaul that would establish the origins of the B.1.i shaft furnace beyond doubt.

However, certain clues can be derived from the regions in Europe for which some evidence in available. The furnaces from the Siegerland and the Eifel are of the domed type B.1.ii, whereas the Jura furnaces are of the cylindrical shaft type B.1.i. The Jura furnaces are described in earlier works (eg Weiershausen 1939; Coghlan 1956) as having been worked on a natural draught (type B.2.i), being sited so that the tuyeres faced' the prevailing wind. However, the experimental work using a facsimile of the Ashwicken furnaces (Tylecote et al 1971) would seem to disprove this assertion: these furnaces must have operated on a forced draught (ie bellows-blown). There is thus a presumption that two technological traditions maybe distinguished, both using slag-tapping furnaces: the domed furnace has a distribution along the Rhine, whereas the cylindrical shaft furnace may be postulated to have a more westward distribution.

Both traditions are represented in pre-Roman and Britain. The domed furnace appears to be the earlier type, on the evidence of Minepit Wood and Pippingford

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Park, whilst the cylindrical shaft furnace was apparently not introduced until the 182/183 Roman period, since all the known examples, such as Ashwicken, Holbeanwood, Broadfields, etc, have not been dated earlier than the first half of the 2nd century. The data on which these comments are based are admittedly scanty; however, they would seem to be adequate to justify the advancing of the hypothesis that iron metallurgy was introduced into the Lowland Zone of Britain before the Roman conquest from the Rhine, but that the technology introduced by the Romans had a more westward origin. The complete absence of information on furnace types from northern Italy or France is regrettable, since this technology is represented only by the Jura examples.

5.2 The pre-Roman iron industry in Britain

Evidence for pre-Roman ironmaking in Britain is slight. Most of the available evidence has been collected together by Tylecote (1962, 175-216) and, although his survey was made over eighteen years ago, it is still largely representative: only a few additional sites need to be added. His Table 70 lists 28 sites where evidence of ironmaking (often very slender indeed) has been recorded; these sites are widely distributed, from Shetland down to Somerset and Sussex. Unequivocal evidence of iron smelting in the form of furnaces is recorded from only a handful of these sites – Kestor, Devon (Fox 1954), Chelm's Combe, Somerset, Rudh' an Dunain, Skye (Scott 1933-4), and Rowberrow Warren, Somerset (Taylor 1922-3). All these sites have produced remains of what are described as 'bowl' furnaces (Cleere's type A.1), whilst a number of others are reported as having iron slag and ore, which may betoken ironmaking activities. The only sites that need to be added to Tylecote's list are the early Wealden sites – Broadfields, Cowpark, Minepit Wood, and Pippingford Park – on all of which domed slag-tapping furnaces of Cleere's type B.1.ii have been found.

The distribution of the furnace sites listed by Tylecote is entirely westerly, arid the same applied to all those reported in his Table 70. Nine are in the English south-
183/184 western counties, four are in Wales, and four in Scotland, two in the Hebrides. Four of the remainder are in Wessex, two in the south midlands, and the rest in the south-eastern counties. It is significant that the four A.1 furnaces have a distribution quite distinct from that of the B.1.ii furnaces discovered subsequent to the compilation of his Table. Their dating range is shown as from 400 BC to the 1st century BC for the A.1 furnaces and the early 1st century AD for the B.1.ii furnaces.

This seems to indicate two separate traditions of ironmaking coming into pre-Roman Britain. The earlier, based on a non-slag-tapping furnace, appears to have been introduced in the earlier part of the pre-Roman Iron Age and to have a westerly distribution, probably implying an origin in north-west Gaul (or even further south), whilst the later, utilizing a domed slag-tapping furnace, dates from the century preceding the Roman invasion and may be assumed to have close affinities with north-eastern Gaul and the Rhineland. The conclusions are inescapable: the former group can be equated with the Iron Age B communities and the latter with the later Belgic invaders. It is unfortunate that so little is known of furnace technology in the putative homelands of these cultural groups: the only clear link that can be pointed to is between the Siegerland (see 5.1 above) and the B.1.ii furnaces in the northern part of the Weald.

The scale of the industry in pre-Roman Britain is largely unknown. Only at Camerton in the western group of sites is there any evidence of what may be a concentration of industrial processes; the other sites mentioned by Tylecote are small settlements, such as All Canning's Cross and Little Woodbury, where a small amount of iron seems to have been made occasionally to meet the requirements of a single community. However, the southern part of this group of sites corresponds quite well with the distribution of iron-'currency bars' and it may be that a concentration of ironmaking still awaits discovery in the south-west of Britain. Judging from later developments, the Forest of Dean would appear to be the obvious candidate, but pre- 184/185
Roman working would be difficult to distinguish there, in view of the intensive working in later periods. None of the sites recorded in the catalogue (Chapter 1 above) has produced any evidence of pre-Roman working. Any possibility may lie in the Mendips, a strongly metalliferous region, where ironmaking seems to have been abandoned in favour of non-ferrous metal working in the Roman period.

A slightly more coherent picture appears to emerge in the southeast. The earliest ironmaking seems to have been in Surrey, where at Purberry Shot and Brooklands respectively bog ore from the gravel and lean ore from the Lower Greensand was being smelted. This was small-scale working, no doubt inhibited by the relative scarcity of ore. So far as can be judged, non-slag--tapping furnaces of the A.1 type were being used, but this is difficult to be dogmatic about owing to the nature of the evidence. Some time around the end of the 1st century BC there appears to have been a movement southwards into the Weald. It is possible that this was the result of political pressure, but it may have been the result of a deliberate decision to exploit the richer ores of the northernmost ridge of the Wadhurst Clay. Defended enclosures such as Saxonbury and Garden Hill appear to have been established at this time, based on ironmaking. It is significant that the workplaces in this area were all based on the 'continental' B.1.ii furnace,* an apparent change from the earlier technology of the Surrey sites. On the eve of the Roman invasion this penetration of the Weald had resulted in the establishment of a distinct industrial region, with sites apparently operating on a far larger scale than any of the western site.

A second industrial concentration was also set up around this time to exploit the ores of the southernmost Wadhurst Clay ridge above Hastings. Pottery from Crowhurst Park and Footlands is securely identified as being of Cunliffe's Southern Atrebatic type. Unfortunately, neither of these sites (which both continued into the Roman period) has produced furnace remains datable to this period and so it is

* However, excavations at Garden Hill in 1977 have produced two furnaces of the B.1.i shaft type, although probably in an early Roman phase of the site (J H Money, pers comm).

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impossible to assign them to one or other of the two technological traditions. Later furnaces in this region all appear to be of the B.1.i shaft furnace type, whose region 185/186 of origin is unknown. In all probability, this was an initiative quite independent of the incursion into the Weald from the north. It is put forward as an hypothesis (Cleere 1974) that this venture may have originated with the Regni, further along the coast to the west; this view is certainly supported by the pottery evidence.

There is some evidence of pre-Roman exploitation of the Jurassic ores of Northamptonshire. Slag was found at Hunsbury, and pre-Roman working is attested at the ironmaking settlements at Bulwick, Geddington, and Wakerley. Here again the absence of securely dated early furnaces has made it impossible to relate this operation to one or other of the technological traditions. All the later furnaces known from this area are of the standard Roman B.1.i shaft furnace type.

It seems, therefore, that knowledge of ironmaking technology first came to Britain between 400 and 250 BC, most probably into the western part of the island, from north-west Gaul. Iron was manufactured on a small scale, probably using non-slag-tapping furnaces. There may, however, have been some larger settlements later on, at Camerton and possibly in the Mendips and the Forest of Dean, owing their existence exclusively to the specialized production of iron. This technology probably spread across the whole of Britain in the 2nd and 1st centuries BC; it was certainly in use in the south-east of Britain in the 1st century BC.

A new technology, using domed slag-tapping furnaces, was introduced in the later 1st century BC by the Belgic invaders, and exploitation of the Wealden ores began with penetration from the north. Around the same time exploitation of the ores of the southeastern Weald began, probably by the Regni. There is a possibility that they may have been using a slightly different technology, based on the shaft slag-tapping furnace.

By the time of the Roman invasion there were probably industrial settlements devoted exclusively to ironmaking in the northern and south-eastern areas of the 186/187 Weald, on the Jurassic Ridge in Northamptonshire, and in the west (certainly at Camerton, possibly in the Mendips and the Forest of Dean). The scale of operations in the southeastern Weald may have been quite substantial and produced a surplus for export: whilst Caesar in the mid 1st century BC reported that production in this area was then modest (BG.v.12), Strabo, writing only half a century later, includes iron in the list of raw materials exported from Britain.

5.3 The development of the Roman iron industry

The following is a summary, synthesizing more detailed information given in the surveys of the individual ironmaking regions (2.2ff above) and the account of the economic structure of the industry (6.1-6.3 below).

During the early years of the Roman conquest the development of the iron industry in Britain appears to. have been on a modest scale. However, it seems likely that the Weald was early designated an Imperial estate (see 3.2.b above) and that ironmaking activities in the south-eastern region in particular were encouraged to expand. There is no indication as to the organization of the industry in this area at that time. *Classis Britannica* involvement is not attested until the end of the 2nd century, but this does not preclude direct procuratorial control at an earlier stage. However, the course of Imperial administrative involvement with mining estates in other provinces, such as Noricum or Dalmatia (see 3.1. above), suggests that in the early years of Roman occupation minerals exploitation rights were granted to entrepreneurs. One possible such entrepreneur in this part of the Weald may have been Cogidubnus: the award of a franchise for a rich mining area to a client-king (especially one whose people may have been responsible for opening it up in the first place) seems to be consonant with Imperial policy in the early Empire. The revenues derived from producing and selling iron, to the army or on the civilian market (or perhaps both), might explain the affluence of Cogidubnus, which is reflected in his palace at Fishbourne and his capital at Chichester, which was romanized early. On his death this franchise would, 187/188 of course, have reverted to the *patrimonium*, and that event, towards the end of the 1st century AD, may coincide with the transfer of the main *Classis Britannica* base in Britain from Richborough to Dover.

Elsewhere, existing ironworking settlements seem to have been granted franchises to continue working. The Northamptonshire settlements expanded slowly, and ironmaking began (or perhaps continued on a larger scale) in the Forest of Dean, which may have become an Imperial estate after the headquarters of the II Legion was moved from Gloucester to Caerleon in AD 74. The works in the western Weald continued, although those based on the defended settlements seem to have closed down early in the 2nd century. However, a number of new sites were set up on the trunk roads from Chichester and the South Downs to London.

Two factors would have contributed to the growth of the iron industry in the later decades of the 1st century: the requirements of an army that was campaigning in the west and north and consolidating its conquests by building forts in the conquered territories (constructed in wood in the initial phases) and the policy of romanization actively fostered by Agricola and his successors, which would have involved very extensive rebuilding, requiring large quantities of iron for structural purposes. In the 80s and 90s the demand for iron must have been considerable, and the archaeological evidence suggests that the Weald and Jurassic Ridge settlements expanded considerably at that time. Evidence for 1st century ironmaking in the Forest of Dean is-confined to Bream, but it is not unlikely that some of the larger settlements such as Ariconium and Whitchurch date from the closing years of that century.

By the early years of the 2nd century it may be argued (see 6.1 below) that Britain had reached self-sufficiency in iron production and had begun to export its surplus across the Channel. A new demand arose in the 120s and 130s, to meet the requirements of the builders of Hadrian's Wall. There are indications that this demand 188/189 was met not by diverting part of the export surplus, but by expanding the industry of the south-eastern Weald: the Beauport Park works seems to have been enlarged (including the construction of a substantial bath-house of military type) and a new large settlement was established at Bardown, in the High Weald. This would seem to reinforce the view that part of the Wealden industry had by this time been taken into direct Imperial control.

The Forest of Dean industry appears to have grown considerably during the 2nd century. It is possible that here, too, there was direct Imperial involvement, through the procurator's department or the army, and that part, if not all, of the output was being used for supplying the army. However, it seems more likely that this was largely a civilian operation, supplying a large sector of the province's civilian market and perhaps also producing iron for export. The level of production in the Jurassic Ridge settlements seems to have increased to a much small extent: its markets were probably the less intensively settled areas of East Anglia and Lincolnshire, and commercial expansion westwards and southwards was frustrated by the larger industrial concentrations of the Forest of Dean and the western Weald settlements. Production seems to have continued at Camerton, and less extensive ironmaking centres developed at Worcester and Wilderspool, supplying distinct local markets. The requirements of the south-east were no doubt met by the entrepreneurial works of the western Weald, which seem to have maintained a high level of production throughout most of the Roman period.

This overall pattern continued unchanged until the mid 3rd century, when the Imperial-controlled ironworks of the eastern Weald, by then associated in some way with the *Classis Britannica* closed down, for reasons that are not apparent. Their closure coincided with the abandonment and demolition of the great *Classis Britannica* base at Dover, and it may be that these events were connected with a radical reorganization of the Roman forces at that time, which involved the disbandment of the Fleet as a separate unit (Cleere 1977). However, it is difficult
to understand why the ironworks were closed down, since it would be necessary 189
to make up a substantial deficit in iron production, which may well have served the 190
armies on the Rhine *limes* as well as those in Britain. The only explanation must be that an alternative ore field on the mainland had been adopted for army use, as being less vulnerable in the event of invasion. It is also possible that part of the Forest of Dean production was diverted to supply the army in Britain, although there are indications that there was some contraction of the Forest of Dean industry in the later 3rd century.

From the mid 3rd century there was a slow decline in iron production in the regions outside the eastern Weald, no doubt reflecting the political unrest and economic stagnation of the time. However, the general pattern of production and trade illustrated in Figure 9 seems to have been maintained until the end of the 4th century, when the collapse of economic and social life in the province led to most of the works in the major iron-producing areas closing down. In the closing quarter of the 4th century centralized production and distribution was no longer possible, and iron began again to be made, as it had at the beginning of the pre-Roman Iron Age,
in individual settlements – towns and villas – to meet purely domestic needs. 190
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6 The Economics of the Industry

6.1 Iron production and consumption

6.1.a Production

Earlier chapters have demonstrated the very fragmentary state of our knowledge of the iron industry in Roman Britain. Only the Weald has been studied in any depth, but even there the data available are derived from a somewhat random and not necessarily representative group of sites.

The data from which any attempt to evaluate total production and consumption figures must be based are twofold: slag dumps give an idea of the total production during the life of a site, and associated finds (pottery, coins, etc) enable that life to be quantified in years. In theory, at any rate, it should be possible to calculate from the slag volume remaining the iron production that was required to produce it as refuse and from this to estimate an average annual tonnage output during the lifetime of the site. However, there is a considerable degree of uncertainty in making such calculations.

Slag dump volumes are not easy to calculate. First, their exact extent is often known only approximately: on a sloping site contours can be transformed radically by slag dumping, and the shape of individual slag lumps can often result in a very stable heap being created with a surprisingly steep angle of repose, as a result of the interlocking of individual lumps. In this way depth estimates can be made which are significantly too low. This was demonstrated by excavation in the Bardown slag dump, where calculation had suggested a maximum depth of 2m, but which proved to exceed 3m over a large area. It is clearly desirable wherever possible to ascertain the depth of slag dumps if calculations of volume are to be carried out.

Another complicating feature of slag dumps is that they appear in a number of cases to have been sited on earlier man-made features, notably ore pits. Perhaps the
191/192 best illustration of this is Ashwicken, where an ore pit appears to have been utilized, after the ore had been extracted, for smelting furnaces. The excavator suggested that this was probably in order to escape from the prevailing easterly winds in that part of north Norfolk, a view which struck a sympathetic chord in his diggers. For some reason that remains unknown, iron-smelting operations ceased on that part of the settlement and the furnaces were abandoned. The pit, some 3m deep, was then backfilled with slag from other smelting furnaces elsewhere on the settlement. The volume of slag represented by the contents of the pit was considerable: had its existence not been discovered and the extent of the slag deposit estimated from the total surface area of the slag and the depth outside the area of the pit, the resulting volume would have been a considerable underestimate. A similar situation may well have existed at Bardown, where there is some evidence that part of the slag dump represents backfilling of earlier ore pits.

Another source of error is introduced by contemporary use of slag for metalling purposes. Fieldwork and excavation around the Bardown settlement have revealed the existence of a network of small roads linking it with its 'satellite' workplaces and with ore pits. All these roads, as well as the service roads within the settlement itself and the main access road, were metalled with iron slag, often to a depth of 0.3m and more. This represents a considerable amount of waste product, and means that a simple calculation of the volume of the slag dump can give an answer that falls short by as much as 40% (Cleere 1976, 234).

Slag dumps are, of course, not made up solely of smelting slag. Other industrial refuse, such as charcoal and ore fines, forging slags and cinders, and furnace structural debris, was also tipped on to slag dumps, which were also used for domestic refuse, such as broken pottery and food debris. The eastern end of the slag dump at Bardown, lying below the area of the settlement, contains considerably more non-industrial refuse than the western part, which lies below the area reserved for industrial purposes. A correction factor has to be introduced to take account of this component of dumps. 192/193

The actual volume of slag within any dump also needs careful evaluation. This depends to a large extent on the practice at the settlement. Smelting slag was tapped from furnaces into shallow depressions where it solidified (see 4.4 above). In some cases this slag appears to have been left to cool and. was then removed en bloc, without any degradation; at Ahrweiler, for example (Gillies 1960), most of the slag was found in the form of massive cakes measuring some 400mm across, which were stacked around the settlement. However, on other sites slag is found in the form of small particles, often no more than 20mm cube and with relatively globular gas voids, suggesting that the slag cakes were broken up by having water poured upon them while still very hot. Elsewhere the slag lumps were larger – up to 100mm cube – which may imply that the cakes were removed after they had cooled down and were then broken up with hammers to make them easier to transport for disposal. It will be evident that different practices will result in wide variations in slag densities within dumps. A reasonably accurate figure can only be obtained by the excavation and weighing of measured volumes of slag from dumps where different practices may be inferred.

The final source of uncertainty in studying slag dumps is the removal of Roman slag for re-use in subsequent periods. It was used for two purposes – road metalling and re-smelting. A vast quantity of Roman slag from the Weald was used for road metalling. The best known case is probably that of Beauport Park, where thousands of tonnes of slag were removed in the mid 19th century: a contemporary engraving showing the dump in the course of removal is reproduced by Straker (1931, 331). Much of the present-day A21 road between John's Cross and Hastings is based on a bed of Roman slag, either from Beauport Park or from Oaklands Park, where the same highways superintendent derived his materials for over 20 years. There are, incidentally, two by-products of this activity. First, intermediate dumps of quarried slag

would doubtless have been established along the routes of roads being resurfaced, which means that adjacent fields may produce apparent surface evidence of Roman
192/193 iron smelting. Fieldworkers in the Weald have learned to be suspicious of sites apparently bisected by modern roads. Secondly, the material dug out was screened to remove fine material, in the case of Beauport Park apparently below in mesh size. The resulting secondary dumps alongside the original deposit, or even backfilled on areas already cleared, are rather misleading, in that they contain only fine slag particles; if the earlier history of a site is not known, this evidence may be taken as representing Roman practice, which would introduce a false component when making calculations.

The re-use of Roman slag for modern road metalling is well attested for the Wealden sites, but it can only be inferred elsewhere, where sparse fragmented slag deposits are recorded. The Wealden sites were not apparently subject to the second form of re-use, re-smelting in early modern blast furnaces. This practice appears to have been confined to the sites on and around the Severn – the Forest of Dean and Worcester. The fayalite slag produced by the bloomery process without the use of fluxes (see 4.1.b above) was rich in iron, averaging 50% and above. This was an excellent source of iron for the more advanced technology of the blast furnace, where higher temperatures and the use of limestone for fluxing permitted the iron oxide in the fayalite to be reduced. Roman slag from the Forest of Dean was re-smelted in the blast furnaces of the Forest itself, and it was also exported in large quantities up the Severn to Shropshire. The blast furnaces of Shropshire were also using Roman slag from Worcester, according to Yarranton (1698).

The extent of modern quarrying of slag dumps is rarely known: it is only the engraving referred to above that enables an assessment of the Beauport Park slag dump's original volume to be made. This is perhaps the most serious obstacle to any valid assessment of the outputs of the Roman industry. Knowledge that it was a common practice, for one purpose or the other, makes any kind of classification into 'large' and sites on the basis of surface indications alone a very dubious exercise. For example, the existence of a major industry at Worcester could not have been inferred
193/194 on archaeological evidence alone: without Yarranton's comment, it would probably have been dismissed as a minor urban site, producing a small amount of iron for local use in periods of political and commercial disturbance. For this reason it is proposed only to cover the three major iron-producing areas in this section.

Slag production can be equated directly with iron production. Work on reconstructed furnaces and calculations based on furnace remains (eg Bielenin 1974; Cleere 1976; Gillies 1961; Tylecote et al 1971) indicate a 3:1 slag:metal ratio: ie 3 tonnes of slag were produced for every 1 tonne of iron. The weight of slag in a dump can be calculated from the volume measured by assuming a specific gravity of 3.0: thus, a slag volume of l00m^3 is equivalent to a slag weight of 300 tonnes, which represents an iron production of 100 tonnes, which can be simplified to the equation:

Slag volume (m^3) = Iron production (t)

The author has estimated the equivalent iron production at the six major eastern Weald sites (Cleere 1976, table 1, 238) as follows:

	Slag volume, m^3	**Slag weight, tonnes**	**Iron production, total**	**tonnes annual**
Bardown	4500	13,500	4500	40
Beauport	30,000	100,000	30,000	210
Chitcombe	10,000	30,000	10,000	70
Crowhurst	10,000	30,000	10,000	50
Footlands	15,000	45,000	15,000	40
Oaklands	20,000	60,000	20,000	140

The production figures are broken down into an average annual production based on the scanty dating evidence for most of these sites. To the total of 550 t/a for these six major sites should probably be added a further 50 t/a for the other eastern Weald sites.

Three sites in the western Weald are worthy of consideration in the same way – Broadfields, Great Cansiron, and Oldlands. The area of the slag dump at Great Cansiron seems to be at least 1.5ha; its depth is not known, but it may be assumed 194/195
to average lm, giving a volume of 15,000m^3, However, this is not solid slag and a correction factor of 0.5 needs to be applied, to account for voids, domestic rubbish, etc, which gives a slag volume of 7500m^3, equivalent to a total iron production of 7500 tonnes. Finds suggest a 2nd-3rd century date: if this is interpreted as a 150-year life, iron production was 50 t/a. No data are available on Oldlands, since most of it has disappeared, but it was apparently comparable in size with Great Cansiron, and so a similar annual production rate may reasonably be inferred. At Broadfields, by contrast, the extent of the slag dump is unknown, but many furnaces have been discovered, and so here again a production of 50 t/a may be assumed. To these three sites should be added the other western Weald sites, whose production may also be represented as 50 t/a, giving an annual production for the western Weald of 200 tonnes.

The eastern Weald settlements, which appear to have been under State control, were in operation from just before AD 100 until the mid 3rd century, whilst the western settlements had a longer life – until at least the mid 4th century in most cases. This gives total estimated production figures as follows:

Date	Production (t/a)
43-I00	150
100-150	700
150-200	750
200-250	750
250-300	200
300-350	200
350-400	50

For the Forest of Dean settlements, the calculations must be even more approximate. At least nine major industrial settlements have been identified in the region (see 3.3.a above). Evidence of extent is virtually non-existent, but two at least (Ariconium and Whitchurch) were in all probability as large as any of the Wealden settlements. Only Bream shows clear 1st century working; the remainder seem to
195 have been in operation from the 2nd to the 4th century (although evidence for 4th
196 century working is rare). Assuming an annual production for two sites of 200 t/a (cp Beauport Park) and 50 t/a for the remainder, with some falling off in the 4th century, the following pattern of production may be postulated for the region:

Date	Production (t/a)
43-100	50
100-150	500
150-200	550
200-250	750
250-300	550
300-350	500
350-400	100

The Jurassic Ridge settlements appear to have been rather smaller than those in the other two major regions: only four can be put forward as 'major' settlements with any confidence (see 3.3.a above). There was working from the 1st to the 2nd century at Bulwick and Wakerley, and in the 2nd and 3rd centuries at Bedford Purlieus; no details on dating are available for Scawby. Assuming an annual total production rate of 40 tonnes from these four settlements and an equivalent amount from all the smaller sites, the following production pattern is suggested:

Date	Production (t/a)
43-100	80
100-150	200
150-200	200
200-250	200
250-300	200
300-350	80
350-400	40

The remainder of the sites listed in the catalogue probably represented in total no more than the equivalent of two middle-sized settlements in the late 1st century and
the late 4th century, and even less in the intervening period. Gross iron production 196
figures for the province as a whole are put forward in Table I; these highly speculative 197
figures are shown as histograms in Figure 8. 5

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Region	43-I00	100-150	150-200	200-250	250-300	300-350	350-400
	Average annual production (tonnes/year)						
Weald	150	700	750	750	200	200	50
Forest of Dean	50	500	550	750	550	500	100
Jurassic Ridge	80	200	200	200	200	80	40
Other areas	80	40	40	40	40	40	80
Totals	360	1440	1540	1740	990	820	270

Table I: Estimated iron production in Roman Britain, AD 43-400

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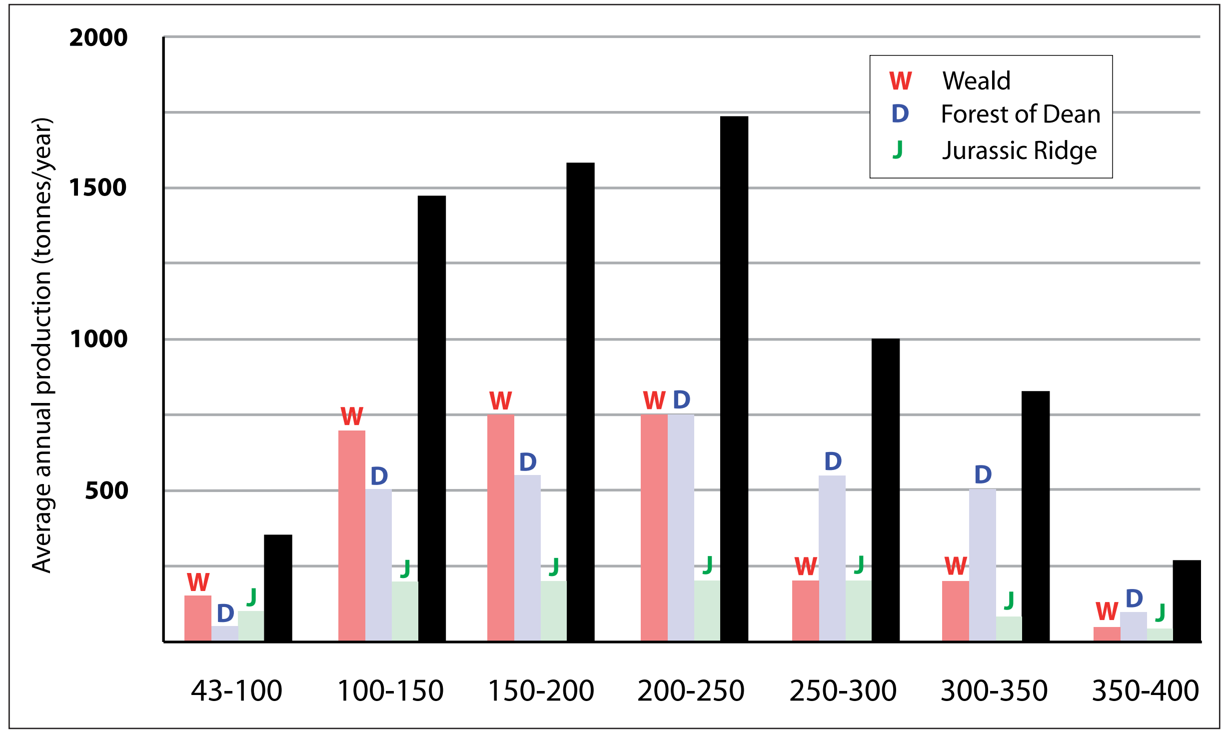

Figure 8: Histograms showing estimated average annual production in Roman Britain, AD 43-400

They suggest that iron production rose steeply at the end of the 1st century and 199
remained at a high level until the mid 3rd century, tapering off until there was a steep 197
decline in the mid 4th century. The Weald and the Forest of Dean seem to have developed together in the 2nd century, with the Weald slightly ahead until the mid 3rd century, when the closure of the State-owned works led to the Forest of Dean becoming the major producing region, a position it probably retained until the end of the Roman period.

6.1.b Consumption

If the calculations of iron production are based on slender evidence, calculations of consumption are pure speculation. Never-the-less, it is desirable to attempt an assessment of the general trends and indications of consumption in order to put the production figures into some kind of perspective.

As a starting point, a classification of broad categories of iron usage in the Roman period is essential. The following may be identified:

- i Tools and implements (knives, chisels, scythes, hammers, ploughshares, etc)
- ii Weapons (swords, javelins, etc)
- iii Constructional ironwork (nails, hinges, window fittings, locks, etc)
- iv Miscellaneous uses (boat and cart fittings, horseshoes, barrel hoops, furniture and cabinet-making fittings, etc)

Tools and implements may be assumed to have had a relatively long life: a carpenter, for example, would collect a set of tools chisels, hammers, saws, augers, planes, etc) at the outset of his career and would care for these, replacing them only when they were worn out or irreparably broken. Modern craftsmen would not reckon
197 to replace most of their tools more than once over a working life of say 40 years.
200 This applies to the 'lighter' trades – carpenters, joiners, saddlers, cartwrights, etc – working with softer materials such as wood or leather and equally to the 'heavier' trades, such as blacksmithing, where tools were made more robust to withstand the heavier duties they were called upon to perform. An average carpenter's toolkit (based on modern tools) probably contains about 6kg of iron; the weight of a smith's tools – hammers, swages, tongs, etc, but excluding his anvil – was by contrast probably about 15kg of iron.

In agriculture usage tends to be somewhat more severe: axes, hoes, bill hooks, scythes, and sickles, for example, are exposed to more hazards in the form of stones and rocks which can cause breakage; they are also more likely to be mislaid or lost. A modern farm-worker would expect to go through at least three sets of the more common tools during a working life, each set representing some 8kg or iron. Ploughshares are subject to even severer usage and need frequent replacement, since they become abraded and cannot be re-forged.

Domestic implements are generally subject to less rigorous conditions, though they are liable to loss by being thrown out with rubbish. However, a set of knives in constant kitchen use may be expected to last a long time, and, indeed, to be passed down from one generation to the next as heirlooms.

The above comments are based on a present-day average working life of about 40 years, and on the use of steel tools and implements, which are harder and more durable. It should be borne in mind, however, that the average working life of artisans and agricultural workers in the Roman period was probably shorter – probably no more than 25 years on average -which would offset the effect of using a softer and more easily abraded material. It is believed, therefore, that these general criteria may
be assumed to hold good for Roman Britain. 200

Similar considerations apply to iron weapons. A well made sword or *pilum* was a 201
personal weapon whose owner would have taken a professional pride in it and kept it clean and sharp. There would have been an irreducible wastage due to breakage or loss in the field, and projectile weapons such as javelins or ballista bolts were not always recoverable. However, it is not unreasonable to assume that a Roman soldier would not have replaced his entire weight of weaponry more than twice during his career, representing say 30kg in total.

An accurate estimate of the usage of iron in domestic building construction is well nigh impossible. No quantitative survey has ever been made of the total weight of iron in any Roman building. Such a survey should be theoretically possible: whilst stone and tile robbing or re-use was common, the likelihood of nails being reused is not great, since most would quickly have corroded, once removed from their timber, very quickly to a point where re-use was impracticable. Careful recording of all nails in the excavation of a Roman building should give a picture that is accurate to within 10% of the total use of nails in that building before demolition or decay. The amount of iron used would, of course, have varied according to the type of construction: a timber building would have contained a greater weight of iron in relation to its cubic capacity than a stone-built one (although iron nails and holdfasts would have accounted for a considerable weight of metal in a villa, from the roof timbers, the *tegulae* the box-flue system, and the door and window fittings).

The cache of one million nails found in the legionary fortress at Inchtuthil (Angus et al 1962), which comprised nails ranging in length from 30mm to 0.35m (the vast majority being in the smaller sizes) was estimated to have weighed 7 tonnes. If it is assumed that an average dwelling, small workshop, or shop contained 1000 nails (or their equivalent in fittings), the weight of constructional iron in an average building
was 7kg; for larger buildings the figure may have been 5000 (35kg) or even 10,000 201
(70kg) nails or their equivalent. Military buildings, such as barrack blocks, would 202
come into the latter category.

