THE DEVELOPMENT OF THE EARLY STEELMAKING PROCESSES - AN ESSAY IN THE HISTORY OF TECHNOLOGY

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<u>SUPPLEMENTARY VOLUME</u>

Appendix to Thesis submitted to the University of Sheffield for the Degree of Doctor of Philosophy

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SUPPLEMENTARY VOLUME

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Extracts from G. Broling, Anteckningar under en Resa i England Aren 1797, 1798 och 1799, Vol.III (Stockholm, 1816), pp.24-70, 80-101 and 143-147.

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SS THE DIRECT PROCESS OF PRODUCING STEEL FROM IRON ORE

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TT COLLATED TECHNICAL DETAILS RELEVANT TO THE STEEL PUDDLING PROCESS

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XX NOTES ON THE PRODUCTION OF CRUCIBLE STEEL IN SHEFFIELD PRIOR TO 1914

A private communication from J. O. Vessey, Esq.

YY AN ATTEMPT TO DERIVE THE PATTERN OF PRODUCTION LEVELS FOR THE CEMENTATION AND CRUCIBLE STEEL PROCESSES FROM 1825 TO 1925

A revised version of the paper by the author which originally appeared in Historical Metallurgy, Vol.8 (1974), pp.103-111.

ZZ COLLECTED INFORMATION ON THE COST OF PRODUCING CAST STEEL BY THE CRUCIBLE PROCESS

AAA CEMENTATION STEELMAKING IN THE NO.5 FURNACE AT OSTERBY BRUK

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CCC FRENCH CEMENTATION TRIALS IN 1780

Extracts from a Mémoire presented to the French Academy of Sciences in Paris, September 1782, by Chevalier Grignon. It is printed as an appendix to Analyse du Fer (Paris, 1783), a translation of Bergmann's Dissertatio Chemica de Analysi Ferri (Uppsala, 1781). The translation here given covers pp.234-251 of the volume and is by the author.

DDD PROCEDURES FOR THE CONVERSION OF IRON INTO STEEL

Extracts from a Mémoire, signed by Sanche, the proprietor of the Steel Works at Amboise, dating from 1780-85, entitled 'Procédés sur la fabrication de l'acier propre à la taillanderie et le coutellerie' (Procedures for the manufacture of steel suitable for edge tools and cutlery). A copy of the document was kindly provided by Professor J. R. Harris. The translation is by the author.

EEE INSTRUCTIONS CONCERNING THE MANUFACTURE OF STEEL AND ITS USES

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GGG CRUCIBLE STEELMAKING IN AUSTRIA

Extracts from R. F. Bohler, 'Tool Steel Making in Styria', School of Mines Quarterly, Vol. xxix (1908), pp.329-341.

HHH EARLY AMERICAN STEELMAKING

Extracts from Rev. Daniel Little, 'Observations upon the Art of Making Steel, Memorials of the American Academy of Arts and Sciences, Vol.1 (1785), pp.525-528.

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TABLE 1

"STEEL TRADE" SALES

Financial Year	Sales of Blistered or Ruff Steel (cwt.)	Sales of Faggott or Drawn Steel (cwt.)	Sales of Gadd Steel (cwt.)	Sales of Slitt Steel (cwt.)	Total Sales (cwt.)	Selling Price £. s. d.	Proceeds £. s. d.	Profit on Cost %	Mean Selling Price per ton £. s. d.	Derived Cost per ton £. s. d.
1699-1700) 1700-01) 1701-02)	272.53	87.00	35.00	Nil	394.53	461. 8. 7.	(47.15. 5.)	-9.4	23. 8. 0.	25.16. 0.
1702-03	154.40	26.50	17.50	Nil	198.40	228. 2. 6.	(17.10. 6.)	-7.2	23. 0. 0.	24.16. 0.
1703-04	156.92	39.00	18.00	Nil	213.92	254.18. 9.	71.19. 1.	39.3	23. 9. 0.	16.17. 0.
1704-05	196.15	23.00	24.00	Nil	243.15	273.16. 3.	22.14. 1.	9.0	22.10. 0.	20.13. 0.
1705-06	182.74	31.00	18.00	Nil	231.74	241. 2. 2.	23. 8. 0.	10.7	20.16. 0.	18.15. 0.
1706-07	173.24	25.50	0.50	Nil	199.24	204.14. 2.	29. 8. 7.	16.8	20.11. 0.	17.12. 0.
1707-08	165.08	41.00	Nil	Nil	206.08	210. 2. 8.	25. 3. 8.	13.6	20. 8. 0.	17.19. 0.
1708-09	316.39	29.00	Nil	Nil	345.39	369.18. 5.	63.10.11.	20.7	21. 8. 0.	17.15. 0.
1709-10	354.80	93.00	Nil	Nil	438.80	429.10.11.	77.13.10.	22.1	19.12. 0.	16. 1. 0.
1710-11	445.95	157.50	Nil	Nil	603.45	592.13. 5.	60.17. 2.	11.4	19.13. 0.	17.13. 0.
1711-12	408.46	101.50	Nil	Nil	509.56	521.11. 3.	94.13. 8.	22.2	20. 9. 0.	16.15. 0.
1712-13	245.78	50.00	Nil	Nil	295.78	324.16. 6.	33. 1.11.	11.3	21.19. 0.	19.15. 0.
1713-14	417.70	132.50	Nil	Nil	550.20	493.11.11.	77. 6. 3.	18.6	17.19. 0.	15. 3. 0.
1714-15	323.84	98.00	Nil	Nil	421.84	425.19.11.	49.11. 4.	13.2	20. 4. 0.	17.17. 0.
1715-16	369.68	77.00	Nil	Nil	446.68	508. 5. 1.	116. 2. 5.	29.6	22.15. 0.	17.11. 0.
1716-17	305.85	45.00	2.00	Nil	352.85	498. 4. 4.	92.11.11.	22.8	28. 5. 0.	23. 0. 0.
1717-18	520.39	26.50	26.00	Nil	572.89	866. 0. 5.	91.19.10.	11.9	30. 5. 0.	27. 0. 0.
1718-19	637.79	35.50	28.00	Nil	701.29	1097. 2. 6.	136.17.10.	14.3	31. 6. 0.	27. 8. 0.
1719-20	787.52	34.06	36.00	Nil	857.58	1250.12. 0.	151. 7. 4.	13.8	29. 3. 0.	25.12. 0.
1720-21	942.10	83.00	14.00	Nil	1039.10	1285.14. 4.	157.18. 0.	14.0	24.15. 0.	21.14. 0.
1721-22	1065.99	117.33	15.50	Nil	1198.82	1493.19. 2.	234. 7. 4.	18.6	24.18. 0.	21. 0. 0.
1722-23	1057.15	149.88	30.50	Nil	1237.53	1553. 4. 8.	277. 7. 8.	21.7	25. 2. 0.	20.12. 0.
1723-24	1224.93	162.89	20.00	Nil	1407.82	1710. 6. 6.	249. 6. 8.	17.1	24. 6. 0.	20.15. 0.
1724-25	970.57	78.72	8.00	Nil	1057.29	1334.11.10.	124. 5. 5.	10.3	25. 5. 0.	22.18. 0.
1725-26	1166.40	99.18	9.00	Nil	1274.58	1621. 7. 8.	193. 7.11.	13.5	25. 9. 0.	22. 8. 0.
1726-27	716.09	52.50	14.50	Nil	783.09	1022.12. 5.	198.13. 4.	24.1	26. 2. 0.	21. 1. 0.
1727-28	954.29	94.52	7.00	Nil	1050.81	1391. 6. 8.	215. 2. 9.	18.3	26. 9. 0.	22. 7. 0.
1728-29	966.90	159.56	8.00	Nil	1134.46	1361.13. 3.	215. 3. 0.	18.8	24. 0. 0.	20. 4. 0.
1729-30	1174.22	135.00	12.00	Nil	1321.22	1649. 1. 0.	226. 9. 1.	15.9	24.19. 0.	21.10. 0.
1730-31	1078.98	111.00	9.00	Nil	1198.98	1421.11. 6.	185.15. 8.	15.0	23.17. 0.	20.15. 0.
1731-32	1032.85	148.00	3.00	Nil	1183.85	1310. 3. 5.	166. 1. 1.	14.5	22. 3. 0.	19. 7. 0.

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TABLE 1
continued

Financial Year	Sales of Blistered or Ruff Steel (cwt.)	Sales of Faggott or Drawn Steel (cwt.)	Sales of Gadd Steel (cwt.)	Sales of Slitt Steel (cwt.)	Total Sales (cwt.)	Selling Price £. s. d.	Proceeds £. s. d.	Profit on Cost %	Mean Selling Price per ton £. s. d.	Derived Cost per ton £. s. d.
1732-33	1121.98	10.00	10.00	Nil	1141.98	1387.16. 6.	215. 4. 9.	18.4	24. 6. 0.	20.10. 0.
1733-34	1368.99	26.45	8.00	Nil	1421.44	1629.13. 8.	211. 7. 4.	14.9	22.19. 0.	20. 0. 0.
1734-35	1187.66	13.50	11.00	Nil	1212.16	1490. 7.11.	237. 7. 6.	18.9	24.12. 0.	20.14. 0.
1735-36	1272.42	39.50	4.00	Nil	1315.92	1601. 4. 2.	236.10. 8.	17.3	24. 7. 0.	20.15. 0.
1736-37	1397.05	69.00	5.00	Nil	1471.05	1734.14. 4.	269. 9. 6.	18.4	23.12. 0.	19.19. 0.
1737-38	1277.95	160.00	5.00	Nil	1422.95	1609.17. 0.	140. 2. 2.	9.5	22. 6. 0.	20. 7. 0.
1738-39	1002.16	7.55	Nil	Nil	1009.71	1259. 2. 7.	121.11. 3.	10.7	24.19. 0.	22.11. 0.
1739-40	951.21	10.00	Nil	Nil	961.21	1383.19.11.	139.11. 6.	11.2	28.16. 0.	25.18. 0.
1740-41	894.71	10.00	Nil	Nil	904.71	1125. 5.10.	122. 7.10.	12.3	24.16. 0.	22. 1. 0.
1741-42	952.68	11.00	2.00	40.50	1006.18	1178.10. 5.	121. 2. 5.	11.5	23. 9. 0.	21. 1. 0.
1742-43	1158.80	3.50	1.50	52.00	1215.80	1422. 5. 6.	48. 6. 7.	3.5	23. 8. 0.	22.12. 0.
1743-44	1426.42	8.00	Nil	21.50	1455.92	1737. 5. 9.	71.17. 9.	4.3	23.17. 0.	22.17. 0.
1744-45	1898.52	10.50	Nil	45.00	1954.02	2238.18. 4.	322.19. 8.	16.8	22.18. 0.	19.12. 0.
1745-46	1650.87	9.00	Nil	53.00	1712.87	2012. 2. 3.	305. 8. 2.	17.9	23.10. 0.	19.19. 0.
1746-47	1702.57	1.50	Nil	25.50	1729.57	2061.16. 4.	121. 8. 2.	6.3	23.17. 0.	22. 9. 0.
1747-48	2010.58	24.00	Nil	71.50	2106.08	2438.10. 2.	304. 2. 2.	14.2	23. 3. 0.	20. 5. 0.
1748-49	2062.84	6.00	Nil	73.50	2142.34	2554. 4. 5.	320.18. 2.	14.4	23.17. 0.	20.17. 0.
1749-50	2128.86	6.00	Nil	66.50	2201.36	2616.15. 0.	350. 0. 6.	15.4	23.15. 0.	20.12. 0.
1750-51	1883.83	2.00	Nil	53.00	1938.83	2337. 5. 7.	340.13. 0.	17.1	24. 2. 0.	20.12. 0.
1751-52	2132.33	Nil	Nil	48.00	2180.33	2885. 6. 3.	302. 5. 7.	11.7	26. 9. 0.	23.14. 0.
1752-53	1970.30	Nil	Nil	55.00	2025.30	2639.10. 9.	203.17. 9.	8.4	26. 1. 0.	24. 0. 0.
1753-54	1845.70	Nil	Nil	127.00	1972.70	2625.14. 7.	201.13. 3.	8.3	26.13. 0.	24.12. 0.
1754-55	1454.77	Nil	Nil	119.00	1573.77	1979.15. 5.	69. 5.11.	3.6	25. 3. 0.	24. 5. 0.
1755-56	1258.92	Nil	Nil	152.00	1410.92	1705. 0. 8.	103.11. 4.	6.5	24. 3. 0.	22.14. 0.
1756-57	1232.09	Nil	Nil	188.00	1420.09	1680.15. 0.	70.14. 5.	4.4	23.13. 0.	22.13. 0.
1757-58	1239.45	Nil	Nil	145.00	1384.45	1701.18. 9.	93. 3. 9.	5.8	24.12. 0.	23. 5. 0.
1758-59	1646.21	Nil	Nil	120.50	1766.71	2196.16. 8.	101. 0. 7.	4.8	24.17. 0.	23.14. 0.
1759-60	1346.45	Nil	Nil	77.50	1423.95	1751. 2. 6.	137. 5.11.	8.5	24.12. 0.	22.14. 0.
1760-61	1621.62	Nil	Nil	32.00	1653.62	2289. 3. 6.	106. 5. 1.	4.9	27.14. 0.	26. 8. 0.
1761-62	1153.24	Nil	Nil	37.00	1190.24	1615. 5.10.	90. 5. 1.	5.9	27. 3. 0.	25.13. 0.
1762-63	1445.18	Nil	Nil	26.50	1471.68	2054. 0.10.	139. 8. 7.	7.3	27.18. 0.	26. 0. 0.
1763-64	1751.51	Nil	Nil	38.50	1790.01	2384.12. 8.	179. 8.10.	8.1	26.13. 0.	24.13. 0.
1764-65	2077.93	Nil	Nil	77.00	2114.93	2844. 9. 2.	301. 9. 2.	11.9	26.18. 0.	24. 1. 0.

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TABLE 1
continued

Notes

1 The weights quoted in the ledgers are in tons.cwt.qr.lb; they have been converted to decimals of cwt. in order to allow the inclusion of all the necessary data in one table.

2 The first two figures in the Proceeds column given in parentheses are losses. It will be noted that the profit in the financial year 1703-04 is a high one; if the total is taken for the period 1699-1704 (just over 40 tons sales), there is an overall profit of 0.7%.

3 The values for mean selling price and the derived cost per ton are quoted to the nearest whole shilling.

TABLE II

SUMMARY OF CEMENTATION COSTS
(PER TON OF BLISTER STEEL)

	Date	Fuel £. s. d.	Charcoal etc. £. s. d.	Wages £. s. d.	Rates & Interest £. s. d.	Freight £. s. d.	Misc. Expenses £. s. d.	Repairs £. s. d.	TOTAL £. s. d.	Furnace
Blackhall Mill	1754	3. 0.	NQ.	8. 4.	1. 8.	6.	NQ.	NQ.	13. 6.	10T
Cutlers' Co.	1759-62	6.11.	1. 3.	15. 9.	17. 0.	NQ.	NQ.	7. 3.	2. 8. 2.	3¾T
Cutlers' Co.	1769-72	9. 2½.	1. 5½.	5. 5¾.	NQ.	1. 0¾.	5. 3.	3.11½.	1. 6. 5.	7¾T
Birmingham	1767	1.19. 2.	NQ.	9. 5.	NQ.	NQ.	NQ.	7. 6.	2.16. 1.	8-11T
Halstahammar	1787	1. 2. 5½.	1. 9½.	6.10.	2. 3½.	NQ.	NQ.	5.	1.14. 2.	8½T
Marsh Bros.	1834-36	8. 5.	1. 5.	6. 1.	7.	NQ.	2.10.	NQ.	19. 6.	10T(?)
Le Play	1836-42	6. 4½.	2. 4½.	5. 7½.	3.10½.	NQ.	1. 6.	2. 4½.	1. 2. 1½.	18T
Gruner and Lan	1862	5. 5.	3. 9.	6. 0.	3. 0.		2. 4.	2. 8.	1. 3. 8.	20T(?)
Seebohm	1869	7. 3.	2. 4.	5. 7.	1. 9.	2. 0.	6.	8.	1. 0. 1.	NK
Seebohm & Dieckstahl	1887	10. 0.	3. 6.	6. 0.	1. 6.	NQ.	4. 0.	1. 0.	1. 6. 0.	NK

NQ = Not Quoted

NK = Not Known

TABLE III

CRUCIBLE STEEL MELTING TRIALS - BRAND, 1885

CRUCIBLE COMPOSITION				DETAIL	ANALYSIS					COMMENTS
C	SiO_2	Al_2O_3	Fe_2O_3 etc.		C	Si	Mn	S	P	
18.60	42.78	34.71	2.84	Original charge	.23	.12	.74	.029	.223	
(Coke-clay crucible made on premises)*				On fusion	.38	.10	.36	.040	.223	
				45 mins. after fusion	.44	.12		.040	.224	
				90 mins. after fusion	.50	.25		.046	.224	
				135 mins. after fusion	.53	.30	.38	.051	.224	Sound sample
40.43	24.63	27.89	6.78	Original charge	.23	.12	.74	.029	.223	
(Graphite crucible from Becker and Piscantor)				60 mins. after fusion	.84	.21		.035		Rising slightly
				210 mins. after fusion	.95	.30		.039		Sound sample
Nil	53.92	40.57	5.28	Original charge	.36	.14	1.09	.028	.219	
(Clay crucible made on premises)‡				60 mins. after fusion	.33	.13		.037		Rising markedly - unsound
				120 mins. after fusion	.28	.18		.041		Rising slightly

* Said to be made from a mixture of three parts 'white clay', two parts calcined 'blue clay' and two parts coke.

‡ Said to be made from a mixture of two parts 'white clay' and three parts 'fine blue clay'.

TABLE IV

CRUCIBLE STEEL MELTING TRIALS - MULLER, 1886

Crucibles made from 60 parts Palatine chamotte pipe clay, 25 parts Palatine clay and 15 parts Ceylon graphite

CHARGE	COMMENTS	ANALYSIS Charge C	Si	Mn	Ingot C	Si	Mn
9 kg white iron + 21 kg bar iron (all Swedish)	Liquid after 3¾ hrs. Held for further 1¾ hrs. Ingot sound	1.22	.05	.45	1.21	.14	.19
9 kg white iron + 17½ kg bar iron (both Swedish) + 1 kg charcoal spiegeleisen	Liquid after 2¾ hrs. Held for further 2 hrs. Ingot sound	1.49	.05	.80	1.61	.23	.43
As above; crucible lined with clay	Clay coating destroyed, otherwise as above	1.49	.05	.80	1.54	.24	.35
29.2 kg Siegerland raw steel + 0.8 kg ferromanganese	Liquid after 3½ hrs. Held only a further ¼ hr. Crucible badly attacked; ingot slightly porous	1.04	.14	2.45	1.05	.19	1.82
As above	Held for further 1¾ hrs. after fusion. Much slag, crucible seriously attacked, ingot sound	1.04	.14	2.45	1.36	.64	.83
Half the ingot from original trial with raw steel + ferro-manganese	Liquid after 2½ hrs. Held a further 3¼ hrs. Crucible very strongly attacked	1.05	.19	1.82	1.27	.84	.94

TABLE V

TYPICAL HIGH SPEED STEEL COMPOSITIONS

Date	Description	C	Cr	W	V	Mo	Co	
From Seebohm Records (BDR 97):								
1904	SA30	0.6	3.4	13.6	-	-	-	
1905	SA34	0.6	3.7	15.2	-	-	-	
1906	SA43	0.7	3.8	18.5	-	-	-	
1908	SA80	0.5	3.6	20.0	0.4	-	-	
1909	SA95	0.6	3.6	18.0	0.8	1.8	-	
1911	SA147	0.7	3.7	18.4	0.2	-	1.0	
1912	SA157	0.6	6.3	19.8	1.9	-	-	
1913	SA181	0.6	3.5	17.4	0.2	-	5.0	
1913	SA183	0.7	4.6	16.7	1.0	1.1	5.0	
1913	SA187	0.7	3.7	18.4	1.0	-	1.3	
?	SA230	0.6	3.7	nil	1.0	6.4	6.0	
?	SA234	0.6	3.6	nil	1.7	9.4	-	
From Vickers, Son and Maxim Crucible Book:								
1903	VSM HS	0.7	2.0	11.3				
1903	VSM HSA	0.7	3.5	12.5				
1903	NOVO	0.7	2.8	18.0				(1)
1904	VSM HST	0.6	3.5	18.0				
1905	OSBORN MUSHET	0.6	5.1	14.0				
1905	SEEBOHMS CAPITAL	0.5	3.0	13.0				
1907	VSM HS3V	0.6	3.0	18.0	0.3			
1907	BEARDSHAWS	0.5	4.9	13.5				
1908	NOVO SUPERIOR	0.6	2.7	18.0	0.8			(1)
1910	VSM HS3P	0.7	3.3	18.7	0.9			
1915	TRIUMPH SUPERB	0.7	4.3	15.8	1.2	-	1.2	(2)
1915	VSM AE105	0.7	4.3	18.0	1.3			
1921	VSM SBST	0.8	4.1	18.8	1.7			
From John Brown Analysis Book:								
1903	FIRTH SPEEDICUT	1.1	6.1	9.5				(3)
1904	ATLAS SH	0.4	7.0	10.9	0.5			(4)
1904	ATLAS SH	0.7	5.9	12.7	0.4			(4)
1905	NOVO	0.8	3.3	16.2				(1)
1905	ATLAS HS	0.7	4.5	16.9				
1906	EDGAR ALLEN	0.8	3.8	12.6				
1906	GERMAN SH	0.9	6.3	23.7				
1907	A & D MAXIMUM	0.7	5.3	17.7	1.1			(5)

continued

TABLE V
continued

Date	Description	C	Cr	W	V	Mo	Co	
1907	OSBORN SH	0.8	2.7	14.4				
1908	OSBORN SH	0.6	3.7	13.4	0.2			
1909	ATLAS EXTRA	0.4	3.0	15.6	0.4			
1909	NOVO SUPERIOR	0.6	3.0	18.9	0.2			(1)
1909	FLOCKTON & TOMPKINS	0.7	2.7	16.2	0.9			
1909	NOVO SUPERIOR	0.6	2.8	17.7	1.2			
1909	INMANS	0.6	4.9	17.2	0.8			
1910	FIRTH SPEEDICUT MAX	0.8	5.5	15.5	0.8	0.8	-	
1910	HUNTSMAN HS	0.5	5.0	13.7	0.1	-	-	
1911	EDGAR ALLEN HS	0.7	3.9	13.9	1.9	-	-	
1911	SAVILLE TRIUMPH	0.6	3.7	15.4	1.1	0.5	-	
1912	SAVILLE TRIUMPH SUPERB	0.8	3.7	15.1	1.6	0.6	-	
1912	OSBORN	0.7	4.1	14.0	0.4	-	-	
1912	GOODWINS	0.8	3.2	13.6	-	-	-	
1914	ALFRED HERBERT	0.6	5.3	12.4	0.7	-	5.1	
1914	VICKERS IRIDIUM	0.7	4.4	15.8	1.2	5.0	-	
1914	INMANS	0.6	3.8	12.7	0.1	-	-	
1914	KAYSER ELLISON	0.4	3.3	12.8	0.2	-	-	
1914	ARMSTRONG WHITWORTH	0.5	3.0	13.3	0.5	-	-	
1915	APEX HS	0.6	4.3	14.9	-	-	-	(6)
1915	Not identified	0.5	3.3	14.1	0.1	-	-	
1917	AMERICAN CRUCIBLE	0.6	4.5	-	-	3.8	-	
1918	HADFIELD HSS	0.8	4.1	14.1	0.4	-	-	
1918	ATLAS HS	0.5	3.6	17.9	0.6	-	-	
1920	HOWELLS HSS	0.7	3.4	15.5	1.3	-	-	
1920	HOWELLS HSS	0.7	3.6	16.7	1.0	-	-	

(1) These are grades by Jonas and Colver, Sheffield.