The only constructional use where an exceptional weight of iron was involved was the 'composite bloom' used as the stokehole arch in certain bath houses (Wacher 1971). Finds of these massive objects, discussed in 4.6 above, have been rare; it is, perhaps, symptomatic of their unusual nature that they were not used at the Beauport Park bath house, where iron was plentifully available, and so they may safely be disregarded in this survey.

Finally, there are two categories of 'miscellaneous' use which must have been substantial consumers of iron. Horseshoes were used to reduce abrasion of hooves, and therefore by definition they were subject to extreme wear; there must consequently have been a steady demand for replacements. However, since even less is known of the equine population of Roman Britain than is known of the human Population, it is impossible to quantify this demand in any way. Boat building was another heavy consumer of iron: nails were used both in construction and to hold in caulking, as one of the London boats reveals (Marsden 1974). It would appear not unlikely that the larger Roman boats could have contained at least 50kg of iron, and possibly even more, if iron anchors were used. Again, however, the shipbuilding industry of Roman Britain is totally unknown, and so this consumer sector must be disregarded – somewhat reluctantly, in view of the connexion demonstrated between the *Classis Britannica* and the iron industry of the eastern Weald.

It is now necessary to relate these approximate figures to the estimated annual production figures shown in Table I. On the basis of a figure of 7kg for a modest building shown above, the average production in the 1st century is equivalent to about 50,000 buildings a year. However, bearing in mind that the estimate for the early 2nd century is over 1000 t/a higher, it is probably reasonable to assume a fairly rapid rate of growth from the Agricolan period onwards: the industry doubtless
202/203 expanded to meet the demands arising from Agricola's policy of encouraging romanization. At the end of the 1st century production was equivalent to some 200,000 buildings per annum. Assuming a population of some 1.5 million) working backwards from Frere's (1974, 296-7) estimate of 2 million at the end of the 2nd century, it seems safe to assume that the province had reached self-sufficiency in iron production be the early 2nd century.

It should not be overlooked, however, that the eastern Weald settlements appear to have been under direct Imperial control by this time, and so some 600 t/a may not have been available for the civilian market. However, by the end of the century the non-military production was over 1000 t/a, which would imply a per capita production of about 0.6kg annually. At a period when expansion was coming to an end and the province had reached social, if not political, equilibrium, this would seem to indicate a position where a modest surplus may have become available for export. A population of 2 million probably needed in general terms about 250,000 buildings for all purposes; their replacement rate is unlikely to have exceeded 10%, ie 25,000 a year. In terms of iron this would require about 200 tonnes per annum, leaving over 800 tonnes for other uses. The demands of craftsmen, agricultural workers, shipbuilding, etc might be of the order of 200 t/a, which leaves a surplus which could have been as high as 600 t/a.

In the latter part of the 3rd century the situation remained the seine, but the military may have absorbed a certain amount of the surplus, following the apparent closure of the eastern Weald ironworks. It is only towards the middle of the 4th century that iron production seems to have dropped off markedly, to a point where the major producing areas were unable to meet the potential demand from the civilian market. Significantly, it is at this period that the urban and villa ironmaking activities seem to have flourished.

Production from the military ironworks of the eastern Weald is estimated to have been of the order of 600 t/a. With a military presence of 63,000 in the 2nd century
203/204 (Frere 1974, 296-7), this represents a per capita production of nearly 10kg per annum. It is inconceivable that the army could have maintained a rate of iron usage at this level for some 150 years, especially at a time of relative political stability and. one when, moreover, most of the military establishments had been rebuilt in stone. Either this iron was released on to the civilian market or it was shipped across the Channel to the army on the Rhine limes The latter would seem to be the more likely, in view of the lack of major iron-producing regions between the mouth of the Rhine and Noricum. This is discussed further in 6.3 below.

6.2 Markets

As discussed earlier, there were three major iron-producing regions in Roman Britain – the Weald, the Forest of Dean, and the Jurassic Ridge. From the late 1st to the early 4th century they appear to have dominated the market for iron.

The non-State-owned sector of the Wealden industry, based on the roads between London and the South Downs, had natural outlets for its products in London itself and Chichester. It would seem likely that the bulk of the output was carried northwards to the mercantile centre of the province. From here it could be carried by road into East Anglia and the Home Counties; waterborne transportation would have been possible along the east coast, up the Thames valley, and across the North Sea to the Rhine provinces. Chichester would act as a secondary distribution centre by road and/or sea to the south-west.

The author has discussed the harbours of Roman Britain in a recent paper (Cleere 1978). London was the pre-eminent port for the province, and recent excavations there have revealed 1km or more of riverside wharves and other installations on the north bank of the Thames. A study of the road system of the province suggests that there were two subsidiary mercantile ports, Gloucester and Lincoln, serving most of the remainder of the civilian zone. It is interesting to note that both are adjacent to 204/205
major iron-producing regions.

Iron from the Forest of Dean, as Figure 4 shows, would have been moved by road eastwards to Gloucester, where it could be distributed by river up the Severn into the vest midlands or by road or coastwise shipping into the west arid south-west. It could also have been moved by water westwards into south Wales, although a good road also existed along the coast through Blestium. It seems likely that the eastward limit of the Forest of Dean iron market was in the Cunetio-Salisbury Plain area. Northwards it would probably have covered much of the west and south midlands, although the industry based at Worcester would probably have accounted for the settlements in its immediate hinterland.

The Jurassic Ridge settlements along Ermine. Street look naturally to Lincoln as a distribution centre. However, Durobrivae probably dealt with products from the southern group of sites: it was producing pottery on a substantial scale, and so it would doubtless have established commercial links into East Anglia and southwards. It is unlikely, however, that the products of the Jurassic Ridge works would have penetrated the London market to any great extent: the main markets for their products would have lain to the east and north, with some proportion being sold in the midlands, probably as far as Ratae. 206

An indication of possible areas of commercial influence for the three major industrial regions is given in Figure 9.

The military 'market' was dictated by strategic considerations. For most of the Roman period there were three legions in Britain, based at Caerleon, Chester, and York, auxilia in a series of forts in Wales and in the northern military district, and the garrisons of the northern frontier works. As discussed in the author's recent paper on harbours, military port installations are to be identified, albeit exiguously, at all three legionary fortresses, the coastal forts in Wales such as Carmarthen and Segontium, and at South Shields and Maryport at opposite ends of the northern frontier defences.
205 Iron Cram the eastern Weald sites would have been taken by road (and perhaps also
207 by river down the Bother, from the ironworks to the .port at Bodiam, whence it would be shipped by se across the shallows of modern Romney Marsh to the main *Classis Britannica* base at Dover. From Dover it could be distributed by sea up the east coast to York and South Shields and westwards to Wales, Chester, and Maryport.

With the closure of the eastern Weald sites in the mid 3rd century and the possible disbandment of the *Classis Britannica* (Cleere 1977), the supply of iron to the Roman army in Britain becomes something of an enigma. As Table I shows, the non-military industry did not apparently expand to cater for a new demand from the army. It is possible that part of the Forest of Dean industry may have come under direct Imperial or military control (or may even have remained under military control from an earlier period). On the other hand, a policy change may have resulted in the army's relatively modest requirements being obtained on the civilian market.

6.3 Export of iron from Roman Britain

It would appear from the preceding sections that Roman Britain reached self-sufficiency in iron production for the civilian market by the early 2nd century, and continued to produce a surplus for about two centuries. At a recent conference several papers discussed the trade between Britain and the Rhine provinces: it is clear that glass and pottery were coming into Britain until at least the end of the 3rd century on this route, and doubtless other perishable commodities accompanied them (J Price, K T Greene, M G Fulford, D P S Peacock, and M W C Hassall: contributions *Roman Shipping and Trade Britain and the Rhine Provinces*, CBA Res Rep 24 (1978)). There is no evidence of the cargoes being exported in return from Britain, beyond the often quoted passage from Strabo which refers to a much earlier period, before the Roman occupation. It is, nevertheless, significant that iron was apparently being imported into Gaul at the beginning of the 1st century from Britain:
207 traditional commercial links of this kind are often enduring.
208 The iron industry of Gaul has received hardly any attention; however, there

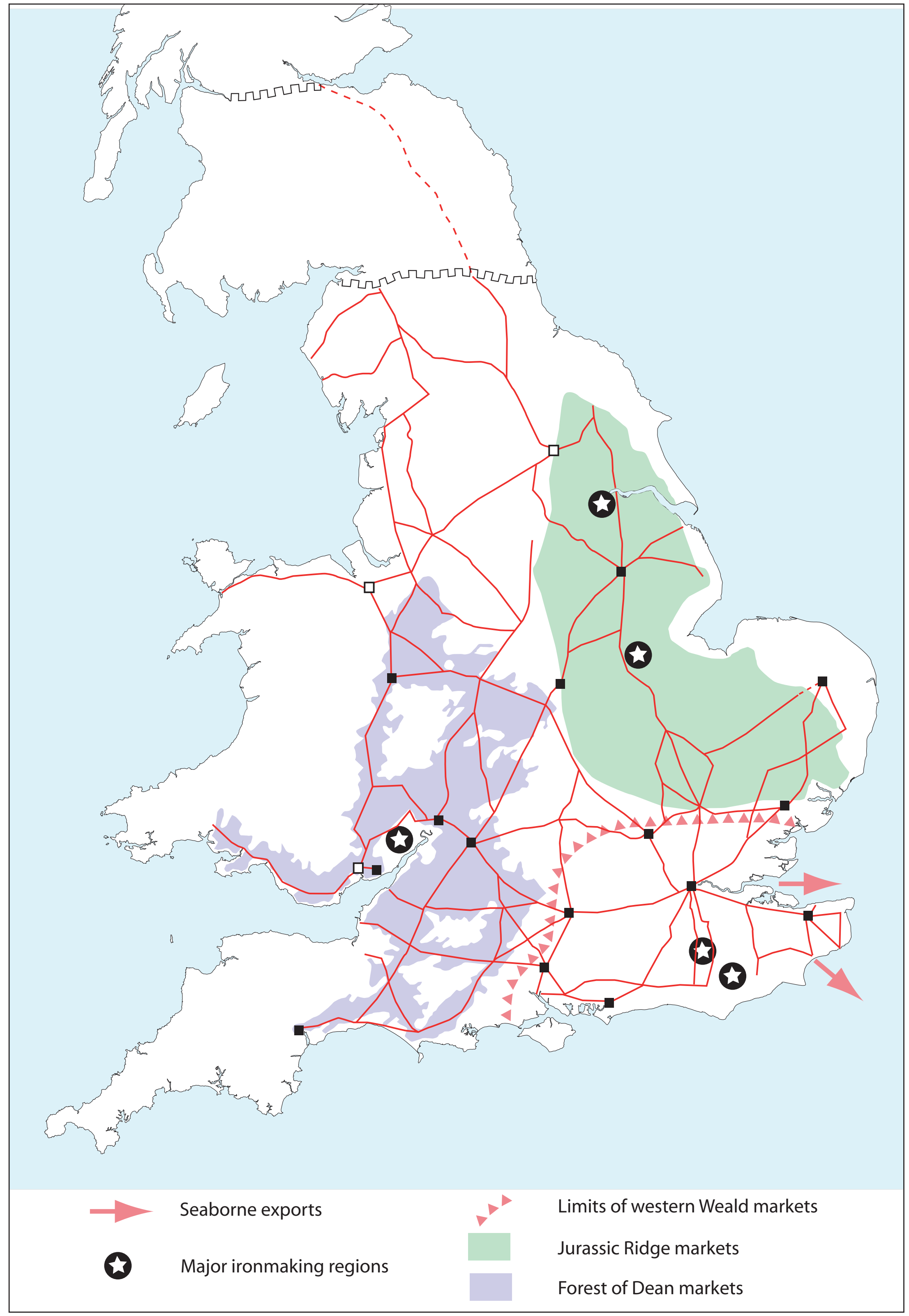

Figure 9: Suggested patterns of iron trade in Roman Britain 206

appears to be no major concentration comparable with the Weald or the Forest of Dean in the north (Davies 1935). There may have been an imperial estate based on iron in Lorraine, although the evidence is largely inferential, and there was also a concentration in the Jura. There appears to have been small-scale ironmaking in Gallia Belgica, possibly villa-based (see 3.3.e above). However, the nearest major ironmaking concentration in Gaul to the Rhine *limes* was in all probability the Massif Central. It seems reasonable therefore to postulate the existence of a trade in iron from Britain to northern Gaul and the Rhineland, a region that was intensively settled and where the total iron requirement would have been considerable, in all probability beyond the modest capacity of the local industries. No doubt historic tribal links between southeastern Britain and north-eastern Gaul would have helped in establishing and maintaining this trade.

The picture is clearer and more substantial in relation to the military iron production of Roman Britain. As stated above (6.2), the annual per capita production of the eastern Weald settlements in relation to the size of the army in Britain was c.10kg. It is difficult to conceive of an annual military per capita consumption of much more than 3kg in a period of relative inactivity on the part of the army. It seems reasonable to suggest, therefore, that from about AD 120 until AD 250 some 400 tonnes of iron was being exported annually to the army on the Rhine *limes*. This would have been transported on the short sea crossing from Dover to Boulogne (ie between the two main bases of the *Classis Britannica*) and thence distributed by water coastwise to the mouth of the Rhine for distribution by barge – possibly by the *Classis Germanica* – to the legionary fortresses and other military installations on the frontier.

The securing of supplies of this important military material by the army for its own use was obviously a sound strategic step, and it becomes more important when it is seen as covering several provinces from a single base. It is tempting to see the
208 original decision as having been made by Hadrian when he initiated his programme
209 of frontier works. Initial, state involvement in the iron industry of the eastern Weald, perhaps on the initiative of Agricola, was expanded considerably at the start of the 2nd century, when large quantities of iron would have been needed on the northern frontier of Britain (this seems to be borne out by the expansion of the more southerly sites such as Beauport Park and the extension into the High Weald represented by the establishment of Bardown). Once the initial demand for iron for the Wall had been met, there was obviously a surplus available; instead of dismantling the successful and productive industry of the eastern Weald, the military high command made arrangements for the surplus to be shipped across to the garrison of the Rhine frontier, which had in all probability been dependent hitherto for its supplies of iron on the industry of distant Noricum or on the local small-scale operations.

To summarize, it is suggested that iron was exported from Britain to the Rhine provinces and north-eastern Gaul from the early 2nd century until the end of the 3rd (and perhaps into the 4th). For most of that period this was predominantly a military exportation, some 400 tonnes going annually from the eastern Weald sites to the Rhine garrisons. The remainder -probably not exceeding some 100 tonnes a year for most of the period – would have derived from the civilian iron industry in Britain – primarily the western Weald and the Forest of Dean – and would most likely have been shipped from London, although subsidiary exports may have been made through Gloucester.

6.4 Manning

The present author's experiments on a reconstruction of a furnace of the B.1.i type (Cleere 1971), which were designed more to study the operating conditions for Roman ironmakers than to investigate the technology involved, combined with observations of a similar type of furnace operated by primitive Indian ironmakers (Cleere 1963), produced information on which it is possible to base some calculations
regarding the likely manning requirements of Roman furnaces, and thereby the 209
industry as a whole during the Roman period. 210

It became clear from the experiments that the process could be operated without undue fatigue by a team of three at the most: two would be responsible for alternating between operating the bellows for blast and preparing the charges of ore and charcoal, whilst the third would be needed as foreman or charge-hand, supervising the additions to the furnace of charge materials, checking slag evolution, etc. This was the pattern with the Indian furnaces, where one worker was responsible for the arduous work of pumping the double foot-bellows and adding the charge to the furnace for a shift of about two hours, while his colleague prepared more stocks of burden material, removed slag, and generally tidied up the site. The supervisor (an elderly woman) was clearly the master ironmaker and checked all activity around the furnace. It is possible, of course, that a charge-hand of this kind could supervise the work of several furnaces operating at the same time: at Holbeanwood, for example, where it appears that groups of three furnaces were operating simultaneously, probably only one supervisor would be needed for each group.

Examination of slag and refuse dumps at Bardown, Holbeanwood, and Beauport Park suggest that the ironmaking process was a cyclical one (Cleere l970a). Successive layers of distinctive materials charcoal and roasted ore fines, tap slag, and furnace structural debris -were observed on all these sites. These are interpreted as signifying that the operations of ore mining and treatment, timber felling and charcoal burning, smelting, forging, and furnace reconstruction were not carried on simultaneously at a major settlement but were performed consecutively on an annual cycle. This would result in characteristic refuse material being dumped in succession.

This hypothesis was applied quantitatively to the Bardown settlement, where it was calculated that seven or eight furnaces would have been in operation in any year in order to produce the 40-45 tonnes of iron annually that is calculated to have
been the output from the size of the slag dump (Cleere 1976). It was calculated that 210
some 13-15ha of woodland would need to be cleared to produce sufficient charcoal 211

to sustain this output of iron (although in a personal communication since the paper was published Dr Oliver Rackham has suggested to the author that coppicing may well have been practised in the Roman period and so the area to be cleared would have been smaller: nevertheless, the amount of wood that had to be cut and charked remained the same at nearly 6000 tonnes). This is a very large amount of timber indeed, and it seems very unlikely that a unit of some 25 men (assuming three workers per furnace plus a manager) could have cut and charked this in a season.

Similarly, a large quantity of iron ore had to be dug to feed the furnaces for this production. Bielenin (1974, 265) indicates an ore/iron ratio of 6:1 for bloomery smelting, which means that the Bardown annual iron output of 40-45 tonnes required 240-290 tonnes of ore a year. At Bardown the good-quality Wadhurst Clay nodular ore lies some distance below the surface, and so a considerable quantity of overburden – weighing perhaps three times the ore extracted – had to be moved. Here therefore there was a further requirement for 1000-1200 tonnes of material to be moved by hand in a year.

Thus, to prepare the charge materials for smelting it was necessary for some 7000 tonnes of material to be dug and cut and transported. If it is assumed that each worker could deal with 2 tonnes of material per day, some 140 days would be needed by a 25-man unit to dig the ore and cut the timber. The smelting itself, assuming that seven furnaces were in operation continuously, and that the average daily make per furnace was 30kg (Cleere 1976, 236), would have taken at least 200 days. It is possible, of course, that a larger number of furnaces was in operation, which would obviously shorted the smelting phase of the cycle; however, calculations based on the Holbeanwood satellite workplace, which was almost completely excavated and where the total number of furnaces and approximately the total slag production are
211 known, indicate that the smelting phase was indeed of the order of 200 days.

212 A smelting phase of 200 days and a combined ore mining and timber cutting phase of 140 days leaves only two weeks in a year for ore preparation and charcoal burning, which is manifestly too short a period for these lengthy processes. The evidence of the slag dumps, however, does not suggest that they were concurrent operations; it looks, therefore, as though the time for ore mining and timber cutting and hauling was considerably shorter. To reduce these periods more personnel must therefore be postulated. If the number of workers per furnace is increased to five, giving a total workforce at Bardown of 41 (assuming eight furnaces to be available), the time needed for this operation would be some 15 days to dig the ore and 75 days for the timber cutting, which leaves 75 days for the charge preparation stage. This seems a more realistic organization, and so it will be assumed that a minimum of five workers was needed for each furnace.

With an average daily make of 30kg and a smelting phase of 200 days the annual output of a furnace of the B.1.i type was around 6 tonnes. If the estimated iron production figures shown in Table I are used as the basis, the numbers of people directly concerned with iron production in Britain during the Roman period are as shown in Table II: it will be seen that they rise from about 300 in the late 1st century to a peak of over 1400 in the early 3rd century and fall to about 200 at the end of the Roman province. These were, of course, the production workers; it may be assumed that in the larger establishments at least there was a non-productive staff of clerks, carters, overseers, and general labourers, but this is unlikely to increase the total workforce by more than about 20%. It seems remarkable that the requirements for iron of an estimated total population in the 2nd century of 2 million could have been satisfied, and a considerable surplus made available for export, by about 1500 craftsmen. 212

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Region	43-l00	100-150	150-200	200-250	250-300	300-350	350-400
Weald	125	580	625	625	165	165	40
Forest of Dean	40	420	460	625	460	420	80
Jurassic Ridge	70	165	165	165	165	165	35
Other areas	70	35	35	35	35	35	70
Totals	305	1200	1285	1450	825	825	225

Table II: Estimated workforce of the iron industry in Roman Britain, AD 43-400

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223/224 # Ironmaking in a Roman Furnace*

by HENRY CLEERE

The paper describes experiments in ironmaking using a facsimile of second/third century furnaces from the Weald. Iron was produced, along with other types of waste material (slag, burnt clay, etc.), similar to that found on archaeological sites. Indications were obtained about yields, process times, and manning requirements, which will help in the interpretation of excavation results.

In the past few decades, the spread of the knowledge of ironmaking technology from its origins in the Near East throughout the Old World has been the subject of considerable study. Archaeologists and metallurgists have collaborated in the investigation of technological material, notably furnace remains, slags, and iron artefacts. Slowly a coherent picture is beginning to emerge, but many questions remain unanswered.

One of the most important fields of research is that of the practical operation of early smelting furnaces, known as 'bloomeries'. Iron artefacts of the prehistoric, 224/225
Roman, and early medieval periods reveal, on metallographic examination, structures often difficult to interpret in terms of their production processes. The excavated remains of smelting furnaces are usually fragmentary and the relationships between these and their raw materials on the one hand and metal artefacts on the other are not always easy to establish. The archaeologist is faced with another problem, less technological but just as important in terms of his research. Many early smelting sites have enormous slag banks, accumulated over long periods. These can be related from dated finds such as coins and pottery directly to the period of occupation of the site, but it is necessary to have some idea of process time and yield in order to be able to assess the man-hours that the slag heaps represent. Complete excavation of extensive sites is rarely practicable, and so the man-hour content of the slag heaps can give valuable information about the population of the associated settlement.

For the early periods there are no written records available. Some indication of the technology involved can be obtained from modern pre-industrial societies; the comprehensive review by Tylecote[1] is of enormous value in this connection. However, furnace types and raw materials vary greatly, and it has proved necessary for those studying the early technology of ironmaking to carry out their own experiments, using facsimiles of specific types of early furnace and raw materials approximating to those used in antiquity, in order to gain first-hand data. Experiments of this kind have been carried out in Austria,[2] Czechoslovakia,[3] Denmark,[4] Gcrrnany[5] and Poland.[6] In addition, important laboratory investigations are being carried out by Tylecote and co-workers in Britain.[7]

The present investigation was carried out to study the ironmaking technology in the Weald of Kent and Sussex during the first half of the Roman occupation of Britain (first to third centuries A.D.). The Wealden industry was a large-scale operation, perhaps second only to that of Noricum (modern Steiermark, Austria) during the Roman period. There is 'a strong presumption that it was at least partly a state enterprise, operated by the British Fleet (classis Britannica),[8] and as such it is at present the object of co-operative study by members of the Wealden Iron Research Group, of which the author is Joint Convener.

Theory

The earliest ironmaking technology made use of the *direct process*, i.e. iron was reduced directly from the ore, without passing through an iron-carbon alloy stage, followed by refining, as in the modern blast-furnace process. It was a relatively low-temperature process, the metal never attaining its melting point but collecting as a sponge of metal at the bottom of the furnace. The basic problem was that of separating the stony part
of the ore (the gangue) from the reduced metal; this was achieved by the formation 225/226
of a slag, i.e. an artificial mineral with a relatively low melting point. The determining factor in the process was in fact not the reduction temperature nor the melting point of

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224/225 encouragement and understanding throughout the planning and execution of the trials.

the metal, but rather the temperature at which a fluid slag could be obtained. In modern ironmaking practice the gangue (largely silica – SiO_2) is removed by the addition of limestone (CaO) as a flux. However, the use of fluxes is not attested until well into the Middle Ages (at least in Europe: the development of ironmaking technology in ancient China followed a completely different course). The gangue could only be separated from the ore by sacrificing a considerable amount of iron. The major constituent of all ancient bloomer), slags[9] was favalite ($2FeO.SiO_2$), the melting point of which is c. 1,215°C.[10] The slags were not pure fayalite, and their actual melting points probably lay up to 50°C lower, depending upon the natural lime content of individual ores. However, it was axiomatic that temperatures in excess of 1,100°C should be obtained before a proper separation could be ensured between metal and slag.

The earliest type of furnace was probably a simple hollow in the ground, lined with clay and filled with ore and fuel: the so-called 'bowl-furnace'.[11] Blown with bellows, this would produce a quantity of small lumps of reduced metal in a matrix of slag. The metal would have to be separated by hand, as in modern Indian primitive practice[12] and worked up into a bloom of consolidated iron. The developed version of the bowl-furnace was the shaft-furnace[13] of which there are many design-variants in both the archaeological and the anthropological record. This had the important advantage of making provision for the removal of molten slag, either by running it out of the furnace, as in the Austrian and German furnaces[2, 5] or by consolidating it below the hearth of the furnace, forming the Schlackenklole of the Danish and Polish furnaces.[4,6] The shaft furnace consists of what its name implies, a simple hollow cylinder with an internal diameter of 9-18in. and standing 4-6ft. high. An aperture at the base was used for three purposes: inserting the bellows, running off the molten slag, and removing the spongy 'bloom' of iron. It was fed from the top with a mixture of iron ore and charcoal. Slag would have been tapped off once it began to form, either periodically or, as the present experiments suggest, continuously; and at the end of the process the sponge of metal would have been removed. This would then have been repeatedly heated and hammered, so as to remove entrapped slag and to consolidate the metal.

The Background to the Experiments

The experiments were based on the industry of the Weald during the Roman period.
226/227 Iron was being manufactured in this area before the Roman invasion of AD. 43; Caesar refers to the industry in his *Gallic War*.[14] It was based on the carbonate ore of the Wadhurst Clay, a reducible material with an average iron content of 40 per cent. This very heavy clay also produced the other raw materials needed: it supported a mature forest-cover of hardwoods which produced excellent charcoal, and the clay itself was refractory enough for furnace construction.

The Roman industry began immediately after the invasion of 43 in the Hastings-Battle-Sedlescombe area. By the mid-second century the ore and fuel resources in this area were considerably depleted, and it would appear that the centre of the industry began to move to the High Weald, between East Grinstead and Wadhurst.[15] This survived until the mid-third century, when the deforestation and over-exploitation of the ores resulted in a virtual closure, apart from some small sites such as that at Withyham,[16] which survived until the end of the Roman period. Supremacy as the major ironmaking region would appear to have passed to the Forest of Dean, although this area has not been studied as thoroughly as the Weald.[17]

The organization of the Wealden industry is far from dear. There were certainly some very large establishments; at Beauport Park, Battle, for example, the slag heap is estimated to have contained some 50,000 tons of slag before being largely quarried away for road metalling in the nineteenth century. The hand of some central authority might be inferred from the scale of operations, and this is reinforced by the finding of tile fragments stamped with the CL BR monogram of the Fleet at Beauport Park and at the High Weald settlements at Bardown (Sussex) and Cranbrook (Kent).[18] Mineral rights in the Roman provinces were vested in the Emperor. Generally, only precious metals were exploited directly on his behalf by the provincial *procuratores*: for the most part, licence for iron-ore exploitation were assigned to private enterprises, as attested by inscriptions from Lugdunum.[19] In Britain, however, these rights seem to have been assigned, in part at least, to the Fleet, which was in many ways a supply arm of the Army rather than a fighting arm at this period.[20]

Excavations on Roman Sites in the Weald by the author and others[21] provided the data on which the experiments were based. The archaeological record has produced indications in great detail of furnace design and construction, ore selection and preparation, and fuel sources and production; the experiments were designed to encompass the variations observed and inferred. The smelting furnace itself was based on a group excavated by the author at Holbeanwood, Sussex,[15] the only shaft- 227/228
furnaces of this type known from the Weald. However, other examples are known from Ashwicken, Norfolk,[22] from Starnford,[23] and elsewhere.

Raw Materials

Iron Ore

The iron industry of the Weald was based, until its last phase in the seventeenth century, principally on the carbonate ores of the Wadhurst Clay, a formation in the Hastings Beds (Lower Cretaceous). The ore occurs at the base of the Wadhurst clay in the form of carbonate nodules ranging from 2in. to 18in. across. The nodules are enclosed in a skin, up to 1in. thick, of limonite (hence the name 'boxstone' frequently applied to them). In antiquity the ore, which occurs in a discontinuous layer, was dug in opencast pits. These are very common in the Weald, and are now usually filled with water. Dr. R. G. Thurrell of the Institute of Geological Sciences drew the author's attention to an exposure of the ore in a brick-clay quarry at Sharpthorne, near West Hoathly, and about 12 cwt. were quarried by hand. It was found that the nodules could be disengaged quite easily since the limonite matrix was friable, and that the ore was quite clean, with little or no adherent clay. This observation was important, since ore washing has been postulated as having been necessary in the Weald; this would appear not necessarily to be so. Analysis of the ore showed it to contain c. 50 per cent of iron, the remainder being c.10 per cent SiO_2, 3 per cent CaO, and considerable CO, and water. It is an easily reducible material and so it was easy for the ancient ironmaker to smelt it.

Charcoal

The hardwoods of the mature forest-cover of the Weald provide an excellent source of fuel. Charcoal burning is still carried on in the region, although most of it is now made in retorts rather than in the traditional heaps. It had been hoped to burn the charcoal for the experiments in the old way, but this proved impracticable, and so the material was purchased from a Sussex manufacturer. Observations on excavated sites suggested that about 1in cube was the preferred size in the Roman period, and material of this size was purchased. In the earlier trials this was sieved to remove material less than 1in., but it was recognized that the proportion of smaller pieces was only about 5 per cent maximum, and so in the later experiments un-sieved material was charged.

Examination of a random sample of the charcoal showed that birch and oak predominated; this compares with observations made on sites such as Bardown. It reflects the general distribution of trees in the mature Wealden forest. However, other materials had found their way into the retorts, as illustrated by an unmistakable piece of carbonized plywood from a
228/229 jigsaw puzzle.

Fig 1: Romano-British ore-roasting furnace No 2 from Bardown, Sussex

Ore-Roasting

Carbonate nodules may be presumed to benefit from roasting. Heating to 300-400°C for short periods converts the carbonate to Fe_2O_3 and drives off water. There is ample evidence for ore roasting in the archaeological record; Fig 1 shows a structure excavated at the Bardown site[24] in 1964. It consisted of a trench about 8 ft. long dug in the natural clay; it was lined with blocks of sandstone and closed at one end, the interior being lined with clay, leaving an effective volume of 8 × 1 × 1ft. It was flanked by a deep deposit of roasted fine ore less than ½ in. in size and the clay lining was reddened by heat.

Fig 2: Experimental ore-roasting furnace at Horam

The experimental ore-roasting furnace was dug in the clay to the same proportions but was not faced with stone. However, the sides were lined with puddled clay (Fig 2). The ore nodules were broken with hammers to a maximum size of 2-3 in. cube and the 1in. material was sieved out. They were then charged to the furnace in shallow layers, alternating with 1in. layers of charcoal. For the first ore-roasting a deep charcoal layer was laid first at the bottom; this was then ignited and combustion was allowed to proceed without any forced draught. The ore was roasted in this way, but the process was very slow indeed and so it was decided to apply a blast. There is archaeological evidence to justify blowing the ore-roasting furnace, since the bed of ore fines associated with the Bardown furnace contained several flagon necks which had been neatly trimmed off to form hollow cylinders and showed signs of heating; these are interpreted as having been used to support and protect the nozzles of bellows, which were probably made of wood. Use of an old vacuum cleaner as a blower proved very effective and the ore was roasted rapidly. It was found that too much blowing caused partial reduction of the ore; it was converted to magnetite very quickly. The effect of the roasting was judged by eye: the natural carbonate ore varied from creamy-pink to light-grey in colour, and changed to a maroon shade when converted to Fe_2O_3. Further reduction to Fe_3O_4 resulted in a second colour change, to blue-black.

Roasting was a somewhat hazardous process: the ore lumps tended to explode violently, thereby producing very effective degradation. The hand splitting of nodules

in the later stages was therefore less thorough since it was recognized that roasting produced effective breakdown. As an experiment, several lumps of 9in. cube and greater were roasted whole; when these did not explode they roasted slowly, and were much easier to break up with hammers than in the freshly mined condition. However, this process was a slow one, and it is assumed that a preliminary hammer-crushing to about 3in. cube was the most efficacious method. Roasting went on continuously throughout the working day, roasted ore being raked away from the hot zone immediately in front of the blower and allowed to cool slowly, and unroasted material mixed with equal amounts of charcoal being added. The cooled material was shovelled out and screened
229 to retain material between ⅜ and 1in., the undersize fines being discarded. Weighed
230 amounts were put into polythene bags, ready for charging to the smelting furnace.

Smelting

The furnace used was based on a group of early third-century Roman furnaces excavated at Holbeanwood, an outlier of the Bardown settlement,[15] in 1968. Fig 1 shows the best preserved of these furnaces. As excavated, they consisted of truncated cylinders, 1-2 ft. high with an internal diameter of 12-15 in. and walls 9-12 in. thick. They were constructed entirely of clay; only No. 4, that shown in Fig 3, contained any stone. In this case a block of sandstone was used to form the top of the front arch, a half circle of 6in. radius. The clay, which is yellow in its natural state, showed progressive colour changes across its thickness, from yellow on the outside through pink and red to light grey on the internal surface; the bottoms of the furnaces were also grey in colour, but with a much narrower heat-affected zone, as would be expected. The bottoms of the furnaces showed a slope of 10-15 degrees down from the back wall to the front arch, at which point the slope increased slightly into a shallow depression 4-6 in. deep and roughly 18 in. in diameter in front of the furnace. The latter was also lined with heat-affected clay.

Fig. 3: Romano-British smelting furnace No 4 from Holbeanwood, Sussex

Samples from the Holbeanwood furnace were examined in order to establish whether any filler material (chaff, grog, etc.) had been used. No traces were found; the material was identified as a sand-clay, corresponding to the Ashdown Sand that overlies the ore-bearing Wadhurst Clay and outcrops at Bardown, Holbeanwood and Horam. It was decided therefore to build the experimental furnace of Ashdown Sand from the Horam site, without adding any filler material. The clay was dug from the site at an exposure near the proposed smelting area. It was puddled with water and trodden with bare feet in order to homogenize and consolidate it. Occasional sandstone nodules were removed by hand.

The design of the experimental furnace is shown in Fig. 4. It was built up with roughly moulded lumps of puddled clay, which were consolidated by hand round a cylinder made from flexible PVC sheet. It seems likely that a former of some kind was used by the Roman furnace builders; Tylecote[22] suggests that a tree-trunk was used for the Ashwicken furnaces. The interior and exterior of the furnaces had been finished off with a clay slurry at Holbeanwood, and the same technique was used for the experimental furnace. The furnace was built originally to a height of 2 ft. 6 in.; however, after the first trial, it was raised to 3 ft. by the addition of a collar of clay

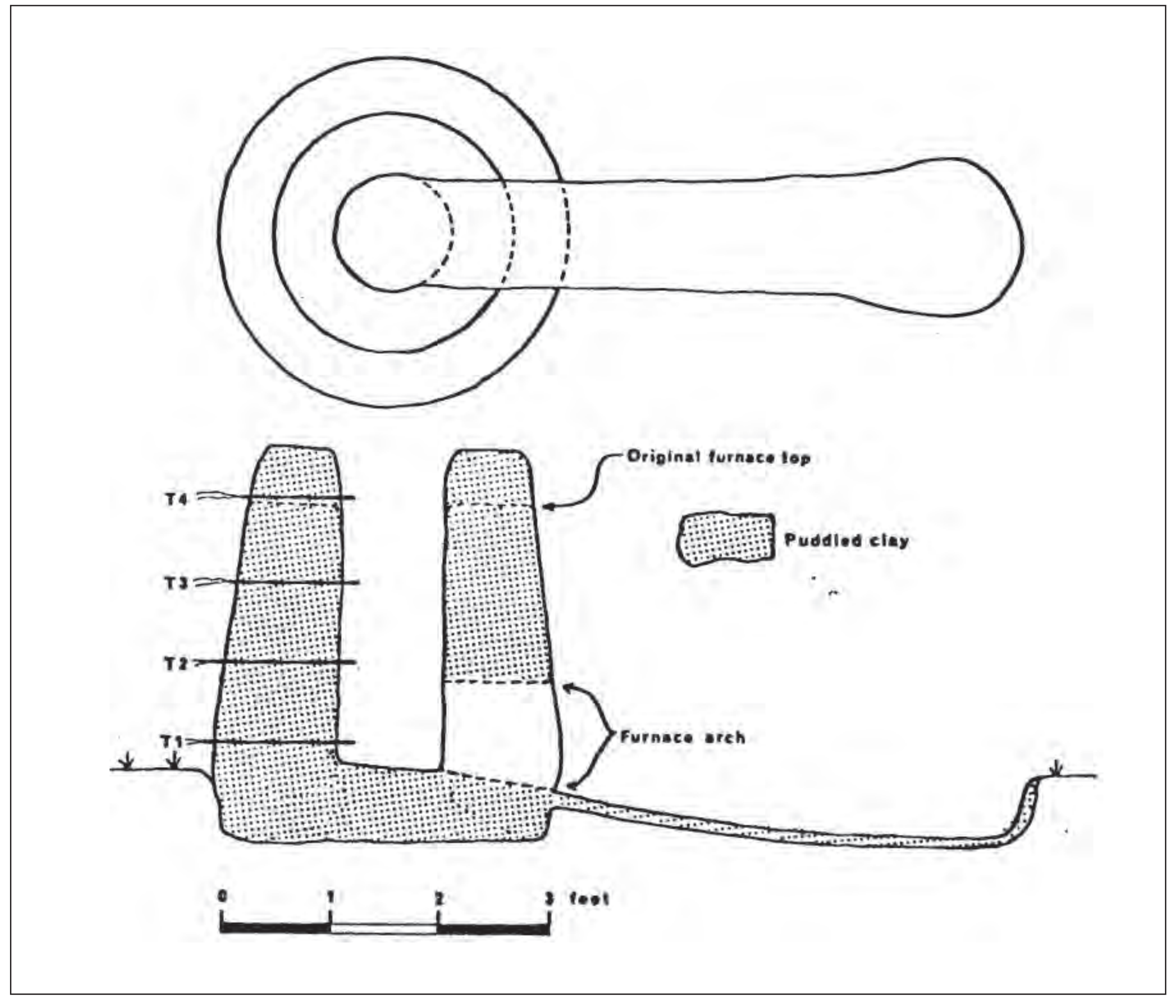

Fig. 4 The experimental furnace

Fig 5: The original 2ft 6in experimental furnace preparatory to drying.

Fig 6: The enlarged experimental furnace showing method of stopping up the furnace arch

keyed into the previous top. The final form of the furnace is shown in Fig 6. After building, the furnace was left to dry in air for six days. Some superficial cracking was observed after that period, and this was made good by the application of clay slurry. A fire of green wood was then lit and kept going for about six hours, the bottom aperture being left unblocked. On the following day, this fire was rekindled and stoked with charcoal. The front was closed with roughly-preformed lumps of clay, a clay nozzle or tuyere being inserted, and the furnace was blown using a vacuum cleaner. Cracking was observed on the exterior and further parging became necessary. During the course
230 of the trials, further cracking was experienced, in a much more severe form. However,
231 few of the later cracks appeared to penetrate through the thickness of the wall. Parging with clay (to which some grog derived from the bottom arch filler-material had been added) sealed these cracks quite effectively; in any case, gas/air tightness was ensured by the build-up of slag on the inside walls (see below). As a safety precaution, wire bands were put round the furnace. However the structure was very robust; the hearty use of a crowbar at the end of the final trial, to remove bloom and slag, appeared to have no effect on its stability.

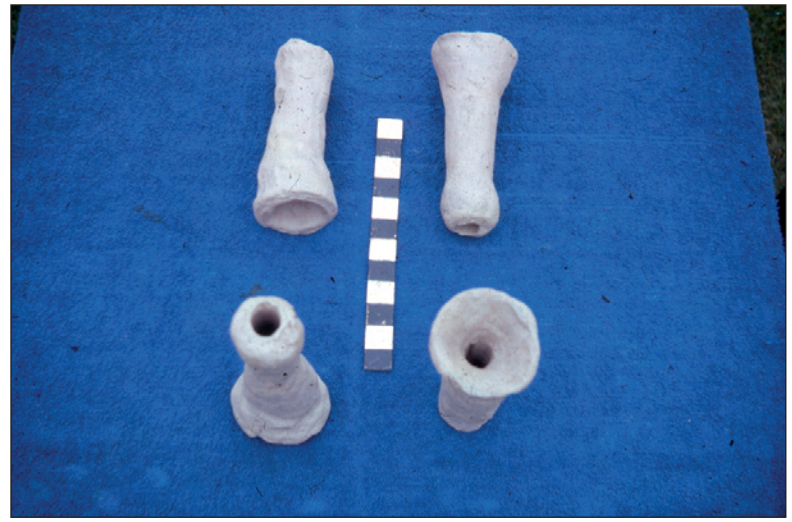

Fig 7: Experimetal clay tuyeres – single

Fig 8: Experimetal clay tuyeres – double

Tuyeres

No examples of Roman bellows are known. However, it has been assumed that these would have had nozzles of wood. This view is reinforced by the frequent finds of clay nozzles or tuyeres on early smelting sites during excavations. Two types of tuyere are known from the Weald in the Roman period: a simple trumpet 231
nozzle and a twin-channel 232
type, the latter known only in this area.[25] For the experiments, facsimiles of both types were made, using Ashdown Sand from the Bardown area. These were moulded by hand, air-dried, and finally dried for about four hours at 300°C. The tuyere was inserted into the frontal arch of the furnace. The exact position and angle of the tuyere were varied during the trials (see below). The nozzle of the bellows or blower was then inserted into the trumpet-mouth of the tuyere; in Trial 1 it was fixed with clay wedges, but this practice was abandoned for the later trials. Examples of the tuyeres used are shown in Figs 7 and 8.

Experimental Details

Instrumentation

Although the purpose of the trials was to reproduce Roman ironmaking practice, some instrumentation was used, primarily to record results rather than for control purposes. Gas analyses were made at 30-minute intervals during Trials 2 and 3. Measurements of O_2, CO_2, and CO were made during Trial 2 and of CO_2 and CO in Trial 3. No measurements were made during Trial 4 because of shortage of operating personnel. Thermocouples for temperature measurement were inserted into the back wall of the furnace at the points shown in Fig. 1 and protruded 2 in. into the interior.

Blowing Equipment

It has been established by other workers (see notes 3, 4, 7) that introduction of a volume of 300 litres of air per minute gives the optimum results in early furnaces of this type. Unfortunately it did not prove possible to obtain a suitable blower, and so the trials were carried out using an electric blower that produced about 450 litres per minute and an old vacuum cleaner which gave about 200 per minute. Attempts were made to reduce the volume delivered by the former by withdrawing the nozzle from the mouth of the tuyere. The vacuum cleaner was used principally for the ore-roasting furnace.

Procedure

The charge was prepared by screening both charcoal and ore to reject material below 3/8 and over 1in. Weighed amounts were put into polythene bags and stored alongside the furnace; the amounts varied as follows:

		Charcoal lb.	Ore lb.
Trial	1	4	4
	2	1 1/2	3
	3	1	2
	4	1	2

232/233

The furnace was kept hot overnight by filling it with charcoal and closing the arch with clay and the top with a steel sheet. The arch was refilled with the tuyere in position in the morning and the sheet was removed. (At this point the bloom would normally be removed – see below.) The stack was then filled with charcoal and blowing began. The stock level was maintained with charcoal for about 15-30 minutes, at which point the top gas was ignited and the first charge of ore was made. The stock level was kept constant at the level of the furnace top (except in Trial 4) with additions of ore and charcoal for the rest of the trial. The blast was taken off periodically in order that a sight might be taken through the tuyere. A steel rod was inserted through the tuyere into the furnace, so that the amount of slag formed could be estimated. It was also necessary to clear cold slag from the nozzle of the tuyere with the rod from time to time.

The front arch was stopped with clay alone in the first two trials; slag could only be tapped by removing most of this material. In Trial 3 the bottom part of the arch was filled with a sandstone block, which it was hoped to remove to allow the slag to run out; unfortunately the attempt to do so was left too late and it had become welded indissolubly into a mass of cold slag at the base of the furnace. In Trial 4 a turf was used, with conspicuous success, as a stopper. The organic material in the turf was burnt away by the hot slag (at a temperature above 1,200°C) and the slag ran out continuously, being kept fluid by the flame which burnt at the aperture. When charging of the ore was completed, extra charcoal was added and blowing continued until the stock level had dropped about 1 ft. At this point, the furnace was closed up and left overnight (for Trials 1 and 2 only) or for several hours. The bloom, which had built up behind the arch, bridging the furnace, was then loosened from above with a crowbar and removed with tongs through the arch. The slag that had collected at the base of the furnace was broken up with crowbar and hammers and removed through the arch; after repairing the inside wall, the cycle could begin again. It was found that the bloom and slag could be removed in about 30 minutes, and that the furnace remained reasonably hot during this operation.

Results

Trial 1

The furnace was lit at 09.55 and 30 lb. of charcoal had been charged by 11.10, blowing being by means of the vacuum cleaner. The stock level was maintained to the top of the furnace throughout this trial; it should be remembered that the furnace in this trial was 2 ft. 6 in. high. The first ore charge was made at 11.35 (10 lb.). Equal 4 lb. additions of ore and charcoal were made at intervals up to 15.40 as the stock level dropped. The blower was substituted for the vacuum cleaner at 13.45. An unsuccessful attempt was made to tap slag at 14.40; cold slag built up at the base of the furnace while the arch was open, and by 15.55 it was recognized that the furnace had gone cold. It was therefore closed up and cleared on the following morning.

Fig 9: The furnace as enlarged, showing thermocouples. (T1 is not visible)

It was realized that the ore additions had been too large and had cooled the furnace too much, and also that the vacuum cleaner did not supply an adequate 233/234 blast; the 300°C rise at thermocouple 1 when the blower was put on emphasized this. The slowness in clearing the arch and in attempting to tap slag cooled off the combustion zone so severely that it became impossible to achieve adequate temperatures. No iron was produced in Trial 1; the resulting slag was in effect fused ore, since temperatures in excess of 1,200°C were not achieved. Trouble was experienced in this trial with slag blocking the tuyere. The tuyere had been positioned in the centre of the arch, inclined upwards at an angle of about 5 degrees.

Trial 2

The furnace was raised to 3 ft. internal height, and the tuyere was positioned at the top of the arch, inclined upwards at about 15 degrees to the horizontal. The furnace bottom was also built up, with a slope of about 15 degrees to the horizontal from front to back (Fig. 1). An extra thermocouple (T4) was added. After 30 minutes preheat, ore and charcoal were added in the ratio of 1:1.5 from 09.00 to 11.00; the ratio was then changed to 1:1 for the remainder of the trial, the last addition of ore being made at 18.21. The electric blower was used throughout the trial; from 09.30 to 10.05 and again from 10.40 to 11.40 an intermittent blast was used, the nozzle from the blower being screened from the tuyere for 2 seconds in every 5 seconds. This tended to depress the temperatures and also resulted in rapid descent of the burden in the furnace, owing to the fluctuations in pressure.

An unsuccessful attempt to tap slag at 11.40 was quickly abandoned, and blowing resumed, without any obstruction; the temperature at T1 rapidly rose to 1,300ºC. Fluid slag ran out at 12.00 and continued running from a small aperture for 30 minutes; the T1 temperature quickly came down to about 1,100°C. The aperture was widened at about 12.50, the bellows-nozzle being inserted directly into it. By 13.55 the slag at the bottom was cold and solid, but once the crust had been broken with a crowbar slag began running again and continued to do so throughout the remainder of the trial. However, continual clearing of cold slag was essential. After the final ore addition at 18.21, two more lots of charcoal were added. Blowing was reduced by gradual withdrawal of the nozzle, and the furnace was finally closed down at 19.30.

This was the most successful of the trials, nearly 20 lb. of iron being produced from 201 lb. of ore and 265.5 lb. of charcoal. However, the open-arch practice cooled the bottom zone severely, and there was ample evidence of re-oxidation of the lower part of the bloom.

Trial 3

Blowing began at 10.10 and the first ore charge was made at 10.37; the ore-charcoal ratio used was 2:1 (2 lb. of ore, 1 lb. of charcoal). The last ore charge was made at 13.50 and the furnace was closed up at 15.00. It was reopened at 18.00 and the bloom and slag were removed. The electric blower was used throughout the trial. The experiment with the sandstone plug in the tapping arch proved disastrous; when an attempt was
234 made to remove this at 12.20 it was found to have become welded to the cold slag on
235 the hearth. Moreover, it had splintered under heat. The furnace was off blast for 30 minutes while attempts were made to move the block. Heat was lost in the bottom zone, as in Trial 1, and there was considerable re-oxidation of the bloom, although this had formed properly. No more than 2 lb. of iron was recovered from the 12 lb. bloom by magnetic separation when it was broken up with hammers.

The comparative failure of this trial is adjudged to have been due to inability to tap the slag (which caused the furnace to clog up at the base with cold slag) combined with use of an over-powerful blower.

Trial 4

Blowing began at 10.39 and the first 2 lb. ore charge was made at 17.05. The ore-charcoal ratio was 2:1, as in Trial 3. The last ore charge was made at 13.35 and the furnace was closed up at 14.05. During this trial, the stock level was maintained at 6in. from the top, i.e. at the level of thermocouple T4. This trial was less serious than the others, since the experimental site was associated with a charity event and there was some onus on the operators to 'put on a show' for the benefit of visitors. A small quantity of ore was charged, and the bloom was removed at 17.00, with a good deal of showmanship.

The most successful aspect of this trial was the use of a turf to stop up the lower part of the arch. This had burnt through by 11.50 and slag ran out steadily throughout the remainder of the trial. The aperture was about 6 in. wide by 2 in. deep, and a flame burnt over the emerging slag. It was clear that the blast from the tuyere went both upwards and downwards inside the furnace; the combustion of charcoal below the tuyere level produced a hot flame which kept the slag fluid. It appears therefore that a 'running slag notch' is effective in the bloomery process. The iron yield was disappointing, however: only about 2 lb. of iron, as in Trial 3. This was probably due again to the use of the electric blower, which produced highly oxidizing conditions inside the furnace and re-oxidized the bloom as it formed.

Examination Of Products

Iron

The nature of the bloom is illustrated in Fig 10. In this portion of the main mass, the reduced iron is embedded in a matrix of slag. However, in Trial 2, from which the specimen illustrated was produced, attempts to tap slag were not successful. Better furnace-operating conditions would have resulted in a more consolidated iron sponge, with considerable slag inclusions.

Iron from the raw bloom was first worked by repeated heating and hammering (to expel entrapped slag and weld the metal particles) into small blanks for further working. A typical microstructure is shown in Fig 11. The degree of consolidation was poor, as shown by the voids and slag inclusions. Some small arrowheads were made from the semi-finished blanks. The shaft of one of these was examined metallographically. As

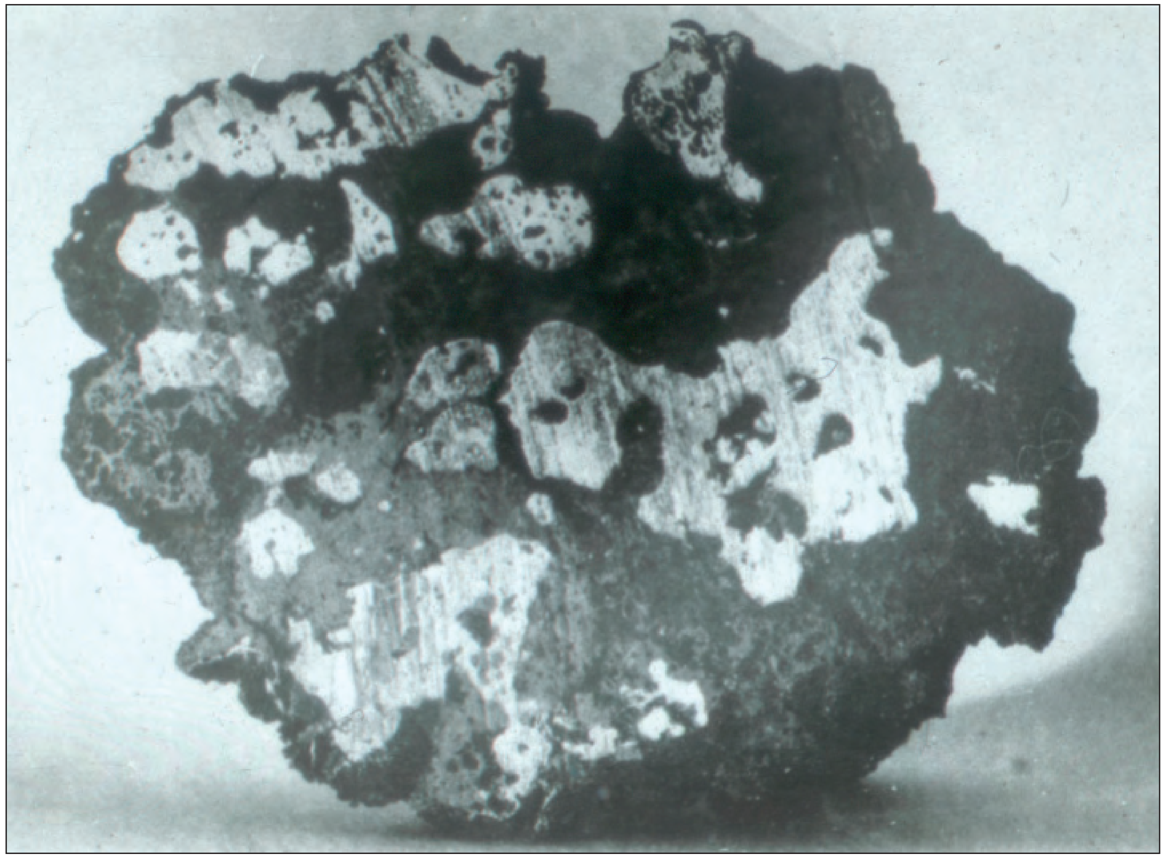

Fig 10: Section of bloom. light areas iron, dark areas slag

Fig 12 illustrates, the consolidation was not perfect even at this stage; slag stringers
235 and voids remain. Variations in carbon content were observed which would be expected
236 from material forged from small discrete particles of reduced iron and repeatedly
heated in a charcoal fire. The microstructures observed are very characteristic of bloomery iron, and can be paralleled by innumerable examples from objects derived from archaeological excavation.

Slags

Since no flux was used in antiquity, none was used in the trials. The gangue was removed only at the expense of the iron yield, and slags from antiquity are always principally composed of fayalite. Two distinct materials produced during the trials were examined; material remaining at the base of the furnace at the end of a smelt, and tap slag. The former was a coarsely crystalline material, enclosing much charcoal and with pores encrusted with fayalite and with hercynite ($FeO.Al_2O_3$). The principal minerals present were fayalite, hercynite, wüstite, and iron monticellite ($CaO.FeO.SiO_2$) in an interstitial finely crystalline silicate matrix; small amounts of metallic iron were also present. The large size of the fayalite crystals (up to 3 mm.) is due to the slow cooling of this material in the furnace.

The tap slag is a massive mamillated dense material, with pieces of refractory and glassy material included. The main components are fayalite, hercynite, wüstite, magnetite, and iron monticellite. Metallic iron and, in oxidized regions, hematite also occur, and there are lime-rich pockets with di-calcium silicate and various calcium ferrite compounds (e.g. $2Ca.Fe_2O_3$) or anorthite ($CaO.Al_2O_3.2SiO_2$) crystals set in a glassy matrix.

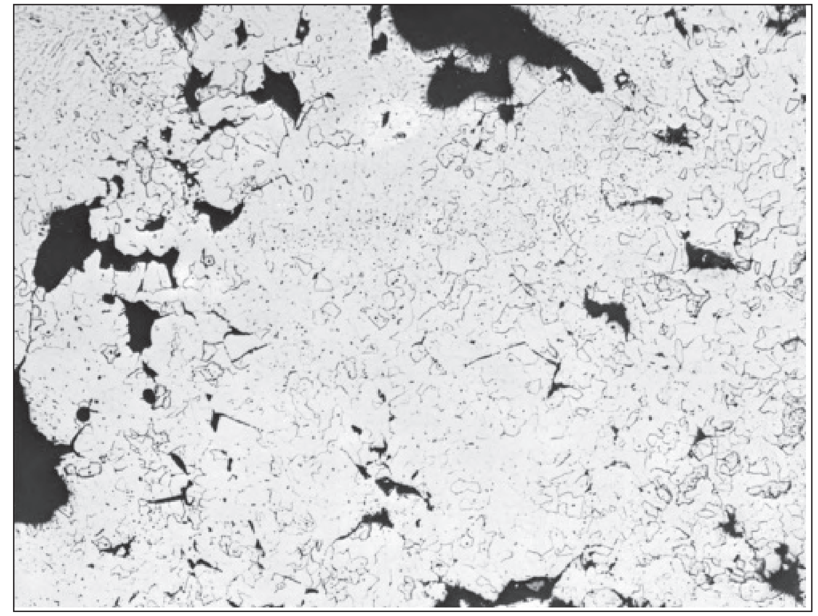

Fig 11: Microstructure of partially worked iron (x50)

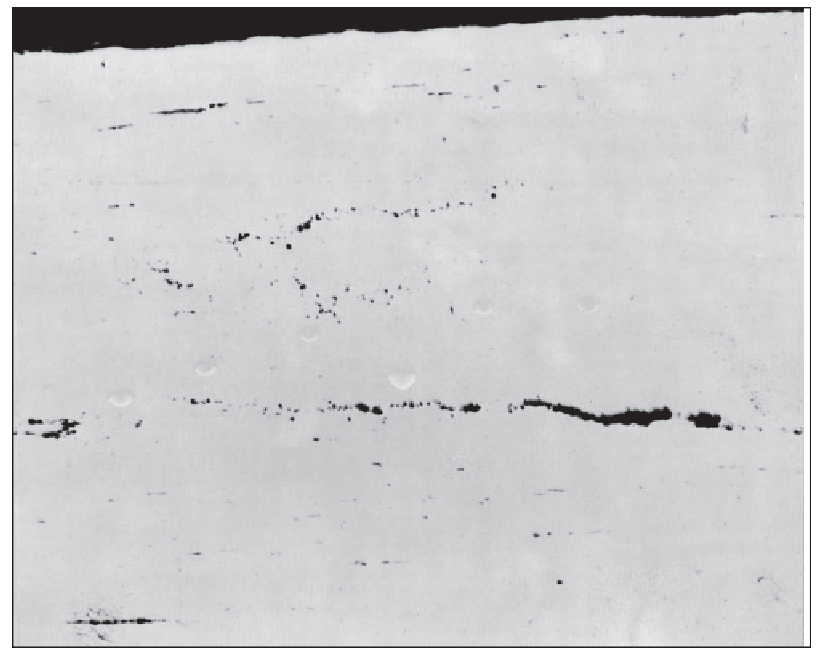

Fig 12: Macrostructure of forged shaft (x15)

Furnace Structures

On examination after the trials were completed, the furnace showed the features observed in the Holbeanwood furnaces. The colour-change sequence from the outside was from yellow through pink and red to grey, and there was a coherent coating of slag on the inside of the furnace, which had built up to about 4 in. during the four trials. The lumps of clay used for stopping the furnace arch, particularly those used when the furnace was being preheated using charcoal alone, exhibited vitrification on the face that had been on the inside of the furnace. This was presumably due to the combination of alkalis in the charcoal with the silica in the clay. The slag lining was seen to have attacked the clay wall of the furnace, but there was no evidence that it had been hot enough to melt and run down the furnace. Thus the composition of the slag can be related solely to the ore and fuel compositions, contrary to the view expressed by some workers in the field that the refractory lining played a part in the formation of slags.

Conclusions

Ironmaking Technique

The experiments were hampered by the inadequate blowing equipment available. However, iron was produced and certain observations could be made that help in the
236 greater understanding of the primitive process. First, it appears that an ore-charcoal
237 ratio of 1:1 gives the best results. This observation should perhaps be viewed with some caution, since it holds good only for the blowing rates used in the trials. Tylecote and others[7] claim good results with a ratio of 2:1, but using a blowing rate of 300 litres of air a minute. It is clear that small frequent additions of ore and charcoal are more effective than large additions. The 4 lb. ore unit of Trial 1 demonstrably caused considerable cooling of the reduction zone. No obvious distinction could be observed between the results using single and double tuyeres. However, they may be a reflection of the type of bellows used in antiquity; it is possible that double bellows were used with the double tuyeres, the bellows operating alternately so as to maintain a continuous blast.

The most important result was connected with the practice at the furnace arch. The process clearly operates most efficiently if slag can be removed continuously from the hearth area, without loss of heat. Breaking down the whole furnace arch is time-consuming (and disagreeable) and results in considerable heat loss while the blower is off. Continuous slagging with an open arch, with blowing maintained, is effective up to a point, but causes overcooling in the lower zone and severe re-oxidation; moreover, the cold air from the blower cools the escaping slag quickly, and a weir quickly builds up. A removable stopper is a possibility, but this can become welded to the slag inside all too rapidly. The use of a consumable stopper of turf or some similar material seems to give ideal conditions, with continuously running slag, a source of heat to keep the slag fluid and no extra access of air.

As mentioned above, the main reason for the low yields in the trials is assumed to have been the over-powerful blower that was used. The considerable volume of cold air injected at the tuyere appears to have cooled the bloom as it formed. Some degree of re-oxidation would be inevitable under these conditions. The non-metallic portion of the bloom is high in fayalite, i.e. slag, which was unable to run away at the tapping hole or arch because it was solidified at the bloom level. The low temperatures at the front of the hearth zone prevented both the proper disposal of slag and the completion of the reduction process. It is thus essential to maintain this zone at a temperature of at least 1,200°C, and to reduce heat loss during slag-tapping to a minimum.

Archaeological Considerations

The trials produced valuable data for archaeological studies in three main fields:

1. The durability of furnace structures. The furnace proved to be very tough; after four trials it was still strong, and with more skilled operation combined with proper maintenance and repair it could easily have lasted for at least a dozen smelts. The Holbeanwood group of furnaces[15] all showed signs of rebuilding; the twelve furnaces found so far must between them have represented at least forty separate builds. If a life of twelve smelts is assumed for each and an average production of 40 lb. of iron per smelt (this is to assume that the ancients were at
least twice as skilled as the author and his team, which is probably unfair to the 237
Romans), a minimum production of over 8 tons of iron may be postulated from 238
this group of furnaces.
2. Identification of products and waste materials. The distinction between the different types of slag produced became much clearer once these materials had been seen in the course of production. It is hoped that this evidence will permit more positive identification and classification of slag materials found on future excavations. The lumps of clay used for stopping up the furnace arch also exhibited characteristics (e.g. finger grooves made by the furnaceman when forming them, vitrification on the inner surface, etc.) with parallels in the archaeological record which have never been properly explained before.
3. Manning requirements. It was found that a minimum of four people were needed on the site, to operate the ore-roasting and smelting furnaces, weigh out the charge material and screen it, clear away slag, etc. If it is assumed that at least three men would be needed to operate hand- (or foot-) powered bellows on each furnace, working in shifts, the minimum manning per basic furnace unit of ore roaster and smelter would have been ten.[26] This enables deductions to be made about the possible population of ironmaking settlements such as Bardown.

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245 The Classification of Early Iron-smelting Furnaces

by H. F. Cleere F.S.A.

1. Introduction

For the successful smelting of iron from its ores, it is necessary to have a reaction vessel that can produce a temperature in excess of 1,200°C, together with an adequate supply of reducing gas (CO). There must not be an excess of oxygen, otherwise the carbon fuel is completely oxidized to CO_2, or the newly reduced metal is re-oxidized.

In recent years, increased attention has been paid to the typology of iron-smelting furnaces from the prehistoric and classical periods. The most generally accepted classification in the English language is that of Coghlan, who identified three types, on the basis of their morphology alone, although he admits that '… the fairly numerous furnaces found in Europe seem, according to the published reports, to represent a confusing number of types'.[1]

Coghlan's three types are as follows:

(a) The simple bowl furnace.
(b) The domed or pot furnace.
(c) The shaft furnace.

He goes on to make the point that a further distinction must be made between furnaces operated with a natural or induced draught and those operated with a forced draught (i.e. bellows-blown), in order to achieve adequate temperatures.