(2) Made by J. & J. Saville (later amalgamated with Wm. Jessop & Sons).

(3) This is quite clearly a transitional stage between Self Hard and High Speed.

(4) These two are the earliest known examples of the use of vanadium; again they are transitional types.

(5) Made by the French firm Aubert et Duval.

(6) Produced by Huntsmans.

Please note that the manganese and silicon contents of all the alloys are all under 0.5% each and in the majority of cases are under 0.3%, in contrast to the Self Hard steels which mainly show manganese contents over 1.5% and sometimes in excess of 3.0%; the silicon contents also tend to be in excess of 0.5%.

TABLE VI

SEEBOHM AND DIECKSTAHL/ARTHUR BALFOUR

CRUCIBLE STEEL OUTPUT, INGOT TONS PER ANNUM

Year	Carbon Steel	Self Hard	High Speed	Other Alloy Steel	Total
1883	2371	-	-	-	2371
1884	2373	-	-	-	2373
1885	2209	-	-	-	2209
1886	2157	-	-	-	2157
1887	1633	6	-	45	1684
1888	2379	33	-	9	2421
1889	2890	49	-	7	2946
1890	2939	17	-	17	2973
1891	2143	16	-	5	2164
1892	1972	43	-	7	2022
1893	2015	20	-	7	2042
1894	1890	16	-	7	1913
1895	1984	11	-	12	2007
1896	2506	24	-	17	2547
1897	2726	16	-	17	2759
1898	2864	22	-	18	2904
1899	3568	35	-	15	3618
1900	3396	33	-	17	3446
1901	2014	12	64	270	2360
1902	1877	4	100	236	2217
1903	1825	2	128	206	2161
1904	1952	-	149	95	2196
1905	2886	1	221	319	3427
1906	1866	1	284	152	2303
1907	2908	1	406	148	3473
1908	1712	2	218	116	2048
1909	1696	3	429	121	2249
1910	2120	2	399	144	2665
1911	2329	4	390	154	2877
1912	2500	5	457	115	3077
1913	2449	3	571	112	3135
1914	1765	2	484	140	2391
1915	1549	1	753	127	2430
1916	1798	-	1235	137	3170
1917	1678	1	1539	126	3343
1918	1592	4	1135	67	2794
1919	1332	2	643	52	2027
1920	1370	3	794	147	2311
1921	363	-	129	34	526
1922	492	-	113	54	659

TABLE VII

SEEBOHM AND DIECKSTAHL

PERCENTAGE DISTRIBUTION OF PRODUCTION FOR SELECTED YEARS

Year	Total Tons (Nominal)	Grade 0 1.50% C	Grade 0½ 1.45% C	Grade 1 1.35% C	Grade 3 1.25% C	Grade 3½ 1.20% C	Grade 4 1.10% C	Grade 5 1.00% C	Grade 6 0.90% C	Total C	SH	HS	Other Alloy
1884	2373	0.55	0.42	30.59	20.27	9.28	23.30	6.49	9.10	100.0	nil	nil	nil
1889	2946	2.27	1.46	23.39	21.15	29.39	16.40	2.51	1.53	98.10	1.66	nil	0.24
1899	3618	1.33	0.66	19.57	43.42	11.61	14.40	1.13	6.50	98.62	0.97	nil	0.41
1905	3427	2.74	0.41	9.13	33.62	5.95	13.42	5.46	13.48	84.21	0.03	6.45	9.31
1913	3135	4.72	0.32	13.36	11.58	15.73	16.24	4.31	11.86	78.12	0.10	18.21	3.57
1917	3343	3.26	2.42	19.47	16.30	nil	3.38	0.87	4.45	50.15	0.03	46.05	3.77
1922	659	11.08	0.61	27.92	28.07	nil	2.88	0.30	3.79	74.65	nil	17.15	8.20

TABLE VIII

PRODUCTION OF STEEL BY THE UCHATIUS METHOD
AT VIKSMANSHYTTAN, SWEDEN

(C. Sahlin, Med Hammare och Fackla, vol.IV
(1932), p.90)

(Figures in tons)

1864	14.2	1898	451.4
1870	120.4	1899	578.7
1875	88.0	1900	597.5
1876	91.1	1901	647.4
1877	100.0	1902	723.4
1878	132.0	1903	758.8
1879	53.3	1904	742.3
1880	90.0	1905	713.7
1881	70.6	1906	753.8
1882	94.8	1907	610.2
1883	170.0	1908	677.0
1884	261.0	1909	462.0
1885	276.0	1910	1028.2
1886	211.0	1911	1245.4
1887	175.0	1912	1448.3
1888	230.0	1913	1991.0
1889	293.5	1914	1693.0
1890	431.0	1915	2039.0
1891	483.0	1916	1821.9
1892	208.3	1917	1289.0
1893	264.7	1918	605.0
1894	151.6	1919	927.8
1895	287.8	1920	1012.6
1896	288.9	1921	437.6
1897	274.7	1922	302.0
		1923	455.0

TABLE IX

PRODUCTION OF CRUCIBLE STEEL IN FRANCE

(in thousands of metric tonnes)

Year	Crucible Steel	Total Steel Production
1904	8	2096
1905	15	2255
1906	15	2452
1907	17	2767
1908	16	2723
1909	18	3039
1910	20	3413
1911	24	3837
1912	22	4429
1913	24	4687
1914	22	2802
1915	24	1111
1916	32	1784
1917	40	1991
1918	40	1800
1919	19	2156
1920	22	2706
1921	15	3099
1922	8	4538
1923	*	5302
1924	14	6670
1925	13	7446
1926	15	8388

* The figure is given as 280 but this is clearly in error as the melting capacity was just not available.

TABLE X

STATISTICS OF GERMAN STEEL PRODUCTION, 1837-1850

Year	Raw Steel (tons)	Refined Steel (tons)	Cast Steel (tons)
1837	5115	2090	34
1838	5010	2968	40
1839	4947	2771	36
1840	4819	3376	31
1841	4955	3427	45
1842	4720	3026	45
1843	5301	2992	45
1844	4953	3366	74
1845	5385	3468	86
1846	4034	2335	60
1847	5545	2668	214
1848	5181	2541	249
1849	4332	2640	547
1850	5297	3365	868

Cemented steel is included in the weight of raw steel, from which material both the refined and the cast steel were made.

The above information is derived from J. S. Jeans, Steel: Its History, Manufacture, Properties and Uses (London, 1880), pp.170-171. The figures are quoted in centners in the original; they have been converted to tons on the basis of 1 centner = 50 kilograms = 0.0492 tons.

TABLE XI

PRODUCTION OF CRUCIBLE STEEL IN GERMANY
(in thousands of metric tonnes)

Year	Crucible Steel	Total Steel Production
1908	88	11186
1909	84	12050
1910	83	13699
1911	79	15019
1912	79	17302
1913	85	18935
1914	95	14946
1915	101	13258
1916	108	16183
1917	130	16587
1918	87	14980
1919	41	7847
1920	37	9278
1921	36	9997
1922	36	11714
1923	16	6305
1924	92	9835

(1 metric tonne = 0.984 British ton)

TABLE XII

STEEL MAKING FACILITIES IN PITTSBURGH IN 1876

Information taken from G. H. Thurston, Pittsburgh and Allegheny in the Contennial Year (Pittsburgh, 1876), p.196

Style of Firm	Name of Works	Founded	Original Founder	Coke Melting Holes	24 Pot Siemens Furnaces	Cemen-tation Furnaces	Puddling Furnaces	Annual Steel Capacity in Tons
Anderson and Woods	Pittsburgh	1845	Isaac Jones	48	4	6	25	7,000
Singer, Nimick & Co.	Sheffield	1848	Singer, Nimick & Co.	30	4	8	17	12,000
Hussey, Wells & Co.	-	1859	Hussey, Wells & Co.	75	6	none	16	13,000
Park Brothers & Co.	Black Diamond	1862	Park Brothers & Co.	72	2	6	not stated	10,000
Smith Sutton & Co.	La Belle	1863	Reiter, Hartman & Co.	24	none	4*	6	6,000
Miller, Metcalf & Parkin	Crescent	1865	Barr & Parkin	34	4	3	none	4,000
Reese, Graff & Woods	Fort Pitt	1865	Reese, Graff & Dull	12	2	2	6	not stated
Brown & Co.	Wayne	1870?	Brown & Co.	24	1	2	none	not stated
Jones, Ingold & Co.	Pitt	1875	C.E. Jones & Co.	none	1	none	none	2,400

* 25 ton capacity each

In addition, the Crucible Casting Company Ltd., making only steel castings, commenced operations in 1875 with three cementation furnaces and 8 melting holes, with an annual capacity of 600 tons.

TABLE XIII

AMERICAN STEEL PRODUCTION STATISTICS (NET SHORT TONS)

Year	Crucible Steel		Cementation and Miscellaneous	Total Production (All Processes)
1863		9,044		9,044
1864		10,369		10,369
1865		15,262		15,262
1866		18,973		18,973
1867		19,000		22,000
1868		21,500		30,000
1869		22,000		35,000
1870		33,500		77,000
1871		35,000		82,000
1872	29,260		7,740	160,108
1873	34,786		13,713	222,652
1874	36,328		6,353	241,614
1875	39,402		12,606	436,575
1876	39,383		10,306	597,174
1877	40,430		11,924	637,972
1878	42,906		8,557	819,814
1879	56,780		5,464	1,047,506
1880	72,424		8,465	1,397,015
1881	89,762		3,047	1,778,912
1882	85,090		3,014	1,945,095
1883	80,455		5,599	1,874,359
1884	59,662		5,111	1,736,985
1885	64,511		1,697	1,917,350
1886	80,610		2,651	2,870,004
1887	84,420		6,265	3,739,759
1888	78,713		4,124	3,247,373
1889	84,969		5,734	3,792,020
1890	79,716		4,248	4,790,320
1891	71,296		5,022	4,372,748
1892	94,874		5,094	5,518,891
1893	71,247		3,143	4,502,395
1894	57,906		4,571	4,941,476
1895	75,786		961	6,848,614
1896	67,972		2,681	5,915,492
1897	78,354		3,373	8,015,792
1898	100,517		4,257	10,064,800
1899	113,359		5,571	11,916,640
1900	112,629		5,446	11,410,928
1901	110,335		6,127	15,090,426
1902	126,305		9,392	16,740,920
1903	114,726		10,981	16,279,175
1904	93,398		10,293	15,523,071
1905	114,501		10,039	22,426,821
1906	142,815		16,105	26,205,913

.... continued

TABLE XIII
continued

Year	Crucible Steel		Cementation and Miscellaneous	Total Production (All Processes)
1907	146,892		15,764	26,166,105
1908	71,267		6,868	15,706,037
1909	120,238		10,288	26,829,624
1910	136,979		3,577	29,226,309
1911	109,371		3,185	26,517,238
1912	136,099		3,195	35,001,459
1913	135,773		4,291	35,056,979
1914	100,653		4,057	26,334,594
1915	127,436		1,710	36,009,161
1916	145,255		676	47,906,522
1917	141,922		554	50,467,880
1918	128,925		368	49,797,823
1919	71,201		3,306	38,831,779
1920	80,937		3,959	47,188,886
1921	8,527		1,058	22,157,853
1922		32,039	*	39,875,277
1923		49,368		50,336,940
1924		25,170		42,483,772
1925		21,910		50,840,747
1926		17,352		54,089,014
1927		10,120		50,327,407
1928		8,701		57,729,481
1929		7,442		63,205,490
1930		2,523		45,583,421
1931		1,733		29,058,961
1932		722		15,322,901
1933		763		26,020,229
1934		595		29,181,924
1935		719		38,183,705
1936		914		53,499,999
1937		1,046		56,636,945
1938		7		31,751,980
1939		931		52,798,714
1940		1,024		66,982,686
1941		2,313		82,839,259
1942		2,010		86,031,931
1943		146		88,836,512
1944		25		89,641,600
1945		24		79,701,648
1946		nil		66,602,724

* Hereafter negligible and included in crucible steel total.

TABLE XIV

TYPICAL AMERICAN CRUCIBLE CHARGES FOR HIGH SPEED STEEL(1)

	Using Scrap	Virgin Charge
Muck Bar*	53 lb.	66 lb.
High Speed Scrap	25 lb.	nil
Ferrotungsten (75% W)**	18 lb. 6 oz.	22 lb. 11 oz.
Ferrochrome (55% Cr)**	4 lb. 9 oz.	5 lb. 14 oz.
Ferrovanadium (34% V)	3 lb.	3 lb. 1 oz.
Ferrosilicon (50% Si)	15 oz.	12 oz.
Ferromanganese (80% Mn)	14 oz.	15 oz.
Total	105 lb. 12 oz.	99 lb. 5 oz.
Carbon contained in charge	0.36%	0.25%
Graphite pots	2nd heaters	1st heaters
Added to each pot		
Brick dust	1 lb. 8 oz.	1 lb. 8 oz.
Sand	1 lb.	8 oz.
Analysis of final steel		
Carbon	0.64%	0.68%
Silicon	0.22%	0.19%
Manganese	0.28%	0.24%
Sulphur	0.019%	0.018%
Phosphorus	0.019%	0.022%
Chromium	3.94%	4.04%
Tungsten	18.02%	18.40%
Vanadium	1.03%	0.97%

* 'Muck bar' is the American term for wrought iron and here refers to what the English would term 'bar iron'.

** There is a discrepancy here. If there was no loss on melting this mixture on the virgin charge would require 80.5% W in the ferrotungsten and 68.3% Cr in the ferrochrome. These are nearer the percentages in the alloys in this country when I first became aware of them in 1936.

(1) M. A. Grossmann and E. C. Bain, High Speed Steel (New York, 1931), p.4.

TABLE XV

PRODUCTION OF CRUCIBLE STEEL IN JAPAN

Year	Number of Furnaces	Ingot Tons
1905	-	280
1907	-	91
1909	-	138
1911	1	284
1912	-	662
1913	-	538
1914	-	550
1915	-	1746
1916	-	4946
1917	-	11476
1918	31	8830
1919	29	6608
1920	-	1751
1921	51	2427
1922	51	2902
1923	-	1517
1924	30	797
1925	20	1204
1926	26	2747
1927	26	1175
1928	26	1503
1929	26	1778
1930	26	1771
1931	-	1536
1932	-	2296
1933	-	2191
1934	-	1120
1935	-	1200
1936	-	1238

FIGURE 1

FIGURE 1 STEEL: RELATIONSHIP BETWEEN TENSILE STRENGTH, DUCTILITY, HARDNESS AND TOUGHNESS

The Tensile Strength and Toughness values are quoted in terms of the units which were used prior to the introduction of the S.I. units :

1 ton per square inch = 15.44 Newtons per square millimetre.

The relationship between hardness and tensile strength remains reasonably constant for any material. The figures shown for ductility and toughness, here, are reasonably typical for a medium carbon steel in small bar size in the hardened and tempered condition. They should only be considered as showing typical trends.

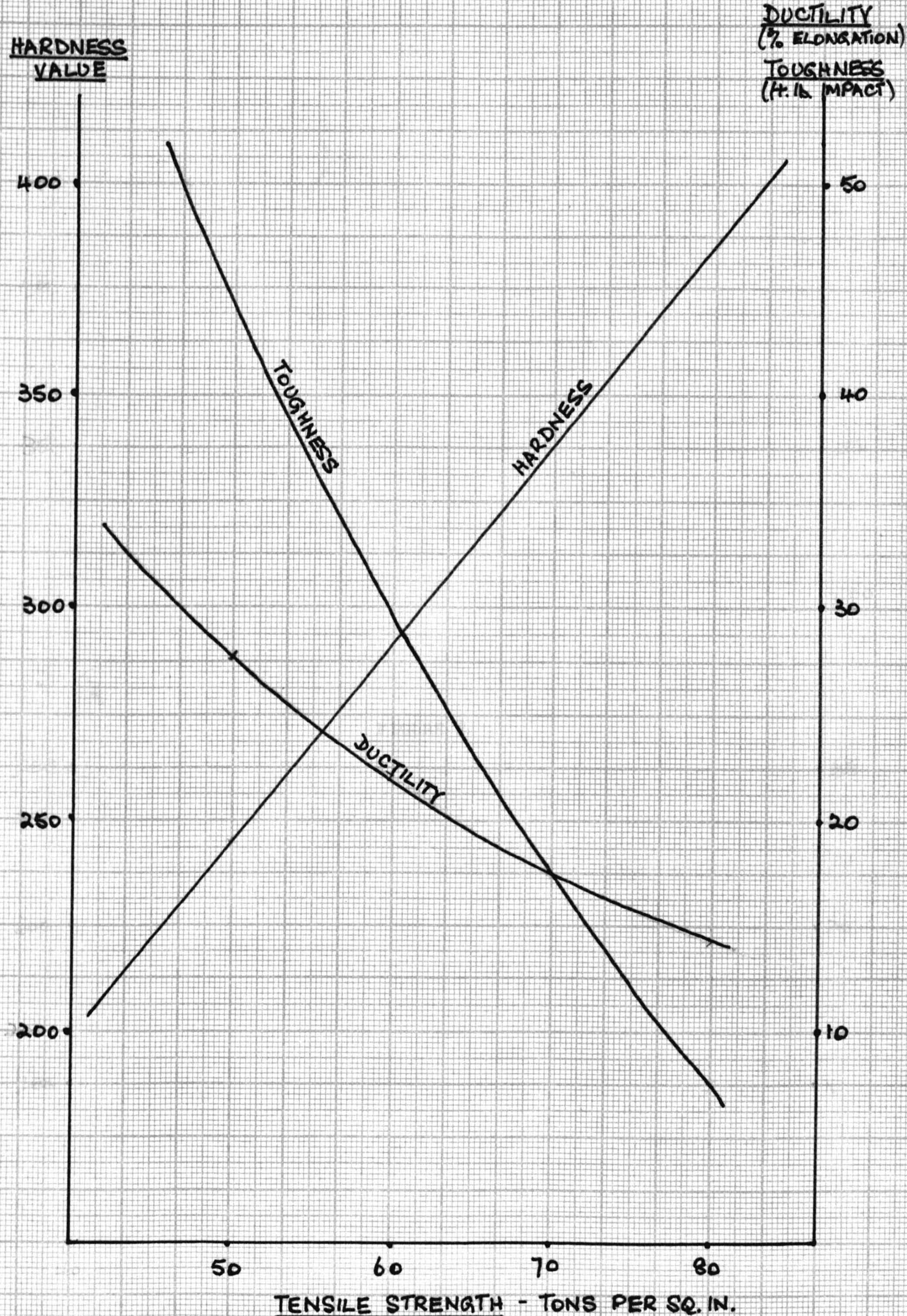
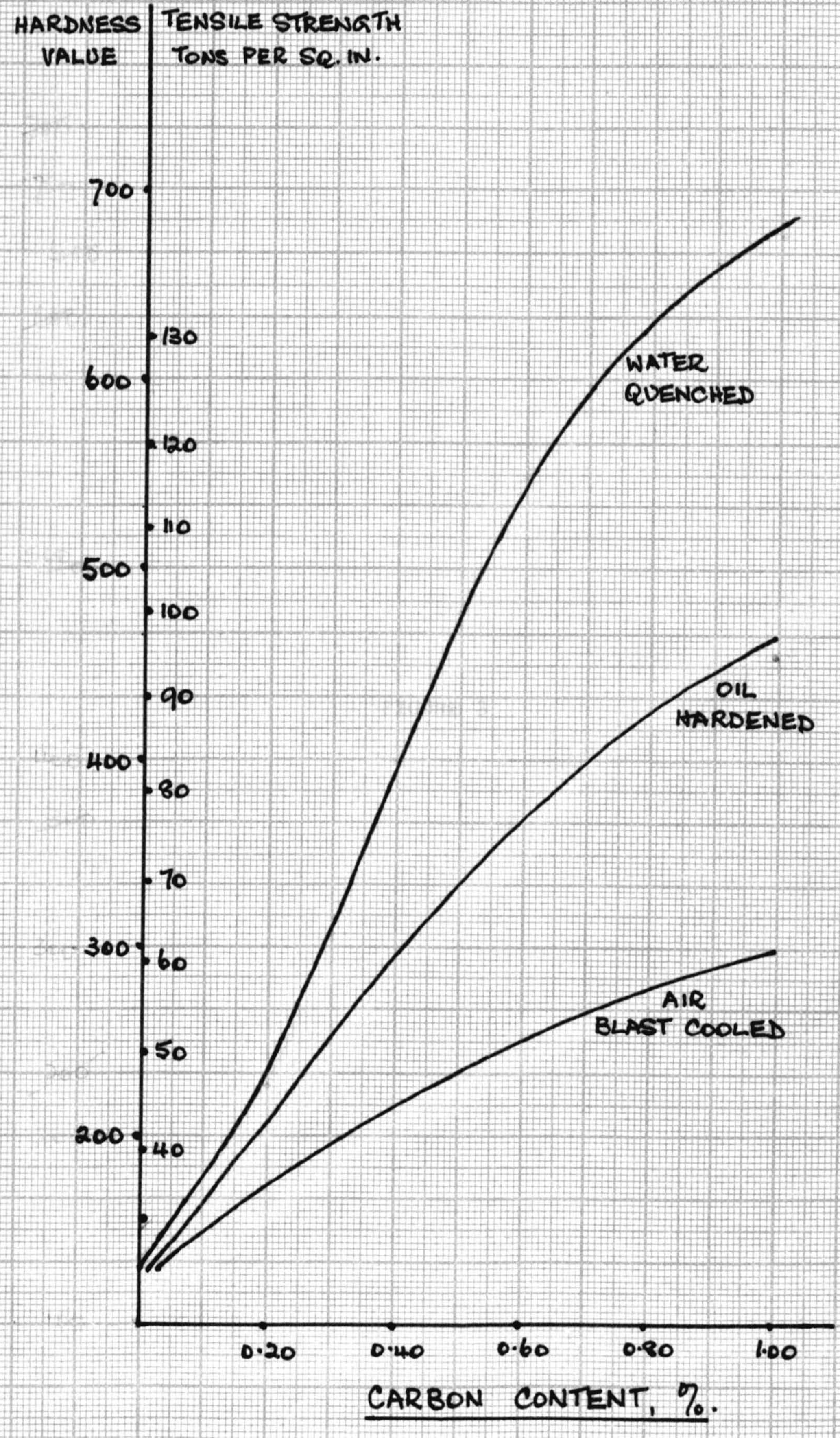

HARDNESS VALUE
DUCTILITY (% ELONGATION)
TOUGHNESS (ft. lb. IMPACT)
400
350
300
250
200
50
40
30
20
10
TOUGHNESS
HARDNESS
DUCTILITY
50
60
70
80
TENSILE STRENGTH - TONS PER SQ. IN.

FIGURE 2

FIGURE 2 THE RELATIONSHIP BETWEEN HARDNESS AND CARBON CONTENT FOR SMALL SECTION BARS IN CARBON STEEL IN VARIOUS HARDENED CONDITIONS

The figures are typical of the values likely to be obtained by heating small bar samples of steel to a temperature of between 900 and 1000°C and then cooling to room temperature by the treatments indicated.