2. The Morphological Classification

(a) The bowl furnace

This type of furnace is essentially a hollow in the ground, usually hemispherical, ranging in diameter between 30cm. and 1.50m., and lined with clay. Into this was packed a mixture of ore and charcoal, which was heaped above the bowl, and a bellows was inserted into the side of the charge. In order to minimize heat loss and the re-oxidation of reduced iron, it would seem likely that the mass was covered over with turf or clay, a hole being left in the top for the escape of waste gases.

As the temperature inside the bowl increased, reduction of the ore began. A slag was formed between the non-metallic part of the ore (the gangue), usually consisting principally of silica (SiO_2), and part of the iron oxide in the ore, which became liquid at about 1,200°C and began to fill up the lower part of the bowl, where it tended to solidify, often entrapping particles of unburnt charcoal and partly or wholly unreduced ore.

The metal that formed was not at a sufficiently high temperature to become molten, 245
and coalesced slowly as a spongy mass, known as a 'bloom', above the slag cake. When 246
the process was completed, the charcoal having been totally consumed, the bloom could be removed, in order to be heated and hammered repeatedly to consolidate it and to expel the considerable amount of entrapped slag. The slag cake or 'furnace

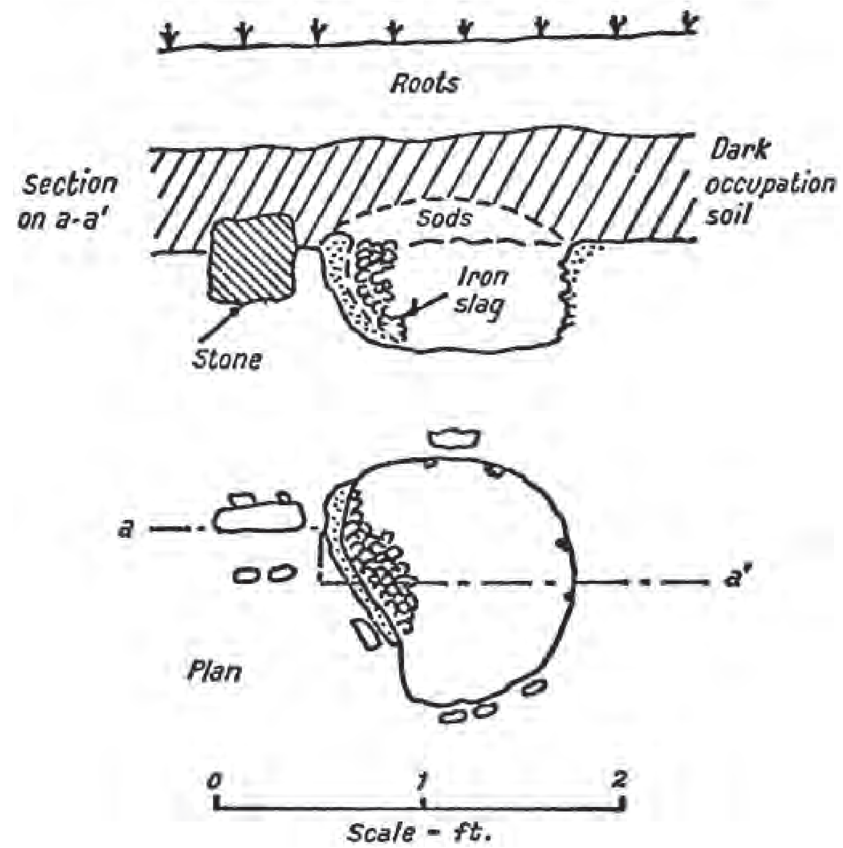


Fig 1: Bowl furnace from Kestor, Devon
(Tylecote,** Metallurgy in Archaeology**, fig 45, after Fox)

bottom' could easily be prised out and discarded.

This then is the principle of the process. A number of 'bowl furnaces' have been excavated in various parts of the world, and two representative samples are shown in Figs. 1 and 2. However, there are certain aspects of this picture which require further examination.

First, there is the matter of whether the heap was covered or not. If it is assumed that the furnaces were in fact covered by turf or clay, it would be difficult to make further

additions of ore or charcoal. Thus for a bowl hearth with a diameter of only c.30cm. (i.e. a working volume of not more than 5,000 cu. cm.), the iron yield is likely to have been very small indeed – probably less than 1kg. This would appear to be a highly
246 unremunerative operation, and so the 'uncovered bowl' concept has found favour with
247 a number of writers, additional material being added as the heap subsided.

Heat insulation and restriction of oxygen access to the reaction mass are essential, as Wynne and Tylecote[2] found when they carried out experiments with a laboratory facsimile of a 9-inch diameter bowl hearth. It was only when the furnace was covered that significant iron output was achieved; with the furnace uncovered, virtually slag alone was the result. To the best of the author's knowledge, no successful experiments

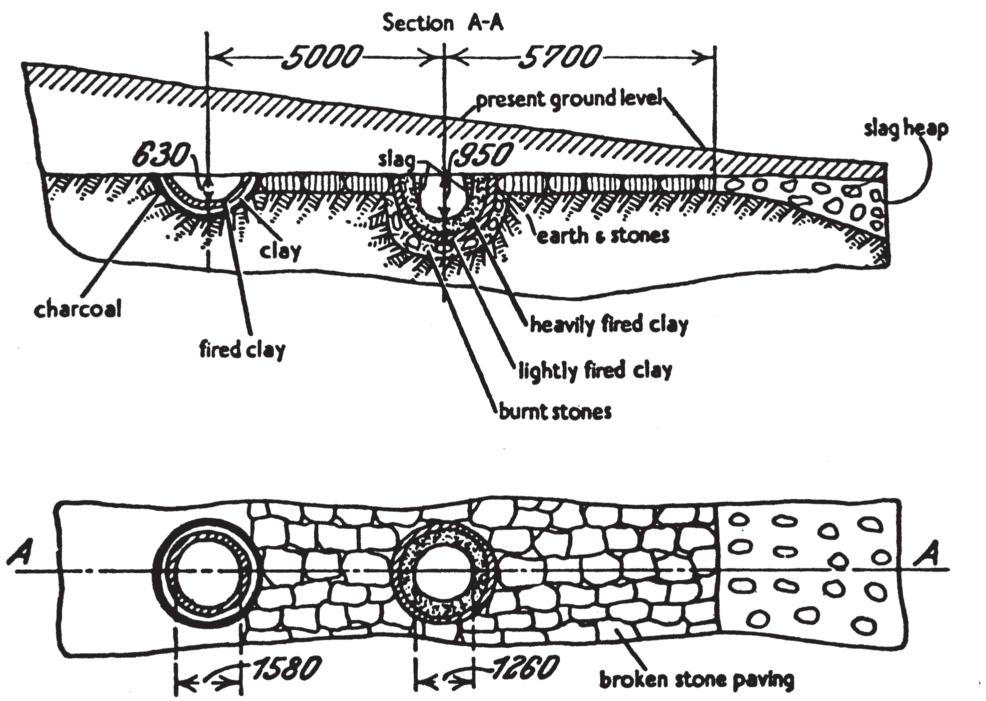
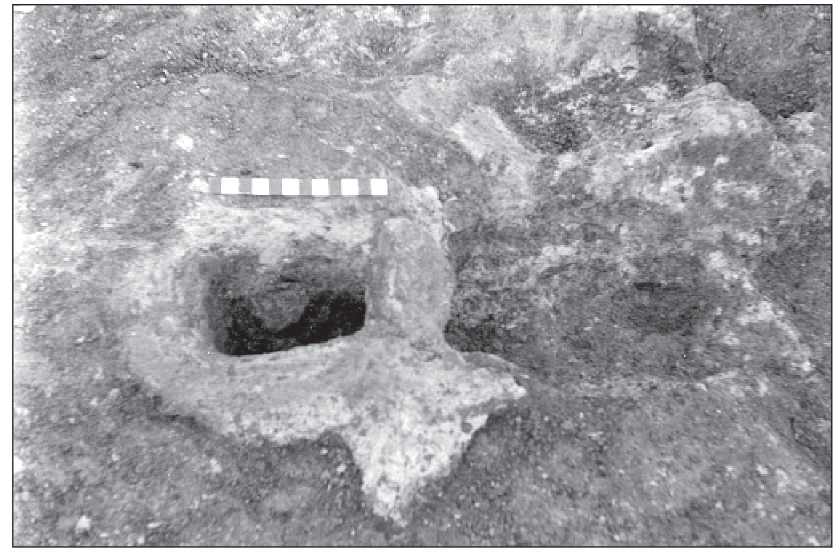


Fig 2: Bowl furnaces from Hüttenberg, Austria (Coughlan, *Prehistoric and Early Iron in the Old World,* **Fig 5, after Weierhausen)**

(i.e. producing a significant amount of iron) have been made using facsimiles of open bowl hearths.

It might be argued that the metal yield might be increased by using a larger hearth: Weiershausen[3] cites so-called bowl furnaces from the Hüttenberg (Austria) measuring 1.26m. wide × 0.95m. deep and 1.58m. wide × 0.63 m. deep respectively. These may be compared with a structure from Great Casterton, Rutland (in Tylecote[4]), with an
247 internal diameter of 36 inches and a maximum depth of 18 inches. A replica of the latter
248 was built in 1969 and attempts were made to smelt the easily reducible siderite from the Wadhurst Clay in it, but without success.[5] The single bellows and tuyere were incapable of supplying adequate heat to bring about complete reduction of the ore, and there was considerable heat loss from the large surface area of clay overlying the charge. Either multiple bellows were used or, as appears more probable, the Hüttenberg and Great Casterton examples were used for other purposes – ore roasting or smithing.



Figs 3 and 4: Furnace base (above) and lower part of shaft furnace (below) from Holbeanwood, Sussex.

For primitive societies, the yield of iron from a covered bowl furnace of 30-50cm. diameter would probably have been economically viable and justified. However, examples of bowl furnaces from more developed societies (e.g. late La Tène Europe or the Roman provinces) need careful appraisal before they are identified as such. The author has recently excavated a group of furnaces at an early third-century Roman site at Holbeanwood, Sussex.[6] So far, twelve furnaces have been found, nine of which retained only their hearths, measuring 30-35cm. across (Fig 3). These were slightly concave, and might easily have been described as the bases of bowl furnaces. However, the remaining three furnaces still fortuitously preserved the lower part of their walls, in one case standing to 50 cm. (Fig 4). When these furnaces were 'dissected', they showed, once the walls had been removed, identical features to the putative 'bowl' furnaces. Having regard to the fact that the majority of the iron-smelting furnaces described in the literature were excavated by archaeologists without any specialist knowledge of ironmaking

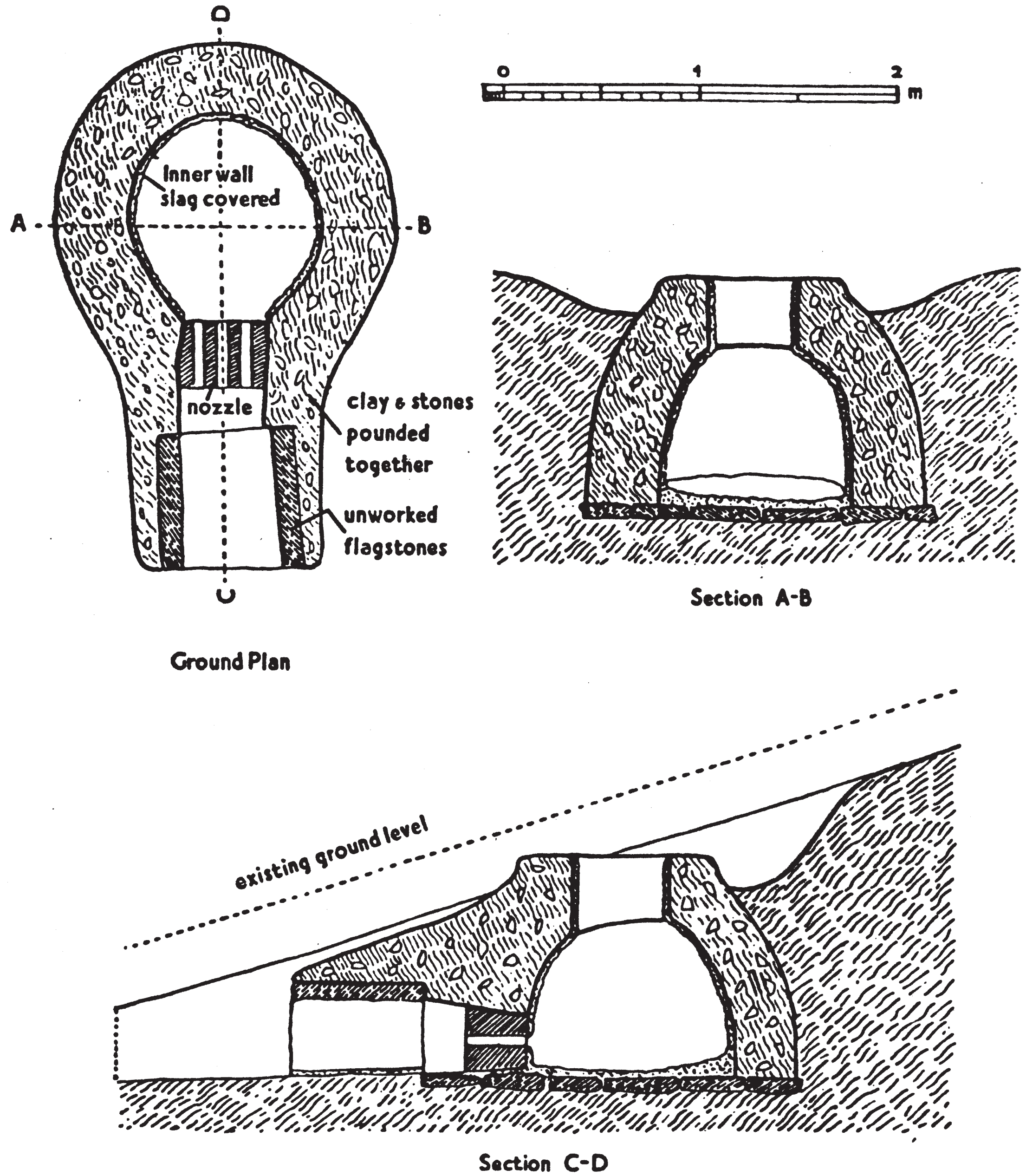


Fig 5: *La Tène domed furnace from Engsbachtal, Germany (Cochlan, Fig 6, after Weiershausen)*

technology, it is reasonable to enter some caveats about the accuracy of their interpretations of their finds. Without some degree of experience in the interpretation of such material, it is easy to overlook apparently unimportant features, which provide invaluable diagnostic criteria for the expert.

To summarize, bowl furnaces are likely to have been in operation in the earliest ironmaking cultures and in backward communities in later periods, up to the present

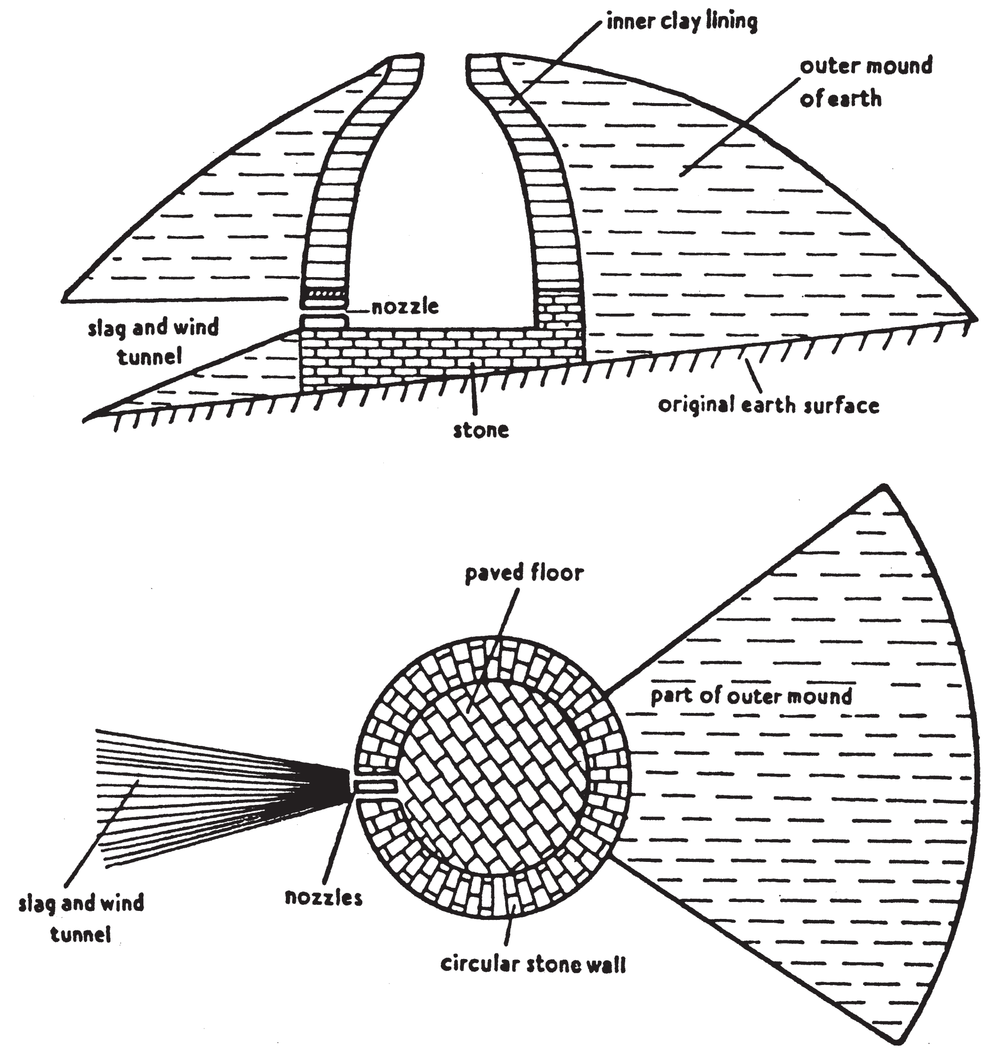


Fig 6: Domed furnace from Aalbuch, Germany (Cochlan, Fig 7, after Weiershausen)

day (see Tylecote[7]). The diagnostic feature of this type of furnace is that it was built below the surface of the ground (and thus had no provision for tapping slag) and must have been fired by forced draught.

(b) The domed furnace

Coghlan describes this type of furnace as having a circular hearth that is flat or hollowed, with a domed superstructure above it, rising to a central aperture. The furnaces could be built into a bank or free-standing, and were blown by natural or forced draught.

This type of furnace is common throughout northern Europe. Coghlan illustrates the late La Tène furnaces from Engsbachtal in the Siegerland[8] (Fig. 6) and from Aalbuch, Württemberg[9] (Fig. 5). Many other examples are known, including two first-

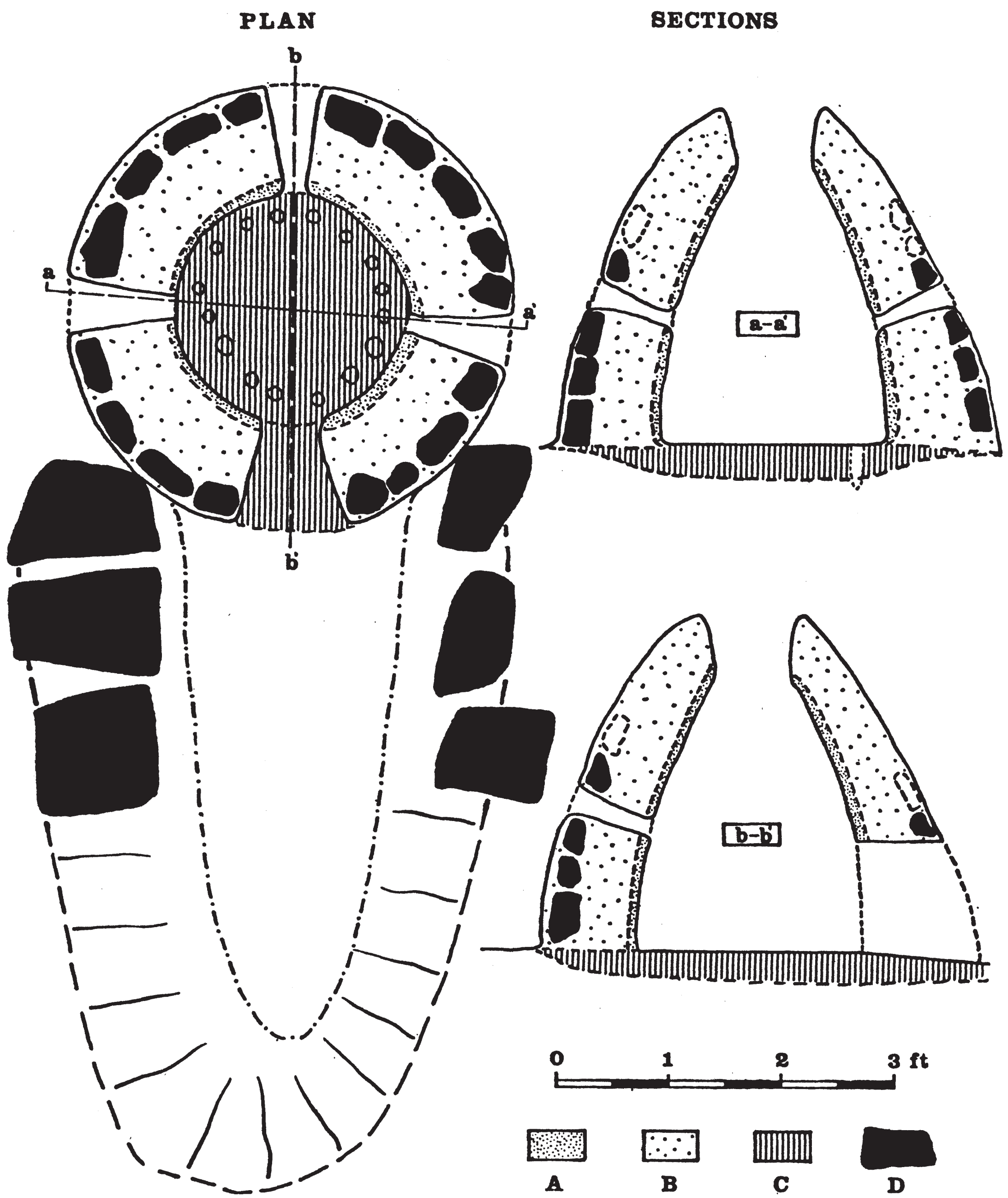


Fig 7: Domed furnace from Minepit Wood, Sussex (reconstruction by H. F. Cleere).

A Furnace lining (prepared clay
B Puddled clay superstructure
C Clay hearth
D Sandstone blocks

century A.D. examples from Sussex – Minepit Wood[10] (Fig. 7) and Pippingford Park.[11]

It will be seen that this type of furnace represents a technological advance over the bowl furnace. First, the charge over the reaction zone in front of the air blast is protected by the thick dome-like covering of clay and stone. Secondly, the output is not determined by the volume of the original charge, since the permanent nature of the dome makes it rigid enough to withstand the progressive lowering of the charge as the smelting operation proceeds, and so additional ore and charcoal can be added through 250
the top aperture. Thirdly, since the hearth is not below ground, the fluid slag can be 252
tapped away, either continuously or intermittently. This means that the iron bloom can be made much larger, since the working volume of the furnace is not permanently blocked with slag.

Coghlan states that, 'In general, the domed furnace of the European Iron Age relied upon natural draught'.[12] This is a somewhat questionable statement. Experiments by Tylecote[13] suggest that natural draught using a single wind passage, as in the Engsbachtal and Aalbuch furnaces, is inadequate to achieve high enough wind volumes to permit proper smelting conditions in furnaces under 2-3m. in height. Moreover, induced draught furnaces used by modern pre-industrial societies have multiple wind holes, often as many as 100, at the base of the furnace. Such multiple wind-hole furnaces of a free-standing type are known from the Siegerland area, but the single-hole type is much more common.

Much play is made by the earlier German authors, such as Weiershausen, of the importance of the orientation of these furnaces. It was claimed that they were usually sited with their wind holes facing the prevailing wind, thereby augmenting the blowing rate. This seems to be somewhat illusory: prevailing winds, except in very rare regions, tend to blow somewhat erratically, and gusts below gale force are unlikely to have a significant effect on the blowing rate.

Certainly the Minepit Wood furnace was not worked by natural draught. Tuyere holes have been identified opposite to and flanking the main arch of the furnace, and so it is likely that it was blown with bellows on three or even four sides. It is less easy to appreciate how the Engsbachtal and Aalbuch furnaces could have been blown with bellows; the distance from the mouth of the wind hole to the 'nozzle' is about 8cm. in the former and over 1m. in the latter. It is possible that long bellows nozzles might have been used, or it could have been that the mouth of the wind tunnel was luted up with clay and

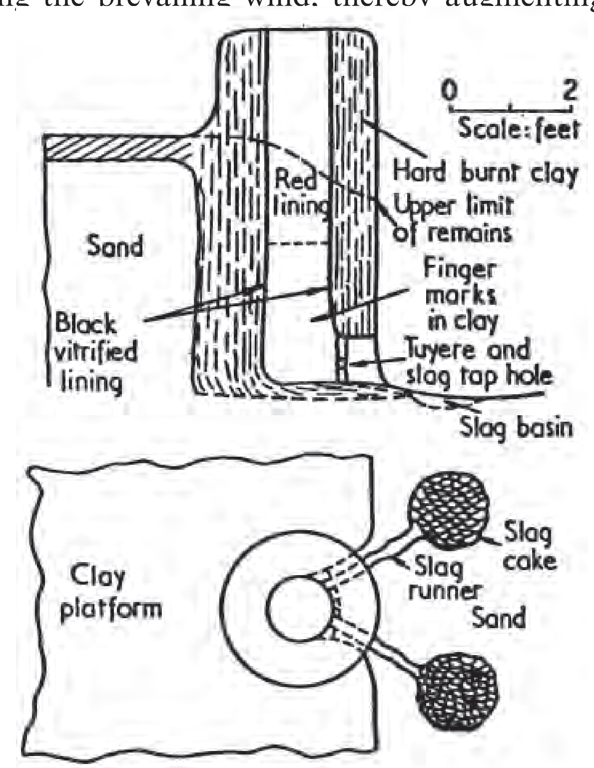


Fig 8: Shaft furnace from Ashwicken, Norfolk (Tylecote, Fig 51).

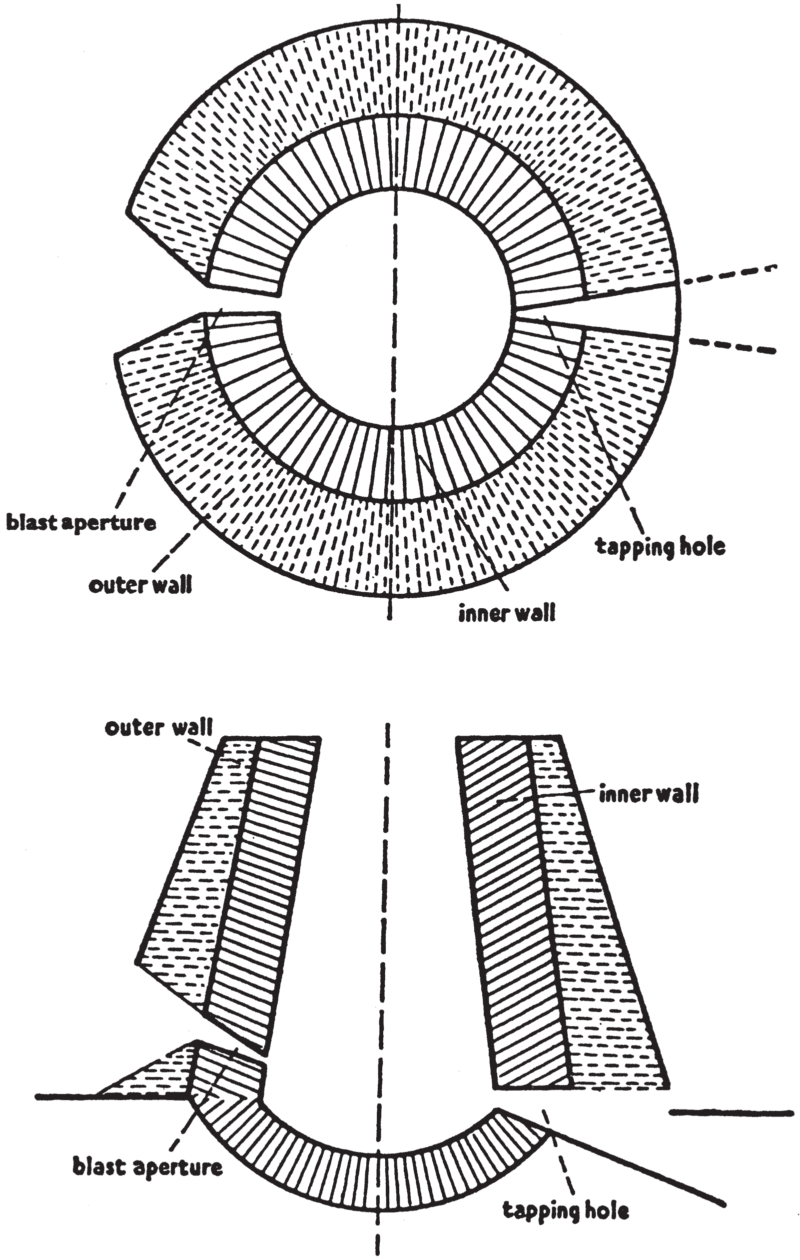


Fig 9: Shaft furnace from Eisenberg, Germany (Coghlan, Fig 10, after Weiershausen).

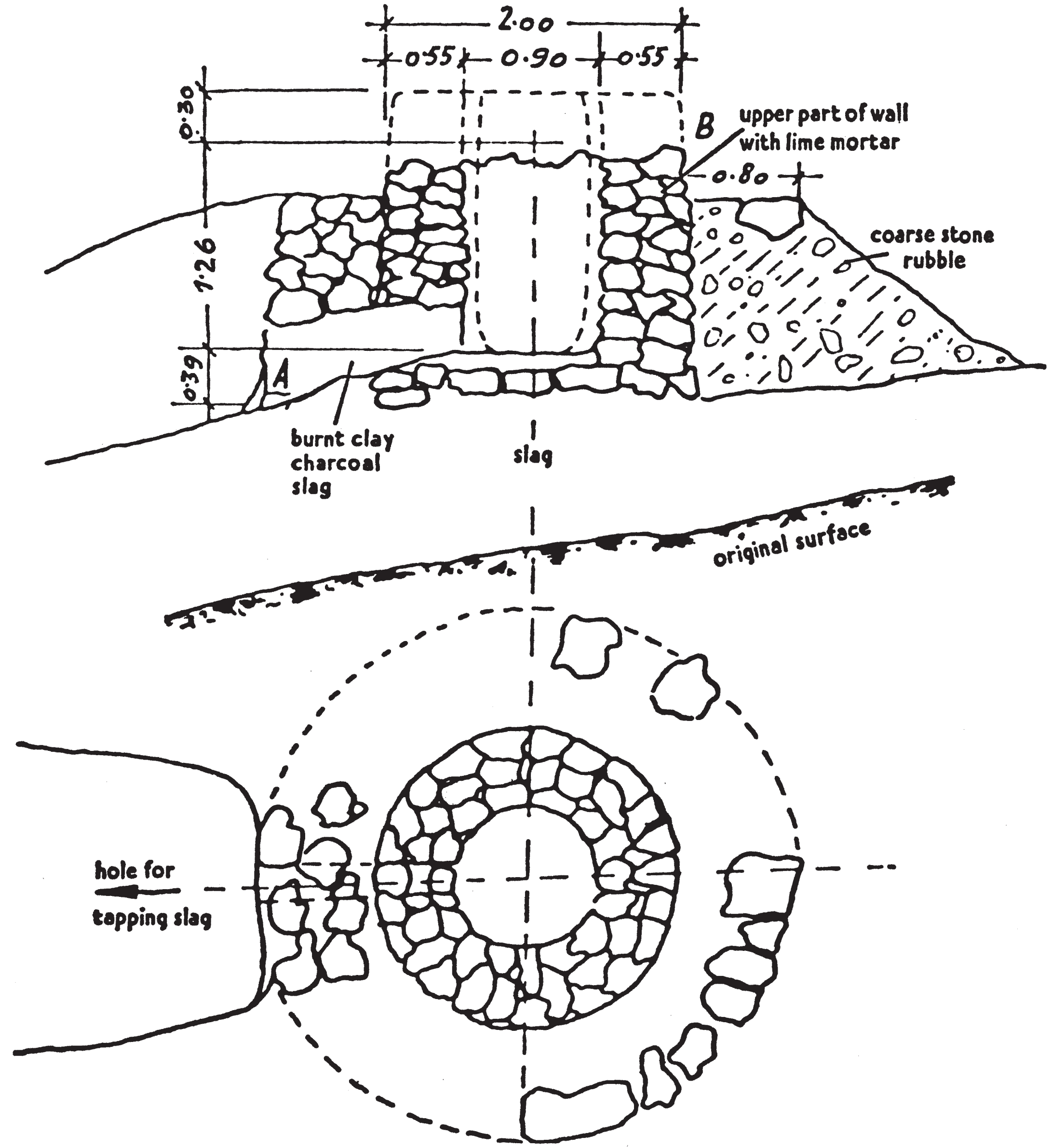


Fig 10: Shaft furnace from Lölling, Germany (Coghlan, Fig 9, after Weiershausen).

several bellows inserted at this point. The indications are, however, that these furnaces did operate with a natural draught.

The length of the wind tunnel raises another point, however. It is assumed, justifiably, that the slag was allowed to run out of these tunnels. Those who have operated replicas of early furnaces know how crucial it is to have easy access to the front of the furnace. The molten slag collects at the bottom of the furnace and quickly solidifies in front of the tuyeres;[14] constant rabbling and ramming with an iron bar is necessary to keep the tuyeres open and prevent the furnace from growing cold. This would be a difficult task to carry out along a metre-long tunnel. One is tempted therefore to question the accuracy of the reconstructions shown in Figs. 5 and 6.

To summarize, the diagnostic features of the domed furnace are that it was built on or above the ground, it had provision for tapping slag, and was blown by either forced or induced draught.

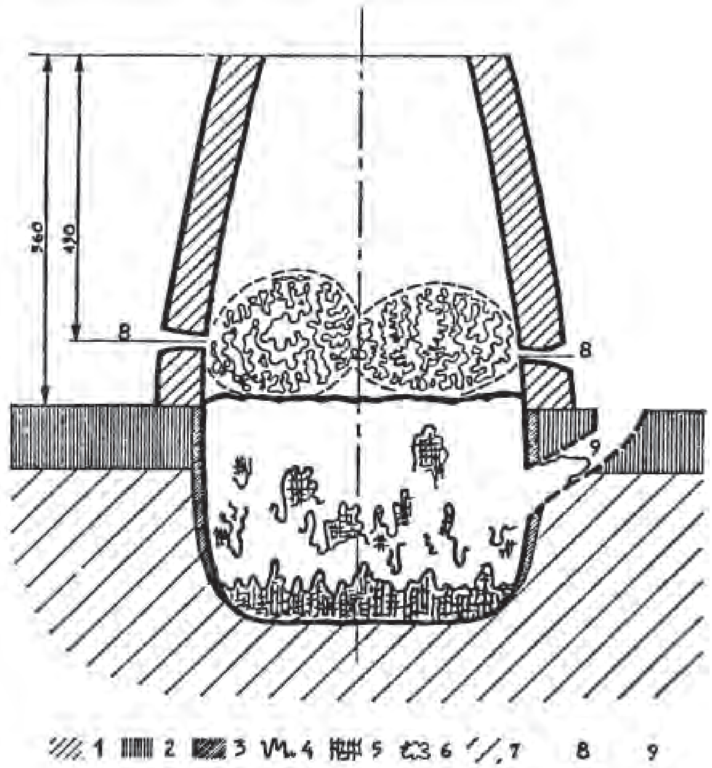


Fig 11: Shaft furnace from Holy Cross Mountains, Poland (from Bielenin in** Liber Josepho Kostrzewski Octogenario a Veneratoribus Dicatus **(1968), pp 263-75)

- ***1 Furnace shaft***
- ***2 Surface layer***
- ***3 Hearth lining***
- ***4 Iron slag***
- ***5 Charcoal***
- ***6 Metallic iron***
- ***7 Subsoil (loess)***
- ***8 Tuyeres***
- ***9 Air duct for pre-heating of hearth and first-stage reduction***

252/253 **(c) The shaft furnace**

The shaft furnace, according to Coghlan, is in most respects identical with the domed furnace, except that it has a cylindrical instead of hemispherical or conical superstructure. It was built above ground, had provision for continuous charging of ore and charcoal, and provision for slag tapping. It could, as in the case of the Ashwicken furnace[15] from the second century A.D. in Britain (Fig. 10), have a single aperture to serve both as a blast entry point and for slag tapping, or, as in the case of the Eisenberg furnace[16] (Fig. 9) from the Pfalz in the Roman period, have both blast aperture and tapping hole. The Ashwicken furnace, like that from Lölling[17] (Fig. 8) or those from Holbeanwood, was built into a bank, whereas the Eisenberg furnace was free-standing.

253/258 The matter of blowing method is much the same as for the domed furnace. Tylecote's work[18] has led him to abandon his original suggestion that the Ashwicken furnace worked on natural draught, and to favour the use of bellows. Coghlan claims natural draught for the Jura furnaces, but states categorically that the Eisenberg and

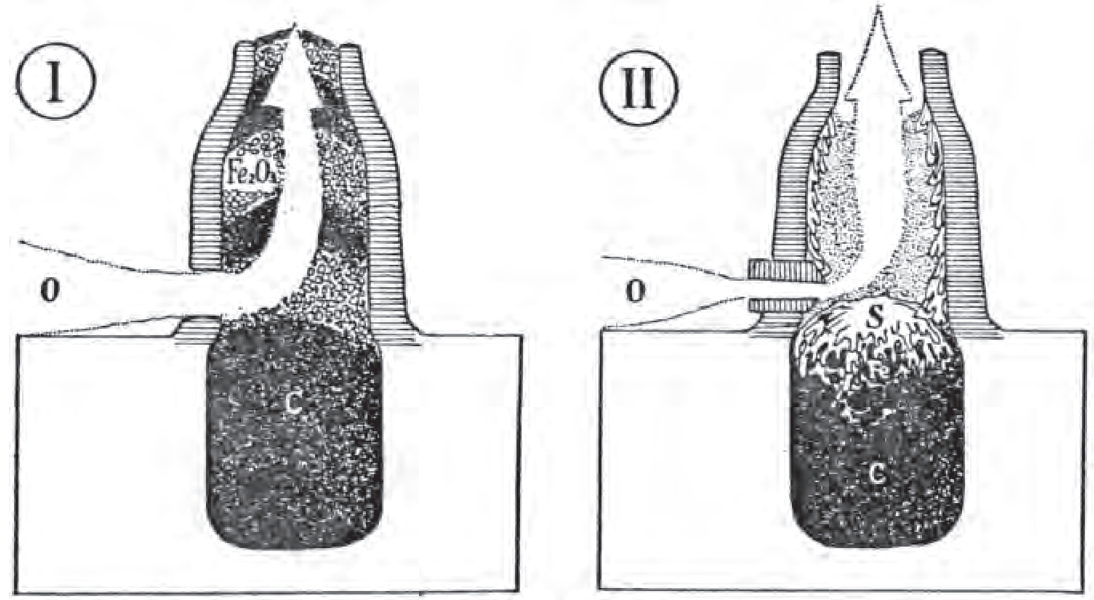


Fig 12: La Tène furnace from Podbořany, Bohemia (Pleiner, Základy Slovanského Železářského Hutnictvi v Českých Zemích, Fig 26).

O = oxygen (air) blast S = slag C = charcoal

Lölling furnaces were bellows-blown. Experiments with a replica of the Holbeanwood furnaces confirmed that bellows blowing was essential. The wind holes in the Lölling and Eisenberg furnaces do not present the difficulties intimated in the discussion on the Engsbachtal and Aalbuch furnaces. Thomsen, working on furnaces from Schleswig-Holstein,[19] however, claims that forced draught was needed only in the initial stages of the process, adequate induced draught thereafter being available owing to the configuration of the shaft (a tall narrow cylinder).

There is, however, another group of furnaces, from Czechoslovakia and Poland, which qualify in form as shaft furnaces, rather than domed furnaces, but which differ in one significant respect from those described above. The example shown in Fig. 11, from the Holy Cross Mountains in southern Poland,[20] is effectively a shaft furnace, since the superstructure is essentially cylindrical, though lower than those from further west. It was, moreover, clearly worked by forced draught. However, the significant difference is that this furnace, like others from Czechoslovakia (Fig. 12),[21] Denmark,[19] and elsewhere, has a considerable part of its working volume underground.

When discovered, it is generally only the underground part of these furnaces which survive. This part of the furnace is always filled with a large cylinder of slag: the so-called *Schlackenklotz*. The method of operation of this type of furnace was identical with that of the conventional shaft furnace, except that the slag was not tapped away in a fluid state, but allowed to collect in the base, in a manner reminiscent of the bowl furnace. Unlike the domed and shaft furnace practice, the iron bloom, which was resting on top of the *Schlackenklotz*, was not removed gingerly with tongs through the wind arch or the top; instead the whole superstructure of the furnace was demolished to remove the bloom, the size of which was not restricted by the aperture available for its removal. With the conventional shaft furnace, the same structure could be reused many times (usually until the front wall gave way at its weakest point, above the wind arch). With the 'eastern type' the structure was demolished, and another furnace constructed alongside: Fig 13 shows a typical Holy Cross Mountains site, with its rows of furnace bases left in position.

We see, therefore, that there were two types of shaft furnace. Both were probably worked on forced draught, but one type provided for the slag to be tapped and the other did not. Continuous charging would have been practised on both. One was a
258/259 semi-permanent structure, but the other was used for a single smelting operation.

Discussion

The similarity of the domed furnace to one type of shaft furnace, and the links between the 'eastern' type of shaft furnace with the bowl furnace, suggest that Coghlan's classification is not entirely satisfactory to describe structures that are excavated at the present time. Moreover, the doubts regarding the use of natural draught make this an uncertain classification criterion.

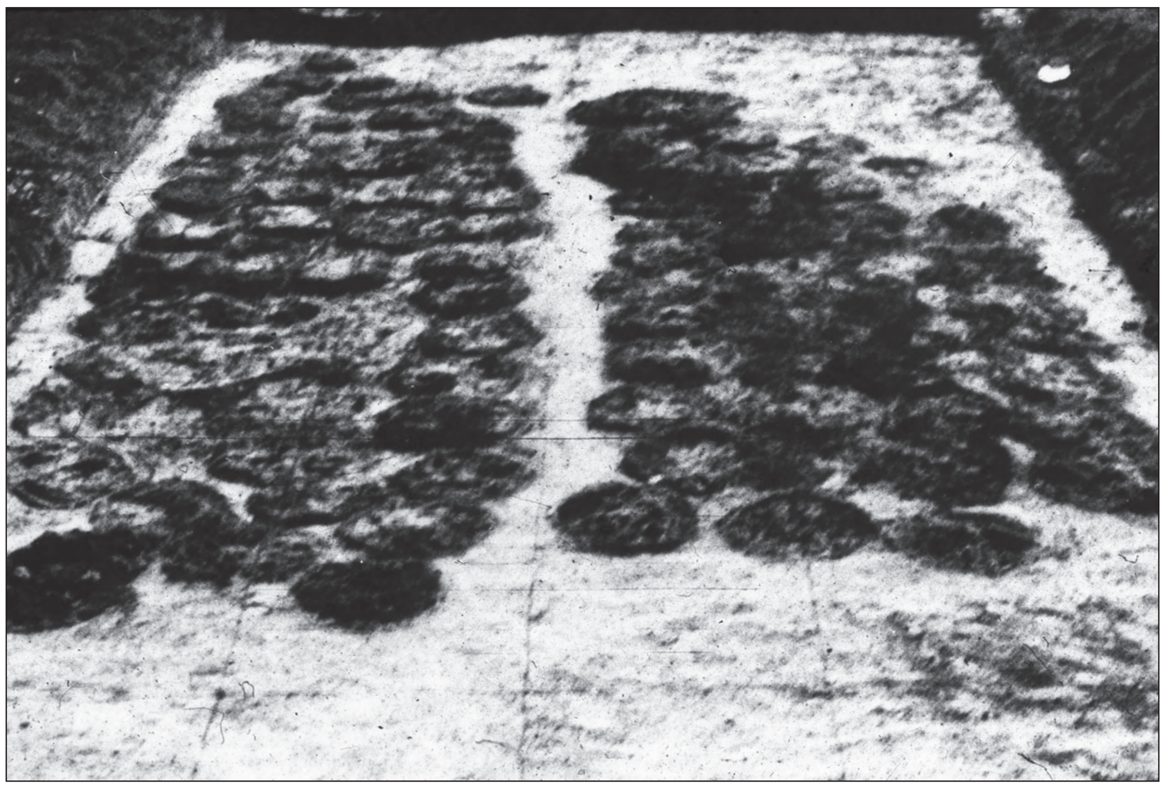


Fig 13: Iron smelting site from Holy Cross Mountains, Poland

The fundamental distinction between the different types of furnace would appear to lie not in their general morphology or in their method of blowing, but in their provision, or otherwise, of means for tapping slag. It is believed that this may represent two major technological currents that existed and developed side by side during the
prehistory of the iron industry, although considerable archaeological research will be 259/260
needed before this can be more than a hypothesis. The work of Pleiner[22] indicates that typological studies of this kind may throw valuable light on processes of technological diffusion in the field of ironmaking.

It is recommended that those working in the field of early ironmaking give serious consideration to the adoption of a classification on the following lines (Fig. 14).

GROUP A. Non-slag-tapping furnaces

Diagnostic features	(a) No provision for tapping of molten slag
	(b) Hearth below surface of surrounding ground
	(c) Blown by forced draught
Sub-group 1	No superstructure ('bowl furnace')
Sub-group 2	Superstructure – cylinder or truncated cone

GROUP B. Slag-tapping furnaces

Diagnostic features	(a) Provision for tapping of molten slag
	(b) Hearth level with surface of surrounding ground
	(c) Superstructure
Sub-group 1. i	Blown with forced draught
	Cylindrical superstructure
Sub-group 1. ii	Blown with forced draught 260/262
	Conical or hemispherical superstructure
Sub-group 2. i	Blown with natural draught
	Cylindrical superstructure
Sub-group 2. ii	Blown with natural draught
	Conical or hemispherical superstructure

It is recognized that the fragmentary nature of many furnace remains will not permit classification beyond the two main groups, but this at least should usually be possible because of the character of tapped iron slag (although slag tapped outside the furnace may sometimes be difficult to distinguish from certain types of slag produced in the Polish-Danish group, where the slag may be considered to have been tapped' into the underlying pit). This basic distinction, however, should be of immense value in the identification of the cultural connections and technological progress of individual communities.

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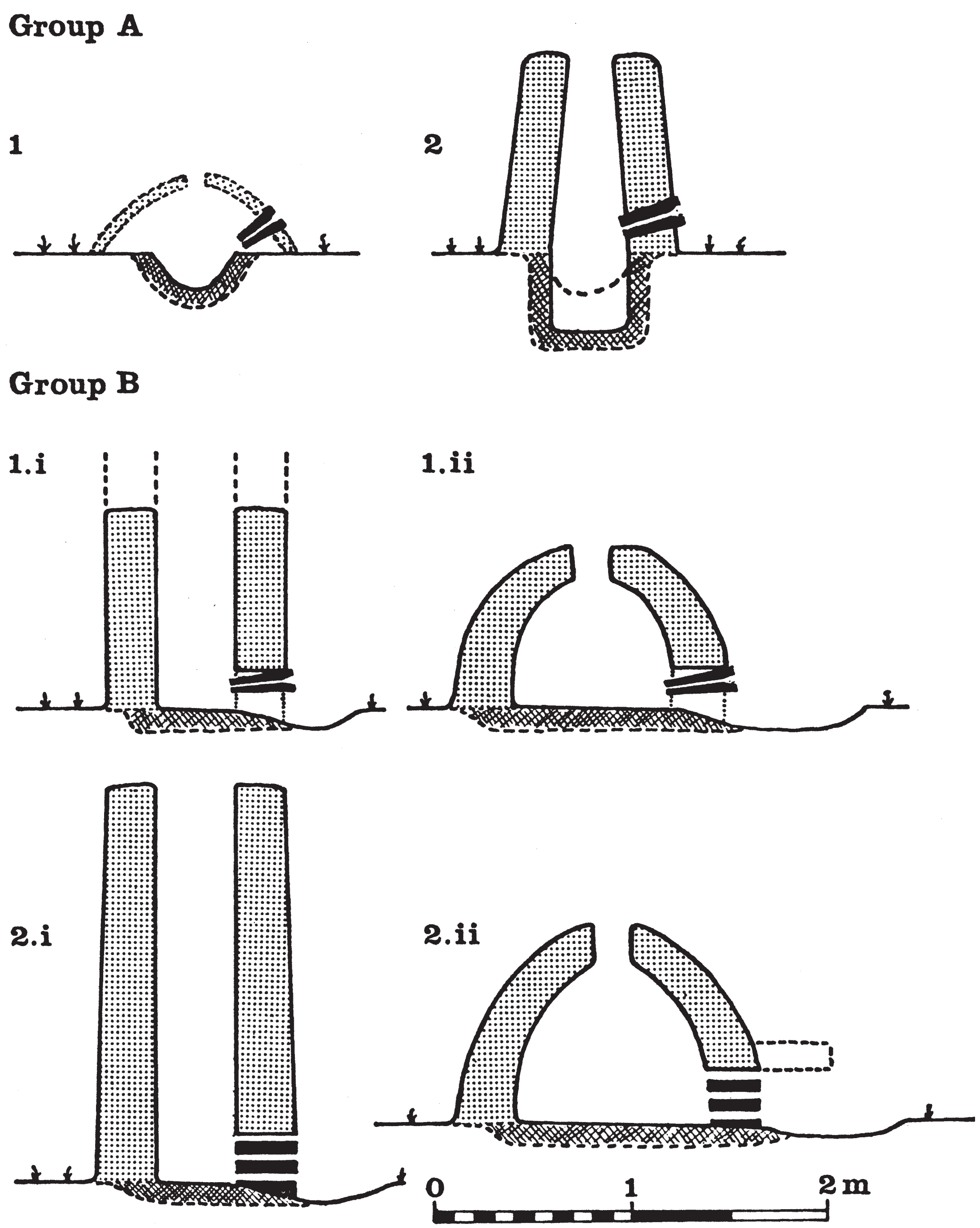

261 262 *Fig 14: Proposed classification of early iron smelting furnaces*

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Summary

The paper begins by surveying the different types of early iron-smelting furnace, based on a tentative classification proposed by Coghlan in 1956. The ambiguities in this classification are indicated, together with examples of furnaces that do not fall easily into one of its three categories.

On the basis of data derived principally from furnaces of the Early Iron Age and Roman periods from northern Europe, the author proposes a new classification into two main groups, differentiated by their provisions or otherwise for the removal of molten slag during the iron-smelting operation. Each of these groups is further subdivided, according to the shape of the furnace superstructure and/or the method of supplying the air blast. 262 263

262/263 The Roman Iron Industry of the Weald and its Connexions with the *Classis Britannica*

by Henry Cleere

Introduction

The first suggestion of a connexion between the *Classis Britannica* and the Roman iron industry of the Weald of Sussex and Kent was made by the late Sir Ian Richmond in his masterly volume of the Pelican History of England.[1] It is typical of the man that a single non-stratified find of a stamped tile at the Bardown site[2] should not have escaped his notice and that he was perspicacious enough to have asserted that 'Direct interest of the provincial government in some at least of the iron workings is … suggested by the occurrence of the official stamped roofing tiles of the *Classis Britannica* … in connexion with slag near Wadhurst (Sussex)'. He was, moreover, directly responsible for initiating the work described in this paper when, during numerous discussions with the author, he postulated that the hoard of over a million iron nails found at the great Agricolan fortress at Inchtuthil[3] were manufactured from iron produced in the Weald. It is only fair to add that this assertion was strongly opposed by the author at the time, and it is his great regret that Sir Ian Richmond did not live to read what amounts in considerable measure to a corroboration of his proposition.

Frere[4] also refers to *Classis Britannica* stamped tiles on Wealden sites, but by the time his monumental work was published in 1967, the number of sites that had yielded such tiles had increased to three (the new sites: Little Farningham Farm and Bodiam). He was, however, more cautious than Richmond; whilst on the one hand he claimed that 'Some of these [iron-smelting] deposits were wholly or partly exploited by the military', he suggested in an earlier passage that 'It is possible … that the sites in the Weald which have yielded stamped tiles of the *Classis Britannica* were concerned with timber for shipbuilding rather than with the production of iron'. The immense heaps of iron slag at Bardown and Beauport Park (Battle) would appear to offer conclusive refutation of the latter statement; iron smelting can by no stretch of the imagination be interpreted as having been a subsidiary operation at these settlements. It is admittedly not improbable that timber was also cut and prepared on these sites for shipbuilding purposes; the trunk wood of oak trees, which would have been most suitable for shipbuilding, was not a satisfactory material for the manufacture of charcoal, the all-important fuel of the iron-smelting furnaces. As yet, however, the
263/264 (admittedly limited) excavations on these two sites have failed to yield any structures that might be readily identified as sawpits, which would indicate the preparation of timber for shipbuilding.

Cunliffe[5] follows Richmond, claiming that 'It may well be that much of the Sussex iron industry was under official control by this time' (i.e. the second century). He summarizes the role of the *Classis Britannica* during this period as '… close naval control exercised over the British Channel coast and extending perhaps to the oversight of certain of the Wealden industries'.

It is, then, the currently accepted view that the Fleet had connexions with the Wealden iron industry, albeit uncertain in extent. The evidence upon which this view is based is only a handful of stamped tiles, from only three sites. The intention of the present paper is to survey the current state of knowledge of the iron industry in the Weald during the Roman period and to attempt to evaluate, by a study of the land and sea communications as well as the distribution of the stamped tiles (of which many more have come to light since the preparation of the most recent of the three works referred to above), such connexions as may be presumed to have existed between all or part of the iron industry in this area and the *Classis Britannica*.

The Wealden Iron Industry

Pre-Roman Working

The pioneer work on the Wealden industry was that of Straker, whose *Wealden Iron*,[6] recently reprinted, is still the only comprehensive survey of the subject (although it is hoped that the Wealden Iron Research Group will be producing a new survey in the course of the next few years). Since 1931, when this great work was published, much research, particularly in the past decade, has been carried out on the technology of early ironmaking processes, and so Straker's comments on this aspect of the subject should be viewed with extreme caution. For example, his assumption that iron could have been smelted in large heaps up to 3 m. in diameter must now be rejected. The standard work of Tylecote[7] has done much to disprove many of the technological fallacies that abound in the work of Straker and other writers of the period, many of which have unfortunately been perpetuated in standard text-books.

Similarly, better knowledge of the coarse pottery types in the south east, and particularly in the Weald, has invalidated some of the dating evidence cited in *Wealden Iron*. For example, the Bardown site, which the present author excavated over ten seasons, is described by Straker, on the basis of pottery identifications made over half a century ago,[8] as having a 'La Tène' horizon separated by two centuries of abandonment from the Roman workings in the and 3rd centuries A.D. This view was effectively disproved in the very first season of excavations, when pottery that fitted the 'La Tène III' ascription was found in the lowest layer of the enormous slag and refuse heap. However, the simultaneous discovery of indisputable late second-century Central 264/265
Gaulish samian in what was conclusively a sealed layer appeared to dispose effectively of the prehistoric phase at Bardown. The coarse pottery of the Weald retains many pre-Roman features well into the second century, as will be demonstrated when the very considerable corpus of pottery from Bardown and Beauport Park is published in due course.

In parenthesis, the author would like to make it clear beyond any doubt that comments such as the above are not intended in any way to belittle the work of Ernest Straker. *Wealden Iron* is a great landmark in that it represents the first detailed study of an early industry of a specific region in depth; only the work of Bielenin and his colleagues in the Holy Cross Mountains of southern Poland, carried out since the end of World War II, can be compared with Straker's achievement so far as the iron industry is concerned. Straker's work was all the more remarkable in that he was not a professional archaeologist or metallurgist and suffered from physical disabilities that must have made his field-work arduous and wearisome.

Straker's datings were reproduced without any attempt to corroborate or analyse them by Schubert in his standard history of the British iron and steel industry,[9] in which he lists over a dozen prehistoric ironmaking sites in the Weald. Indeed, Schubert goes further than Straker. In some of his brief site descriptions Straker refers to the presence of slag 'of an early type', and Schubert interprets comments such as these, which were merely subjective and indicative, as positive evidence of pre-Roman working, something that Straker was too good a scholar to do. Many of the dates given by Schubert should therefore be treated with the utmost circumspection.

A careful study of the available evidence by the present author indicates that only a handful of Wealden sites can be claimed to have a pre-Roman basis. On the basis of the pottery published by Mrs Chown,[10] a probable pre-Roman date can be claimed for Footlands, and the same criteria may apply to Crowhurst Park, but all the other major sites in the important Battle-Sedlescombe complex seem to have been Roman foundations.

Further north, there are indications that ironmaking was carried on at Saxonbury Camp[11] (although it is possible that the slag found resulted from smithing and forging rather than smelting operations). Schubert's claims for pre-Roman working at the sites in the Maresfield area (Crow's Nest, Carr's Wood) seem to be unjustified, being based largely upon dubious slag identifications; and the pre-Roman date for Ridge Hill (East Grinstead) would appear to be attributable to a misinterpretation of the pottery, similar to that at Bardown. There was, however, some exploitation of iron ore based on penetration from the north, similar to that at Saxonbury, as illustrated by the Hascombe Camp (Godalming) site.[12] A recent paper[13] discusses the relationship between some of the later hill-forts on and just below the North Downs and certain
265/266 early ironmaking sites located close to them.

One such site is that at Pippingford Park, which appears to be connected with a first-century Romano-British defended site a short distance away, where excavations are still in progress. This site and that at Minepit Wood have produced pottery of the early 1st century A.D., which may be immediately pre-Conquest, or post-Conquest (a situation paralleled by the earlier finds from Crowhurst Park). It is interesting to note in passing that carbon-14 determinations on charcoal from both sites have given median dates in the fourth century which are completely at variance with the indisputable first-century pottery. A similar discrepancy was produced by charcoal from the late second-century Holbeanwood site. The reason for this apparently regular displacement in the radiocarbon dates has not yet been established; its existence should be borne in mind in interpreting other carbon-14 dates from iron-smelting sites.

It is possible therefore to summarize the pre-Roman ironmaking in the area as being in two areas (and possibly of two types, in terms of organization and economic basis). The first group is that in the Battle-Sedlescombe area, where there seem to have been settlements that were purely industrial in purpose, since no defensive works have been identified. In view of the nature of the terrain, it would seem likely that the products would have been moved away by sea. Margary's[14] ridgeways certainly connect with this area, but they do not seem to relate to the major areas of pre-Roman settlement in the south east. As will be discussed later, it is believed that the network of minor roads in this area is more likely to have been Roman than pre-Roman in origin, although a few may date to the pre-Conquest period.

The second group of sites is associated with defensive works on the northern fringe of the Weald. On these sites ironmaking was performed on only a relatively small scale, and it would appear that the output was destined solely for local domestic consumption and not for trade.

Caesar[15] refers to ironmaking in the maritime region of Britain, and Strabo[16] suggests that iron was exported from the island to Gaul. It is hardly likely that these authorities were referring to the northern group of sites. By contrast, the Battle-Sedlescombe groups fits the bill admirably. As Figure 1 shows, these sites lay very close to the coastline as it was in the 1st centuries B.C. and A.D.; furthermore, there are no large settlements in the area and so the production was unlikely to have been destined for local consumption. One is tempted to read into the well-known Cogidubnus inscription from Chichester[17] a reference to entrepreneurs who had recognized the potential of the iron ore deposits in this area and exploited them, shipping iron ingots both to other parts of the Belgic south-east and across the Channel to Gaul. The existence of a relatively large-scale and geographically concentrated group such as this around the conquest date of A.D. 43 points to a degree of centralized control and organization, and this could well have been under the control of the *collegium fabrorum* of the Chichester inscription. It is clear from military sources that the *faber* was more than a blacksmith, and that he was capable of the reduction of iron from its ores as well as the more conventional working
of the metal into artifacts. 266/267

To summarize, therefore, the indications, drawn from admittedly scanty and for the most part inconclusive evidence, are that ironmaking had begun on the fringes of the Weald before the Roman invasion. In the north there were small settlements, associated with defensive works, serving a small domestic market, and in the Battle-Sedlescombe area there were larger establishments, with no apparent dependence on any neighbouring community, but which may have been operated by an entrepreneurial group from elsewhere on the Channel coast of Britain and connected with its base and its markets by sea routes.

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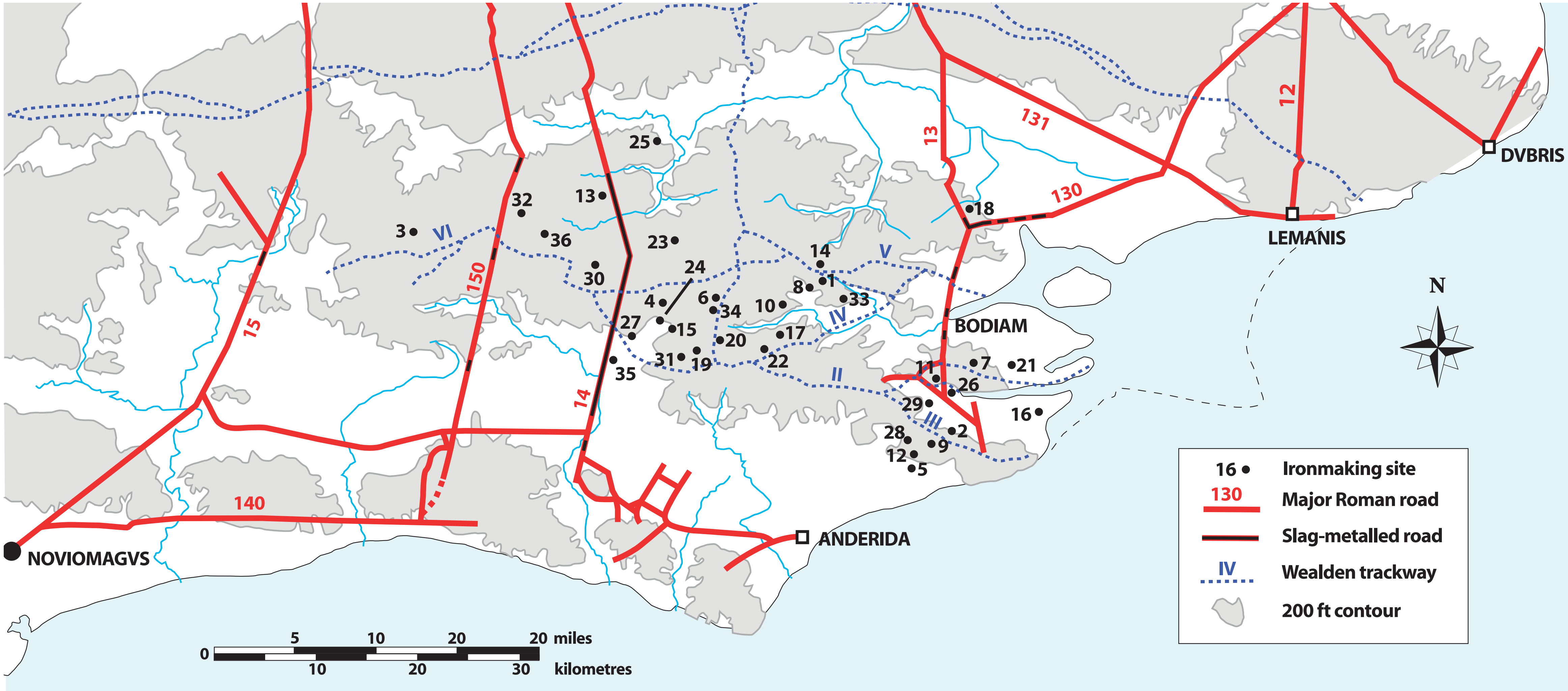

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2. Beauport Park
3. Broadfields
4. Brook House
5. Bynes Farm
6. Castle Hill
7. Chitcombe
8. Coalpit Wood
9. Crowhurst Park
10. Doozes Farm
11. Footlands
12. Forewood
13. Great Cansiron
14. Holbeanwood
15. Howbourne Farm
16. Icklesham
17. Knowle Farm
18. Little Farningham
19. Limney Farm
20. Little Inwoods
21. Ludley Farm
22. Magreed Farm
23. Minepit Wood
24. Morphews
25. Oakenden
26. Oaklands Park
27. Oldlands
28. Pepperingeye
29. Petley Wood
30. Pippingford
31. Pounsley
32. Ridge Hill
33. Shoyswell
34. Streele Farm
35. Strickedridge
36. Walesbeech

Figure 1: Distribution of Roman ironmaking sites in the Weald

271 271
267 267

The Roman Industry

Schubert, following Straker, but with some characteristic looseness of interpretation, lists no fewer than eighteen sites of the Roman period from the Weald.[18] Some of these were only tentatively identified by Straker as Roman, using phrases such as 'Slag of a Roman type was found'. In other cases, the presence of a bloomery was assumed from slag metalling on a Roman road; but, as will be shown below, this does not necessarily imply the existence of an iron-smelting site in the immediate vicinity. In view of the very variable nature of the bloomery process and the fact that different types of slag could be produced by one furnace in successive campaigns – or indeed the same campaign – dating by means of slag type is highly unreliable. This is reinforced by the fact that there was very little technological development in the process from the earliest times until the Middle Ages, so that waste products such as slag show very little variation, at least to the naked eye. Pottery from refuse heaps composed of apparently identical slag has shown these to be separated in time by well over 1,000 years. Work currently in progress[19] offers some hope that chemical and petrographic analytical techniques may one day be developed that will permit approximate dates to be assigned to slags, but so far this work is not conclusive.