HARDNESS VALUE
TENSILE STRENGTH TONS PER SQ. IN.
700
600
500
400
300
200
130
120
110
100
90
80
70
60
50
40
WATER QUENCHED
OIL HARDENED
AIR BLAST COOLED
0·20
0·40
0·60
0·80
1·00
CARBON CONTENT, %.

FIGURE 3

FIGURE 3 THE EFFECT OF CARBON CONTENT ON THE MELTING AND FREEZING POINT OF IRON

Pure iron freezes and melts at 1535°C. An alloy of iron with 4.3% carbon freezes and melts at a temperature of 1130°C; this is a "eutectic" alloy. All other iron carbon alloys melt and freeze over a temperature range. This is determined by the line AC, which is known as the LIQUIDUS, and the line AB, then continued along BC, known as the SOLIDUS. On heating, therefore, when the solidus line is reached, partial melting begins, continuing as the temperature rises, culminating in the alloy becoming completely liquid when the liquidus line is reached. The reverse occurs on cooling. The maximum permissible forging temperature lies below the solidus line, typically as indicated by the line DE. Alloys with more than 1.5% carbon are virtually unforgeable.

Also indicated are the classes of material, as defined by carbon content, steel for the purposes of the current discussion being an alloy of iron containing from 0.5% to 1.5% carbon.

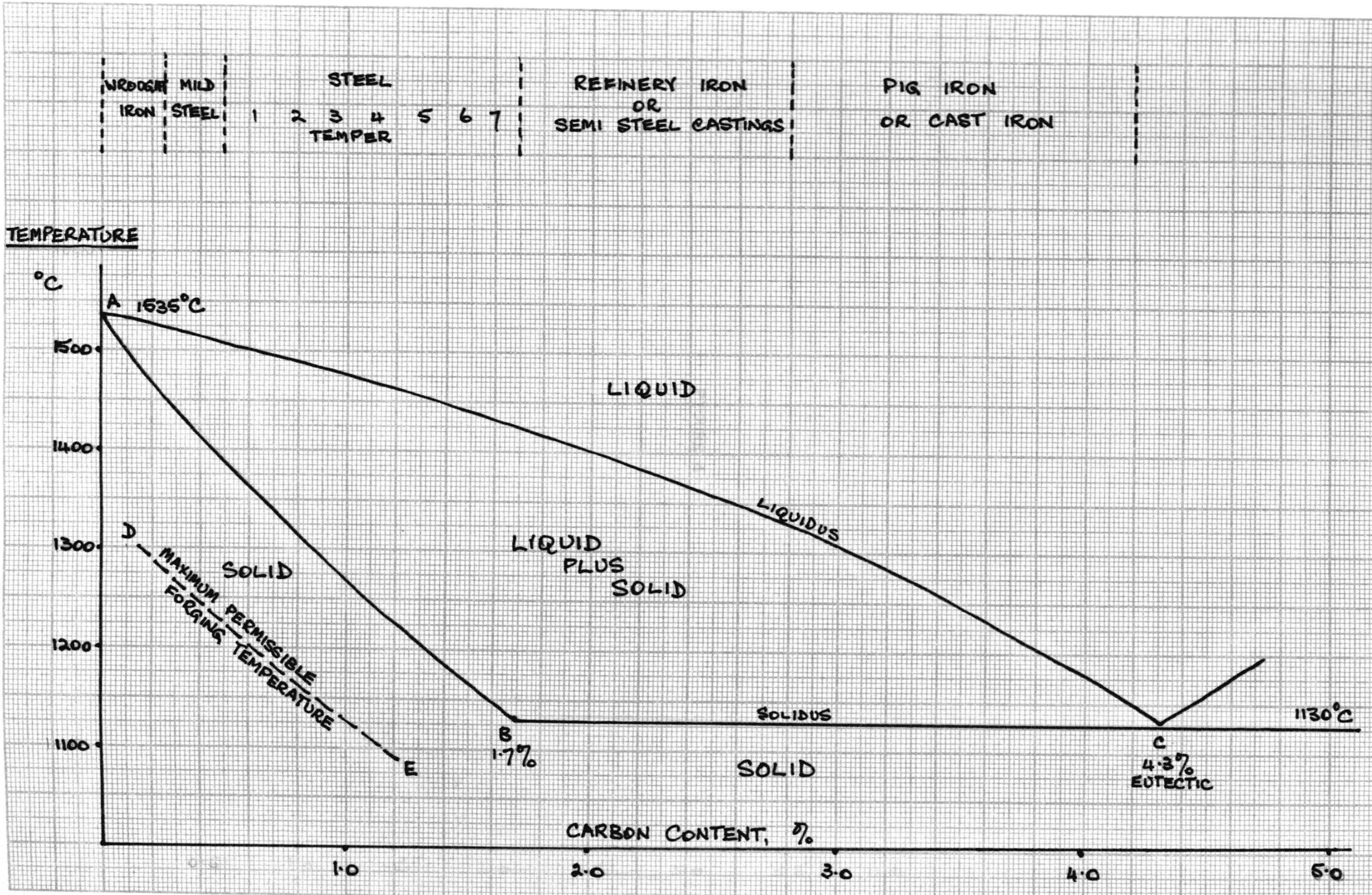
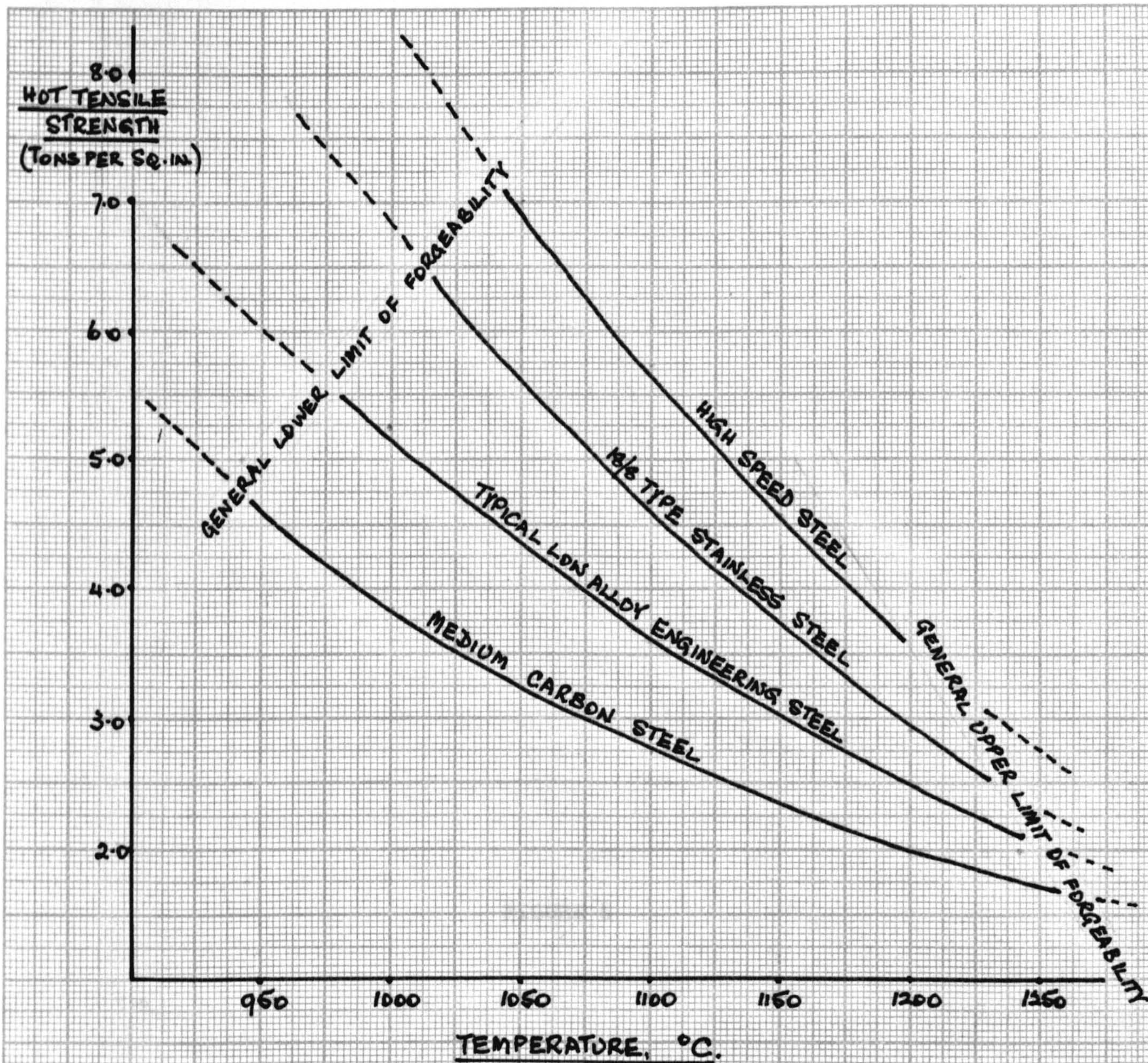

WROUGHT IRON
MILD STEEL
STEEL
1 2 3 4 5 6 7
TEMPER
REFINERY IRON OR SEMI STEEL CASTINGS
PIG IRON OR CAST IRON
TEMPERATURE
°C
A 1535°C
1500
1400
1300
1200
1100
LIQUID
LIQUIDUS
LIQUID PLUS SOLID
SOLID
D
MAXIMUM PERMISSIBLE FORGING TEMPERATURE
E
B 1·7%
SOLIDUS
1130°C
C 4·3% EUTECTIC
SOLID
CARBON CONTENT, %
1·0
2·0
3·0
4·0
5·0

FIGURE 4

FIGURE 4 TYPICAL HOT STRENGTH COMPARISON FOR VARIOUS TYPES OF STEEL AT FORGING TEMPERATURES

The hot strength (or its resistance to deformation) of steel falls as the temperature rises. In general, as alloys are added to steel the hot strength rises at any given temperature. As the strength rises, the brittleness tends to increase. Furthermore, the addition of alloys to steel, in general, lowers the melting point and, in particular, the solidus temperature. The nett combination of these factors is illustrated here, giving rise to a restricted temperature range, with higher resistance to deformation under the forging hammer, for the alloy steels, high speed steel being a particularly difficult alloy.

The effect of carbon content on the hot strength of the plain carbon steels is shown in Figure 4A.


HOT TENSILE STRENGTH (TONS PER SQ. IN.)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
GENERAL LOWER LIMIT OF FORGEABILITY
HIGH SPEED STEEL
18/8 TYPE STAINLESS STEEL
TYPICAL LOW ALLOY ENGINEERING STEEL
MEDIUM CARBON STEEL
GENERAL UPPER LIMIT OF FORGEABILITY
950
1000
1050
1100
1150
1200
1250
TEMPERATURE, °C.

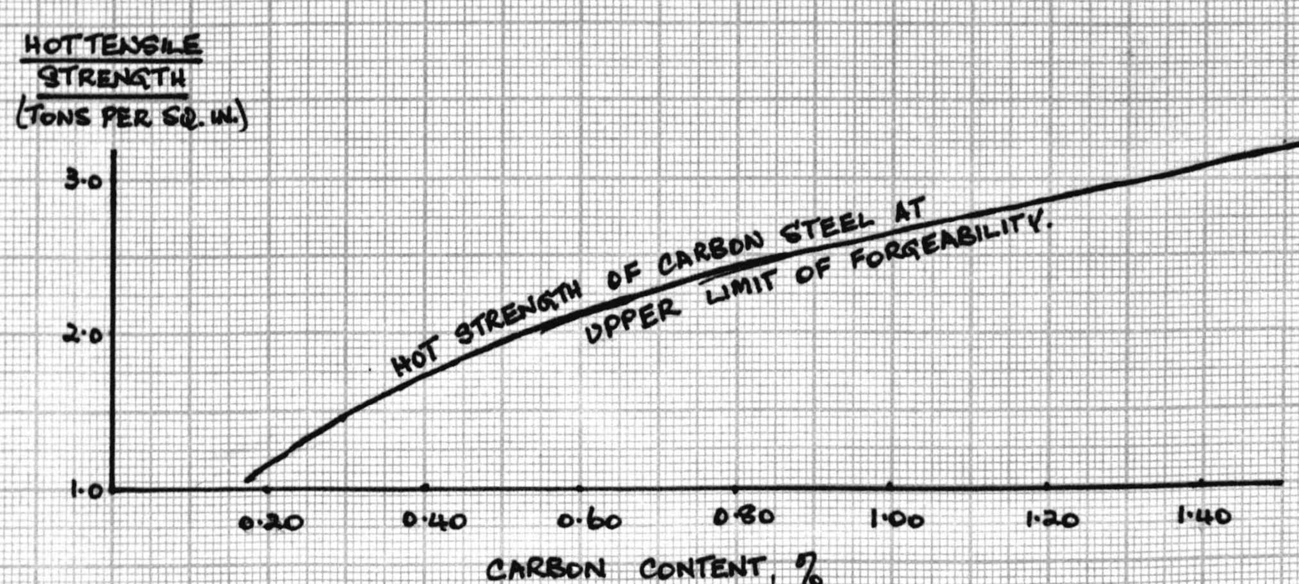

HOT TENSILE STRENGTH (TONS PER SQ. IN.)
3.0
2.0
1.0
HOT STRENGTH OF CARBON STEEL AT UPPER LIMIT OF FORGEABILITY.
0.20
0.40
0.60
0.80
1.00
1.20
1.40
CARBON CONTENT, %

FIGURE 5

FIGURE 5 SCHEMATIC DRAWING OF A HIGH SHAFT MEDIEVAL BLOOMERY
(after Pleiner)

Drying and roasting of the ore takes place in Zone 1.

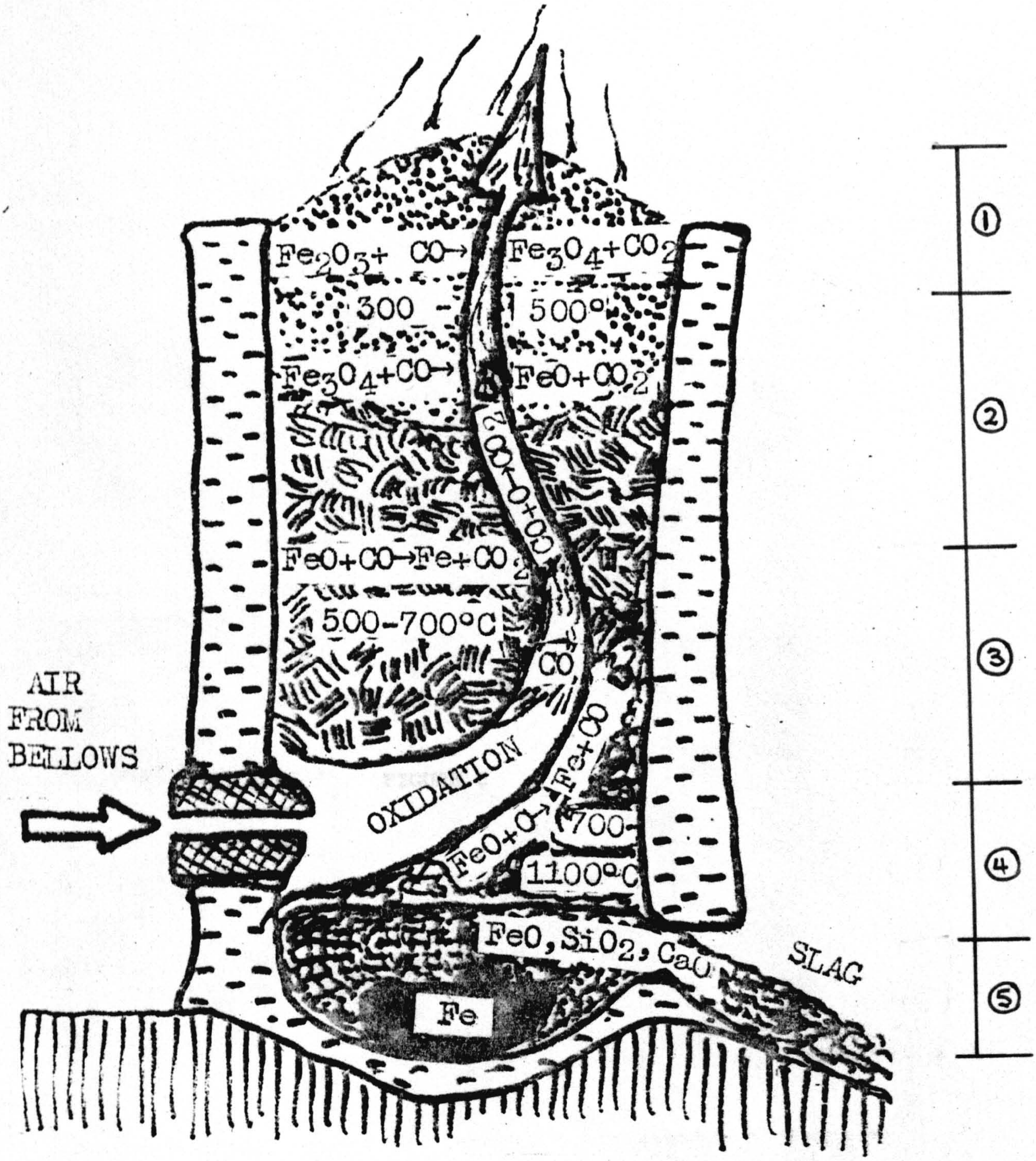
In Zone 2, indirect reduction of the ore takes place by reaction with the carbon monoxide produced below.

Zone 3 is the oxidation zone where charcoal is burned to produce heat and also carbon monoxide for reduction.

Zone 4 is the hearth where direct reduction of iron oxide by the carbon in the charcoal can occur.

Zone 5 is the slag bath, where any adventitious carburisation of the iron tends to be removed and where the slag flows off, leaving a slag-coated bloom of metallic iron.

The gas flow indicated should not be taken literally; there is a general passage of the products of combustion upwards through innumerable small channels in the upper charge materials.



Fe_2O_3+ CO→ Fe_3O_4+CO_2
300 500°
Fe_3O_4+CO→ FeO+CO_2
FeO+CO→Fe+CO_2
500-700°C
2CO+O+CO
CO_2
AIR
FROM
BELLOWS
OXIDATION
FeO+C→Fe+CO
700
1100°C
FeO, SiO_2, CaO
SLAG
Fe
①
②
③
④
⑤

FIGURE 6

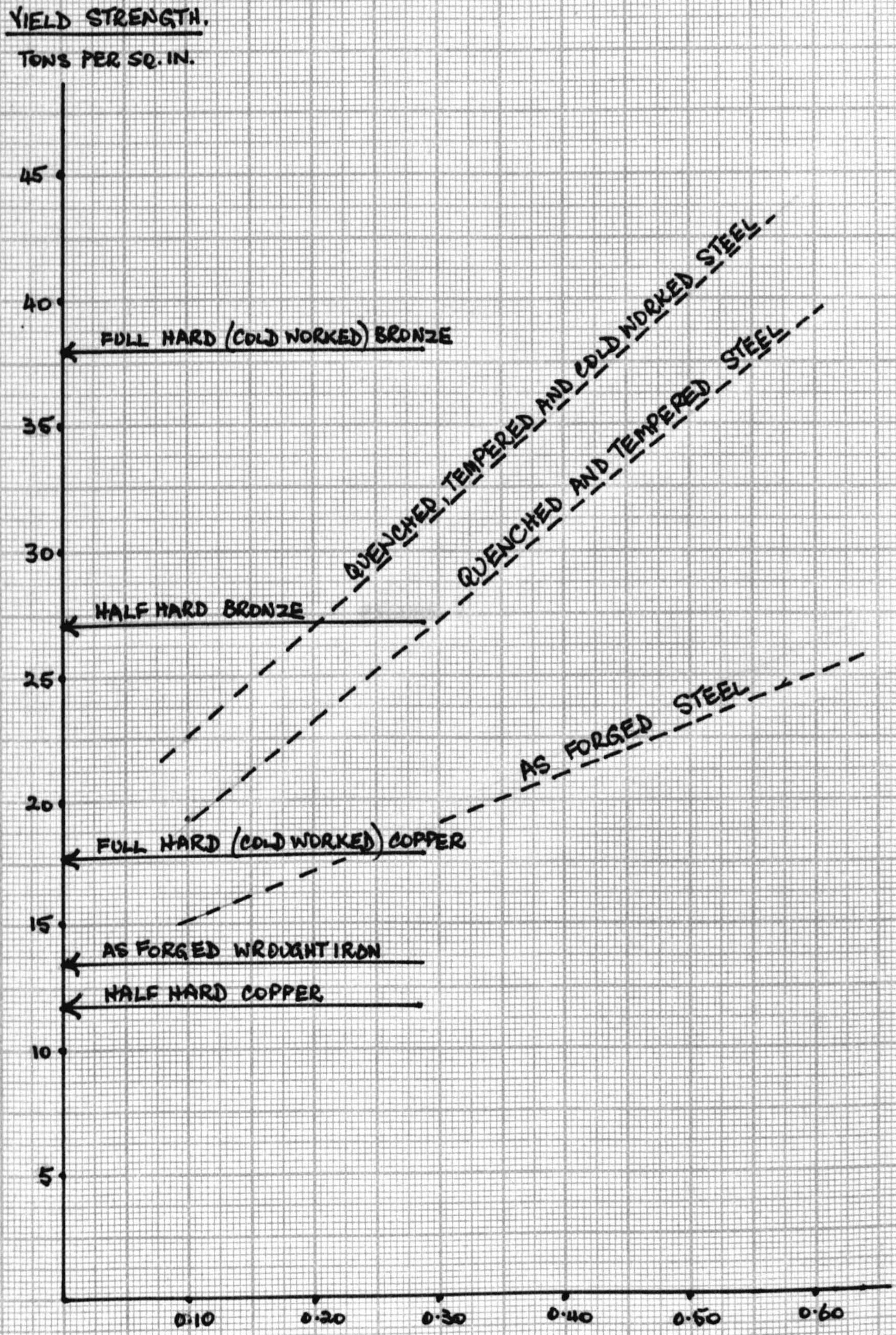
FIGURE 6 A COMPARISON OF THE YIELD STRENGTH OR PROOF STRESS OF COPPER, BRONZE AND CARBON STEEL IN VARIOUS CONDITIONS OF WORK HARDENING

(from J. A. Charles, Journal of Metals, July 1979, pp.8-13)

The Yield Strength or Proof Stress of a material is the force necessary to produce a permanent deformation or distortion at room temperature. It therefore gives an upper working limit to the stress which can be applied to a working tool.

The effect of cold working, that is hammering or otherwise deforming the material, prior to use, but without heating as would be necessary for forging, raises the strength of the material and thus its resistance to further deformation, but there is a limit to what can be achieved by this mechanism. When this is reached the material is said to be "full hard". Such hardening, like that obtained by the quenching of steel, is also accompanied by a loss of ductility; in other words, the work hardened material is more brittle than before working.

The purport of this diagram is to indicate that the introduction of iron did not give a satisfactory replacement for bronze, but that the use of an iron-carbon alloy, i.e. steel, could well be.



YIELD STRENGTH.
TONS PER SQ. IN.
45
40
35
30
25
20
15
10
5
FULL HARD (COLD WORKED) BRONZE
HALF HARD BRONZE
FULL HARD (COLD WORKED) COPPER
AS FORGED WROUGHT IRON
HALF HARD COPPER
QUENCHED TEMPERED AND COLD WORKED STEEL
QUENCHED AND TEMPERED STEEL
AS FORGED STEEL
0·10
0·20
0·30
0·40
0·50
0·60
CARBON CONTENT OF STEEL, %.