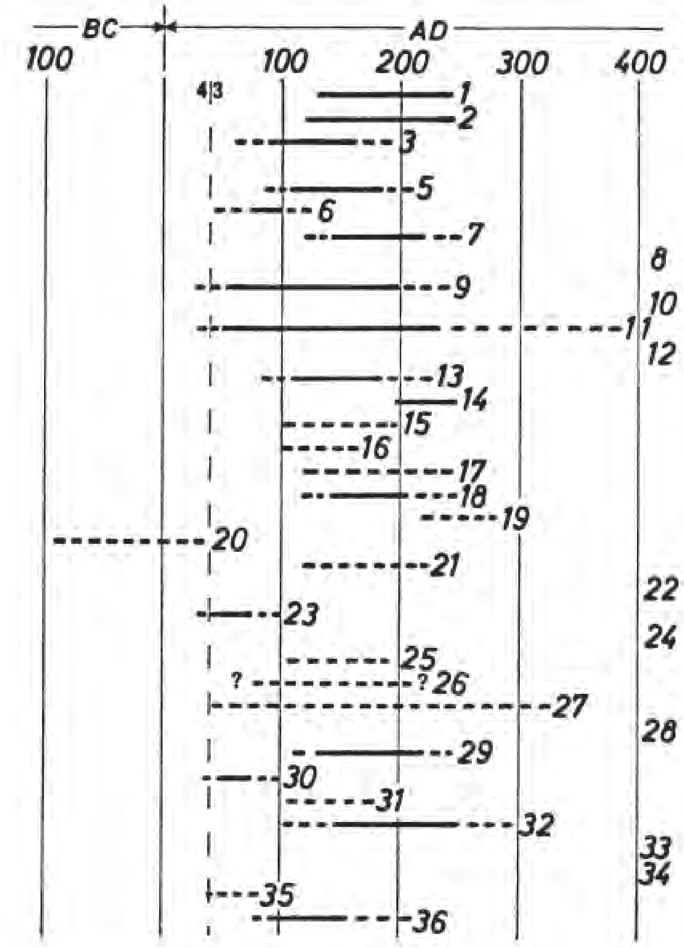
For the purposes of the present paper, therefore, only those sites which have been proved by excavation or by stray finds of pottery and coins to be Roman have been taken into account. These are described summarily in the Appendix. Their locations are shown on the map in Figure 1 and the relative chronological spans are indicated in Figure 2. In addition to these sites, ironmaking activities may be postulated in certain other areas where significant lengths of Roman road metalled with iron slag have been revealed. For example, the site at Little Farningham Farm has so far produced no direct evidence of iron smelting in the usual form of a slag heap, although a number of tuyeres (the clay nozzles used to channel the blast from the bellows into the interior of the furnace) have been found; but the presence less than 100m. away of a section of Roman road with a heavy slag metalling seems to justify the linking of the site with the iron industry. It should be emphasized that this site has been included because excavation has revealed a second-century Roman settlement. Other areas such as that between Benenden and St Michael's, where several miles of road are surfaced with slag, have not been included in the Appendix, although the area itself is discussed in
267 a subsequent section and the slag-metalled portions of the Roman road are indicated
268 on the map (Fig. 1). Until 1971 the long length of Margary's[20] Route 14 between Maresfield and Holtye (where a section of the Roman London-Lewes Road metalled with slag is kept open by the Sussex Archaeological Trust) would have perforce had to be treated in this way. However, field-work by members of the Wealden Iron Research Group brought to light the extensive site at Great Cansiron, which is included in the Appendix.

Geographically, the sites may be said to fall into two main groups: (a) the coastal sites, such as Beauport Park, Chitcombe, Crowhurst Park, Footlands, Icklesham, Oaklands Park etc., and (b) the High Weald sites, such as Bardown, Great Cansiron, Knowle Farm, Minepit Wood, Oldlands, Ridge Hill etc., with an extreme westerly outlier at Broadfields. The former group is concentrated in a relatively small area measuring some 10 by 6 miles, whilst the remainder spread across about thirty miles of the High Weald.

As Figure 2 indicates, by the end of the first century ironmaking was in progress at most of the coastal sites and at the High Weald sites of Broadfields, Oldlands, Ridge Hill, and Walesbeech, and in all probability at Great Cansiron. By the mid-second century, operations had started at a number of other sites in both areas, including Bardown, Chitcombe, Petley Wood, etc.

Fifty years later, at the beginning of the third century, the picture is beginning to change. Operations at the main Bardown settlement had ceased, although the site was still occupied, but the satellite site at Holbeanwood, about a mile away, had started working, and other satellites, such as Coalpit Wood and Shoyswell Wood, were probably also operating at this time. Holbeanwood is the only one of the Bardown satellites to have been excavated; there are several others, all, like Holbeanwood, apparently linked to Bardown by small slag-metalled roads. A similar situation may well have obtained at Crowhurst Park, where the main settlement seems to be ringed by subsidiary sites such as Bynes Farm, Forewood, and Pepperingeye, whilst there are also indications that Oaklands Park and Beauport Park may also have had satellite working sites (see Appendix). Most of the other early second-century sites seem to have continued in operation.

The next important stage comes in the mid-third century. Operations ceased for certain at the Bardown-Holbeanwood complex and Beauport Park, and there are strong indications that many other sites stopped around the same time – Chitcombe, the Crowhurst Park complex, Knowle Farm, Oaklands Park, Ridge Hill, and Walesbeech, for example, have produced no late third or fourth-century material. By the end of the third century iron appears to have been manufactured only at Footlands in the east and Oldlands and Broadfields in the west. The great flowering of the Roman iron industry in the Weald, which left such dramatic remains as the enormous slag and refuse tips at Bardown, Beauport Park, Chitcombe, Oaklands Park, and elsewhere, seems to have



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22. Magreed Farm
23. Minepit Wood
24. Morphews
25. Oakenden
26. Oaklands Park
27. Oldlands
28. Pepperingeye
29. Petley Wood
30. Pippingford
31. Pounsley
32. Ridge Hill
33. Shoyswell
34. Streele Farm
35. Strickedridge
36. Walesbeech

Fig 2: Approximate time spans of Roman ironmaking sites in the Weald

been between the latter part of the first century and the middle of the third century: a period of less than 200 years.

What were the reasons for the decline of this industry, which must have been one of the largest concentrations in the Roman Empire? One explanation must certainly
268 have been that of over-exploitation: The excellent siderite ore of the Wadhurst Clay
269 occurs in fairly small deposits which are quickly exhausted; the multitude of pits and ponds around major sites such as Bardown are evidence of the tireless search for ore. However, the geology of the Weald is complex, with much faulting and discontinuity, and it is likely that the more easily won deposits (identified by Cattell[21] as lying at the junction of the Wadhurst Clay and the Ashdown Sand) eventually ran out.

So far as fuel was concerned, this was a prodigal industry in terms of deforestation; at least two parts of charcoal would be needed for every part of metal produced. The author has estimated that five of the coastal sites (Beauport Park, Chitcombe, Crowhurst Park, Footlands, and Oaklands Park) must have produced between them about 1,000 tons of iron per year during the century between A.D. 7 and 175. This represents 2,000 tons of charcoal, which in turn is only a part of the weight of green wood. It should be remembered also that for the most part only branch-wood would have been used from the great hardwoods – oak, ash, and beech – that made up the mature forest cover of the Weald, and so an idea of the scale of deforestation can be obtained.

It is certainly for these reasons that ironmaking operations ceased at the central Bardown settlement around A.D. 200, after half a century of activity. The amount of labour expended in bringing supplies of ore and charcoal to the central working site from increasingly far distant ore-pits and stands of timber must have been seen to be uneconomic, and so small working sites were set up on the perimeter of the cleared area.

This aspect of deforestation and exhaustion of easily won iron ore was certainly an important factor in the decline of the Wealden iron industry in the third century. However, it is shown later in the paper that there may have been other contributory factors which led to the centre of the ironmaking industry of Roman Britain shifting outside the Weald, most likely to the Forest of Dean.

Classification of the Roman Ironmaking Sites

In the preceding section, the known Roman ironmaking sites were classified geographically into a coastal group and a High Weald group. Whilst this may appear ostensibly to be a tidy and logical classification, it takes account only of the basic topography of the area. The map in Figure 1 shows that the pattern of Roman penetration into and through the great forest of the Weald is not identical as between the western and eastern sections of the region. This is primarily reflected by the road system. It is immediately apparent that all the Roman sites lie within two miles of a known Roman road, either a major arterial road such as the London-Brighton and London-Lewes highways or one of the minor roads and ridgeways. For example, the Ridge Hill/Walesbeech group lie close to the London-Brighton road (Margary's Route no. 150); Broadfields is near Margary's track no. V1[22] and equidistant from Stane Street (Route no. 15) and the London-Brighton Road (no. 150); Oldlands and Great Cansiron lie on the London-Lewes road (no. 14); Bardown and Holbeanwood straddle Margary's track no. V (the Mark Cross-Sandhurst ridgeway);[23] Magreed Farm and Knowle Farm
are on his track no. IV (the Heathfield-Hurst Green ridgeway);[24] and the coastal group 269
lie near or on the complex of minor roads in the south-east corner of Sussex, linked to 270
Watling Street at Rochester by Route no. 13. This suggests an alternative classification of the sites, based on their relationship to their communications by both land and sea and on their possible markets.

This alternative classification, which is believed to be more representative of the organization of the industry, distinguishes two groups of sites: the western group, orientated on the major highways running north-south, and the eastern group, with a primary outlet by sea from the estuaries of the small rivers Rother and Brede.

The Western Group

In considering this group, it is relevant to pause briefly to discuss the mode of occurrence of iron-bearing strata in the Wealden series and the likely circumstances of its discovery. Iron ore of various types occurs in a number of the strata making up the Wealden series, but the best material is the sideritic ore found at the base of the Wadhurst Clay. This is a fine-grained siltstone, containing 55-60 per cent Fe as carbonate. It occurs as nodules, usually enclosed in a capsule of limonite, whence its common name of 'boxstone' derives. This ore was very easily reducible, in that exceptional conditions of temperature or atmosphere were not required for the metal to be smelted, and so it was greatly prized by the early ironmakers. All the known Roman sites appear to have used this ore, although there is some evidence that at the early site of Minepit Wood the inferior tabular form of the ore was also utilized.

This ore does not outcrop very commonly; when the author was seeking a supply of it for smelting experiments using a reconstruction of the type of furnace found at Holbeanwood,[25] the Institute of Geological Sciences was able to point to only one modern source. The most likely places for this ore to outcrop would have been in the valleys of the small streams which cut through the relatively soft clays of the Weald to form very steep-sided watercourses (known locally as 'gills'). It is virtually certain that the Bardown site was established where it was because of an exposure of ore in the bed of the little river Limden, which follows a fault between the Wadhurst Clay and the Ashdown Sand.[26] This lends further corroboration of Cattell's hypothesis that most early sites were located at the junction between these two strata. It is natural that such locations should very often be delineated by a small stream, and this fact led some early antiquaries into the erroneous belief that the Romans were using water power for blowing furnaces or operating mechanical hammers.

There was, however, another way in which deposits of this ore may have been

revealed. Margary's descriptions of the sections that he and others cut through many of the roads running through the Weald confirm that these were fine examples of Roman military engineering. When the surfaces and flanking ditches were being prepared, it is by no means unlikely that a shallowly concealed ore body might have been discovered. This would reveal the mineral potentialities of the area, which could
270/272 lead to prospecting in the vicinity of the road. It is therefore by no means unreasonable to assume that sites such as Broadfields, Great Cansiron, Oldlands, and Ridge Hill may have been set up to exploit ore bodies discovered during road-building operations. This is particularly likely in the case of Great Cansiron, where there is no watercourse of any consequence in the immediate vicinity, but which lies less than a mile from the London-Lewes Highway.

The connexion between these sites and the Roman highways is illustrated in another way. Figure 1 shows those sections of the Roman roads that, according to Margary,[27] were metalled with iron slag. Only one patch of slag metalling is recorded on Route no. 15, at Alfoldean. The nearest site known is that at Broadfields, but it is conceivable that there may be another as yet undiscovered site nearer than this, since its connexions seem to be eastwards to Route no. 150 rather than westwards. Route no. 150 shows patches south of Ardingly, around Selsfield Common (in the proximity of Ridge Hill), and to the north of Felbridge. This would suggest that it might be profitable to search for additional sites near Ardingly and Felbridge. It is Route no. 14 that produces the most abundant evidence of the use of slag for road metalling. Wherever sections were cut between Cowden and Isfield, a thick surface of slag was found, and there is another patch even further south, beyond Barcombe Mills. There are, of course, two major sites on this alignment; Great Cansiron at its northern end, a site which covers at least four acres, and the large site at Oldlands, Maresfield. It is conceivable that slag from these two sites might have been sufficient to provide the metalling for the whole stretch down to Barcombe Mills, but this would represent a gigantic iron production, and it seems not unreasonable to suggest that other sites may exist, probably in the Uckfield-Isfield area. There are possible candidates among the sites recorded by Straker, but so far no Roman material has been found on any of them.

Of this group of sites, only that at Ridge Hill had been excavated until recently (and that by Straker himself in 1927[28]). Unfortunately, this was a very limited excavation, through the slag heap (which Straker interpreted as being a smelting hearth, although the undeniable structure found within the heap was almost certainly used for ore roasting). The pottery found was dated to the first to third centuries A.D. There is no record of any building debris having been found, although this is hardly surprising, having regard to the area of the site that was being sampled. The Broadfields site has recently been excavated, as a rescue dig, by the Crawley Archaeological Group under the leadership of John Gibson-Hill. A large group of furnaces have been discovered, together with pottery from the first, second, and fourth centuries. Unfortunately the evidence that has been forthcoming has been somewhat patchy, owing to the exigencies of a rescue operation; little is known about the settlement pattern or the communications of this, the most westerly site yet confirmed as Roman.

What is of great interest in the Ridge Hill report, however, is Straker's suggestion that this, the farthest north of the Roman sites that he had found, probably had its market outlet in London. This comment probably provides the key to this group of sites. Routes nos. 15 and 150 connected the prosperous and densely populated agricultural areas of the South Downs, with their fine villas and centuriation, to the mercantile centre of the province; they were roads along which goods of great value 272/273
would have passed. Both ends of the roads would be potential markets for iron in large quantities, principally for tools and constructional materials, of the type well illustrated by the assemblage from the Brading (Isle of Wight) villa.[29] During the first and second centuries, and well into the third, there were hardly any military establishments in the south and only the Cripplegate fort in London; and so it can be safely assumed that this was essentially a civilian operation. It is not inconceivable that the large works, such as Great Cansiron and Oldlands, with their relatively long periods of operation, were set up by entrepreneurs, either individuals or corporate groups similar to the *collegium fabrorum* of Chichester.

Mineral rights in the Imperial provinces were, of course, vested in the *imperium*, but the general pattern in the early Empire appears to have been for iron mining and smelting rights to be licensed to private enterprise; inscriptions from Lugdunum[30] refer to *socii ferrariarum*, who were probably exploiting the iron ores of the Jura or the Côte d'Or. Limited companies or guilds of this type could have ensured a steady revenue from relatively modest ironmaking activities along the main highways, supplying markets at their two ends. There is a strong presumption, therefore, that the operations of this western group of sites were in the hands of civilians and based on land transport of their products. Serving as they did markets in the most settled part of the province, they were not exposed to military or economic pressures, and probably continued to operate well into the fourth century.

The Eastern Group

As described earlier, the eastern group of sites can be sub-divided, both chronologically and geographically. The earliest sites are those in the Battle-Sedlescombe area: Beauport Park, Chitcombe, Crowhurst Park, Footlands, and Oaklands Park; Footlands and Crowhurst Park may well have been in existence at the time of the conquest in A.D. 43. The later sites, which seem to have started up in the first half of the second century, Bardown, Knowle Farm, Little Farningham Farm, Magreed Farm, lie further north, in the High Weald. There appears to have been a northward shift some time between A.D. 120 and 140, and at the same time satellite sites, such as Bynes Farm, Forewood, and Pepperingeye, may have been set up around Crowhurst Park.

The iron of southern Britain was evidently a source of interest to the Romans, as evidenced by the comments of Caesar and Strabo. The major iron-producing region of the western part of the Empire was undoubtedly Noricum, but this lay far from the English Channel. Deposits in the Lorraine, the Côte d'Or, and the Mosel valley were

certainly being exploited, but the (admittedly scanty) archaeological evidence does not suggest that production in these regions was on a large scale. It would seem reasonable for the military to secure a major source of this important type of material fairly promptly after the conquest of Britain began, in order to supply its field armies; and such evidence as there is implies that a number of the early sites in the eastern group began producing on a very large scale in the mid-first century. There is no evidence as to who was responsible for the operation of these works. One can only conjecture that the
273/274 apparent increase in the degree of organization bespeaks a government-administered undertaking rather than a native industry, there being little evidence that any of the pre-Roman communities in Britain was capable of such a large-scale conception.

What is certain is that this was essentially a sea-based operation, at least at the beginning. Margary claims a relatively early date for his Route no. 13, though not so early as for the major arterial Routes nos. 14 and 150. He does, however, imply that Routes nos. 130 and 131 are later, largely because of the imperfection of their alignments. He contrasts these two roads with Route no. 13, which he considers to be better aligned; the distinction is effectively one of degree. Route no. 13 compares very unfavourably with the remorselessly straight alignments of Routes nos. 14, 150, and 15. One should not, therefore, see these roads as the primary outlets for the products of the eastern group sites, at least in their earlier phase.

The important roads for this early period are those which appear to wander somewhat purposelessly around the Hastings-Battle-Sedlescombe-Staplecross-Udimore area. If these are studied carefully, it will be seen that they link the five early sites quite efficiently. This was pointed out by Margary in a masterly paper published in 1940, entitled 'Roman communications between Kent and the East Sussex ironworks'.[31] Margary proposed three stages of development in this area. In the first, products from the works were shipped by sea from the south coast in the Hastings area and the Brede estuary. Later, the ironmaking activity moved further inland, local roadways and ridgeways being built to serve the new settlements. These led to ports on the Brede and Rother estuaries for shipment out to sea. Finally, in the third stage road communications were established with East Kent and with London via Rochester.

During the first stage, which Margary suggests lasted from the conquest to AD. 140-150, material could have been moved from Beauport Park along Track III through Ore to a possible harbour near Fairlight. This is an attractive proposition in view of Peacock's recent identification of the Fairlight Clays as the source of CL BR stamped tiles found on Wealden Sites.[32] However, as yet no Roman settlement has been found in this area, and Fairlight would in fact not have been a very secure haven. One is tempted therefore to conceive of iron being moved north-east to the more sheltered Brede estuary near Sedlescombe. The Oaklands Park site lies on the edge of Sedlescombe, and foundation digging in the Pestalozzi Village located there has revealed a slag-metalled road surface of Roman date.[33] Footlands is only a short distance from Sedlescombe and is linked with it by a well proved Roman road. Chitcombe is situated to the north of the Brede estuary, but it is connected by road to Cripps Corner, only a couple of miles from Sedlescombe. The nodal point of all these communications would therefore appear to be the head of the Brede estuary, and it would seem to be justifiable to postulate a port installation somewhere in that area.

In Margary's second period, which from evidence at Bardown and Little Farningham Farm seems to have begun around A.D. 140, or perhaps a decade before, there was a drive into the High Weald. Interestingly, the focal point of the new road system also appears to have shifted north. The Bardown-Holbeanwood complex is served by a road running directly along the Limden valley to join Track IV near Hurst Green; it appears 274/275
to disregard Track V (the Mark Cross-Sandhurst ridgeway, claimed as pre-Roman by Margary), which is crossed by the track joining Bardown and Holbeanwood. The contour road to Hurst Green is clearly marked and has been observed from the air by the author.

The Magreed Farm and Knowle Farm sites lie along Track IV, which joins Route no. 13 at Sandhurst. Little Farningham Farm is just to the east of Route no. 13 itself, about 5 miles north of Sandhurst. From here, Route no. 13 continues southwards to cross what would have at that time been the mouth of the Rother estuary at Bodiam.

It is suggested that Bodiam superseded the hypothetical Brede estuary port some time in the mid-second century. The site lying on the south bank of the river excavated some years ago[34] showed occupation from the first century, but its main occupation levels certainly date from the second century and go through to the early third century. Until the Brede estuary port can be located and excavated so as to give more precise dating evidence for the first stage, it is not permissible to assume that it was replaced by Bodiam; it is quite conceivable that both ports continued in operation. However, it will be seen from Figure 1 that the Rother estuary port was located at a point virtually equidistant from all the main centres of iron production. It was, moreover, connected by road with both the Sandhurst road junction and that in the neighbourhood of Cripps Corner. It is well known that silting has been proceeding steadily on this part of the coast for many centuries, as evidenced by the present location of the former Cinque Ports of Rye and New Romney, for example, and so it is quite conceivable that this was the process that may have led to the transfer of the main port from the Brede estuary to that of the Rother.

One further point concerns the roads in this area. First, the alignments of Route no. 13 from Hemsted and Benenden down to Bodiam fully bear out Margary's strictures about their non-military quality. They resemble in their course much more the ridgeways travelling east-west than the main north-south highways in the western Weald, and so it is tempting to consider that this section of the road may have been in existence before the northward extension via Staplehurst and Amber Green to Rochester was built; in other words, the southern part of Route no. 13 was built as part of the communications system of the sea-based iron industry.

Attention should also be drawn to the western part of Route no. 130. Between the Hemsted junction and St Michael's it is heavily metalled with iron slag for most of its course. There are no confirmed Roman ironmaking sites in this area, but it seems

unlikely that slag would have been brought from the known sites around Battle or the High Weald group solely for road metalling purposes. It may be postulated, therefore, that one or more iron-smelting sites await discovery in this area. It is also worthy of mention that there is a short branch road running down from near Parkgate to the estuary of Roman times near Rolvenden Station and north of the Isle of Oxney. This, too, could have been the site of a small port, serving a group of ironworks as yet
275/276 undiscovered.

Margary's third stage, which is not easy to date accurately but which may have begun in the early third century, involves the construction of the two major roads, Route no. 13 to Rochester and Route no. 130 to Canterbury. These roads must have been built before the industry in this part of the Weald had virtually ceased in the mid-third century, otherwise they would have served no apparent purpose, there being no settlements other than ironworks in the region. The excavations at Bodiam show a marked decline at the beginning of the third century, and so the date for the construction of Route no. 13 from Sissinghurst northwards and Route no. 130 from St Michael's eastwards may be set some time in the second or third decades of the third century.

Why was it necessary for these roads to be built? There are two possible reasons, which are not necessarily mutually exclusive. First, it is likely that, as has been suggested above, the estuaries were silting up rapidly, and that navigation across what is now Romney Marsh was becoming increasingly hazardous, so that it became desirable to switch from seaborne to landborne transportation. Secondly, it is possible that a change in ownership led to the need to open up new markets. By about A.D. 250 most of the major sites were no longer functioning; however, Footlands continued into the fourth century and could clearly have benefited from these new roads.

Another possible explanation that might be considered concerns the relative vulnerability of the sea lanes to attack by pirates and raiders, especially from the beginning of the third century onwards. Road transport would doubtless have been somewhat safer and would have prevented heavy losses of a valuable raw material, with obvious military potential. However, the whole subject of the situation in the Channel in the years preceding the establishment of the Saxon shore forts is one in which reliable data are conspicuously missing, and so this can only be offered very tentatively to explain the construction of Routes nos. 13 and 130.

One final point about the ironmaking sites of the eastern group that needs some emphasis is their size. The slag heap at Beauport Park was largely quarried away for road metalling in the nineteenth century, and Straker reproduces a splendid steel engraving showing this activity in process. It is possible, by measuring the present extent of the slag strew and comparing it with the engraving to estimate that it must have contained nearly 100,000 tons of material before it was used as a quarry. This is a very large amount of slag, representing as it does some 50,000-60,000 tons of iron produced, and that in a period of operation that cannot have exceeded 160-170 years. Similar remnants of great slag heaps can be seen in Oaklands Park. At Bardown, the slag heap was untouched until excavations began in 1960. Taking into account the volume of the heap and the amount of slag metalling on the roads in the immediate area of the settlement, one can derive a minimum quantity of 8,000 tons of iron produced in little over sixty years.

The individual annual production of these sites varied between 100 and 400 tons; this is nugatory in terms of modern blast-furnace outputs, but it must be recalled that this iron was produced in furnaces of 30-50 cm. internal diameter, which would yield, say, 10 kg. of iron after 7 or 8 hours' operation. It is against this background that the scale of operations of the iron industry in this area must be viewed – and it is at this point that the *Classis Britannica* enters the picture. 276/278

The *Classis Britannica*

The existence of the *Classis Britannica* is attested by a number of inscriptions, but it is in many ways a shadowy force, at least up to the time of the establishment of the Saxon Shore defences in the late third century. The scanty information about its role and organization has been marshalled and commented upon by at least three authors in the past forty years: Atkinson,[35] Starr[36] and, most recently, Cunliffe.[37] However, their comments have in the main, owing to the paucity of the evidence, been of necessity confined to the role of the Fleet in the Conquest period of the first century and in the later Saxon Shore period.

The general organization of the Roman Imperial naval units has been discussed in depth by Starr[36] and by Webster.[38] The two praetorian fleets based at Ravenna and Misenum were the premier formations, and command of these two forces was a prestige appointment. In addition, however, there were a number of provincial flotillas – the *Classes Moesica*, *Pannonica*, *Germanica* etc., and it was to this latter group that the *Classis Britannica* belonged. The command of these fleets was a much lower appointment, and their commanders ranked far below legionary legates, for example.

At the outset, it should be made clear that any analogy that might be drawn or inferred between the Roman fleets and the navies of today is a false one. These were not primarily or solely fighting formations; naval warfare as such hardly existed after the 1st century A.D. until the depredations of Channel pirates began in the third century. The Roman provincial fleets acted as adjuncts to the military and civil powers (in so far as these can be clearly differentiated, at least in Imperial provinces) in what would be known in modern military jargon as a 'support role'. There were emergencies, such as that of A.D. 210, when a number of provincial fleets were brought together to assist in a military emergency, but on the whole the statement by Frere holds good:

> The *Classis Britannica* was from time to time used in offensive warfare, such as the Claudian invasion itself, Vespasian's campaign in the south-west, that of Frontinus in Wales, and those of Agricola in the north; but its main and more enduring functions were those of transport and supply … [39]

The sailors certainly received military training; indeed, scratch units raised from the fleets were rewarded for their valour and loyalty in the Civil Wars of A.D. 68-69 by being formally embodied as Legg. I and II Adiutrix. However, the normal fighting role of the fleets was probably that of policing duties, along the sea and river frontiers. The units themselves were small and would have been capable of dealing with little more than minor frontier incursions.

By far the most important function of the provincial fleets was that of transporting and supplying units of the land forces. The role of the *Classis Britannica* in the invasion of A.D. 43 is well enough documented;[40] it supplied and manned the transports that 278/279 brought the Army to Britain. As the legions fanned out from their bridgehead in the south east, the fort at Richborough served as the base-depot for stores for the operation. Before the main military roads, such as Watling Street, were constructed, ships of the *Classis Britannica* would have brought stores and reinforcements by water to the legions in Essex and Wessex. Although the legions were well enough equipped to live off the land if necessary, secure lines of communication across the Channel would have permitted the importation of supplies from settled Gaul, using the fleet's base at Bononia/Gesoriacum (Boulogne).

There was little question of sea-borne opposition to the invasion and conquest of Britain. However, the lines of communications of the legions must have become very stretched; road building could hardly have kept pace with the rapid advance of the legions to the north, the north-west, and the west. In any case, the amount of material that could have been moved by land, using pack animals or ox-drawn carts, would surely have been much less than could have been transported by the ships of the fleet. Certainly it is known that the *Classis Britannica* played an important role in the supplying of the Army during the Agricolan invasion of northern Britain.[41]

The fact that Britain is an island makes the use of sea-borne supply routes obvious and effective. However, much of the *limes* in the western provinces lay along two great rivers, the Rhine and the Danube. Even at the present time, with road and rail transport highly developed, an immense amount of material is still moved along these rivers by boat and barge. It is hardly fanciful therefore to envisage that the garrisons of the chains of forts and fortresses that lay along these rivers were supplied by formations such as the *Classes Germanica*, *Moesica* and *Pannonica*. Their vessels would certainly have carried fighting troops as well, but probably only for defensive purposes and to deal with minor troubles; such marines would have been able to fight holding operations until legionary or auxiliary formations from the garrisons could take over. In the Mediterranean, equally, the provincial fleets played what was essentially a supply role. The Alexandrine fleet, for example, became almost wholly converted to an Imperial corn supply organization, escorting the regular grain convoys from Alexandria to Ostia. The *Classis Syriaca*, based on Seleuceia, played a similar role vis-à-vis the merchant fleets from the east to Rome.

It is against this background that the relationship between the *Classis Britannica* and the iron industry of the Weald must be viewed. Brodribb[42] has catalogued all the finds of stamped tiles of the fleet known up to the end of 1968; whilst the number of individual tiles known has more than trebled since that time, largely owing to the 1,000 tiles found at Brodribb and the present author's excavations at Beauport Park,[43] no new find sites have been recorded. To quote Cunliffe,[44] 'the presence of stamped tiles in quantity is likely to reflect naval activity'. The idea of tiles being manufactured by contractors for the fleet and stamped with the CL BR emblem is possible, but it cannot be paralleled elsewhere. One is obliged therefore to assume a direct connexion between the fleet and the sites that have so far produced specimens of these tiles. This 279/280 view is perhaps strengthened by Peacock's recent work (fn. 33, p. 182) using techniques of petrological analysis to study the origins of CL BR stamped tiles. He has identified two types of clay in the fabric of the tiles that he has examined, one in the environs of Boulogne and the other on the Fairlight Clay of the Weald. There is a strong presumption that all the tiles found on the sites in the Weald were manufactured at a single site, in the Fairlight area itself or perhaps on Romney Marsh.

So far, stamped tiles have been found at the following sites associated with the Roman iron industry: Bardown (28 examples), Beauport Park (over 1,000), and Little Farningham Farm (over 50). They have also appeared in a late second-century context at Bodiam. Of the Bardown tiles, all the stratified examples were found in a late second/early third-century context: in fact, in the rubbish layer overlying the demolished industrial buildings of the first phase, at a time when Holbeanwood and the other satellite sites had been set up. The Little Farningham Farm specimens all come from a late second-century context. Those from Beauport Park come preponderantly from the roof and floors of a bath-house that was probably built in the mid-second century and was rebuilt and enlarged at least twice before its final abandonment in the mid-third century. It can, therefore, be claimed incontrovertibly that the *Classis Britannica* was controlling these sites and the port at Bodiam in the period between the mid-second century and the early third century.