FIGURE 7

FIGURE 7 PHOTOMICROGRAPH (x 300) OF A "STEELED" ADZE BLADE FROM THE FOURTH CENTURY B.C.

(from R. Maddin, J. H. Muhly and T. S. Wheeler, Scientific American, October 1977, p.131)

This gives a section of an adze blade found at El Mina, the ruins of a Greek trading colony on the coast of Turkey. The blacksmith used carburised iron for the working face of the tool but economised by using soft iron for the backing. The junction shown here between the fine grained carburised material and the coarse grained iron is clear proof of the craftsmanship at this early date.

What makes this more interesting, however, is that the same technique was being applied by the cutlers and toolmakers of Sheffield into the twentieth century, the working edges of chisels, plane irons, scythes and the like being backed by iron, forge-welded to the steel; similarly, most shear steel knife blades were forge-welded to wrought iron tangs.

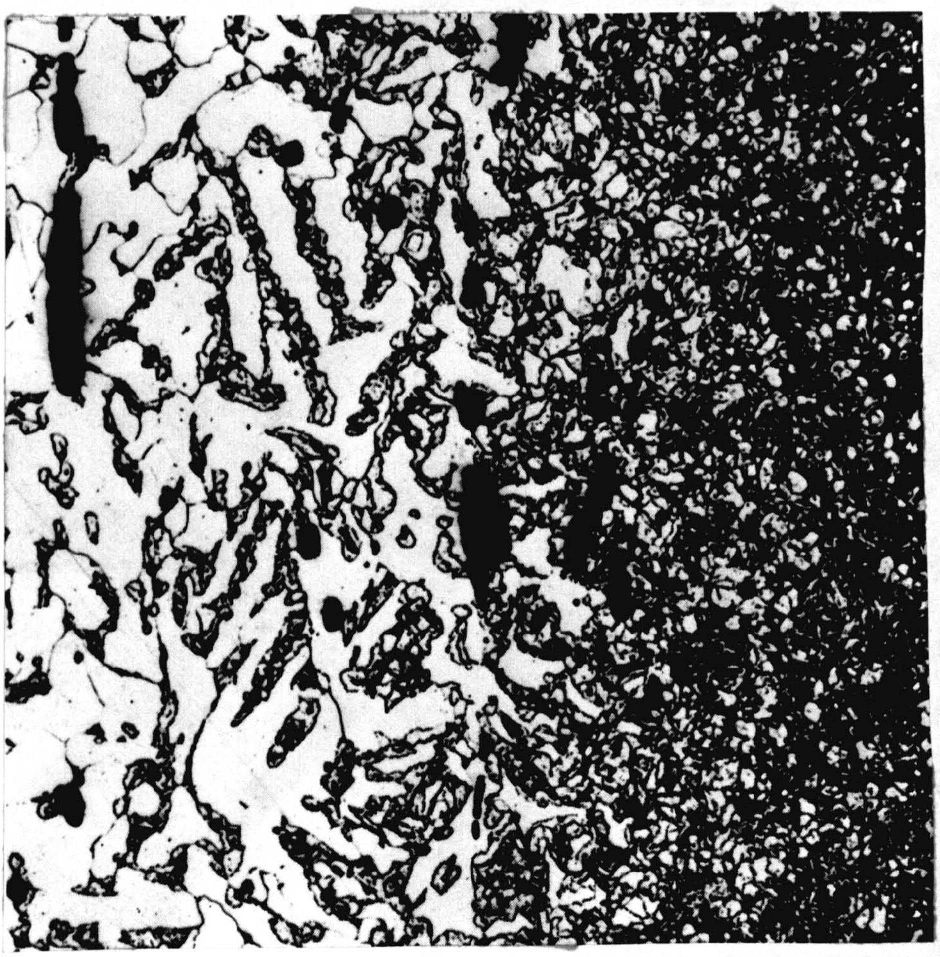


FIGURE 8

FIGURE 8 DERWENTCOTE FURNACE

(Photograph reproduced by kind permission of Frank Atkinson, Esq. of the Beamish Museum)

This furnace is the only cementation furnace remaining in this country in its authentic form. It is stone built, with a heavily buttressed working area. It dates from about 1740 and continued in use until later in the nineteenth century. Plans are now in hand for its restoration and preservation.

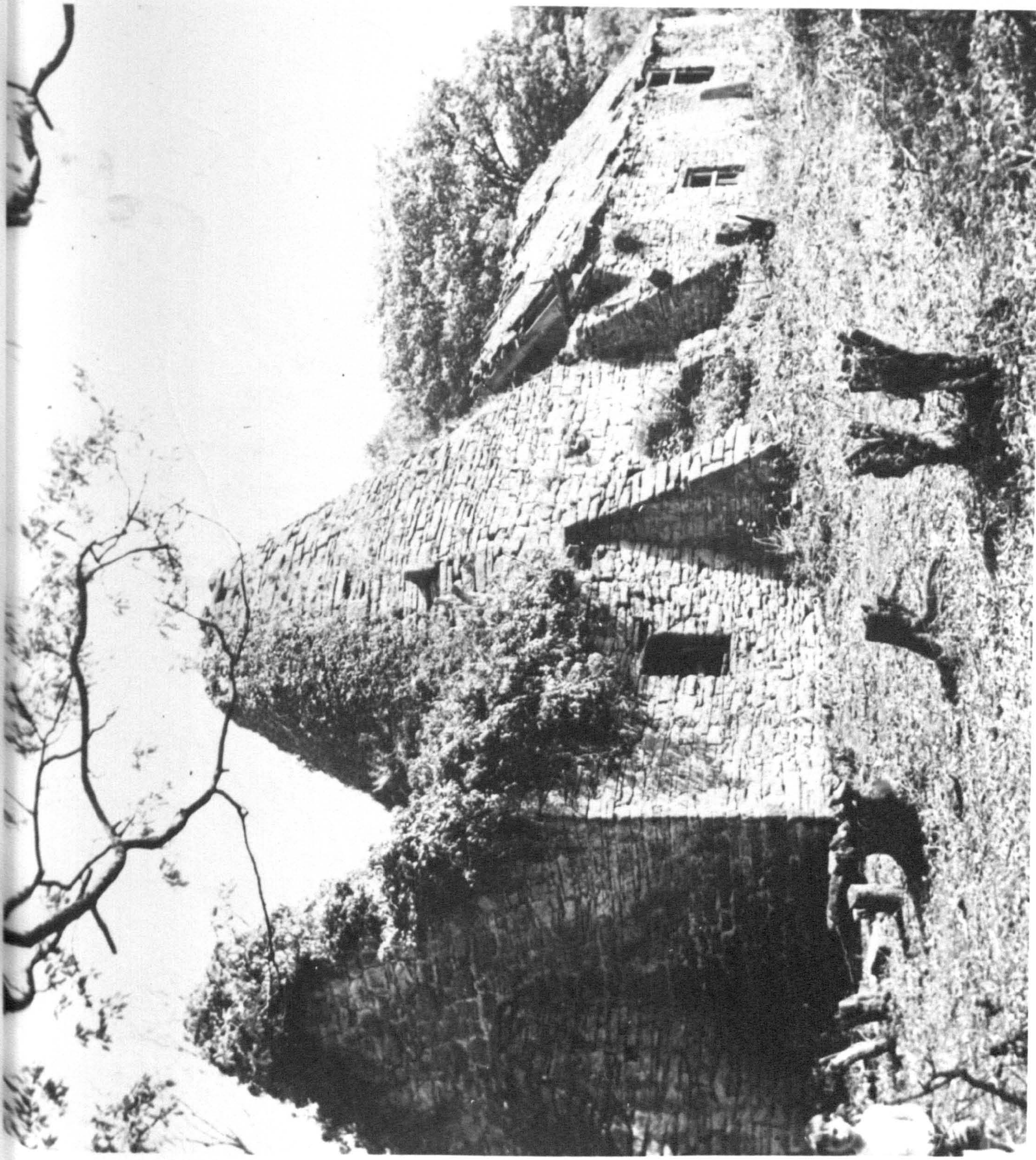


FIGURE 9

FIGURE 9 DERWENTCOTE FURNACE: SECTIONAL PLAN

(Based on a survey carried out by pupils of Eston Grammar School and reproduced by kind permission of John K. Harrison, Esq.)

This shows the two sandstone chests, internally 164" long, 27" wide and 36" deep. It also shows quite clearly the surrounding flues which enabled the chests to be completely enveloped by the flames from the central hearth passage. Also to be observed are the massive buttresses, which, incidentally, are a later addition, the stonework not being keyed into the main structure.

DERWENTCOTE
CEMENTATION FURNACE

NZ 131565
SECTIONAL PLAN

J.K.Harrison 68/72

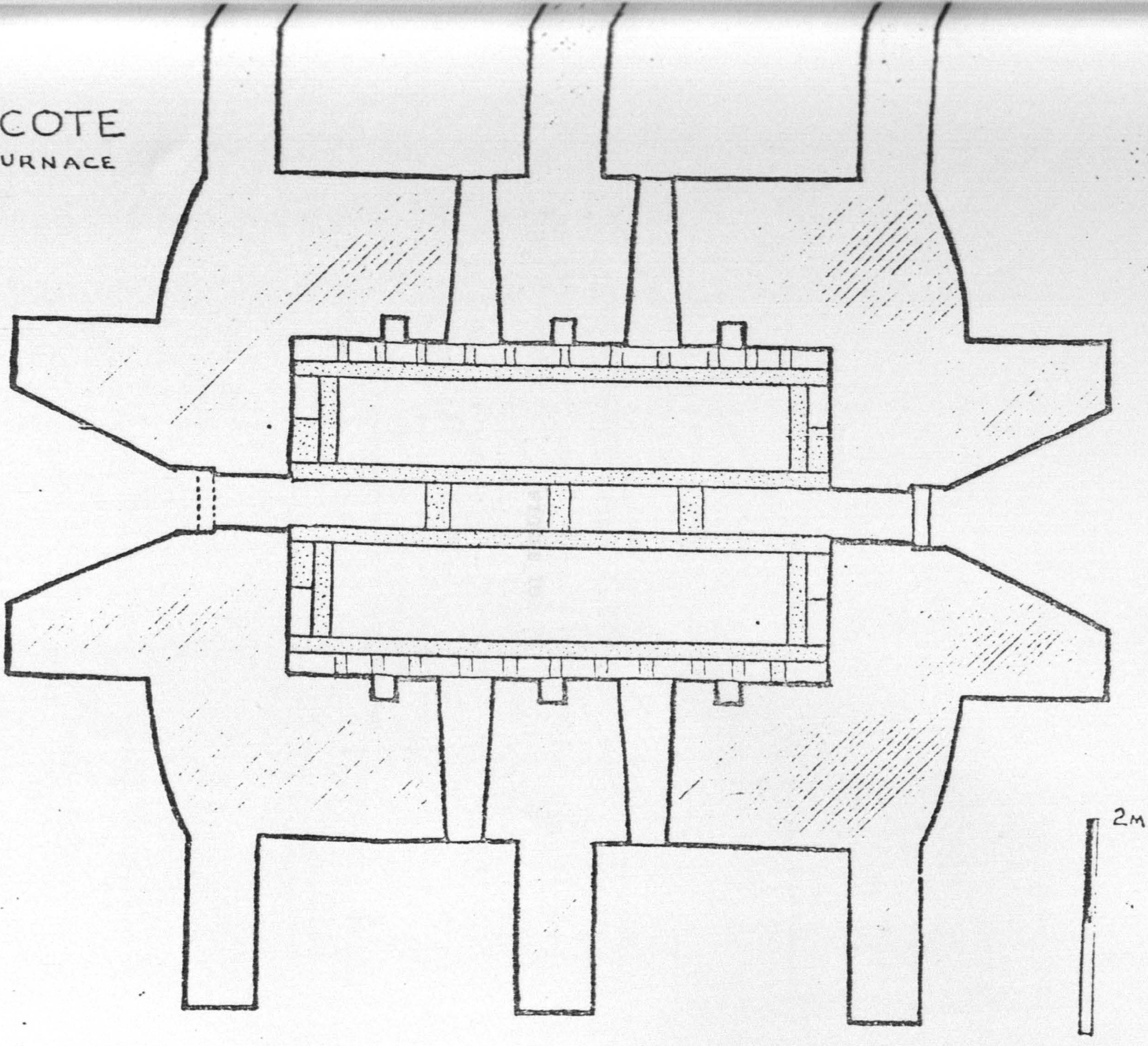


FIGURE 10

FIGURE 10 DERWENTCOTE FURNACE: VERTICAL SECTION

(Based on a survey carried out by pupils of Eston Grammar School and reproduced by kind permission of John K. Harrison, Esq.)

The 36" deep chests are shown with the hearth area between and below them, together with the superimposed vault with the conical chimney to provide the necessary draught.

DERWENTCOTE

CEMENTATION FURNACE

NZ 131565

TRANSVERSE SECTION

J.K HARRISON 68/72

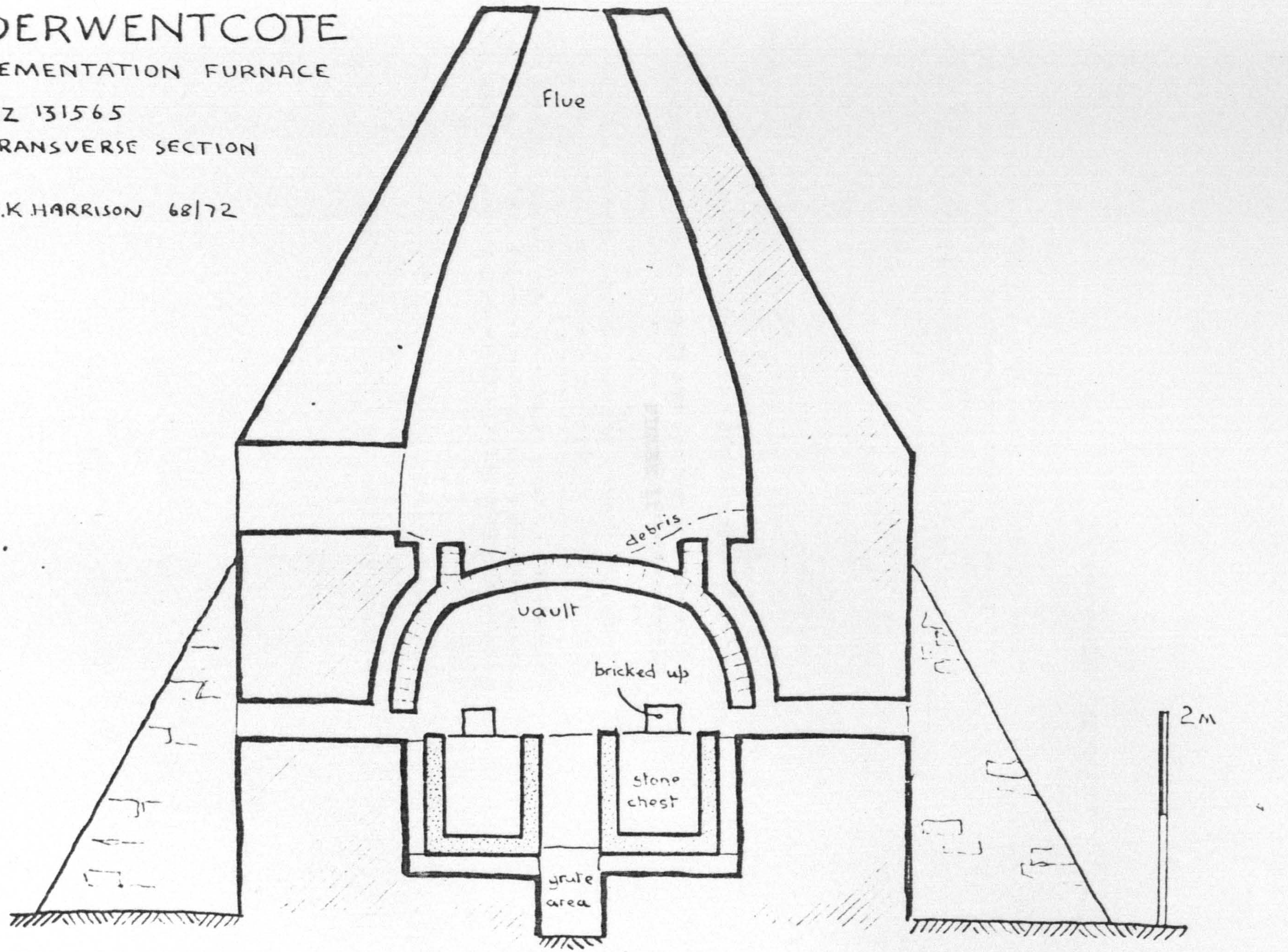


FIGURE 11

FIGURE 11 BLISTER STEEL

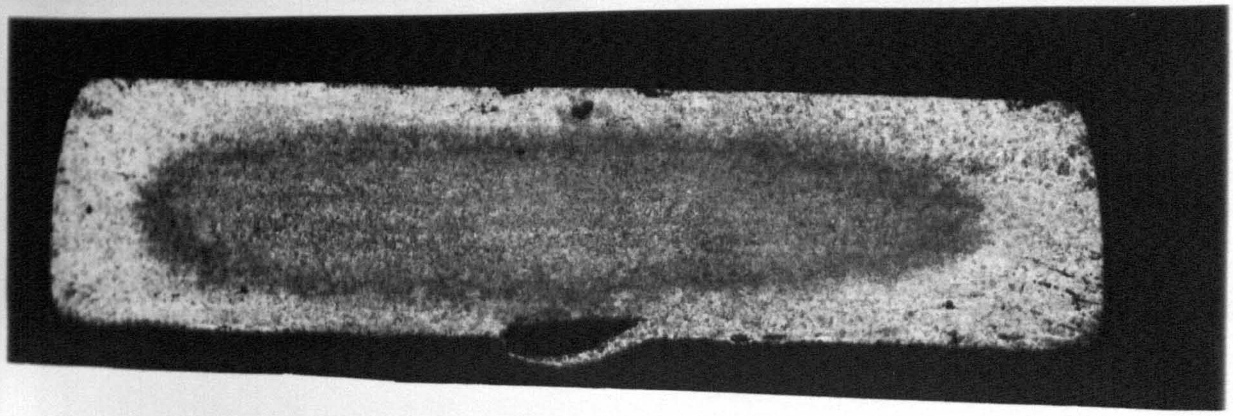
These illustrations are derived from the examination of a piece of blister steel from the last cementation heat on the No.5 Doncaster furnace. The furnace is still preserved, in the premises of the Inter Group Laboratories of the British Steel Corporation at Hoyle Street in Sheffield and is illustrated in Figure 21. A piece of the blister bar was presented to the Sheffield Trades Historical Society who in turn allowed a small portion to be broken off for examination, as reported in K. C. Barraclough and J. Kerr, 'Metallographic Examination of Some Archive Samples of Steel', J.I.S.I., July 1973, pp.470-471. These illustrations come from that paper.

Figure 11A represents the flat surface of the piece, illustrating a blister.

Figure 11B shows a fracture section through the bar, with evidence of slag streaks and some blistering.

Figure 11C shows a similar section, after grinding back, polishing and etching, showing the higher carbon envelope and the lower carbon centre to the bar.

The average carbon content of millings taken immediately below the oxidised surface was 0.97%; that of drillings from the centre was 0.64%.



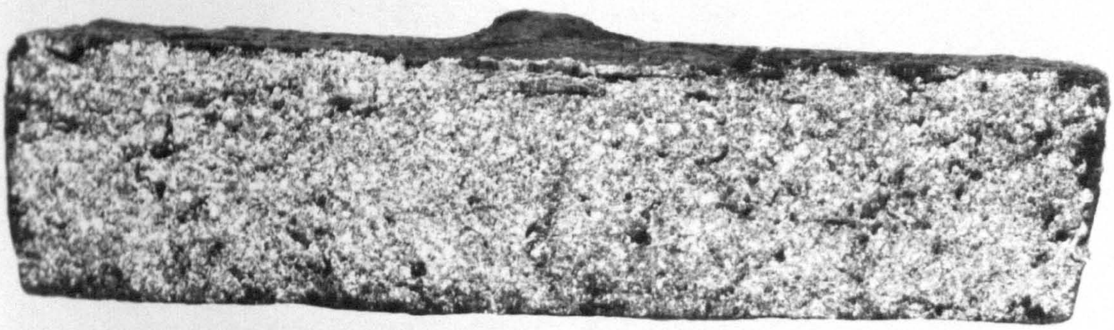


FIGURE 12

FIGURE 12 VARIATION IN CARBON CONTENT ACROSS THE THICKNESS OF BARS OF BLISTER STEEL

(based on J. O. Arnold, 'The Micro Chemistry of Cementation', J.I.S.I., 1898, Vol.2)

This very thorough investigation included the milling of successive layers, 0.020" thick, from a number of blister steel bars, from outside to centre of the section, and the analysis of each separate sample for its carbon content, to give an indication as to the manner in which the carbon diffused into the iron. It also included the examination of an "aired" bar, one which, after almost full conversion, had suffered surface oxidation, with resultant decarburisation, following on the opening of a crack in the chest in its vicinity.