Of this group of sites, only Bardown has been excavated in any detail (only the bathhouse at Beauport Park has been fully excavated). It is clear from Bardown that there is no break between the 'pre-stamped tile' occupation and the unquestionable fleet control period. Little Farningham Farm, like Bardown, appears to have been set up in the mid-second century and also exhibits a 'pre-stamped tile' phase, but again without any discontinuity of occupation, and the same is true of Bodiam, where occupation began in the first century. In default of any evidence to suggest a change of ownership during the latter half of the second century, one is inclined therefore to accept Cunliffe's view that the practice of stamping tiles was not introduced by the *Classis Britannica* until the end of the second century.

This evidence leads to the assumption that the second phase of the eastern group of Wealden ironmaking sites was operated under the direct control of the *Classis Britannica*. At present there is no evidence of a positive nature to confirm fleet control during the first phase, when the large works in the Battle-Sedlescombe area were in operation and sending their products out through the hypothetical port in the Brede estuary. However, the large scale of operations at this time, combined with the continuity of such sites as Beauport Park, makes centralized control seem most probable. The army would have needed iron in large quantities, for weapons, tools, and constructional elements, especially in the early stages of the conquest. A pre-Roman industry existed, but on only a very limited scale and lacking the resources that would permit it to expand to meet the requirements of the army. It would seem logical, therefore, for the fleet to have taken over.

The needs of the army must have been very considerable for at least a century. The Inchtuthil find (fn. 3, p. 171) has illustrated the amount of material needed solely for the manufacture of iron nails, used in the construction of forts and other military
280/281 works in timber. Fort building continued throughout the first and second centuries, culminating in the two great defensive walls. It is known that vexillations from the fleet were working on Hadrian's Wall[45] at a time when the fleet was certainly based in the south east (as evidenced by the Aufidius Pantera inscription from Lympne)[46] and it is not unlikely that control over the iron industry had already begun at that time.

One final point that needs consideration is that of the base of the *Classis Britannica* when it is supposed to have been controlling the iron industry. The accepted chronology has recently been called into question. Cunliffe (fn. 44, p. 187) suggests that in the second and early third centuries the Fleet was operating from Pevensey, Lympne, Dover, and Richborough, in their pre-stone phases. Hassall[47] has modified this view, suggesting that Pevensey and Lympne in their present form cannot be pre-Carausian, and that during the period under consideration Richborough was not military in character. This leaves only Dover as a possible major base. Philp's recent excavations at Dover[48] confirmed the existence of a Saxon Shore fort of the third century but, much more significantly in the present context, revealed a large *Classis Britannica* defensive work beneath the Saxon Shore fort and on a different ground plan, implying a possible abandonment of the fleet base before the Saxon Shore fort was built. A large number of CL BR stamped tiles were found in association with second and early third-century pottery. Philp claims that this was the equivalent on the north side of the Channel of the Bononia/Gesoriacum base.

This is very valuable evidence in support of the view that by at least the mid-second century the Wealden iron industry was under the control of the *Classis Britannica*. It can hardly be a coincidence that evidence of the fleet's connexion with the industry appears at three settlements associated with ironworking and at the Bodiam estuarine port at the same time as a major base is established at Dover. Iron was produced at a number of works, both in the Battle-Sedlescombe area and in the High Weald, and transported by road to the port at Bodiam on the Rother estuary. From here it would have been taken by boat across the shallows of what is now Romney Marsh to the main base at Dover, whence it could be distributed by sea to garrisons throughout the province (and perhaps also via the base at Bononia/Gesoriacum to units in northern Europe).

It is interesting also that the apparent abandonment of the Dover base, or its replacement by the Saxon Shore fort, around the middle of the third century, also coincides with the end of large-scale ironmaking in the eastern group of sites. It is possible that the ironmaking settlements may have closed down not because of over-exploitation of their local natural resources (although this must have been a strong contributory factor) but because they had proved to be vulnerable to raids from Channel pirates. The Bodiam port (tentatively identified by Peacock (fn. 33, p. 182) as Ptolemy's *Portus Novus*) shows no signs of any defensive works, presumably because it was built during a settled period. It would have presented a tempting target for freebooters, since the approach would have been through the tortuous channels leading across modern Romney Marsh. Raids on this port, seizure or sinking of coastal vehicles bound to or 281/282
from Dover, coupled with increasing problems in obtaining ore and charcoal supplies, could well have resulted in what appears from the archaeological record to have been a sudden cessation of fleet activities in the iron industry of the Weald.

This high level of iron production could not, obviously, have been abandoned without being replaced by output from another region. The situation must have been similar to that in the Soviet Union in 1940-41, when heavy industries were moved east of the Urals in the face of a military threat. The development of the iron industry of the Forest of Dean may not be unconnected with the establishment of a state-run industry there; unfortunately, later workings have obliterated most of the evidence of the Roman industry. There is, however, an inscription relating to a naval personage from Lydney[49] which may be of some relevance. All that is known, effectively, about the iron industry of the Roman period of the Forest of Dean is that immense quantities of Roman slags were later transported by barge up the Severn during the early Industrial Revolution to the blast furnaces of Worcestershire and Shropshire and that the Roman sites were more effectively obliterated than those of the Weald.

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APPENDIX: Roman Ironmaking Sites in the Weald

The sites are described in alphabetical order, using the commonly accepted name. The general area or civil parish is indicated, followed by a six-figure National Grid Reference. For each site all known earlier references are quoted, followed by a short description of the site, based either on the sources or on personal observation by the author.

1. BARDOWN, Wadhurst, Sussex TQ 663293

H. Cleere, *The Romano-British Industrial Site at Bardown, Wadhurst, Sussex*, Sussex Archaeol. Soc. Occ. Paper no. 1 (1970).
L. J. Hodson and J. A. Odell, Ticehurst: *The Story of a Sussex Parish* (1925), pp. 27-8.
F. Haverfield in V.C.H. *Sussex*, 111, 31.
F. Haverfield, *Sussex Archaeol. Collect*., **58** (1916), 195.
E. Straker, *Wealden Iron* (1931), pp. 28, 296.

Excavated by the present author (1960-8). The settlement covers about eight acres, on the south bank of the river Limden. It is divided into two areas, the western half being devoted to ironmaking activities and the eastern half being residential. A dump of refuse (largely iron slag, cinder, and furnace debris) extends for about 100m. along the
282/283 south bank of the stream.

Iron-ore workings are attested on the north bank of the stream and in innumerable pits within 1½ miles radius of the settlement, on the Wadhurst Clay.

The settlement appears to have been founded about A.D. 140 and to have continued until the mid-third century. The buildings excavated were timber-framed, with walls of wattle and daub. Ironmaking activities were carried out at the settlement itself during the second century but were discontinued after about A.D. 200, the industrial buildings being dismantled or abandoned and covered with a deep layer of domestic rubbish. Of the twenty-eight CL BR tiles found on the site, twenty-four were found in this layer.

After A.D. 200, ironmaking appears to have been continued at a series of satellite sites, about 1-1½ miles from the main settlement and connected to it by slag-metalled roads. So far seven such sites have been tentatively identified, of which one, Holbeanwood (q.v.) has been excavated.

The finding of a number of wasters suggests that pottery, and probably also tiles, was made at the settlement.

The settlement appears to have been abandoned and possibly dismantled (cf. Beauport Park) in the mid-third century; there was no evidence of destruction by burning in the last phase, although several buildings were destroyed by fire in earlier phases. There was slight evidence of casual re-occupation in the late third century.

It is estimated that 8,000-10,000 tons of iron produced during the life of the settlement are represented by the volume of slag in the main refuse bank. To this must be added the production of the satellite sites in the third century, which was probably the same in total. This gives an annual production of 160-200 tons per year. No smelting furnaces have been located (although two ore-roasting furnaces were identified); however, twelve furnaces were found at Holbeanwood. If an average production of 25 kg. per day is assumed, it can be calculated that each furnace could produce 7-8 tons per year (although it is by no means dear that they were operating throughout the year). Thus there must have been a minimum of twenty furnaces in operation at the main settlement during the second century.

2. BEAUPORT PARK, Battle, Sussex TQ 786140

S. Arnott, *Sussex Archaeol. Collect*., **21** (1869), 138.
J. Rock, ibid., **29** (1879), 567-75.
E. Straker, op. cit., pp. 330-7.
V.C.H., *Sussex*, 111, 32.

This site has attracted the attention of antiquaries and archaeologists for over a century. The main feature was the great slag and refuse bank, covering over two acres; this was quarried away a century ago by Mr Byner, County Highway Surveyor, at a rate of 2000-3000 cubic metres a year for nearly ten years (after he had stripped the heaps at Oaklands Park – q.v.). Luckily, it was visited during this period by James Rock, who reported to the Sussex Archaeological Society in 1879. Even today, the remains of the heap, which must have contained upwards of 100,000 tons of iron slag, are very impressive.

Rock and, later, Herbert Blackman, whose meticulous records are preserved in the Sussex Archaeological Society's archives at Barbican House, Lewes, confined their attention to the slag heap, the principal visible remains on the site. Recent investigations by A. G. Brodribb have revealed that the whole settlement covers a very extensive area, of at least twelve acres; there is evidence of a residential area on the opposite side of the little stream which delineates the slag bank, and excavations by Mr Brodribb and the present author have brought to light a well-built and exceptionally well-preserved
bath-house, of military type, on the slope above the slag bank. 283/284

Coins found on the site range from Trajan to Severus Alexander, some 140 years, and this dating appears to be confirmed by the preliminary analysis of the pottery. The most notable feature of the finds is the great number (over 1,000) of CL BR stamped tiles that have been found in association with the bath-house.

It would appear that the Beauport Park settlement began at the beginning of the second century (no pre-Roman material has yet been identified) and continued in operation until the mid-third century, when it is postulated that ironmaking in this part of the Weald by the *Classis Britannica* came to an end. This view is supported by the fact that the bath-house had been systematically stripped of any re-usable material, such as lead pipes, window glass, etc.

Straker suggests (op. cit., 338), very plausibly, that the possible site at Baldslow Place (TQ 799141) may be an outlier of Beauport Park. By analogy with Bardown, other satellite sites may be postulated in the area of the settlement, although it does appear from the contents of the refuse heap that ironmaking activities continued here much longer than in the main settlement at Bardown.

3. BROADFIELDS, Crawley, Sussex TQ 258353

Surrey Archaeol. Newsletter, **6** (1972).
WIRG, *Wealden Iron* **V** (1973), 14-15.
Bull. Hist. Metallurgy Group, **8** (1974), 51-3.

Continuing rescue excavations in advance of a large building development have revealed domestic and semi-domestic industrial areas, which are thought to spread over about 12 hectares. Many of the stages in manufacturing iron are represented by features which include ore-roasting areas, three slag dumps, thirty-six smelting furnaces, puddling pits, a water reservoir, and a possible blacksmith's shop.

Most of the smelting furnaces seem to be of the present author's type B.1.i, in that they are all equipped for slag tapping, were blown with a forced draught, and had a cylindrical superstructure. Six of them are similar to the Ashwicken type, but at least twenty-seven are of the now classic Wealden type identified at Holbeanwood.

The site spans a shallow valley with sandstone hills to the south. The main occupation is at the base of these hills at about 80m. above sea level, on Weald Clay.

One of the domestic settlements was found to be surrounded on four sides by a ditch and bank, enclosing a rectangular area approximately 76 × 63m. A group of buildings have been discovered in this area, one of which (probably part of the living quarters) has a floor made up of burnt clay and successive layers of unburnt beaten clay, measuring 11 × 5m. Set into the latter was a small horseshoe-shaped oven of clay. Small finds from the site indicate an occupation spanning the late first and second centuries.

4. BROOK HOUSE, Burnt Oak, Rotherfield, Sussex TQ 506273

C. F. Tebbutt, *Sussex Notes & Queries*, **14** (1954-7), 278.

Excavation in a large slag heap revealed a number of sherds of Romano-British pottery.

5. BYNES FARM, Crowhurst, Sussex TQ 752111

Straker, op. cit., p. 358
B. H. Lucas, *Sussex Notes & Queries*, **13** (1950-3), 16-19.

This is a very characteristic bloomery site, on the slope of a small valley. A section was cut through the slag bank in 1949, revealing the typical layers of slag, charcoal,
284/285 furnace debris etc., known from Bardown, Beauport Park and elsewhere. In addition, a number of single and double tuyeres were found. A large amount of pottery was found in the slag, dated to the late first and second centuries.

The excavator drew attention to the contemporary sites in the area (Crowhurst Park, Pepperingeye etc.) and also to the communications of the site.

6. CASTLE HILL – HOME FARM, Rotherfield, Sussex TQ 560280

C. S. Cattell, *Bull. Hist. Metallurgy Group*, **4** (1970), i, 18-20; **4** (1970), ii, 76.

An extensive slag deposit (over 20m. across) at the junction between the Wadhurst Clay and the Ashdown Sand. Carbon-14 analysis (Ref. Hv 2984) gives a central date in the late 1st century A.D.; the determinations were carried out on charcoal entrapped in the cinder and from the heap.

7. CHITCOMBE, Brede, Sussex TQ 814211

J. Rock, *Sussex Archaeol. Collect*., **29** (1879), 175-80.
V.C.H., *Sussex*, 111, 32.
Straker, op. cit., pp. 34-7.

This is a very large site, described by Rock as comparable with Beauport Park (q.v.). The pottery found is described somewhat loosely, but includes samian and so can be assumed to have a similar dating range to Beauport Park.

No excavations have been carried out on the site, but there are remains of masonry (mentioned by Rock) still visible, and finds of tiles in the vicinity indicate the existence of substantial buildings.

8. COALPIT WOOD, Wadhurst, Sussex TQ 652285

A 'satellite' of the Bardown settlement, located about 1 mile to the south west and connected with it by a dearly defined track, metalled with iron slag. There are several large ore pits along the line of the track. The site is identified by a slag deposit on the side of a small gill, measuring about 15 by 10m.

9. CROWHURST PARK, Crowhurst, Sussex TQ 769136

Straker, op. cit., p. 33.
E. Straker and B. H. Lucas, *Sussex Archaeol. Collect*., **79** (1938), 224-9.
C. M. Piggott, ibid., 79 (1938), 229-32.

Straker describes this in his book (1931) as 'a very considerable bloomery of Roman type', and his diagnosis was confirmed by his 1936 excavation. The refuse deposit was sectioned and revealed the characteristic layered structure, containing slag, charcoal, furnace debris, and single and double tuyeres. The pottery was dated to the late first and second centuries; in addition, there was an assemblage of pre-Roman types, very characteristic of the decades preceding and following the conquest of A.D. 4. A starting date at the very beginning of the Roman occupation should therefore be postulated for the Crowhurst Park settlement (cf. Minepit Wood, Pippingford Park – q.v.).

There are a number of mine-pits along both sides of the valley in which the site is located. There are also a number of other sites in the immediate vicinity (e.g. Bynes Farm, Pepperingeye – q.v.) which may be connected with Crowhurst Park as 'satellites', similar to those surrounding the Bardown settlement. 285/286

285/286 **10. DOOZES FARM, Wadhurst, Sussex** **TQ 625273**

This site was discovered during the laying of the gas pipe-line from Rolvenden to Mayfield in 1969-70. A pit containing tap slag, cinder, and burnt day, measuring 3.5-4.0 m. in diameter, was cut through by the mechanical excavator; at the point sectioned, the pit was nearly 1m. deep. Stones enclosing an area about 30 cm. square on the west side of the pit seemed to form some kind of structure, the purpose of which could not be ascertained. Ore nodules, both burnt and unburnt, were found a short distance away. Two sherds of coarse pottery were found, possibly Romano-British.

It is possible that this may be an outlier of the Bardown settlement (q.v.). However, it is some three miles distant from that site, unlike the other known satellites, such as Holbeanwood, which are all located within a radius of 1½miles of Bardown.

11. FOOTLANDS, Sedlescombe, Sussex **TQ 772198**

Straker, op. cit., pp. 327-8.
V.C.H., *Sussex*, 111, 35.
E. Chown, *Sussex Notes & Queries*, 11 (1946-7), 148-51

This is one of the largest sites in the Weald, ranking with Beauport Park, Great Cansiron, and Oldlands in size. It has slag extending along both sides of the small stream and in an area of four acres, which shows up black on ploughing. The pottery finds indicate occupation from before the Roman Conquest down to the fourth century. Unfortunately, only the pre-Roman material deriving from the 1925 excavation by the Sussex Archaeological Society has ever been published, and so definitive evidence for fourth-century occupation is lacking. The pre-Roman material suggests a starting date immediately before or after the conquest (cf. Crowhurst Park, Minepit Wood, Pippingford – q.v.).

12. FOREWOOD, Crowhurst, Sussex **TQ 752129**

Straker, op. cit., pp. 351-2.
J. A. Smythe, *Trans. Newcomen Soc*., 17 (1936-7), 197-203.

Straker describes this as 'an extensive bloomery of Roman type', but appears to have found no direct evidence of Roman working. A 'lump of impure iron' discovered by Straker on the site was examined metallographically and identified as a normal product of smelting by the direct process, namely an unworked bloom, weighing 1.24 kg. (cf. the worked bloom from Little Farningham Farm – G. T. Brown, *Journ. Iron & Steel Inst*., **202** (1964), 502-4).

13. GREAT CANSIRON, Holtye, Sussex **TQ 448382**

I. D. Margary, *Sussex Notes & Queries*, **13** (1950-3), 100-2.
C. F. Tebbutt, *Sussex Archaeol. Collect*., **110** (1972), 10-13.

This very large site, which lies about a mile from the London-Lewes Roman road (Margary's route 14) has been studied by the Wealden Iron Research Group, who have collected a large quantity of pottery and building materials from the surface of the 4-acre 'industrial area' after ploughing. The coarse pottery is largely of the late first and second centuries, but the samian is mainly late second century. The only coin found was a worn *dupondius* of Vespasian.

The site would appear to have been the source of much of the slag metalling used on the London-Lewes road, and the start of its operations may have been contemporaneous with the building of the road 286/287

14. HOLBEANWOOD, Ticehurst, Sussex **TQ 663305**

H. Cleere, *The Romano-British Industrial Site at Bardown, Wadhurst*, Sussex Archaeol. Soc. Occ. Paper no. 1 (1970).

This site is an outlier of the Bardown settlement (q.v.), lying about one mile to the north and connected to it by a track, slag-metalled in places and running alongside a series of ore pits.

Excavation revealed two groups of furnaces, each consisting of six units; these were shaft furnaces of type B.1.i, according to the present author's proposed classification (*Antiq. J*., **52**, (1972), 8-23). The scarcity of pottery and other remains associated with occupation, in sharp contrast with the main settlement, and the lack of any buildings, apart from the timber shelters built over the furnace groups, suggested that this was purely a working place, visited daily by ironworkers who lived at the main settlement.

15. HOWBOURNE FARM, Hadlow Down, Sussex **TQ 516249**

Straker, op. cit., p. 390.
C. F. Tebbutt, *Sussex Archaeol. Collect*., **111** (1973), 115.

Considerable bloomery slag and second-century pottery (including samian and Nene Valley types) were found in association with a mortared stone wall. Straker links the bloomery here with the Tudor forge a short distance away, but the later discoveries would appear to disprove this connexion.

16. ICKLESHAM, Sussex

Straker, op. cit., pp. 340-I.
W. Maclean Homan, *Sussex Notes & Queries*, **6** (1936-7), 247-8.

Straker refers to small bloomeries at Telegraph Mill and Place Farm (in the area TQ8615). Homan found what appear from his short note to have been the bases of six shaft-furnaces, with considerable bloomery slag and a *denarius* of Hadrian at approximately TQ 878165.

An interesting place-name in the area is Burnt Wood, Pett (TQ 871146), lying between Icklesham and Fairlight, in view of Peacock's recent identification of the source of the clay for the CL BR stamped tiles found on several sites (*vide supra*). The Fairlight bloomery mentioned briefly by Straker (op. cit., p. 339) may be relevant in this connexion, as forming part of an as yet not fully identified group of sites.

17. KNOWLE FARM, Heathfield, Sussex TQ 623241

C. S. Cattell, *Sussex Notes and Queries*, **17** (1968-71), 101-3.
C. S. Cattell, *Bull. Hist. Metallurgy Group*, **4** (1970), i, 18-20; **4** (1970), ii, 76.

There is an area of blackened soil, containing tap slag, iron ore, furnace debris etc., about 10m. in diameter, near the head of a tributary of the Rother.

The site has been dated to the second/third centuries by pottery finds.

18. LITTLE FARNINGHAM FARM, Sissinghurst, Kent TQ 809358

M. C. Lebon, *Arch. Cant*., **72** (1958), xlvii, lx-lxii; **76** (1961), xlviii.

There is no direct evidence of ironmaking at this site. It is a substantial stone-built structure, with a hypocaust system, where a number of CL BR stamped tiles were found during excavation. There is no slag in the building itself nor in the vicinity. However, a number of tuyeres, of the type known from Bardown, Crowhurst Park, and
287/288 elsewhere (see H. F. Cleere, *Sussex Archaeol. Collect*., **101** [1963], 48-53, for discussion) were found within the building, together with a worked iron bloom (G. T. Brown, *Journ. Iron & Steel Inst*., **202** (1964), 502-4), suggesting a close connexion between the iron industry and the Fleet in this area. The site also lies very close to the road running towards Rochester (Margary Route 13).

19. LIMNEY FARM, Rotherfield, Sussex TQ 540271/2

Straker, op. cit., p. 387.
WIRG, *Wealden Iron*, **VI** (1973), 22.

Straker found the base of a third-century New Forest ware pot near a large 'marl pit' on this site. When members of the Wealden Iron Research Group visited the site, they found two low mounds of bloomery slag near the small stream and concluded that 'the site has all the appearance of being Roman'.

20. LITTLE INWOODS, Hadlow Down, Sussex TQ 562240

C. S. Cattell, *Bull. Hist. Metallurgy Group*, **4** (1970), i, 18-20; **4** (1970), ii, 76.

A slag dump over 10m. across close to a small stream. Carbon-14 analysis (Hv 2985) of charcoal from the cinder and the heap itself gave a date of 130 B.C.- A.D. 70.

21. LUDLEY FARM, Beckley, Sussex TQ 848208

W. J. Botting, *Sussex Archaeol. Collect*., **111** (1973), 111.

Located in Burnthouse Wood, this site is represented by a large slag and refuse bank (50 × 200m.), which appears to have been disturbed, probably for road metalling. Trial excavation in the slag bank has produced a considerable amount of pottery, including samian, identified as second-century, together with a *sestertius* of Hadrian.

A series of small depressions in Oak Wood (TQ 852209) appear to be filled-in ore-pits.

22. MAGREED FARM, Heathfield, Sussex TQ 601229

C. S. Cattell, Bull. *Hist. Metallurgy Group*, **4** (1970), i, 101-3

A bloomery site with a small (5m.) refuse heap on the edge of the Wadhurst Clay, alongside a small gill. Pottery found on the site has been identified as Romano-British.

23. MINEPIT WOOD, Rotherfield, Sussex TQ 522338

Straker, op. cit., p. 257 ('Orznash')
J. H. Money, *Bull. Hist. Metallurgy Group*, **8** (1974), 1-20.

This site produced on excavation a small slag and refuse dump flanking a very well-preserved specimen of a domed smelting furnace – type B.1.ii according to the author's classification (*Antiq. J*., **52** (1972), 9-23). Pottery finds were scant and were identified as first century, spanning the conquest date of A.D. 43 (cf. Crowhurst Park, Pippingford – q.v.). This was, as at Pippingford, at variance with the implied fourth-century date provided by carbon-14 analysis of charcoal from the base of the furnace. The 'archaeological' date has been preferred, owing to the as yet unexplained discrepancies between archaeological dates and radiocarbon dates on several Roman ironmaking sites in the Weald. 288/289

It would appear that this belongs to the group of ironmaking settlements set up immediately after the Conquest in A.D. 43. Like Pippingford, its period of operation was short, as evidenced by the relatively small deposit of slag, by comparison with Beauport Park, Great Cansiron or Footlands.

24. MORPHEWS, Buxted, Sussex TQ 509255

Straker, op. cit., p. 389.
WIRG, *Wealden Iron*, **VI** (1973), 21.

Straker describes this as 'a very large bloomery', and links it with the later Howbourne and Little Forges. However, trial excavation by the Wealden Iron Research Group in the slag bank produced Romano-British pottery, and a hypocaust tile was picked up in the adjacent stream.

25. OAKENDEN FARM, Chiddingstone, Kent TQ 504428

An area measuring some 30 × 80m. in a field on Oakenden Farm is heavily impregnated with tap slag, cinder, and charcoal. Surface finds of pottery included one samian and one Nene Valley sherd, probably of second-century date. Large depressions in the vicinity are almost certainly ore-pits.

26. OAKLANDS PARK, Westfield, Sussex TQ 785176

Straker, op. cit., p. 329.
V.C.H., *Sussex*, 111, 32.

The slag and rubbish banks at this large site were quarried away in the mid-nineteenth century by Mr Byner, County Highway Surveyor, who later turned his attentions to Beauport Park (q.v.) as a source of road metalling.

The close dating of the site is very questionable, since nothing survives of the material found by Byner; it is known, however, that coins of Hadrian were discovered, which at least gives evidence of second-century occupation.

Observations in the area by local amateurs suggest that an extensive settlement now lies beneath the modern Pestalozzi Children's Village, close to the river Brede, which would certainly have been navigable during the Roman period (see main text). A slag-metalled road has been located at TQ 788173.

The site at Platnix Farm (TQ 798168) referred to by Straker (op. cit., p. 338) may be an outlier of the Oaklands Park settlement or even, conceivably, of the Beauport Park settlement.

27. OLDLANDS, Maresfield, Sussex TQ 476268

Straker, op. cit., pp. 395-7.
M. A. Lower, *Sussex Archaeol. Collect.*, **2** (1849), 169-74.
V.C.H., *Sussex*, 111, 32.
WIRG, *Wealden Iron*, **VI** (1973), 20.

This appears to have been the first Roman ironmaking site to have been identified in Sussex (in 1844), and was graphically described by Mark Antony Lower in a classic paper. The area covered is at least seven acres, and it comprised working areas, refuse heaps, and inhumation burials. The coins found ranged from Nero to Diocletian, indicating a long period of occupation: the relative frequency of coins of Vespasian
289 suggests a late first-century date for the establishment of the settlement.

290 The proximity of the site to Margary's Route 14 suggests that Oldlands was the source of the slag used to metal the adjacent stretch of the road (cf. Great Cansiron – q.v.).

28. PEPPERINGEYE, Battle, Sussex TQ 743140

Straker, op. cit., p. 351.

A 1m. thick layer of slag lies beneath the garden of Pepperingeye Farm, and yielded a small sherd of samian embedded in a vitrified brick. This site could well form part of the Crowhurst Park complex.

29. PETLEY WOOD, Battle, Sussex TQ 764176

C. H. Lemmon, *Trans. Battle & Dist. Hist. Soc.*, 1951-2, pp. 27-9.

This was not a site where iron was smelted, but appears to have been solely an iron ore mining and pre-treatment operation. Pits were discovered, some as large as 15-20m. diameter by 15m. deep; these tapered towards the bottom. The spoil heaps, composed of the overburden removed during mining, produced a considerable amount of second and early third-century pottery.

There was ample evidence that the ore had been roasted and screened before being taken away to the smelting site, probably to Oaklands Park (q.v.), which is only about a mile distant from the Petley Wood site. The large amount of pottery is, however, somewhat surprising, in view of the dearth of finds at the Holbeanwood outlier of the Bardown settlement.

30. PIPPINGFORD, Hartfield, Sussex TQ 446313

C. F. Tebbutt and H. F. Cleere, *Sussex Archaeol. Collect.*, **111** (1973), 27-40.

This small bloomery, consisting of a smelting furnace of the present author's type B.1.ii (*Antiq. J.*, **52** (1972), 8-23), a smithing hearth, a possible ore-roasting hearth, and a small slag heap, was excavated by members of the Wealden Iron Research Group. The sparse pottery finds were dated to the Claudian-Neronian period by B. W. Cunliffe, an ascription somewhat at variance with the radiocarbon date for charcoal from the base of the furnace of 1647 ± 60 B.P. (BM-685). In view of the similar discrepancy between the pottery and the carbon-14 dates at the Minepit Wood site (q.v.), the pottery date has been preferred as the more reliable.

On the basis of the pottery evidence, it is believed that the bloomery began operating shortly after the Roman conquest of A.D. 43, and was worked for only a few years. It may be associated with the nearby site at Garden Hill, Hartfield (*Sussex Archaeol. Collect.*, **108** (1970), 39-49), a hilltop settlement with occupation starting in the mid-1st century A.D. Excavations are still (1974) in progress at this site.

The Strickedridge Gill site (q.v.) may also be connected with the Garden Hill settlement, as may the site at Pippingford East Wood (TQ 442301), where the slag heap has been trial-trenched by members of the Wealden Iron Research Group and has yielded sherds of Romano-British pottery.

31. POUNSLEY, Framfield, Sussex TQ 525222

WIRG, *Wealden Iron*, **VI** (1973), 22.

A fairly large deposit of bloomery slag lies along the banks of a small stream. Trial trenches dug by members of the Wealden Iron Research Group produced two sherds of pottery, one of them second-century samian. 290/291

32. RIDGE HILL, East Grinstead, Sussex TQ 369359

Straker, op. cit., pp. 233-5.
E. Straker, *Sussex Archaeol. Collect.*, **69** (1928), 183-5.
V.C.H., *Sussex*, 111, 31.

A slag heap measuring some 150 × 60m. lies in swampy ground alongside the river Medway. Excavation in 1927 in the heap revealed the characteristic layered structure. The heap appears to have been deposited on top of earlier ore-roasting or charcoal-burning hearths, 2.5-3.0m. in diameter, interpreted by the excavator incorrectly as smelting hearths.

The pottery discovered (including samian) was dated to the period A.D. 100-300 by S. E. Winbolt; pottery from the lowest levels was dated by Reginald A. Smith to the pre-Conquest period, but this ascription should be treated with some reservations (*vide supra*).

33. SHOYSWELL WOOD, Etchingham, Sussex TQ 682279

Straker, op. cit., p. 297.

The site of this bloomery was not located by Straker, but was revealed by the gas pipeline cutting in 1970. A considerable stretch (c. 70 m.) of slag, ore, burnt day etc., was revealed in the trench running through Shoyswell Wood; the deposit was 1m. thick in places. In addition, a number of depressions, probably ore-pits, lie to the north and south of the deposit. One sherd of coarse pottery was found, which appeared to be Romano-British.

This site is located about 1¼ miles south-east of the Bardown settlement (q.v.), of which it is probably an outlying 'satellite' working place.

34. STREELE FARM, Mayfield, Sussex TQ 558268

Straker, op. cit., p. 386.
C. F. Tebbutt, private communication.

Straker is very non-committal about this site. A single sherd of Romano-British coarse pottery has been found by members of the Wealden Iron Research Group among the slag.

35. STRICKEDRIDGE GILL, Hartfield, Sussex TQ 456317

WIRG, *Wealden Iron*, **VI** (1973), 19.

Members of the Wealden Iron Research Group who have studied this site are convinced that it is connected with the nearby Garden Hill first/second-century site (C. F. Tebbutt, *Sussex Archaeol. Collect*., **108** (1970), 39-49). There is an extensive slag bank and a quarry cut into the stream bank for iron ore (cf. Bardown).

36. WALESBEECH, East Grinstead, Sussex TQ 395345

Straker, op. cit., pp. 239-40.
V.C.H., *Sussex*, 111, 31.
WIRG, *Wealden Iron*, **VI** (1973), 18.

The large slag heap observed by Straker is now lapped by the waters of the Weir Wood reservoir, which has cut a vertical section through it, revealing the characteristic make-up. Excavations by Straker and Margary revealed late first and second-century pottery, together with tile. Large ore pits have been identified by members of the Wealden Iron Research Group at TQ 393341 at the edge of the Wadhurst Clay.

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292 Some operating parameters for Roman ironworks

by Henry Cleere

INTRODUCTION

During the past 25 years a great deal of information has been gained about the technology of early ironmaking. Excavations have provided data on furnace construction and disposition, and operating parameters relating to burden composition, blowing rates, slag formation, product control, etc. have been derived from both the study of remains from antiquity and the operation of reconstructed furnaces. Moreover, typological surveys of technological developments (furnace types, fabrication methods, etc.) have produced cultural data that are of significance in the overall study of human development.