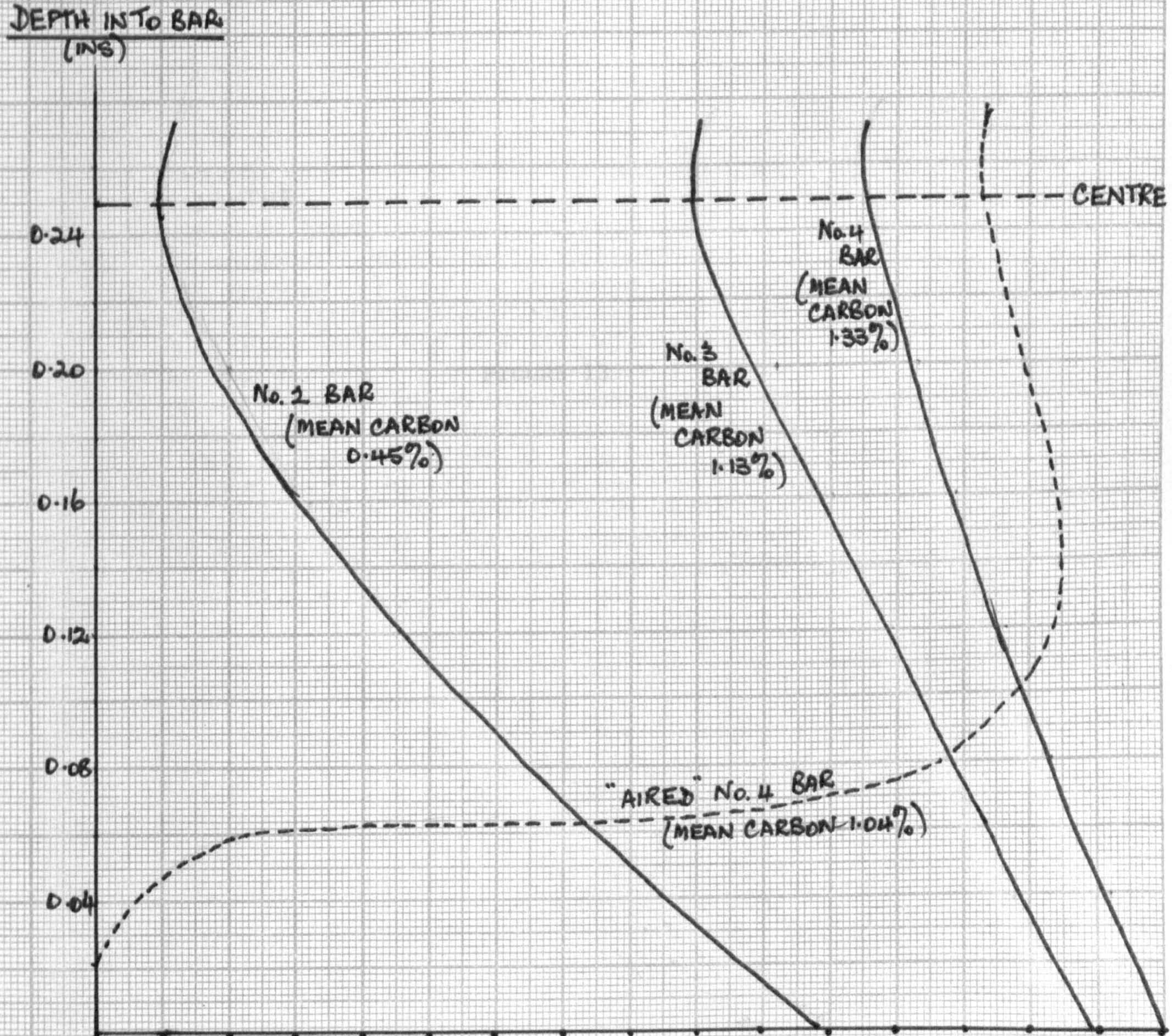

DEPTH INTO BAR (INS)
0·24
0·20
0·16
0·12
0·08
0·04
0·20
0·40
0·60
0·80
1·00
1·20
1·40
CARBON CONTENT, %
CENTRE
No. 1 BAR (MEAN CARBON 0·45%)
No. 3 BAR (MEAN CARBON 1·13%)
No. 4 BAR (MEAN CARBON 1·33%)
"AIRED" No. 4 BAR (MEAN CARBON 1·04%)

FIGURE 13

FIGURE 13 EARLY STEELMAKING SITES ON THE RIVER DERWENT

The establishment of cementation furnaces in the early eighteenth century at Winlaton Mill, Swalwell, Newcastle, Blackhall Mill, Derwentcote and Teams made this area the major centre of steelmaking in the country. Shotley Bridge was the home of the Hollow Sword Company; it is possible that steel by the old German method was produced here in the last years of the seventeenth century. The use of pig iron from Allensford, nearby, for this purpose could be postulated. The later iron and steel centre of Consett is in this area.

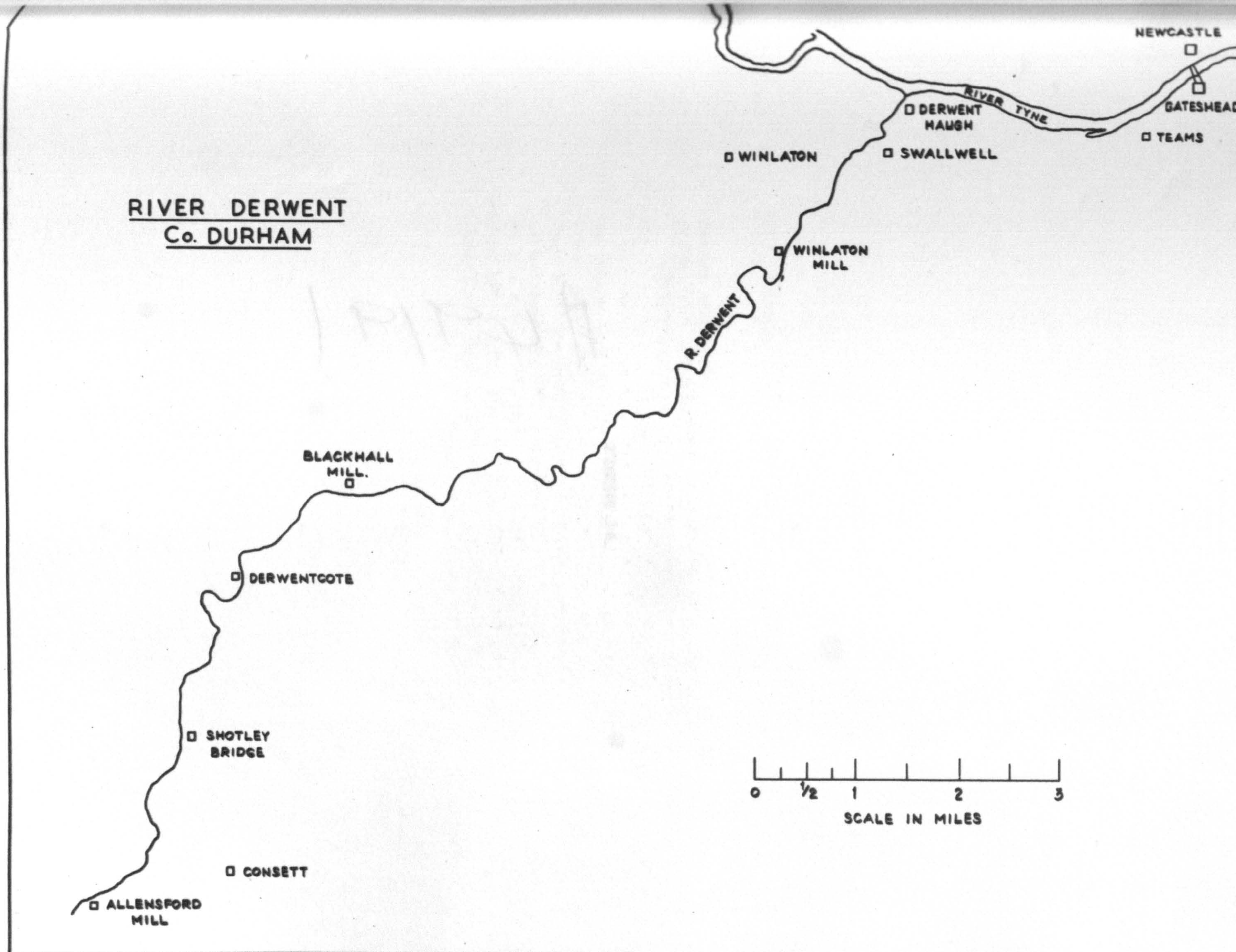

RIVER DERWENT
Co. DURHAM
NEWCASTLE
GATESHEAD
TEAMS
RIVER TYNE
DERWENT HAUGH
SWALLWELL
WINLATON
WINLATON MILL
R. DERWENT
BLACKHALL MILL.
DERWENTCOTE
SHOTLEY BRIDGE
CONSETT
ALLENSFORD MILL
0 ½ 1 2 3
SCALE IN MILES

FIGURE 14

FIGURE 14 NEWCASTLE AND THE TYNE FROM GATESHEAD, 1753

This illustration is taken from the travel journal of Reinhold Angerstein, Resa genom England 1753-55. Vol.2, and was kindly provided by Jernkontoret.

On the level ground north of the river, at the foot of Forth Bank, will be seen two buildings with smoking chimneys. The one on the left is described in the text as a cementation furnace, similar to the one at Blackhall Mill (see Figure 15). The nature of the adjacent building is not disclosed, but it could be a forge.

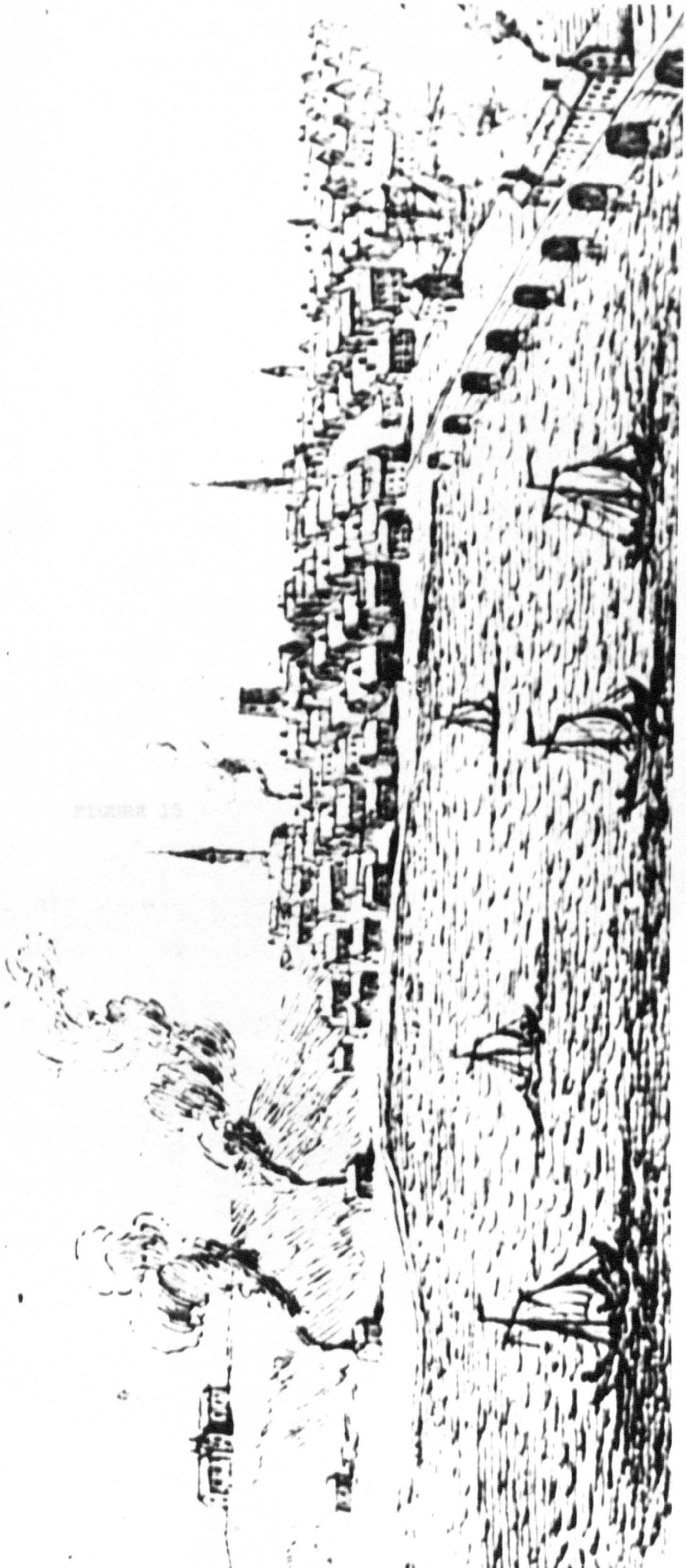


FIGURE 15

FIGURE 15 BLACKHALL MILL, 1753

This illustration is also taken from Angerstein's Journal.

The furnace clearly resembles that at Newcastle and is similar to that at Derwentcote (see Figures 9, 10, 11 and 15). The furnace itself was demolished in 1916 but the abutment on the river bank, shown here, can still be recognised.

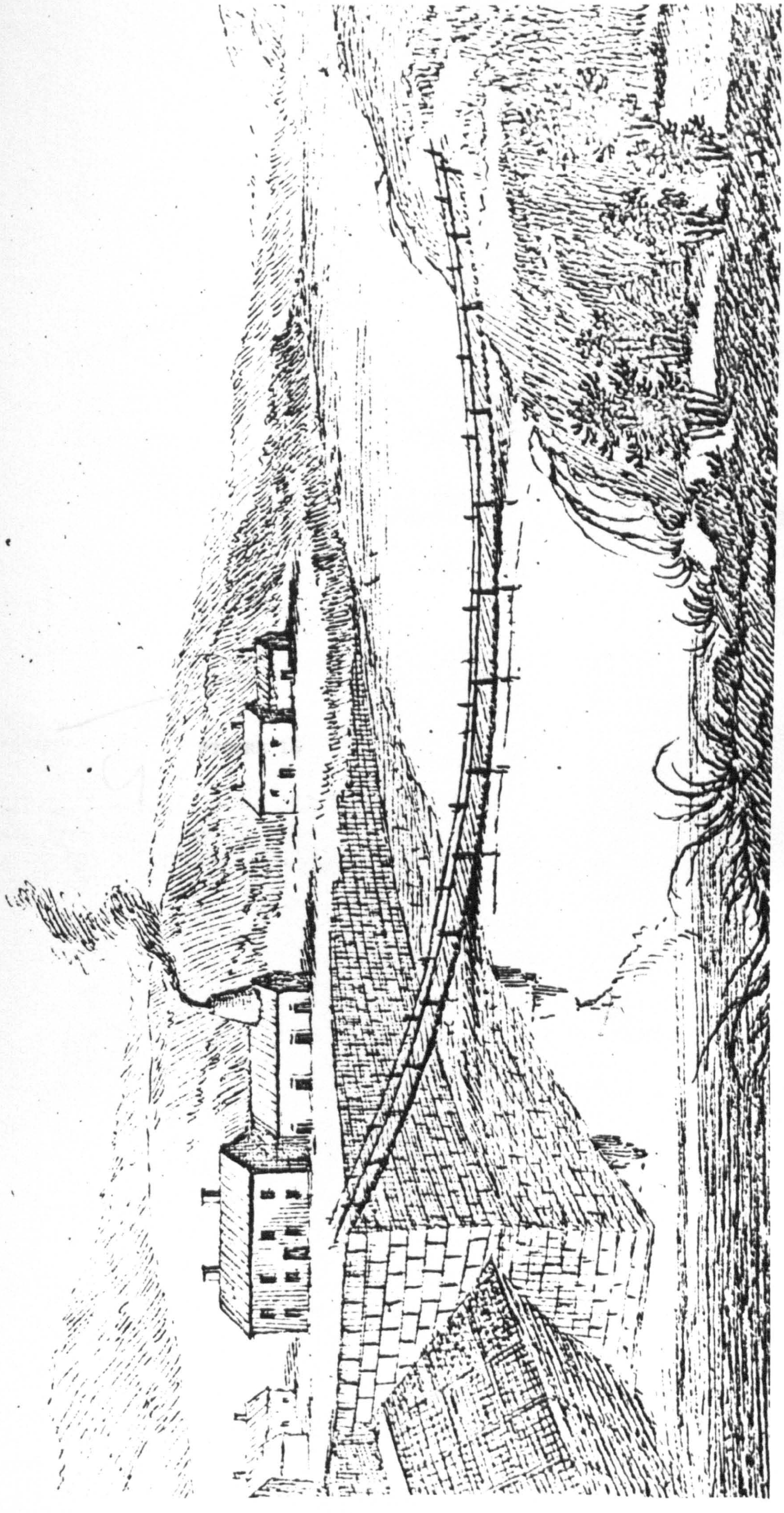


FIGURE 16

FIGURE 16 DERWENTCOTE FURNACE, 1753

A further illustration taken from Angerstein's Journal.

Most of the detail in the building can still be related to this drawing, apart from the buttresses which now support the structure. These are obviously a later addition (see Figures 9, 10 and 11).

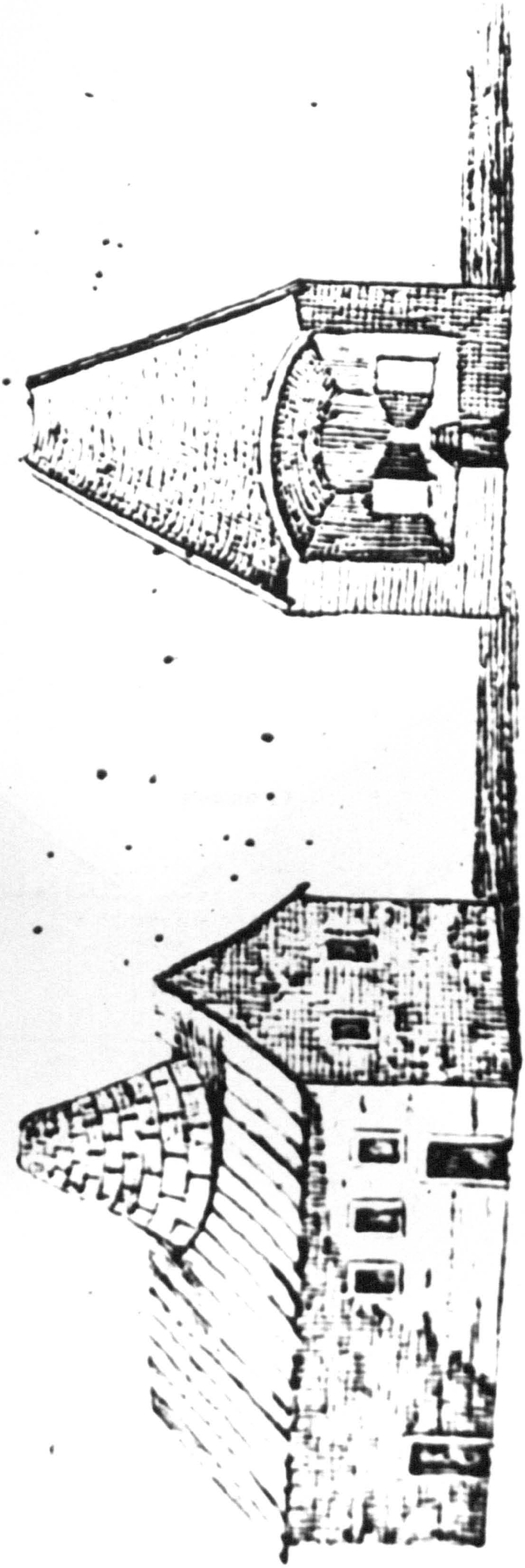
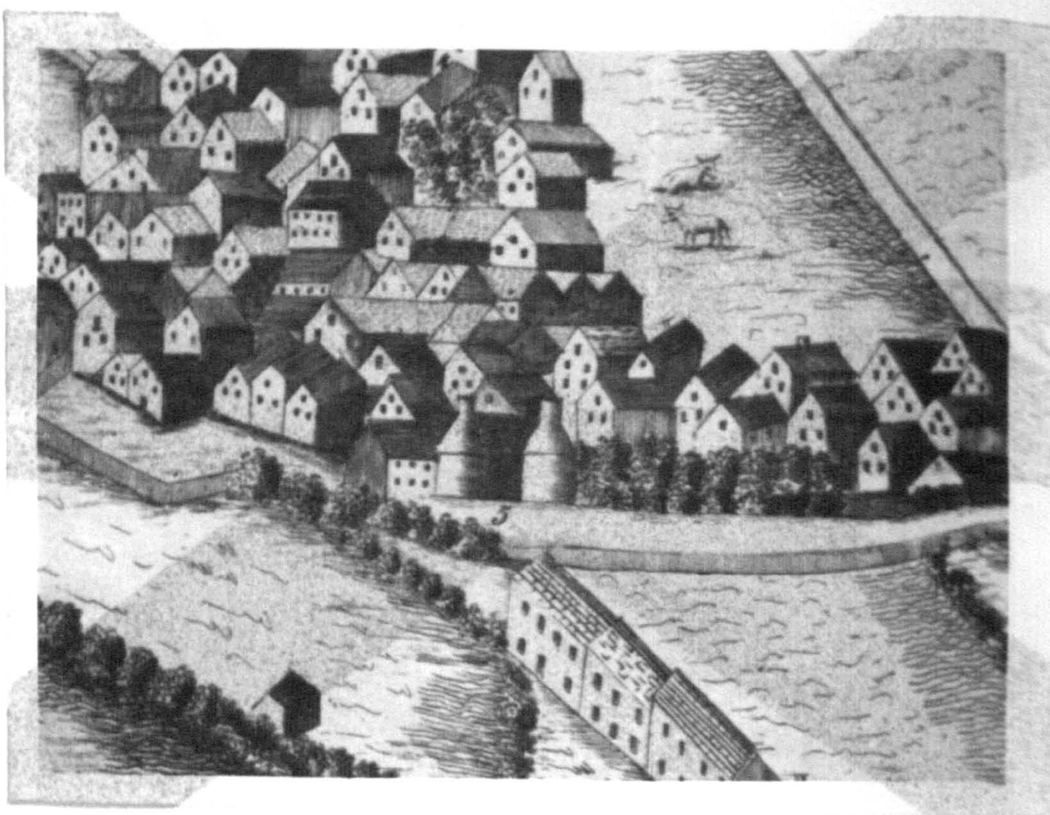


FIGURE 17

FIGURE 17 NORTH PROSPECTIVE VIEW OF THE TOWN OF SHEFFIELD, 1737

This drawing was produced by Thos. Oughtibridge for the Company of Cutlers in Hallamshire and is reproduced from a copy in the possession of the Sheffield City Libraries by their kind permission. It is of interest in that the key refers specifically to "the Steel Furnaces" (Reference 5) at what was then the eastern end of the town. This particular area is reproduced in enlarged form below and will be seen to include two buildings with conical chimneys which are obviously cementation furnaces.



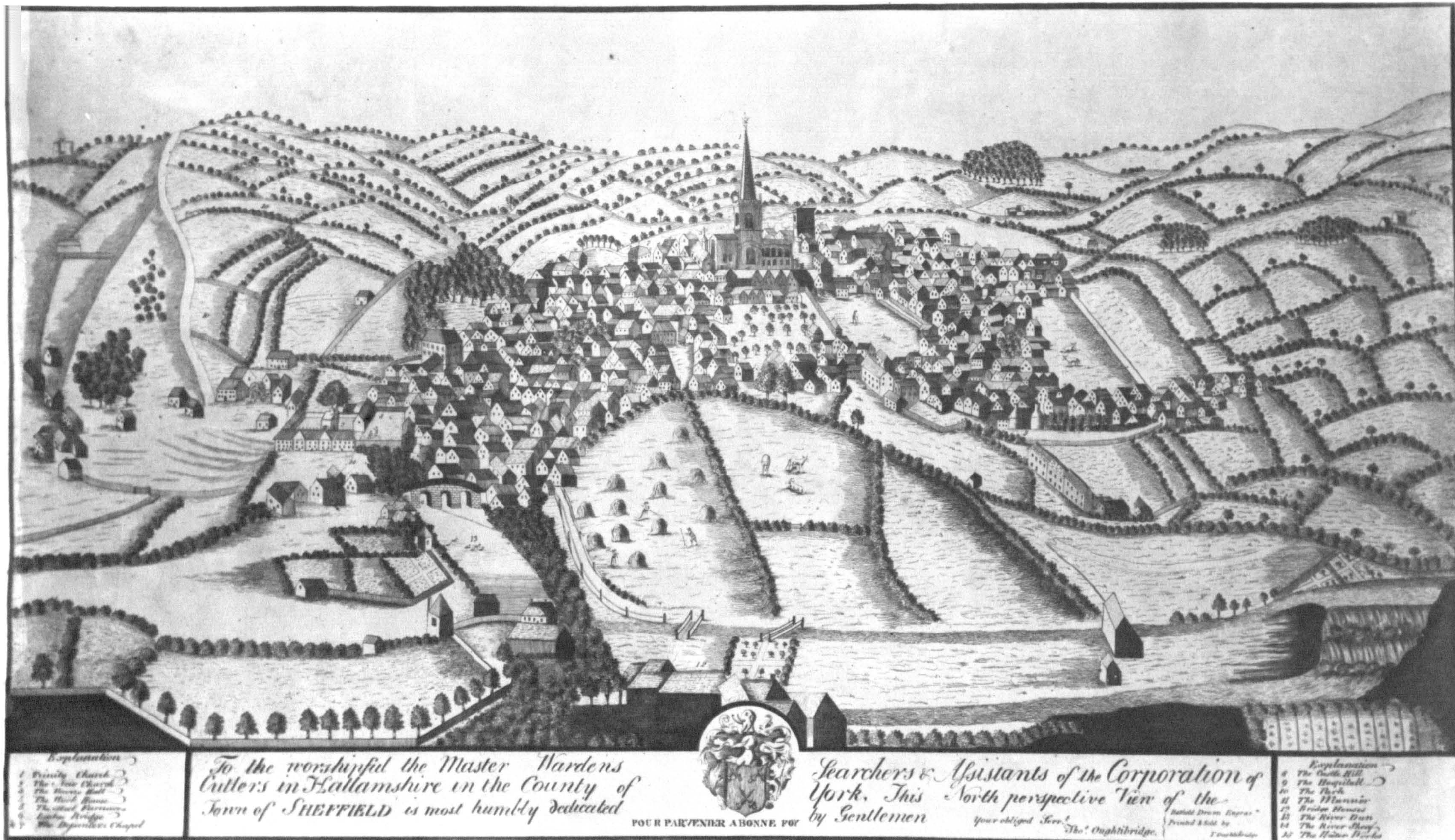

To the worshipful the Master Wardens Searchers & Assistants of the Corporation of
Cutlers in Hallamshire in the County of York. This North perspective View of the
Town of SHEFFIELD is most humbly dedicated by Gentlemen
POUR PARVENIR A BONNE FOY
Your obliged Serv.t
Tho.s Oughtibridge.
Explanation
8 The Castle Hill
9 The Hospitall
10 The Park
11 The Mannor
12 Bridge Houses
13 The River Dun
14 The River Sheaf
15 The Water Works

FIGURE 18

FIGURE 18 COLLECTED DRAWINGS OF CEMENTATION FURNACES - PART ONE

This represents late eighteenth and early nineteenth century furnaces, the key being as follows :

1. Derwentcote Furnace, ?1740, with later modifications. J. K. Harrison, Bulletin of the Industrial Archaeological Society for the North East, Vol.9 (1969), p.13.

2. A Sheffield Furnace, with a single chest, 1766.

3. Osterby Furnace, Sweden, 1765.

4. A furnace in the North East, probably at Swalwell, 1766.

   The above three illustrations are all from G. Jars, Voyages Métallurgiques, Vol.1 (Lyons, 1774), but as redrawn by J. H. Hassenfratz, L'Art de Traiter les Minerais de Fer (Paris, 1812), 3me. Partie, Plates 59-61.

5. A wood fired Swedish Furnace, around 1780, designed by Sven Rinman, Rinmanska Arkivet, Techniska Museet, Stockholm.

6. A furnace belonging to a Mr. Marshall in Sheffield, 1796. The single chest held 6 tons of iron, the bars were 12 feet long and the chimney 30 to 40 feet high. The Hatchett Diary, ed. A. Raistrick, (Truro, 1968).

7. Furnace seen in London, 1798. From Plate XVI of the Atlas of plates accompanying G. Broling, Anteckningar under en Resa i England aren 1797, 1798 och 1799 (Stockholm, 1817).

8. Taken from an illustration to J. Collier, 'Observations on Iron and Steel', Manchester Memoirs, Vol.V, p.109, and reproduced in Philosophical Journal, Vol.3 (May, 1799), facing p.96. The original article has not been traced and the site of this particular furnace is not known.

9. Furnace at Forsbacka, Sweden, around 1805. K. G. Hildebrand, Fagerstabrukens Historia: Sexton och Sjutton Hundratalen (Uppsala, 1957), p.241.

10. A. Rees, Cyclopaedia, 1819. This is a reproduction of Plate III accompanying the article on Iron Manufacture. The date of the engraving is 1812 and the text seems to indicate that it was a Sheffield furnace.

11. C. J. M. Karsten, trans. as Manuel de la Métallurgie du Fer (Metz, 1824), from the plate accompanying the article entitled 'Acier'. It is stated to be a Sheffield furnace.

12. The Bower Spring Furnace, Sheffield. Surveyed by the author. This furnace was built between 1828 and 1830 by Thos. Turton and subsequently was used by Moss and Gamble from 1860 until just subsequent to the First World War.

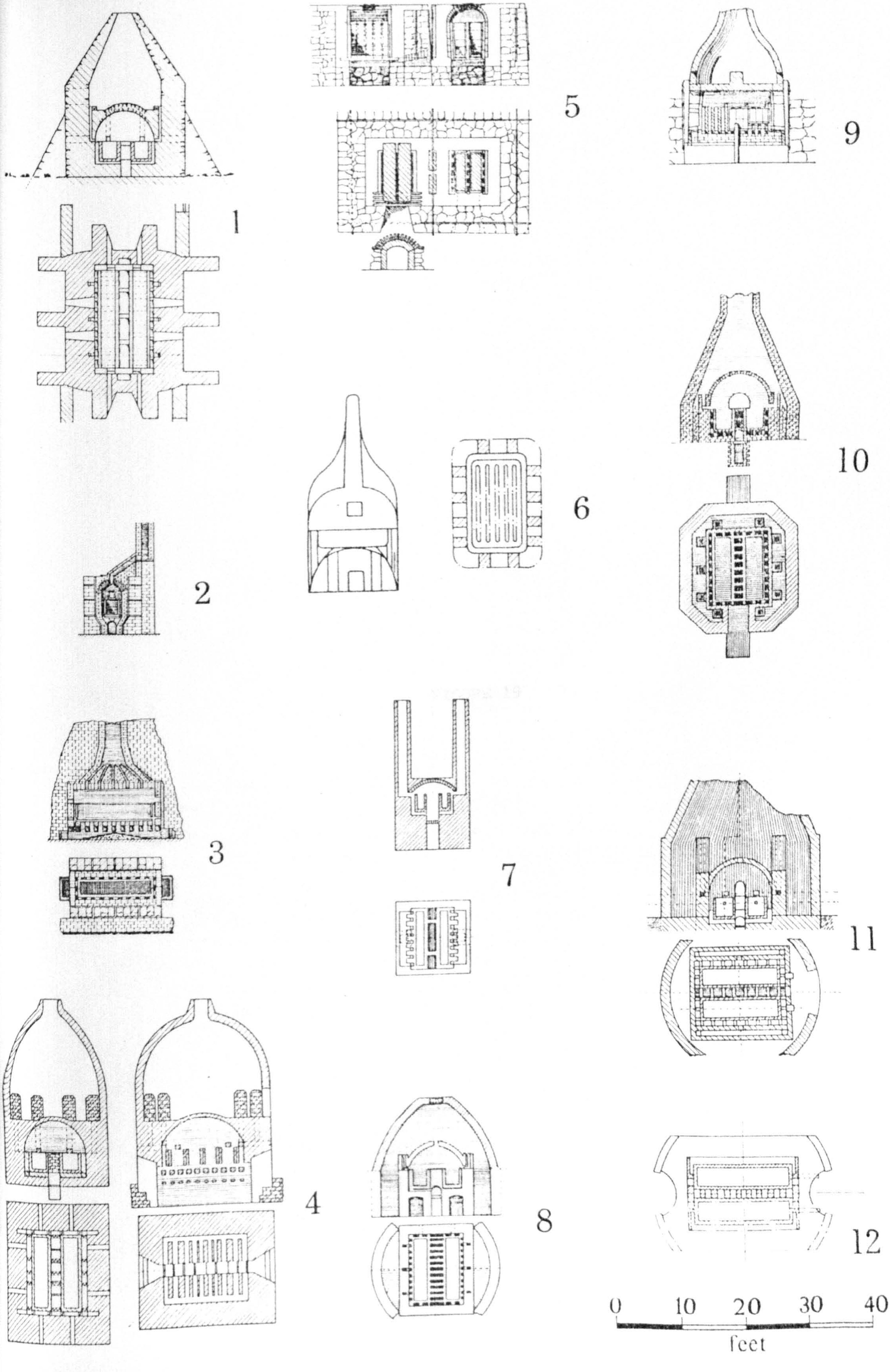

1
2
3
4
5
6
7
8
9
10
11
12
0 10 20 30 40
feet

FIGURE 19

FIGURE 19 COLLECTED DRAWINGS OF CEMENTATION FURNACES - PART TWO

This selection represents the growth in size of furnace, the key being as follows :

13. This is something of a mystery. It was provided to the author with the reference "Lardner, 1832" written on the reverse. It does not appear, however, in Lardner's Cabinet Cyclopaedia of the Useful Arts of that date.

14. Dufrenoy et al., Voyages Métallurgiques (Paris, 1839), Vol.II, Appendix, facing p.711. This is an illustration of a Sheffield furnace of 1836.

15. A French Furnace of around 1840. L. E. Gruner, Traité de Metallurgie (Paris, 1869), Plate XXIX.

16. An "English Type Furnace" at Storfors, Sweden, built 1841-42. C. Sahlin, 'Svenskt Stal', Med Hammare och Fackla, Vol.III (1931), p.97.

17. "A good type of Sheffield Furnace, with a capacity of about 17½ tons". F. le Play, 'Mémoire sur la Fabrication de l'Acier en Yorkshire', Annales des Mines, 4me. Serie, Tome III (1843), Plate XII.

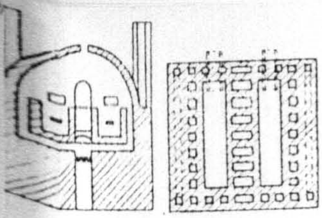
18. Furnace of a modified type, drawn from the description provided by le Play, loc.cit., pp.600-602. About 1840, from an unknown location.

19. One of the six furnaces from Holmes Works, Rotherham. This block was erected in 1842 by Peter Stubs of Warrington and was demolished in 1968. This drawing comes from the survey carried out prior to demolition by a team from the Department of Economic History, Sheffield University.

20. An "old" furnace in use at Osterby in 1860. From a drawing in the Doncaster Archives.

21. The last furnace erected at Osterby, as late as 1889. (See Appendix AAA). From a drawing in the Doncaster Archives.

22. A furnace used in the late nineteenth century in Staffordshire for making puddled steel bars more uniform in carbon content. M. Millard, 'Old Methods of Ironmaking', Proc. Staffordshire Iron and Steel Institute (1911-12), p.189.



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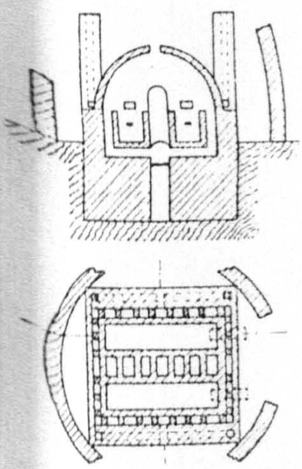

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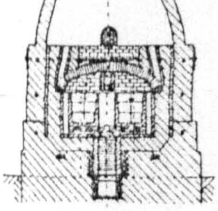

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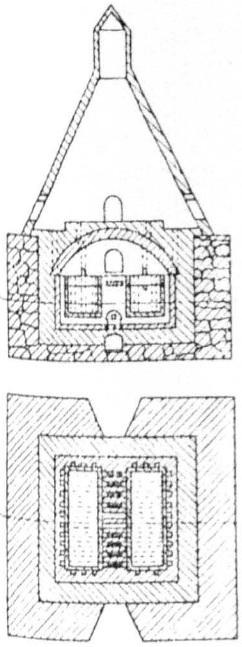

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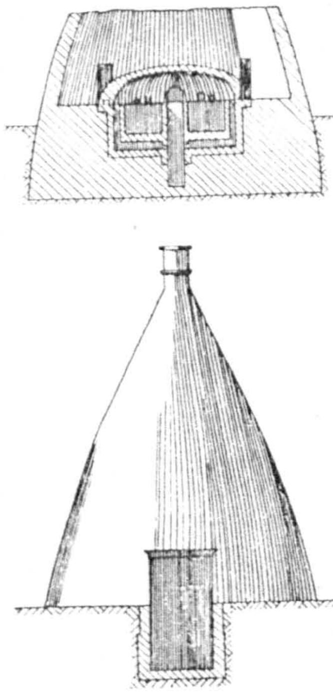

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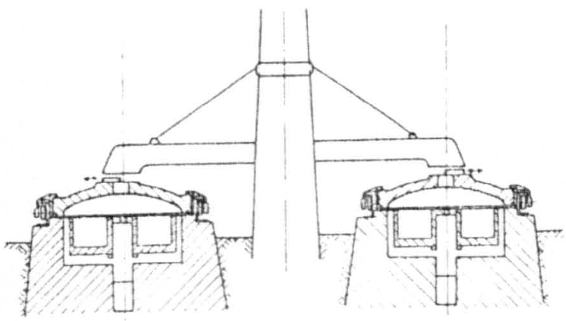

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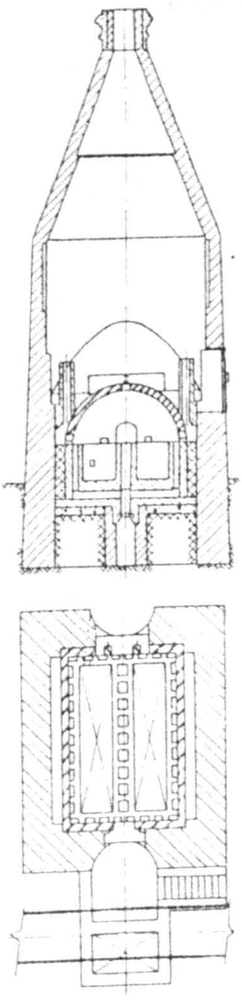

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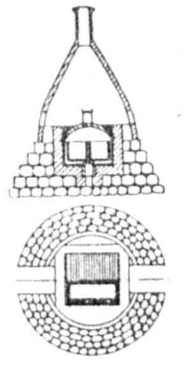

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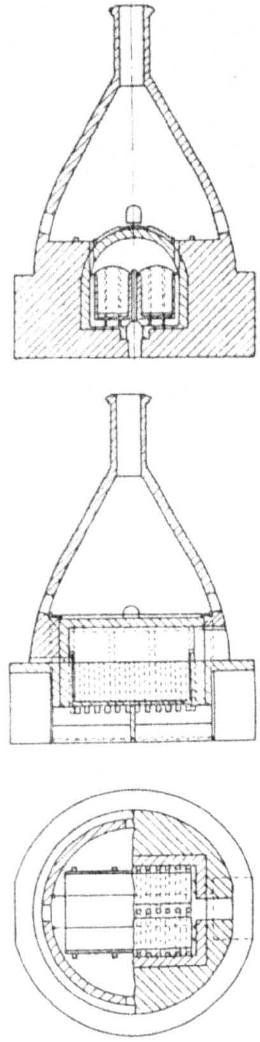

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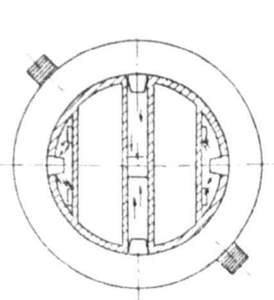

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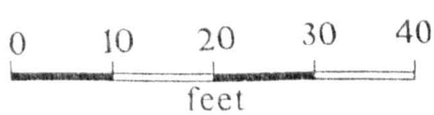


FIGURE 20

FIGURE 20 COLLECTED DRAWINGS OF CEMENTATION FURNACES - PART THREE

This illustrates the fully developed furnaces from the latter half of the nineteenth century. The Holmes furnace (No.19) has also been included for comparison. Details of the remainder are as follows :

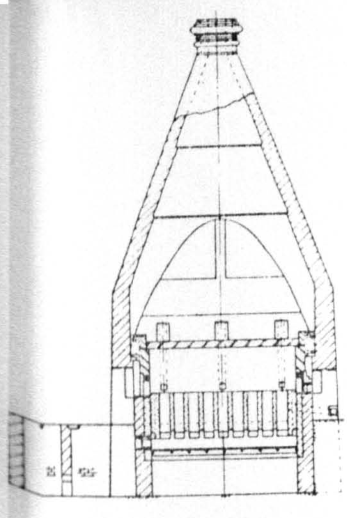
23. A Swedish design of furnace, with a wood fired gas producer feeding two three-chest furnaces (only one of which is shown here, there being an identical furnace block also to the right of the gas producer). This design, by the Swedish engineer Lundin, was erected at Munkfors in 1862. The drawing comes from C. Sahlin 'Svenskt Stal', Med Hammare och Fackla, Vol.III (1931), p.100.

24. A typical Sheffield furnace of about 1860. J. Percy, Metallurgy: Iron and Steel (London, 1864), pp.770-771.

25. A furnace typical of the more general works scale in Sheffield, using bars 12 feet long (as distinct from the larger East End works in Sheffield). W. H. Greenwood, Iron and Steel (London, 1874), p.407.

26. This drawing originally appeared in J. Scoffern et al, The Useful Metals and Their Alloys (London, 1857). The article on steel, probably by William Clay, included this drawing of a pair of furnaces (p.339) which was later copied by J. S. Jeans in his Steel: Its History, Manufacture & Uses (London, 1880), p.322.

27. This represents the largest type of Sheffield furnace ever built, with a total capacity of up to 40 tons. The drawing first appeared in the edition of F. W. Harbord, The Metallurgy of Steel dated 1890. This reproduction is taken from the 1904 edition, pp.220-221.



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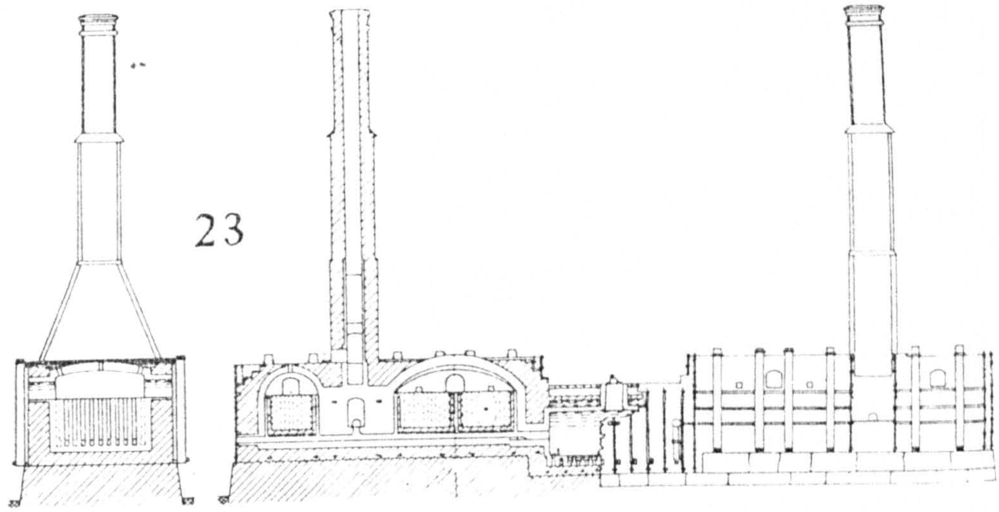

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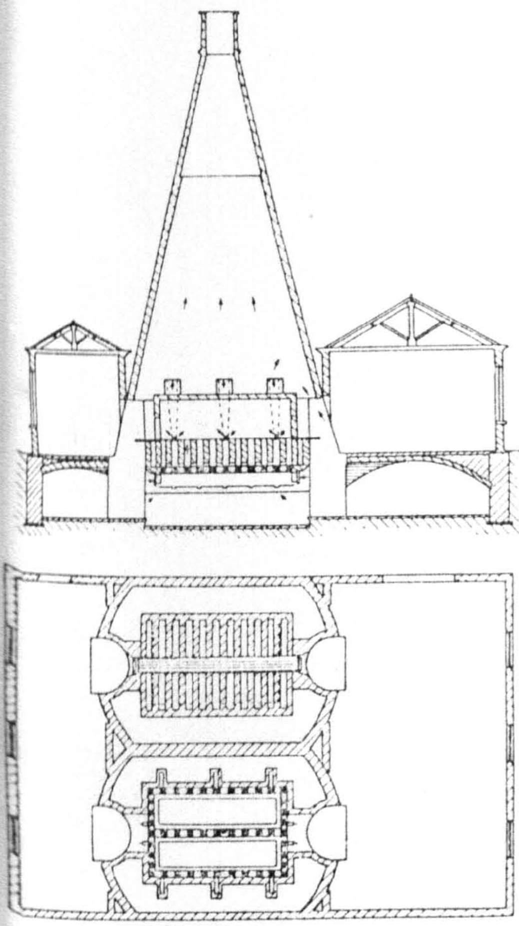

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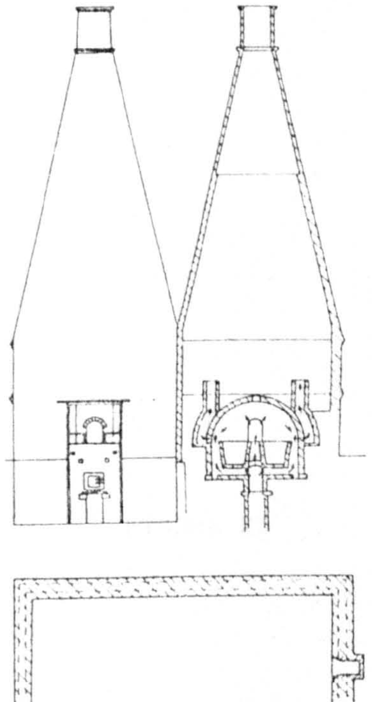

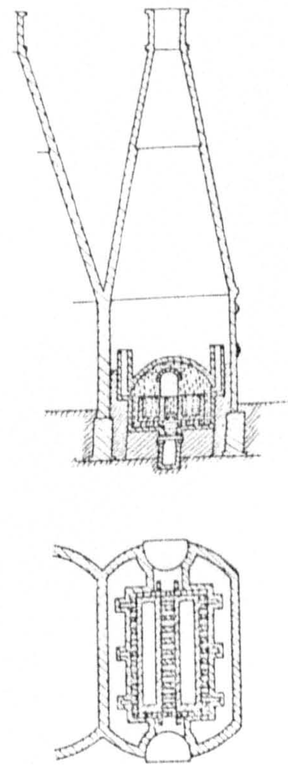

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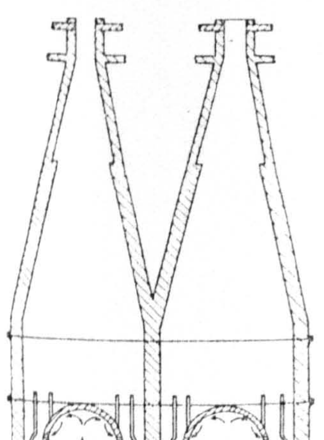

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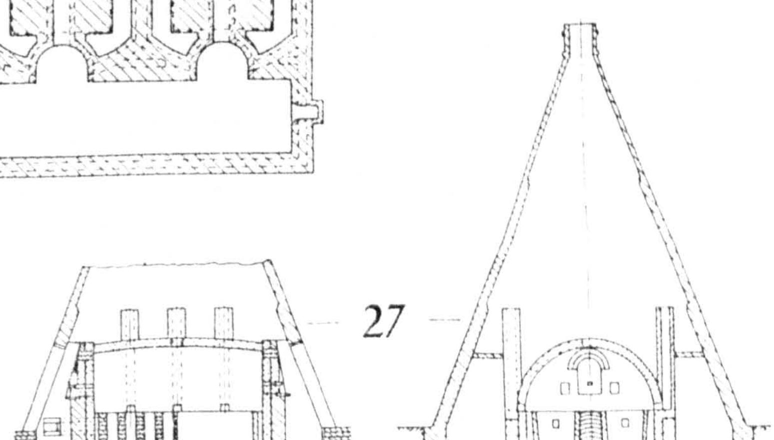

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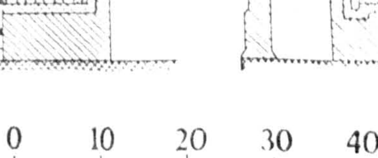


FIGURE 21

FIGURE 21 DANIEL DONCASTER AND SONS: NO.5 CEMENTATION FURNACE

This furnace still stands in the premises of the British Steel Corporation's Inter-Group Laboratories (formerly B.I.S.R.A.) at Hoyle Street, Sheffield, and this photograph, taken by D. W. Crossley, Esq., is reproduced with their permission.