However, there have been very few studies during this period that have attempted to use the growing corpus of information to evaluate the social and economic significance of the iron industry in a given culture. This is in part attributable to the fact that the great majority of excavations have been confined to industrial remains – furnaces, slag heaps, workshops. Only a handful of these excavations have extended to the dwellings of the ironworkers, which alone can provide details of the cultural and social backgrounds to the settlements. Few have attempted to relate the scale of operations on a given site to the overall effect of the industry on both the ancient landscape and the economic structure of the society in which it was operating. The work of Bielenin, recently summarised in a masterly monograph (Bielenin, 1974), can be excepted from this criticism, in that it has attempted to study the early iron industry of the Holy Cross Mountains as a totality. An interesting early approach towards a quantitative study of early ironmaking was made by Gilles (1961) in his report on the Ahrweiler settlement.

The present paper is intended to identify some neglected areas of potential research, based on the author's work on the Roman industry of the Weald of south-eastern Britain, and more specifically to that sector of the industry operated on a relatively large scale by the *Classis Britannica* (Cleere, 1974). The figures given are therefore specific to a region and to a military site and industry. They may well not be directly applicable to other regions and socio-economic frameworks and to different technologies, but it is hoped that the approach and methodology adopted may be such as to be applicable
292 with profit to other regions and industries.
293 The following main subjects are dealt with in the paper:

1. Regional production figures, calculated from remaining slag heaps and slag-metalled roads, related to the production of individual sites and furnaces.
2. Consumption of raw materials (ore, timber), related to sources of supply, and the effect on the landscape (mining, deforestation).
3. Manning requirements, used to produce demographic data.

PRODUCTION AND PRODUCTIVITY

Individual sites

The basic field data for this study in the Weald are provided by the slag heaps that in some cases still survive in what appears to be their original dimensions, plus the long stretches of Roman road that have been shown by excavation to have been metalled with iron slag.

The Bardown site (Cleere, 1970a) provides a useful starting point for this study, since it has been intensively studied by the present author by excavation and field survey for 15 years. The only surface feature is a large slag and rubbish dump extending along the south bank of a small stream. This dump is about 100m. in length, up to 50m. wide at its greatest dimension, and has been shown by excavation to be up to 3m. deep. This is equivalent, assuming an average deposit depth of 1m., to approximately 4,000m^3 of waste material. Of this, one-half may be assumed to be represented by smelting slag, the remainder being composed of charcoal and ore fines, furnace structural debris, and domestic rubbish (including a large amount of pottery). The tap slag on the bank has been assumed for the purposes of this study to be 2,000m^3.

Assuming an average specific gravity of 3.0 for this early bloomery slag (Straker, 1931) the total weight of slag on the Bardown bank may be calculated to be 6,000 tonnes. Gilles (1961: 1072) takes a lower specific gravity of 2.5 for the Ahrweiler slag; however, he applies this to the total volume of slag heap No.1 there, which may represent an adjustment to account for voids, soil, pottery, etc. To this should be added the slag used for the metalling of the roads running across and out of the site, providing access from one part to another, linking the main settlement with ore pits and 'satellite sites' (see below), and joining up with the main known Roman road in the area. These roads, which are assumed to be an average 3.0m. wide, are considered in this connection to cover 10 km. (five 1 km. link roads to ore pits and one major 5 km. access road). Assuming an average depth of metalling of 50 mm., the total volume of slag used for road metalling which may be directly attributed to ironmaking activities at the main settlement is 1,500m^3, equivalent to 4,500 tonnes. Thus the total production of slag from the site during its working period was approximately 10,500 tonnes.

Excavation has shown that the settlement was founded between AD 120 and AD 140, and that it closed down between AD 220 and AD 240. However, it is also clear that industrial operations ceased at the main settlement around AD 200; thus, the
10,500 tonnes of slag may be assumed to have been produced in a period of at most 80 293
years, i.e. c. 125 t/year. 294

After AD 200, ironmaking continued at a number of ‘satellite’ workplaces, located 1.5-2.5 km. from the main settlement and linked with it by slag-metalled tracks; five of these sites have been fairly securely identified and one, at Holbeanwood, has been almost totally excavated (Cleere, 1970a). These satellite workplaces show no evidence of occupation; it is clear from excavations at the main Bardown settlement that occupation continued here after industrial operations had ceased, and so it is likely that the satellites were only workplaces, the workers continuing to live at the main settlement. The general layout of the complex of main settlement and satellites is shown in Fig.1.

The Holbeanwood site produced about 50 m^3 of slag, representing 150 tonnes. To this should be added 150 m^3 (450 tonnes) for a 1 km. stretch of link road. Twelve shaft furnaces of the author’s Type B.1.i (Cleere, 1972) were excavated, in two groups of six, and a third group can be fairly confidently extrapolated. Examination of the slag dumps suggested that the site had been operated for no more than ten years (Cleere, 1971a). If this site is typical of the other four known satellites, one may postulate a total production of 3,000 tonnes of slag over a period of 40-50 years.

The total production of slag for the whole complex was thus about 13,500 tonnes, produced over a period of 80-120 years. Using the slag/metal ratio proposed by Gilles (1961: 1072) and Bielenin (1974: 265) of 3:1, which would appear to be broadly applicable to the slightly different type of process represented by the Holbeanwood furnaces, this represents an iron production of 4,500 tonnes: 3,500 tonnes from the main settlement and 200 tonnes from each of the satellites. Thus the annual rate of iron production at the main Bardown settlement may be estimated to have been 40-45 tonnes and that of the satellites as c.20 tonnes (assuming a ten-year life for each).

As stated above, there were probably 18 furnaces at the Holbeanwood site, apparently in three groups of six, and there are indications from the layouts of the two groups excavated that at most three furnaces would have been operating simultaneously.

The author’s theory of cyclical operation of bloomeries (Cleere, 1971a) is based on observations of the refuse deposits at Holbeanwood and reports of the type of buildup at other sites, such as Beauport Park (Plate I is a mid-19th century view of the heap being sectioned during the course of quarrying for road metalling), Chitcombe, Footlands, and elsewhere. The successive dumping of layers of charcoal fines, roasted ore fines, tap slag, and furnace debris are believed to represent successive operational phases, each probably seasonal. Thus a period of wood cutting and charcoal burning would have been followed by a period devoted to ore mining, roasting, and grading, the resultant furnace materials being stored for use in the third phase, that of smelting. Finally, when the accumulated stocks had been consumed, the furnaces would have been repaired and, where necessary, rebuilt before the whole cycle began again.

The cycle is taken to be one year, which seems justifiable, having regard to climatic and vegetational factors. The charcoal and ore phases would probably have been relatively short (but see below): timber was abundant in the area and the ore was
235/236 relatively easy to extract once it had been located. Smelting, on the other hand, would

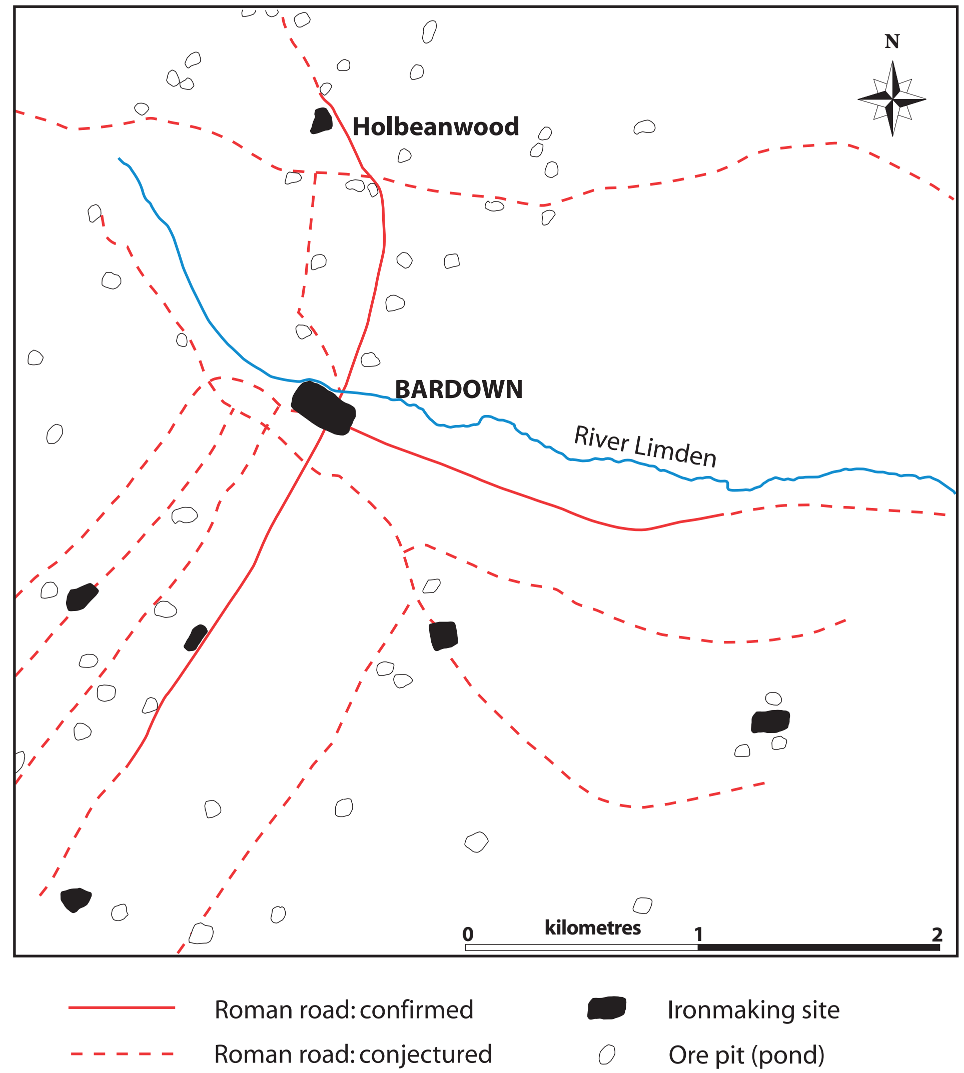

Fig.1: The Bardown ironmaking settlement, showing possible satellite sites, ore pits and roads.

have been a lengthy process: the author’s own experiments on a reconstruction of the Holbeanwood type of furnace (Cleere, 1970b; 1971b) produced only 10 kg. of iron from its most successful smelt, but the Roman ironmaker may safely be assumed to have been more expert and capable of producing blooms of perhaps 30 kg. in one day. Gilles (1961: 1072) assumed a daily output of only 15 kg. from similar furnaces in his calculations, possibly as a result of some rather disappointing smelting experiments (Gilles, 1960). Thus, with three furnaces operating, the daily iron production of the
Holbeanwood satellite workplace could have been in the region of 90-100 kg. 236/237

The total output of 20 tonnes would thus have required some seven months to produce, leaving five months for the charcoal and ore phases (neglecting the repair phase, which would not have taken more than a few days and might well have been

Fig 2: 19th century engraving of the slag dump at Beauport Park, during excavation for road metalling, showing stratification (Straker, 1931, 331)

concurrent with timber felling and charcoal burning). The length of time needed for mining the equivalent amount of ore is discussed in a later section.

If these figures are applied to the main Bardown site, where an industrial phase of c. 80 years has been deduced from dating evidence, it is possible to calculate from an annual iron output of 40-45 tonnes that seven or eight furnaces must have been in operation simultaneously during the smelting phase in any year. The furnaces have not yet been located on this site; however, since it covers nearly 3 ha and only a very small area has been sampled, there is no reason to assume that these calculations are grossly inaccurate.

The region

The present author has recently published a survey of the Roman iron industry in the Weald and its connections with the *Classis Britannica* (Cleere, 1974). In this study, a
296/297 group of six sites in the eastern part of the region have been identified, by virtue of finds of stamped tiles, geographical location as related to road and sea communications, and apparent scale of operations, as forming a homogeneous group, operated under Imperial control by the Fleet. Assessment of the period of operation of these sites and their size is difficult, since none has been properly excavated and, moreover, since several of the slag dumps were quarried away for road metalling in the 19th century (see Fig.2). The figures given in Table 1 for size of slag dump, weight of slag produced, and iron output, together with the dates given, must be considered to be no more than approximations (with the exception of Bardown). The location of the sites is shown in Fig.2.

It will be seen that the estimated annual output of these six sites alone for the period AD 120-240 was c. 550 tonnes. Using the calculations in the preceding section, it emerges that 80-90 furnaces would have been in operation on these sites during the smelting phase of the production cycle in any year during that period. It should be remembered, however, that these are only the major known sites; at least ten smaller sites are known in this part of the region and previously unknown ones come to light frequently. Moreover, there are many kilometres of known Roman roads metalled with iron slag in the region, much in one area where there are no bloomeries so far discovered, and these would increase the slag weight figures substantially. It would be no exaggeration to suggest that the number of furnaces in operation was well over 100, with an annual output approaching 1,000 tonnes.

RAW MATERIALS CONSUMPTION

Charcoal and timber

Bielenin (1974, 266) suggests a 1:1 weight ratio for charcoal consumption in relation to iron ore in smelting, and this has been confirmed by other workers who have carried out experimental work on reconstructed bloomery furnaces (e.g. Cleere, 1970b; 1971b; Tylecote et al., 1971). However, smelting is only one of the processes involved in iron production: ore roasting, forging, and the preheating of smelting furnaces all consume significant quantities of fuel. Moreover, finds of charcoal fines on refuse heaps reveal that the yield of usable charcoal from green wood was less than 100%. It is reasonable therefore to assume that for the whole process sequence the charcoal/ore ratio was 2:1.

The yield of metallic iron from iron ore in the bloomery process was, of course, rather variable, depending on the type of ore and on operating variables that were a function of the skill of the smelter. Bielenin (1974: 265) suggests an ore/slag/iron weight ratio for the Rudki hematite smelted in the Holy Cross Mountains type of

Site	Dating	Slag volume, m^3	Slag weight, tonnes	Iron production, tonnes Total	Annual
Bardown	120-240	4,500	13,500	4,500	40
Beauport Park	100-240	30,000	100,000	30,000	210
Chitcombe	100-240	10,000	30,000	10,000	70
Crowhurst Park	50-240	10,000	30,000	10,000	50
Footlands	50-400	15,000	45,000	15,000	40
Oaklands Park	100-240	20,000	60,000	20,000	140

Table 1:Estimated slag and iron production from major Wealden sites

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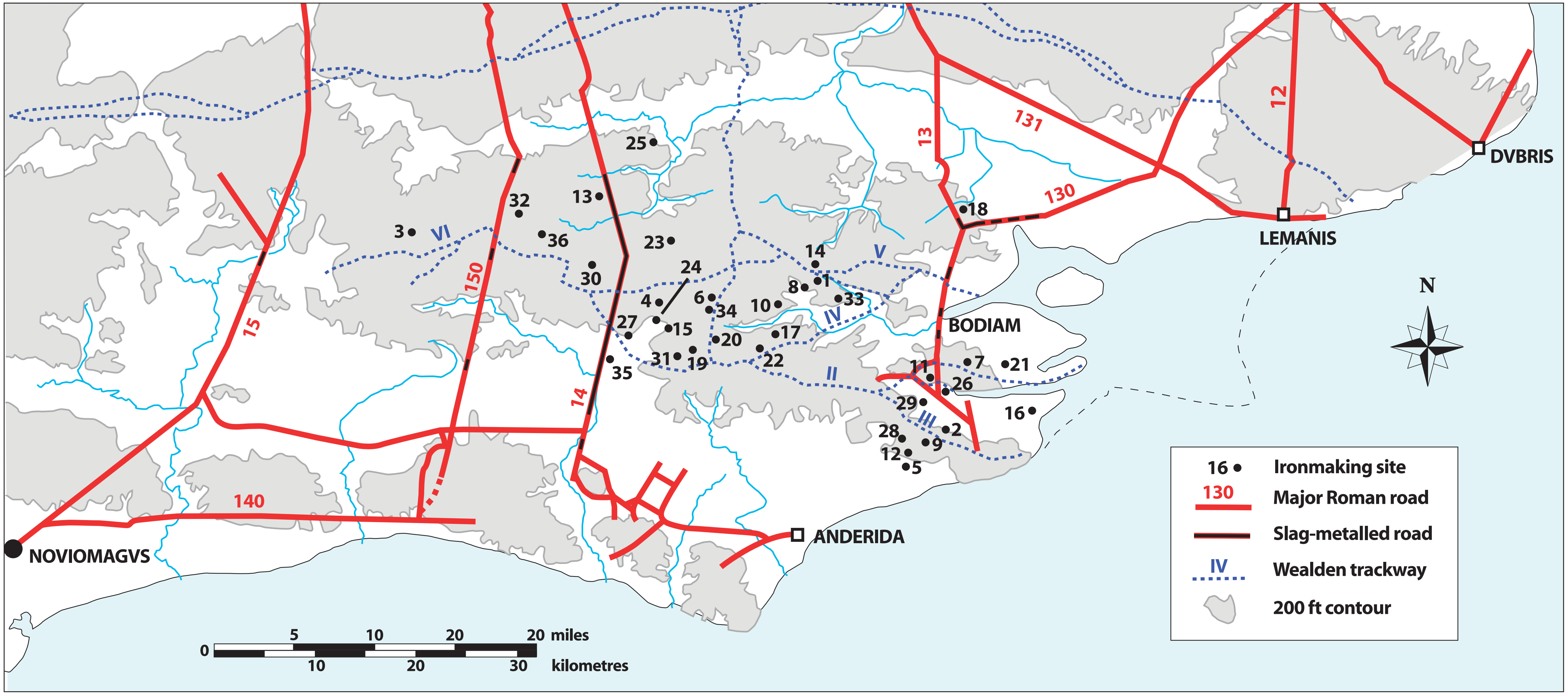

Fig 2: Roman ironmaking sites in the Weald (Cleere 1974; Fig 1). The six sites considered in the paper are Bardown (1), Beauport Park (2), Chitcombe (7), Crowhurst Park (9), Footlands (11) and Oaklands Park (26). The Holbeanwood satellite of Bardown is 14. (Arch. J. *131, 1974, 179, by kind permission of the Editor.)*

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furnace of 6:3:1 for the raw bloom and 10:5:1 for the finished bloom. The former ratio is probably more, relevant to the Wealden carbonate ores and the type of smelting furnace used, where the slag separation in the primary bloom was more effective than in the Holy Cross Mountains type. On the basis of these figures, the charcoal/iron weight ratio may be considered to be 12:1.

When this ratio is applied to the Roman military industry of the Weald and to the Bardown complex, the following charcoal usage may be calculated:

	Iron output, tonnes		Calculated charcoal usage, tonnes	
	Total	Annual	Total	Annual
Weald (AD 120-240)	66,000	550	792,000	6,000
Bardown	4,500	40	54,000	480

Exact values for the yield of charcoal from hardwoods are difficult to come by. The modern retort process uses 5-6 tonnes of wood per tonne of charcoal, and it is reasonable to assume that the Roman charcoal burners using the pit or heap burning process would not have been significantly less efficient. A yield of 1:7 seems probable.

The mature forest cover of the Weald, with its heavy clay soils, was of deciduous hardwoods – mainly oak, with ash, beech, alder, and hornbeam intermingled, and such trees as hazel, hawthorn, and birch colonising gaps. Charcoal from all these species has been found at the Bardown and Holbeanwood sites, but with oak preponderating.

The rate of distribution of mature oaks in the primeval forest of the Weald is not easy to establish, since it cannot be claimed with certainty that this survives anywhere at the present time. Rackham (1974: 68) refers to a 16 ha area which produced 740 trees in the 14th century (46 trees/ha), but also cites Beevor (1924) as an authority for a variation in Norfolk woodland between 12 and 100 trees/ha. His table showing the results of an early 17th century survey in Suffolk (Rackham, 1974: 72) shows a variation between 29 and 50 trees/ha. Waters and Christie (1958) show for quality class I (Best) a rate of 62 trees/ha at 150 years (30 m. height), and this may be calculated to diminish to about 37 trees/ha at maturity (250-300 years). Allowing for a natural cycle of death and regeneration, it would seem acceptable to assume an average cover of 45 trees/ha in a primeval forest (to include trees of several species at various stages of growth).

A mean estimate for the volume of stem wood per hectare based on the data given by Waters and Christie (1958) is 1,200 m^3/ha. However, only branch wood is likely to have been used for charcoal burning, as is evidenced by the material from excavations and from recent charcoal-burning practice. The same authorities give a rough estimate of 50% of the stem volume (600 m^3/ha) for branches; however, the thicker branches of mature oaks could not have been utilised for charcoal burning, and it is probably closer to reality to reduce this figure by one-third, giving an average volume of wood suitable for burning of 400 m^3/ha.

The specific gravity of oak is 0.6, which gives a weight of c. 250 tonnes/ha. With a
299 yield of 1 tonne of charcoal from 7 tonnes of wood, this means that 1 hectare would
300 produce c. 35 tonnes of charcoal. At a charcoal/iron ratio of 12:1 this means that each hectare would produce only enough charcoal for the smelting of 3 tonnes of iron.

Applying these figures to the Bardown main settlement output of 40-45 tonnes/ year suggests that 13-15 ha of woodland would need to be cleared or lopped annually, and that about 1,200 ha (12 km^2) would have been cleared during the period of industrial operations on the main site. Thus, by the time the satellite workplaces were set up, the distance from the centre of the main settlement to the nearest supplies of timber for charcoal was approximately 2 km., i.e. roughly the average distance of the satellites from the main site.

The satellite workplaces themselves, each with an estimated total output of 200 tonnes, would have been responsible for the clearance of some 70 ha of woodland each, or 3.5 km^2 for the five that have been identified. The total impact of the Bardown operation on the landscape of this area was the clearance of 15.5 km^2 of forest in a period of about a century.

On a regional level, Table 2 shows the forest clearance resulting from the operations of the six major presumed military sites listed in Table 1. The annual production of 550 tonnes of iron during the period AD 120-240 would have resulted in the clearance of nearly 2 km^2 of forest per year (or nearer 3.5 km^2 if the larger figure of 1,000 tonnes/ year is taken).

By the time ironmaking in the eastern Weald ceased in the mid-3rd century (with the possible exception of the Footlands settlement), nearly 300 km^2 of forest had been cleared (or 500 km^2 using the larger annual figure), and the area around Battle, where all but Bardown of the six sites listed in Tables 1 and 2 are located, must have been

	Iron production tonnes		Equivalent forest clearance. km^2	
Site	Total	Annual	Total	Annual
Bardown	4,500	40	15.0	0.13
Beauport Park	30,000	210	100.0	0.70
Chitcombe	10,000	70	30.0	0.23
Crowhurst Park	10,000	50	30.0	0.17
Footlands	15,000	40	50.0	0.13
Oaklands Park	20,000	140	70.0	0.47

Table 2: Estimated forest clearance for ironfounding at major Wealden sites.

devastated. Indeed, the deforestation in this area may well have contributed in some measure to the Fleet's abandonment of the eastern Weald as its ironmaking base in the mid-3rd century.

Iron ore

It is somewhat more difficult to assess the effect of ore mining on the landscape in relation to the operations of individual works and a regional industry, since the exact
mode of occurrence of the carbonate ores of the Weald is not fully known at the local 300
level. The Wealden District volume of the British Regional Geology (Gallois, 1956:26) 301
refers to the ores in the following terms:

'Much of the iron ore which formed the basis of the Wealden Iron industry in east Sussex and Kent … was obtained from the Wadhurst Clay in which it occurs both as nodules and in tabular masses. This clay ironstone is sideritic … and weathers to limonite … The most important and consistent ironstone horizon occurs near the base of the formation.'

Observation of an exposure in a brick pit near Sharpthorne by the author showed that the nodular ore appeared to occur in lenses about 0.30 m. thick and varying in size from 5 to 15 m. across. There were three lenses of nodules visible within the main stratum, which consisted of tabular ore, in this exposure, which was about 150 m. long. Unfortunately, this is the only such extensive exposure known to the Institute of Geological Sciences, and there is no evidence as to whether it is representative or not. Ore mining ceased in the Weald at the beginning of the 18th century (apart from an abortive short-lived venture in the mid-19th century), and there are no records of the mode of occurrence of the ores from the earlier period. It is necessary therefore, to attempt to reconstruct this from the remaining traces of early industrial operations.

Mining was invariably opencast in the Weald (with the exception of the 19th century venture), using open pits at first and later, in the medieval and post-medieval periods, bell-pitting. Water-filled pits are a characteristic feature on the Wadhurst Clay around early ironmaking sites. At least 50 such pits or ponds can be observed in the immediate vicinity of the Bardown settlement (see Fig. 1) varying in size from 10 to 30 m. across; in addition, there are two very large excavations into the Wadhurst Clay which forms the north bank of the stream that delineates one side of the main settlement, and it has been deduced that these represent the earliest ore workings, the ore body having been located by the stream cutting through the soft overlying clays.

Finds from Roman sites suggest that the nodular ore (40-45% Fe) was preferred to the tabular form (35-40% Fe). Only the 1st century AD site at Minepit Wood (Money, 1974) has produced relatively abundant evidence of the use of the lower-grade tabular ore. The distribution of ore pits around Bardown seems to confirm the evidence from excavation. On the basis of the observations made at Sharpthorne it might be assumed that the lenses of nodular ore occur at a density of about two per hectare (200 per km^2), but field study in the Bardown area has revealed only 10-20 per square kilometre. The discrepancy may be attributable to the somewhat empirical technique probably used by Roman prospectors to locate nodular ore. It has been assumed for the purposes of the present study that the density was 12 pits per square kilometre and that the average pit was 15 m. diameter, but it is acknowledged that these figures may be inaccurate by a factor of at least 10.

Assuming a constant depth of deposit of 0.30 m., the volume of ore extracted from each pit was therefore:

$$\pi\left(\frac{15}{2}\right)^2 \times 0.30 = 53\ \text{m}^2$$

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The specific gravity of siderite is given by Read (1973:521-2) as 3.7-3.9. However, the characteristic nodule from the Wadhurst Clay consists of siderite enclosed in a skin of up to 0.01 m. thick of limonite, altered by weathering from siderite (giving rise to the local name of 'boxstone'). The same authority (Read 1973: 520) gives a specific gravity of 3.6-4 for limonite.

The friable limonitic material filling the interstices between individual nodules was probably lost in the extraction process. In addition the loss on ignition during the roasting was probably of the order of 25% (Cleere, 1970b: 5) or even higher (Tylecote, personal communication). It would therefore be advisable to assume a net specific gravity factor of 2.6 to derive the weight of ore available for smelting, giving 136 tonnes per pit.

Bielenin (1974: 265) indicates an ore/iron ratio of 6:1; this was derived from experiments using a hematite with a higher Fe content (50%) than the Wealden siderite, but also a higher SiO_2 content of 13.5% compared with 10% for the Wealden ore (Cleere, 1970b: 5), which would reduce the proportion of metal available for smelting, since more would be needed in oxide form to flux the extra silica and produce a fluid slag. It seems reasonable therefore to use this as a convenient rule-of-thumb for the present investigation. Applying it to the average figure for ore yield gives an iron yield of 23 tonnes per pit.

Using the assumed ore-pit density of 12 per square kilometre gives an iron yield of 276 tonnes/km^2. In general terms, it looks as though two pits would have sufficed for one year's iron production at Bardown, and 1 km^2 would have been exhausted in six years. The 3,500 tonnes estimated as having been produced at the main settlement would have resulted in the apparent total exploitation of ore deposits over an area of 12-13 km^2, a figure which is in striking agreement with that calculated for forest clearance and given in the preceding section.

Table 3 shows the calculated exploitation of iron ores in the Weald by the six major military sites listed in Table 1. The total area of land exploited for iron ore by the Roman ironmakers was thus over 300 km^2, corresponding to the area of deforestation. Again, one may reflect on the effect of this intensive exploitation of the natural resources on the political decision taken to close the state-controlled industry in the mid-3rd century. The degree of efficiency in prospecting and extraction of iron ores on the part of the Roman ironmakers is also borne out by the distribution of the medieval and post-medieval iron industry in the areas of Roman working: at none of the major sites listed in Tables 1-3 was there any later working.

	Iron production tonnes		**Equivalent ore exploitation, km^2**	
Site	**Total**	**Annual**	**Total**	**Annual**
Bardown	4,500	40	17	0.15
Beauport Park	30,000	210	108	0.75
Chitcombe	10,000	70	36	0.25
Crowhurst Park	10,000	50	36	0.18
Footlands	15,000	40	54	0.15
Oaklands Park	20,000	140*	72	0.50

Table 3: Estimated iron-ore exploitation at major Wealden sites

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MANNING REQUIREMENTS

The present author's experiments on a reconstruction of a furnace of the type used at Holbeanwood (Cleere, 1970b; 1971b), combined with observations of a parallel type of furnace operated by primitive Indian ironworkers (Cleere, 1963) have produced information on which it is possible to base some calculations regarding the possible manning requirements of Roman furnaces.

The smelting experiments were designed to establish the procedures and personnel for smelting iron in the early furnaces rather than the technological parameters, which have been comprehensively explored under laboratory conditions by Tylecote et al. (1971) and others. It became clear that the process could be operated without undue fatigue by a team of three at the most: two would be responsible for alternating between operating the bellows for blast and preparing the charges of ore and charcoal, whilst the third would have acted effectively as a foreman or charge-hand, making the additions of the furnace, checking slag evolution, etc. This was confirmed by the Indian ironmakers, whose team consisted of two men who carried out the blowing and charge-preparation operations under the strict supervision of an elderly lady, who was unquestionably the 'master ironmaker'.

If these observations are applied to the Bardown situation, where it has already been calculated that seven or eight furnaces were in operation simultaneously, the minimum manning figure for the establishment was of the order of 25 men (assuming that there would have been an officer in command of the establishment). It is perhaps unreasonable to assume that a group of men as small as this would have been capable of clearing 13-15 ha of woodland, cutting and burning it, and grading and stacking, and also of digging two pits containing 106m^3 (272 tonnes) or ore, plus overburden, which may be several metres thick in this area, and roasting and grading it, in a period of only five months. It is not improbable that ore digging at least would have overlapped with the smelting operation to some extent, and that the effective complement of the furnaces was four or even five men. The working strength of the Bardown settlement was therefore probably some 40 men. With non-craftsmen (cooks, orderlies, wagon and mule drivers, etc.), the total manning of the settlement may well have been 50-60 men, housed in the timber barrack block observed from air photographs, of which a substantial section has been excavated.

Extending these calculations to the region as a whole and using the data given in Tables 1-3, it is possible to derive a total strength for the six large sites believed to have been associated with the *Classis Britannica* of 500-700 men, perhaps the equivalent of a quingenary cohort. No doubt there were families and camp followers of various kinds, especially at the larger sites such as Beauport Park and Oaklands Park, bringing the total population up to at least a thousand. The Beauport Park establishment must have been a large one, perhaps the headquarters of the fleet detachment concerned with ironworking, since it boasted a substantial six-roomed bath-house of military type, similar to those known from auxiliary forts elsewhere in the province.

CONCLUSIONS

303/304 This paper represents a first attempt to derive information about the effect of industry on the landscape and demographic data from technological data resulting from excavations and fieldwork.

On the basis of calculations, it is suggested that deforestation for charcoal and ore exploitation were more or less in balance in the conditions obtaining on the Wadhurst Clay of the Weald in south-eastern England. The operations of six major ironmaking settlements, all believed to have been operated by the *Classis Britannica*, resulted in the clearance of nearly 300 km^2 of primeval forest and the exhaustion of ore deposits over an equivalent area between AD 50 and AD 240.

Smelting experiments on reconstructed furnaces of Roman type coupled with observations of modern primitive ironmakers imply that the minimum manning requirement for this level of production was 500-700 men during the 2nd and early 3rd centuries AD.

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Abstract

The paper uses data from excavations and field survey of Roman ironmaking sites in the Weald of south-eastern Britain to assess the effect on an ancient landscape in terms of deforestation to provide charcoal as fuel for smelting and of ore mining. It is calculated that operations on six of the largest sites would have resulted in the clearance in a little over one century of 300-500 km^2 of forest and ore exploitation over an equivalent area.

Data from experiments in reconstructed Roman furnaces and from modern primitive ironmaking are used to assess the probable manning requirements of individual furnaces, settlements, and the entire military operation in this part of the Weald.

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