The furnace probably dates from the third quarter of the nineteenth century. The chests now in the furnace would each take around 18 to 20 tons of iron. The top of the furnace was rebuilt in 1941 after bomb damage and the existing design incorporates a damper device intended as a black-out system when necessary under war time operations. The top originally terminated in the normal chimney (as for instance in Figure 23).

It was this furnace which figured in the film produced by the Iron and Steel Federation of the last cementation steel heat in this country at the end of 1951.

FIGURE 22

FIGURE 22 CEMENTATION FURNACES AT THE BRADES WORKS, 1874

This drawing comes from the Lee Crowder Papers, held by the Archive Division of the Birmingham City Libraries. (Reference: Lee Crowder No. 927).

It is interesting in that it shows a different chimney figuration from the Sheffield type of furnace, a further variant of which, with a number of circumferential stay bands, can be found in the drawings of the Beaver and Minerva Works of Isaac Jenks and Company at Wolverhampton (advertisements in S. Griffiths, Guide to the Iron Trade, 1873). It seems, therefore that this was a Midlands development.

Sketch made standing at point 9

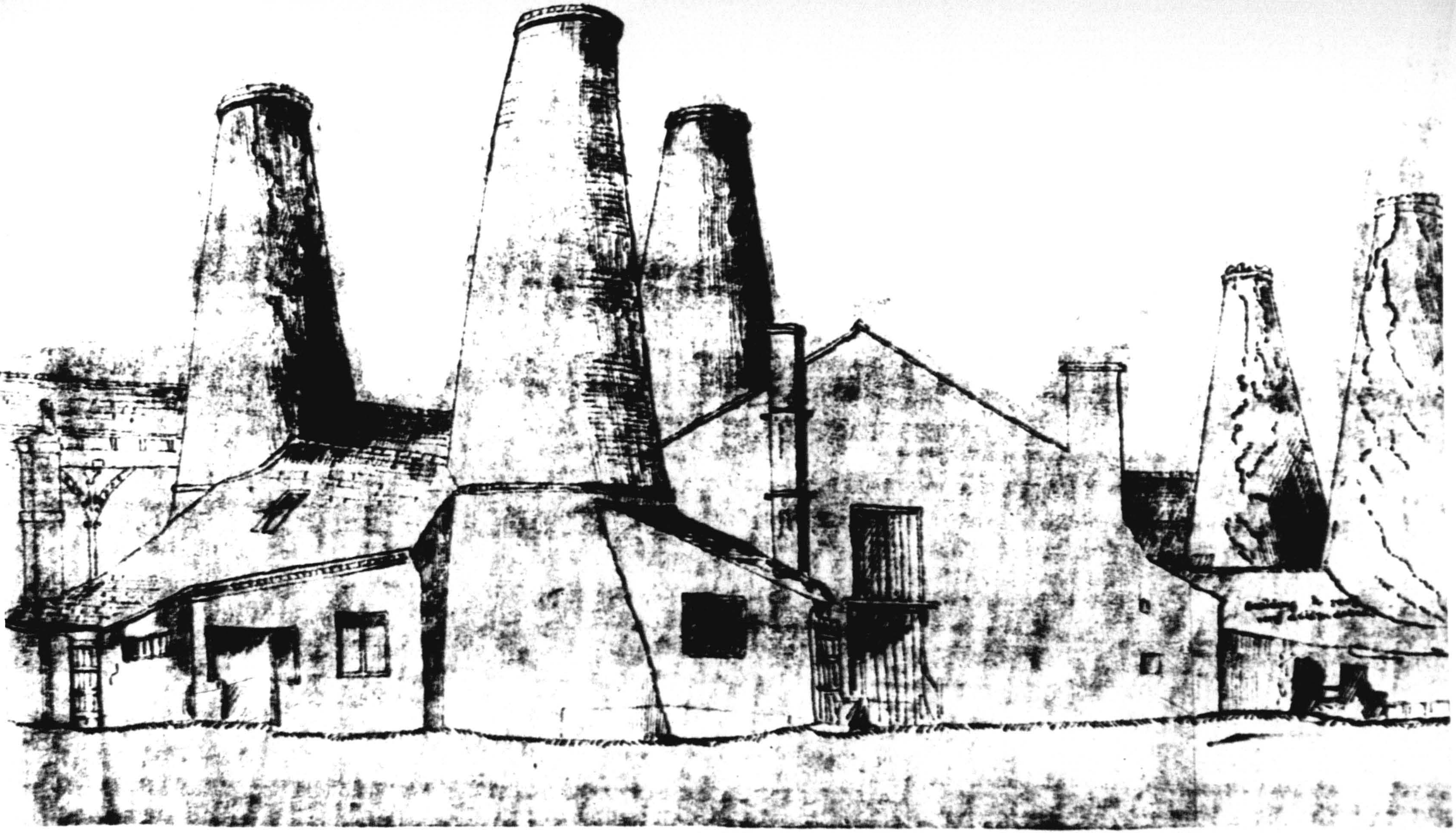
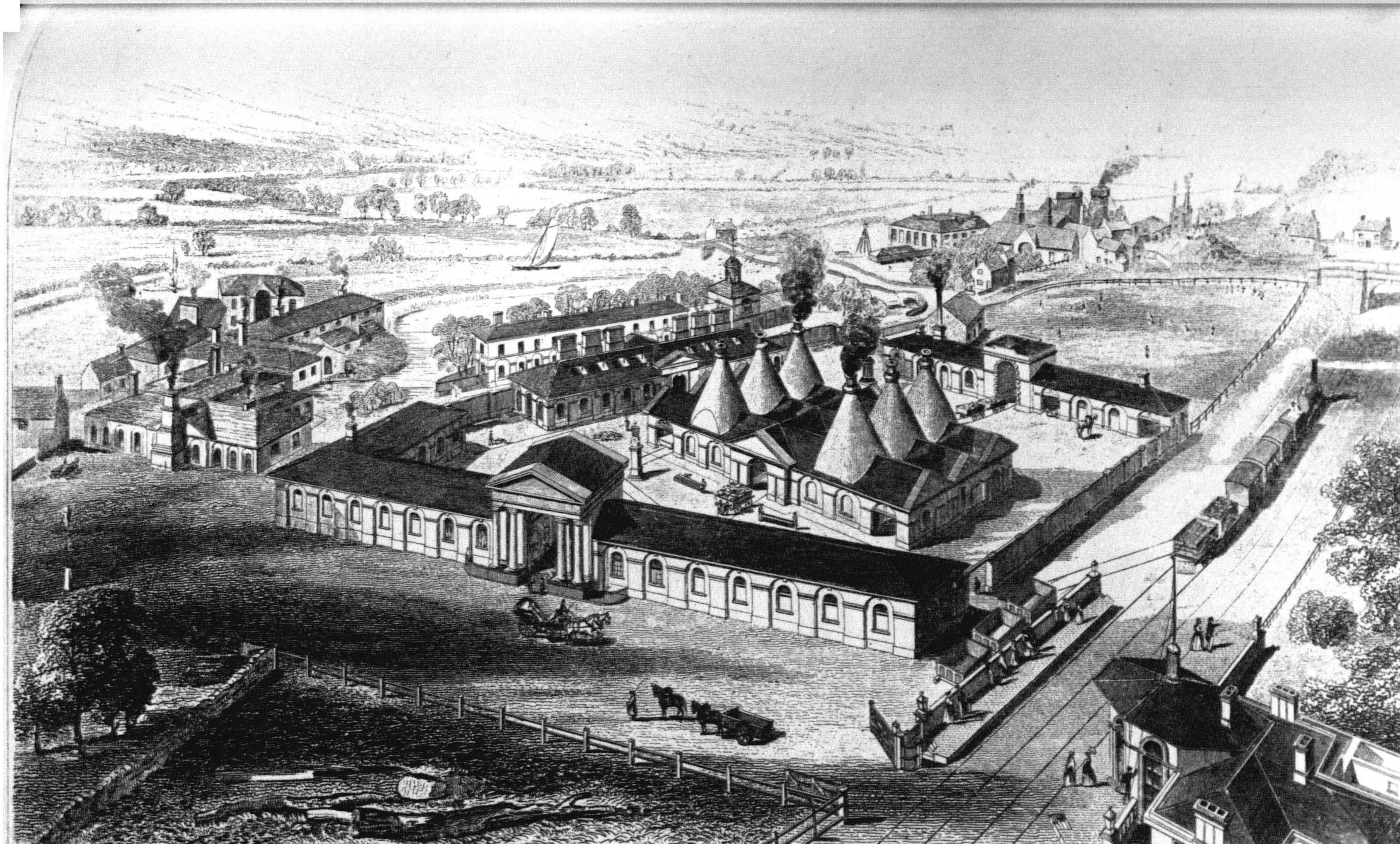


FIGURE 23

FIGURE 23 THE HOLMES WORKS OF PETER STUBS AND COMPANY

The original of this drawing was kindly presented to the Sheffield Trades Historical Society by Peter Stubs and Company. It is, in fact, the architects' impression of the works, drawn in 1842 prior to their erection. The works themselves comprised the block of six cementation furnaces, of about 22 tons capacity each, a crucible melting shop, the chimneys of which may be seen to the left of the cementation furnaces, a forge, across the road from the main block, and offices and workshops, together with a Doric archway entrance to the courtyard. The recently opened Sheffield to Rotherham railway on the right and the Don Navigation, on which a sailing barge may be seen, on the left, ensured good communications. In the background, to the right, may be seen two blast furnaces belonging to the Park Gate Company. The cementation furnaces worked until just after the First World War and stood until 1968, when they were demolished, the archway, however, being scheduled as an ancient monument!



STEEL WORKS, ROTHERHAM.

FIGURE 24

FIGURE 24 CRUCIBLE FURNACES AT ERSTA, STOCKHOLM, 1769

Bengt Qvist Andersson visited Huntsman in Sheffield in 1767. On his return to Sweden, he erected a crucible steelworks of which this is a drawing, as reproduced by C. Sahlin, 'De Svenska Degelstalsverken', Med Hammare och Fackla, Vol.IV (1932), between pp.42-43.

From the scale given, the total height from ground level to the top of the chimneys was about 27 feet. Each hole was about 2'6" square and 3'0" deep. The crucible can be clearly seen on its stand on the firebars, with its lid. Each crucible was about 14" high and 6-7" in diameter. The rectangular chimney block with its multiple flues is quite clearly an early feature.

Fig. 1. Grund Ritning A B tagen efter linierna (ab/ab) och C D tagen efter linierna (cd/cd) på Profilerne Fig 2 och 3. Fig. 2. Section tagen efter linien (ab/ab på planen Fig. 1. Fig. 3. Profil tagen efter linien (cd) på planen Fig 1. aa &c Windtugnarne. bb &c Öppningen på Vindtugnarne. gg &c Eldrör ifrån Vindtugnarne upigenom Skorstenarne. dd &c Jerngaller. ee &c Deglarne uppå deras piedestaller. ff &c Tomma rum inunder gallren och hvalfvet. gg &c Skorstenarne. h Hvalfvet emellan Vindtugnarne och under golfvet (i) i Golf i Gjutstålshuset. kk &c Sjelfva huset. ll Takresningen. Stockholm den 15 December 1769

Benct Quist Anderson.

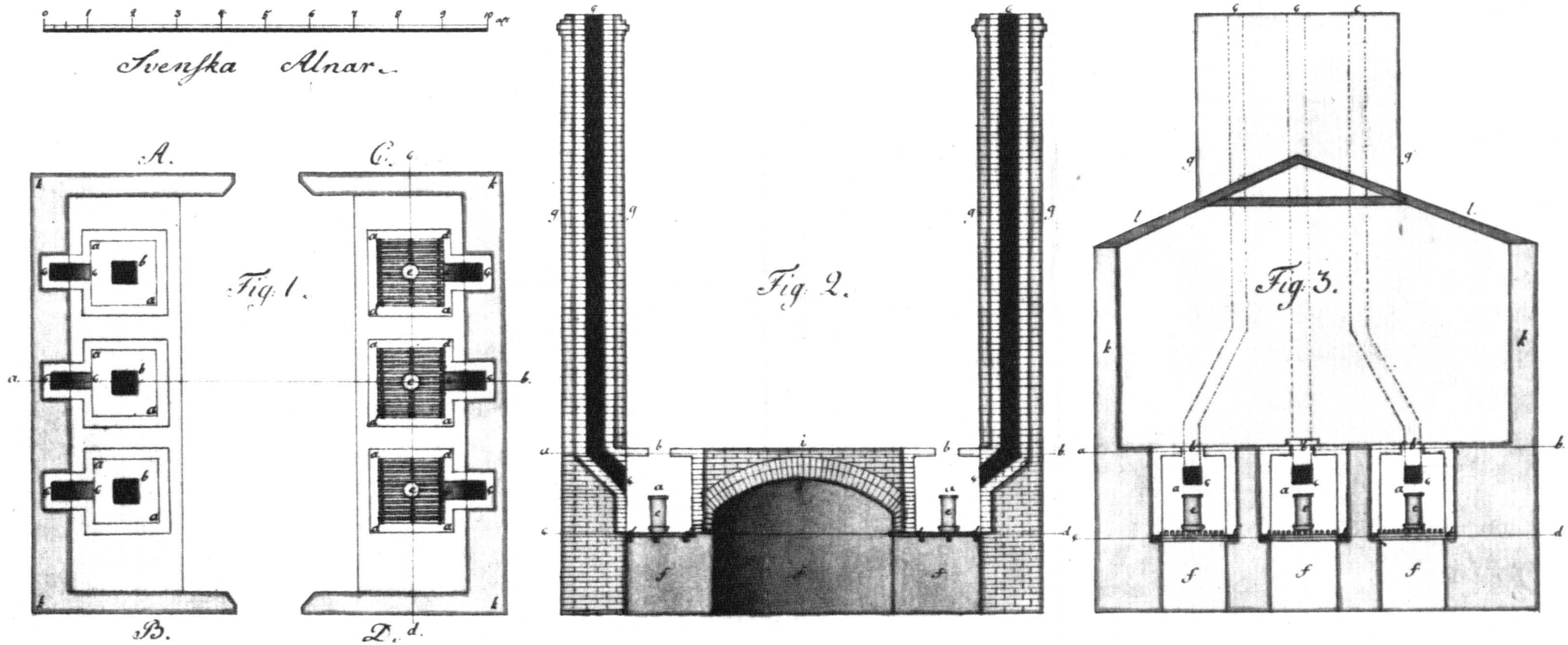


Fig. 2. Ersta degelstålsverk, Stockholm. Ritning av Assessor Bengt Qvist d. 15 dec. 1769.

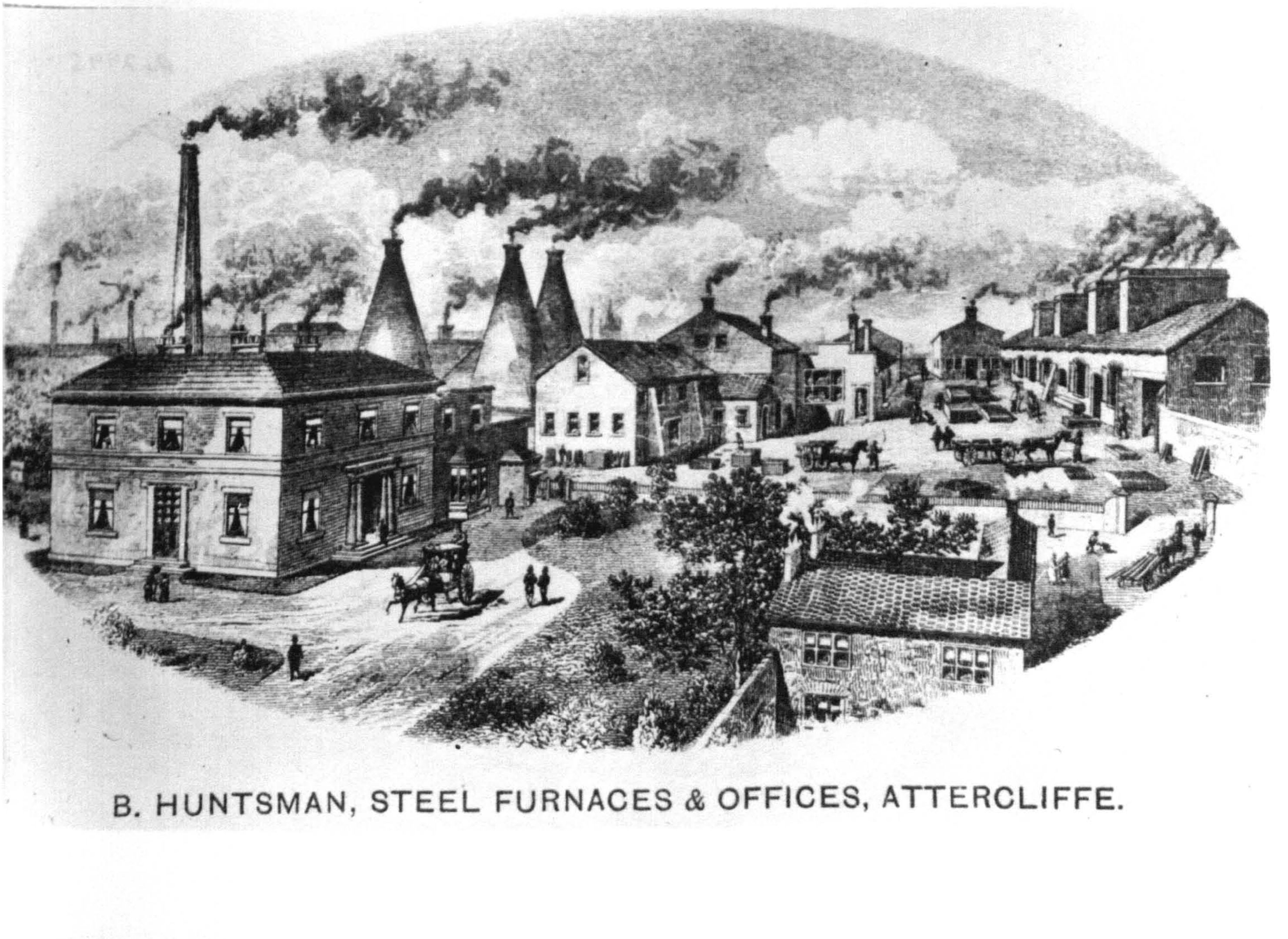
FIGURE 25

FIGURE 25 THE HUNTSMAN WORKS AT ATTERCLIFFE

Benjamin Huntsman moved to a site adjacent to the Attercliffe Road in 1772, or a year or two earlier, from his original works on the Worksop Road, not far away. Successive generations of Huntsmans continued operations on this site until 1899.

These two complementary views come from 1787 and about 1850. The first is of unknown origin and is held by the Archive Division of Sheffield City Libraries; the date 1787 is written on the back of the drawing. The second comes from a catalogue put out by the firm.

The differences are interesting. There appears to have been a cementation furnace added in the intervening years. All other available evidence would deny this. There are only two in the photograph given by R. A. Hadfield, 'The Early History of Crucible Steel', J.I.S.I. (Part II, 1894). Likewise, the Ordnance Survey of 1893 clearly shows two buildings corresponding to the front two furnaces and no building behind them to allow for the third, whilst the space behind the works appears to be a garden in the 1854 Ordnance Survey. In fact, the layout of the buildings on the earlier sketch fits the later plans very well. The possibility of the extension of the crucible furnace shop to give four transverse chimney stacks, as against three, may also be due to artistic licence.

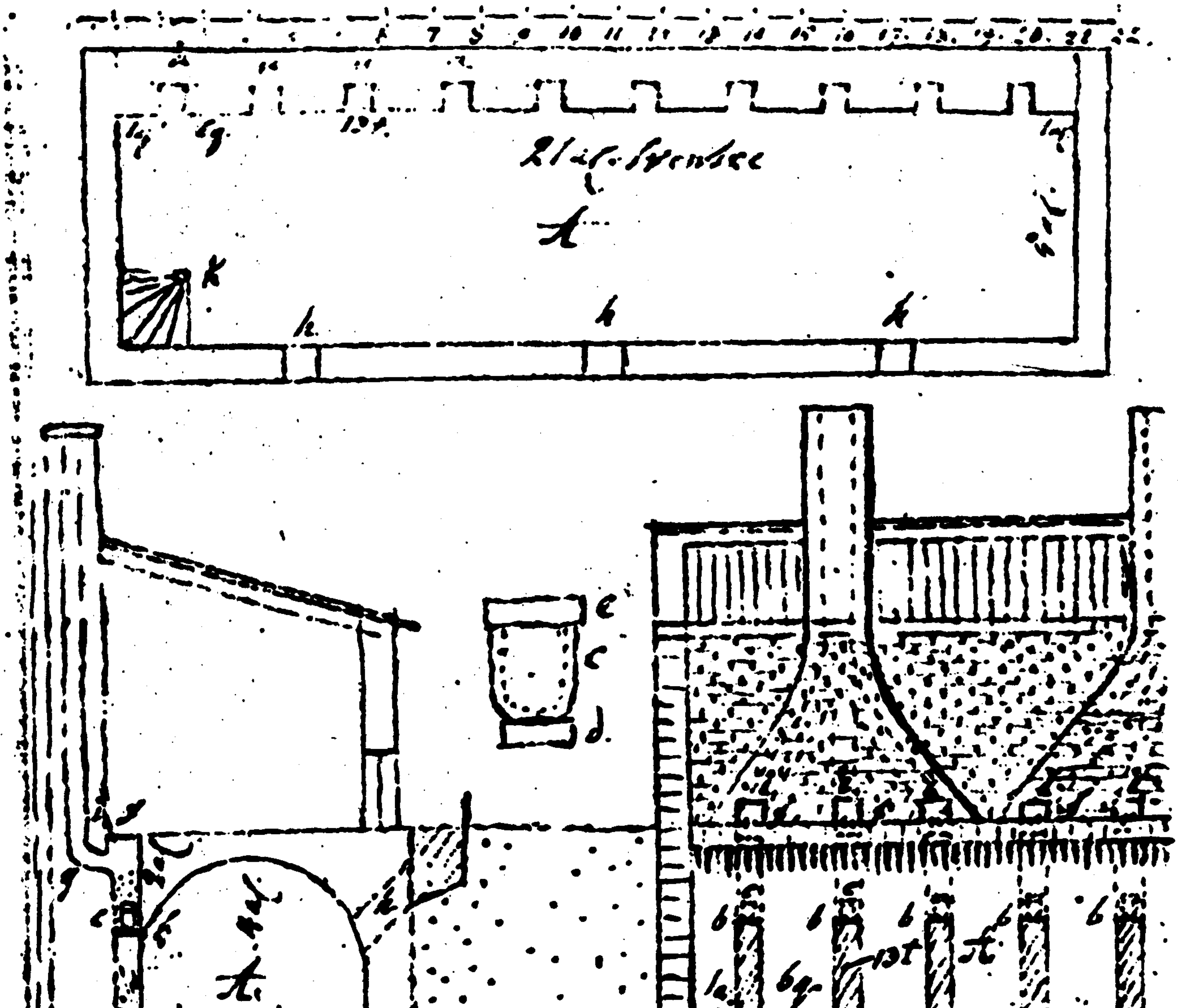


B. HUNTSMAN, STEEL FURNACES & OFFICES, ATTERCLIFFE.

FIGURE 26

FIGURE 26 A SHEFFIELD CRUCIBLE FURNACE SEEN BY ERIK GIESLER IN 1772

Erik Giesler was a Swedish engineer who visited Sheffield and in his report left this drawing, as reproduced by T. Althin, 'Erik Giesler och hans Utlandska Resa, 1772-73', _Med Hammare och Fackla_, Vol. XXVI (1971), pp.32-33. It shows a ten hole crucible furnace, with three chimneys, the end two covering three holes each and the middle one, four. The holes are in line and it therefore seems doubtful that this was the Huntsman Attercliffe Works, which had transverse chimneys; the Swedish text, however, seems to indicate that it could well have been drawn after a visit to Huntsman. The shop floor was 41 feet by 11 feet; each hole was 18" square and almost four feet deep. The cellar was 8 feet high and the same distance wide. The height of the shop was 12 feet over the holes and seven feet at the back; the chimney was 16 feet above ground level and 5 feet above roof level. As far as can be made out, the crucible was about 8" high and 6½" outside diameter, with an internal diameter of about 5".



Capt. Heels tegnarne vid Sheffield fick man händelse vis

FIGURE 27

FIGURE 27 THE CASTING OF A LARGE FORGING INGOT AT THE NORFOLK WORKS OF THOMAS FIRTH AND SONS WITNESSED BY THE PRINCE AND PRINCESS OF WALES, 1875

Illustration from the Illustrated London News, 28th August 1875, p.193.

It is not clear what the size of this ingot was, since the original intention to cast the very largest ingot was abandoned due to the excessive heat to which this would have subjected the Royal party (according to the account in A. C. Marshall and H. Newbould, The History of Firth's, pp.40-45). The gallery erected in the shop was supported by pillars of white and gold and the top of the canopy was hung with red satin carrying the Prince of Wales' plumes. There was a "clever adaptation of an Indian contrivance consisting of some fan-like fixtures in the roof worked by machinery under the flooring". The two seats for the Prince and Princess were of handsome ebonised gilt, upholstered in crimson satin with gold satin trimmings. The floor and stairs were covered with crimson cloth. It is reported that everything went off well and that the Royal party were much interested in their visit.

As far as the shop floor operations were concerned, it can be taken that this was typical of the casting of the many large forging ingots which were made from crucible steel in the East End of Sheffield at this period. There is just one rather surprising error in the drawing; the rounded bottoms given to the crucibles would have made it impossible for them to stand upright on the furnace bars and they would, of course, have come to the tundish for pouring with their stands attached to their bases.

ROYAL VISIT TO SHEFFIELD: CASTING STEEL INGOTS AT MESSRS. FIRTH AND SONS' [illegible]

FIGURE 28

FIGURE 28 AN ANALYSIS OF PATENT APPLICATIONS FROM 1853 TO 1873

The rate of increase in the total number of Patent Applications overall during this period can be seen to be between 2% and 3% per annum.

The rate of increase in Patent Applications related specifically to Cast Iron, and Wrought Iron was double this.

As regards those relating to Steel, however, it is clear from this graph that there was quite an unusual activity over this period. Whilst much of the increase was due to the Bessemer-Mushet-Siemens trio, there was still more than average interest in Steel.

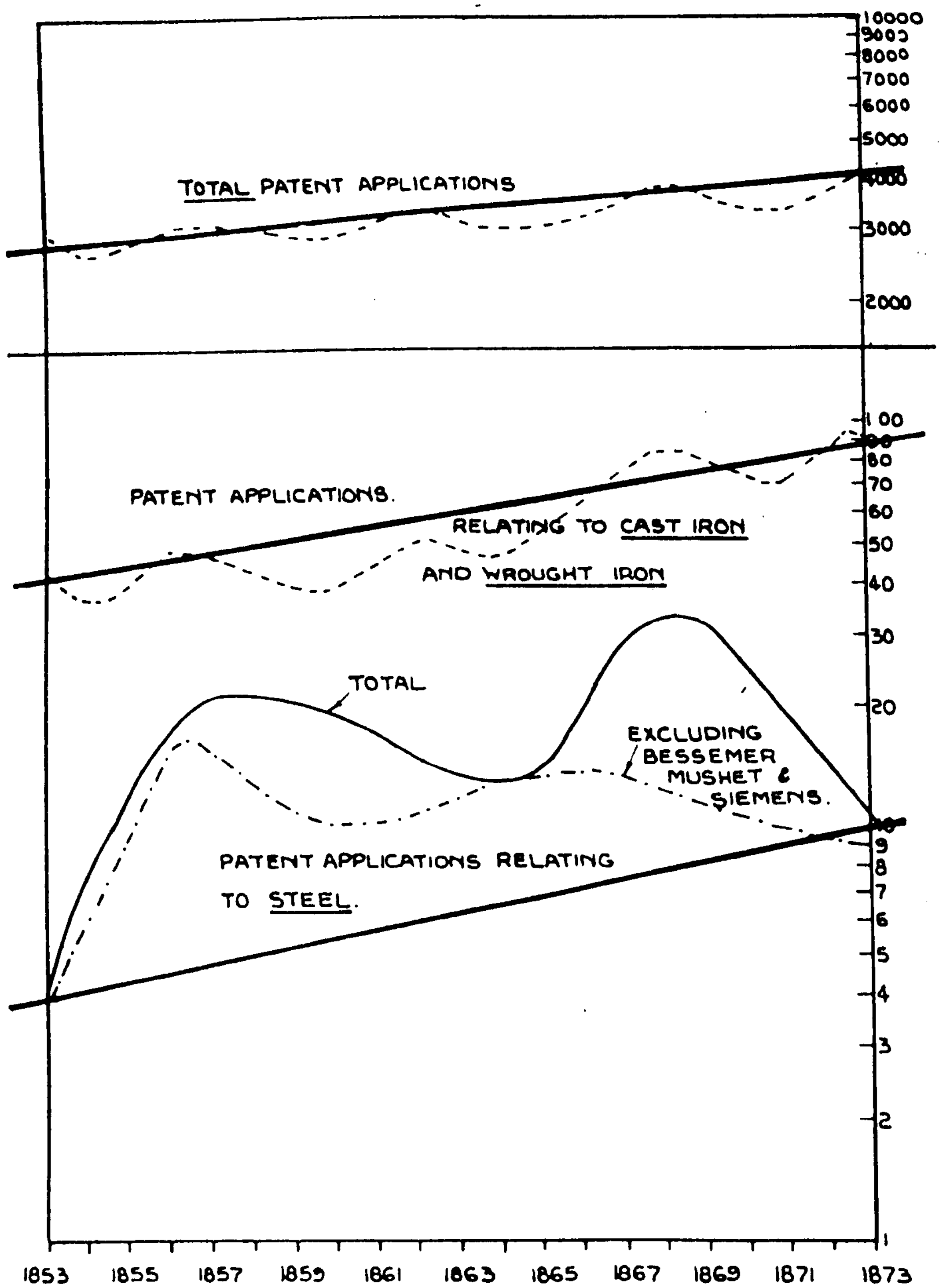
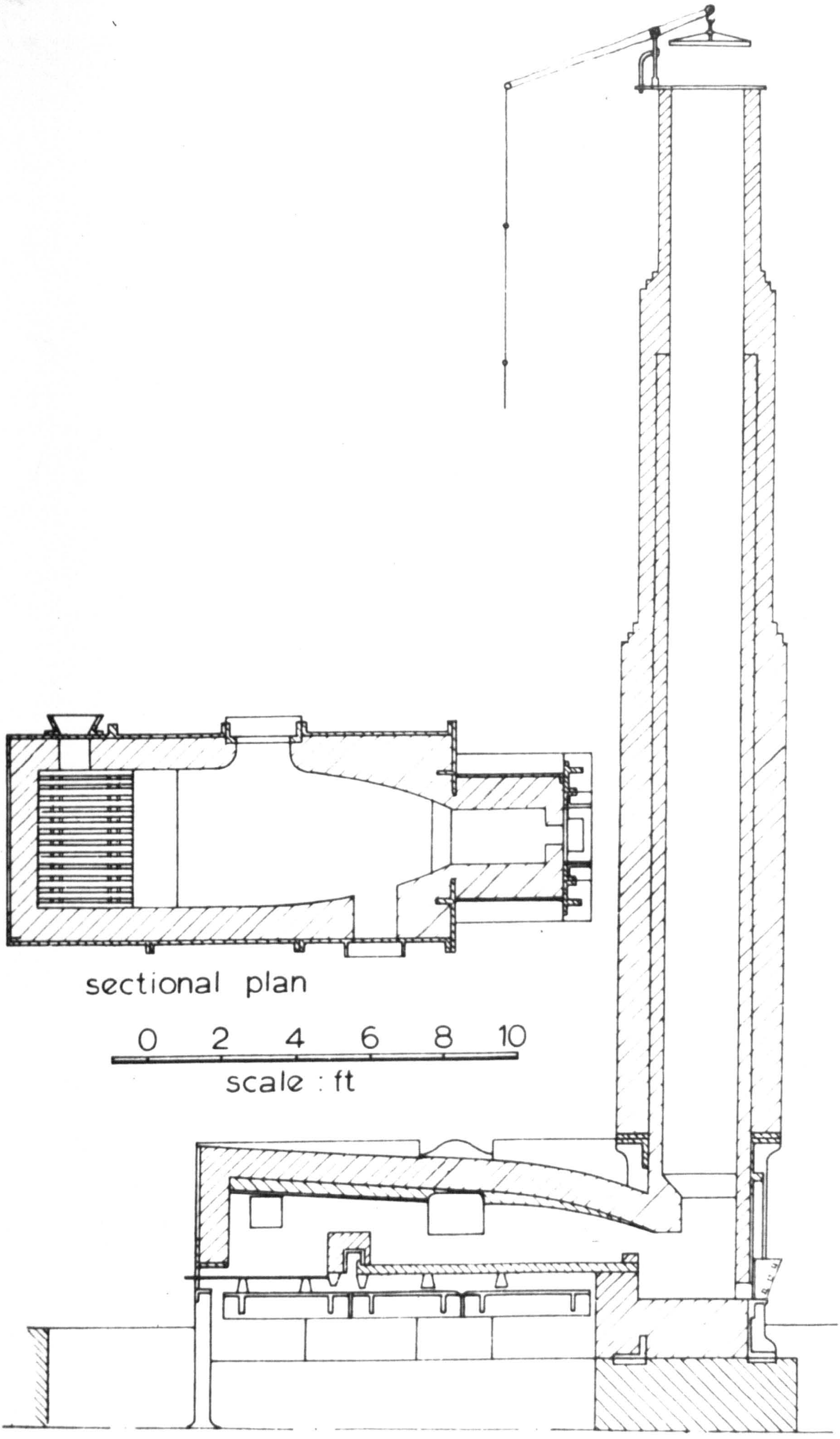

TOTAL PATENT APPLICATIONS
PATENT APPLICATIONS.
RELATING TO CAST IRON
AND WROUGHT IRON
TOTAL
EXCLUDING BESSEMER MUSHET & SIEMENS.
PATENT APPLICATIONS RELATING
TO STEEL.
10000
9000
8000
7000
6000
5000
4000
3000
2000
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
1853
1855
1857
1859
1861
1863
1865
1867
1869
1871
1873

FIGURE 29

FIGURE 29 THE PUDDLING FURNACE

This drawing is of the standard furnace at the Dowlais Ironworks, as given by W. Truran, The Iron Manufacture of Great Britain (London, 1855), Plate 9.

The essentials were a firegrate, shown on the left, separated by a bridge from the working hearth, so that the sulphur in the fuel could be oxidised before the flames had any chance of impinging on the metal. In addition, the heat could reverberate on to the hearth from the furnace roof. An adequate draught was provided by the tall chimney, but the damper arrangement allowed for control of the draught to enable the temperature to be adjusted, as necessary, during the various stages of the operation. There were over 8000 puddling furnaces in this country in 1873. (S. Griffiths, Guide to the Iron Trade of Great Britain, 1873, p.281).



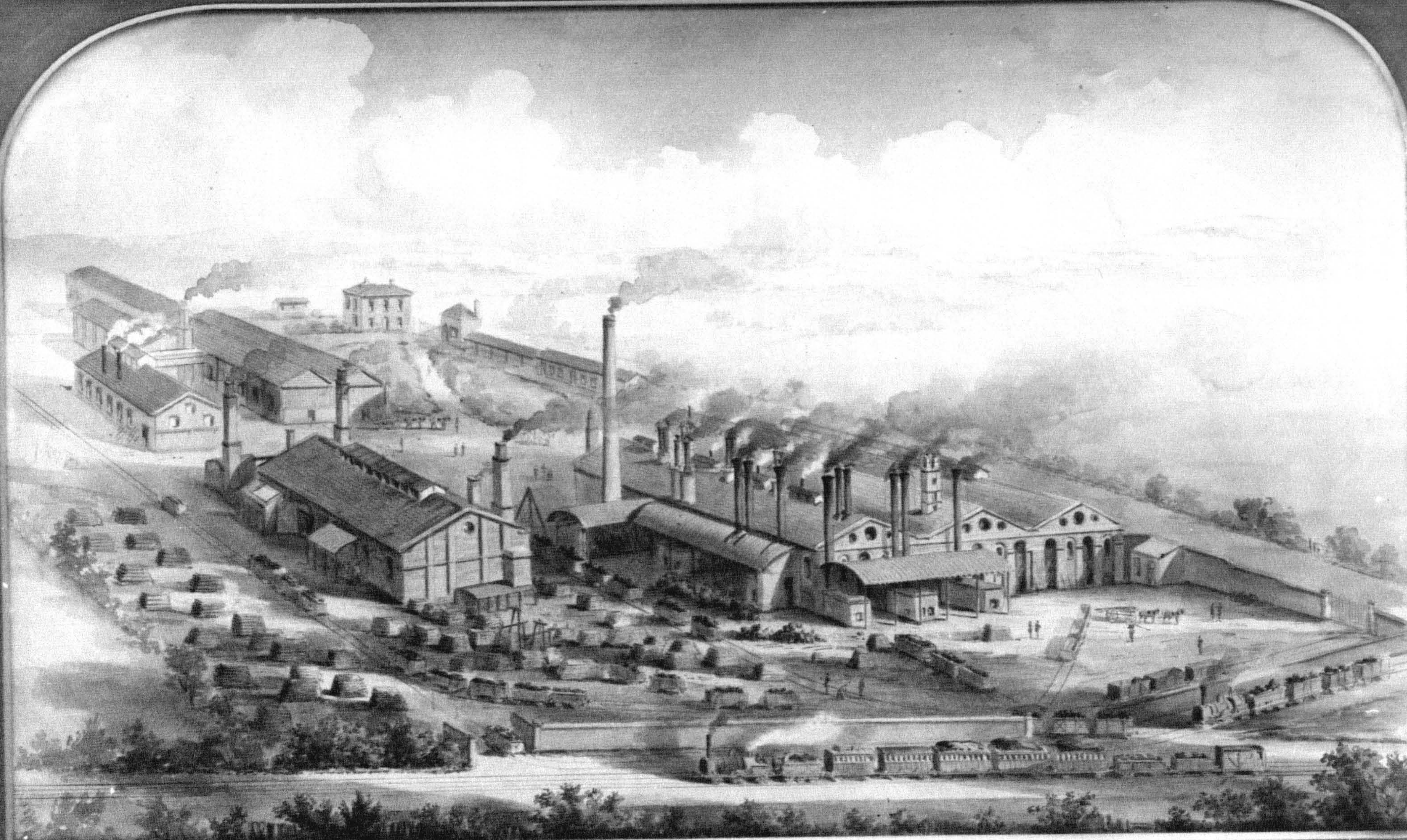
The puddling furnace at the Dowlais Ironworks: from plate 9 of 'The Iron Manufacture of Great Britain', W. Truran, 1855

FIGURE 30

FIGURE 30 THE WHITTINGTON WORKS OF THOMAS FIRTH AND SONS

This is reproduced from a water colour in the possession of Firth Brown Limited and is reproduced by kind permission.

The Whittington Works were erected in 1856 for the production of iron castings and wrought iron in bar and plate form. Very soon they were producing puddled steel, which had a high reputation. In addition, this works produced the ingot moulds required by the Sheffield Works, as well as making crane jibs, bogies, ironwork for roofs and so on which might be needed at either of the works. The plant went out of use about 1887, significantly after the closing down of the large operations in which crucible steel was used at the Sheffield works. After standing empty for many years, the works were sold in 1906.



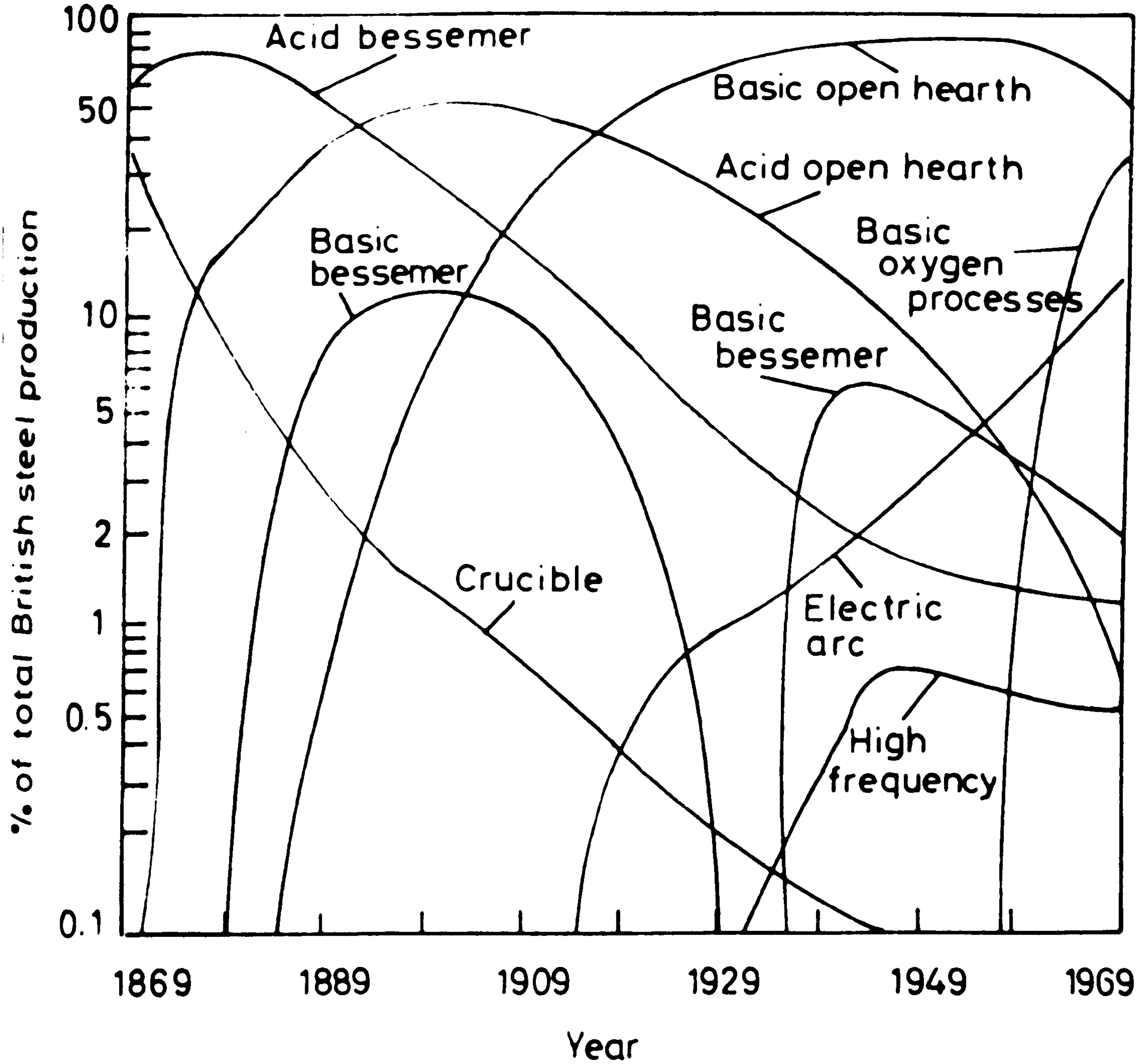
WHITTINGTON WORKS.

[illegible] - [illegible]

FIGURE 31

FIGURE 31 BRITISH STEEL PRODUCTION, 1869 TO 1969, SHOWING THE RELATIVE IMPORTANCE OF THE VARIOUS PROCESSES

This plot was originally prepared in connection with the Centenary Meeting of the Iron and Steel Institute. It shows quite clearly the manner in which the various processes took the stage. The Acid Bessemer process was superseded by the Acid Open Hearth process which was the most important method in this country, until after the First World War. From then until the early 1970s the Basic Open Hearth produced the major tonnage. It has now been rendered obsolete for bulk steel production by the Basic Oxygen Processes. As far as "quality" steel is concerned, the crucible process was gradually replaced by the Acid Open Hearth process which in turn gave way to the electric processes of Electric Arc and, to a small degree, the High Frequency process. The history of the Basic Bessemer in this country is an interesting one; having become obsolete by 1930, it was then reintroduced in one plant, that at Corby, because of the particularly favourable conditions, and continued in operation there until just recently.



British steel production 1869-1969 showing relationship between the various processes

FIGURE 32

FIGURE 32 TWENTY POUNDER RIFLED GUN MADE FROM A SOLID PIECE OF VICKERS STEEL IN 1862

This gun is preserved at the River Don Works, originally Naylor, Vickers and Company. Permission to photograph this exhibit was kindly granted by British Steel Corporation.

The steel block was produced at the Millsands Works, before the erection of the River Don plant, and was converted at Woolwich Arsenal into the gun, which weighs 1832 lb. The bore is 86" long and 3¾" diameter, with 44 rifling grooves. The trunnion is separate and is shrunk on. It withstood two separate proving trials, totalling the firing of 137 rounds, many with double charges and extended cylinders; the only effect was a slight expansion of the powder and shot chambers; the bore was reported to be free from any flaws at the conclusion of the trials. Analyses gave the following figures :

	Muzzle	Breech
Carbon	0.70, 0.71	0.61, 0.63
Silicon	0.26, 0.26	0.26, 0.26
Manganese	0.43, 0.44	0.45, 0.45
Sulphur	0.028, 0.030	0.031, 0.030
Phosphorus	0.027, 0.028	0.027, 0.027

FIGURE 33

FIGURE 33 CAST STEEL BELL MADE AT THE RIVER DON WORKS IN 1873

This item is also preserved at the River Don Works. Permission to photograph this exhibit was kindly given by British Steel Corporation.

This bell, which is 32" in diameter at the base and stands 30" high to the junction with the support ring, is one of many thousands made by Naylor, Vickers and Company, either at their Millsands Works or at the River Don Works after 1863. Used in churches all over the world, they ranged in weight from 32 lb. to 7 tons and were from 12" to 90" in diameter. By 1881, the company had sold over 7,000 of them. It is known that, some time after the English Steel Corporation was formed in 1929 by the amalgamation of the Cammells and Vickers interests, enquiries for bells continued to be received.

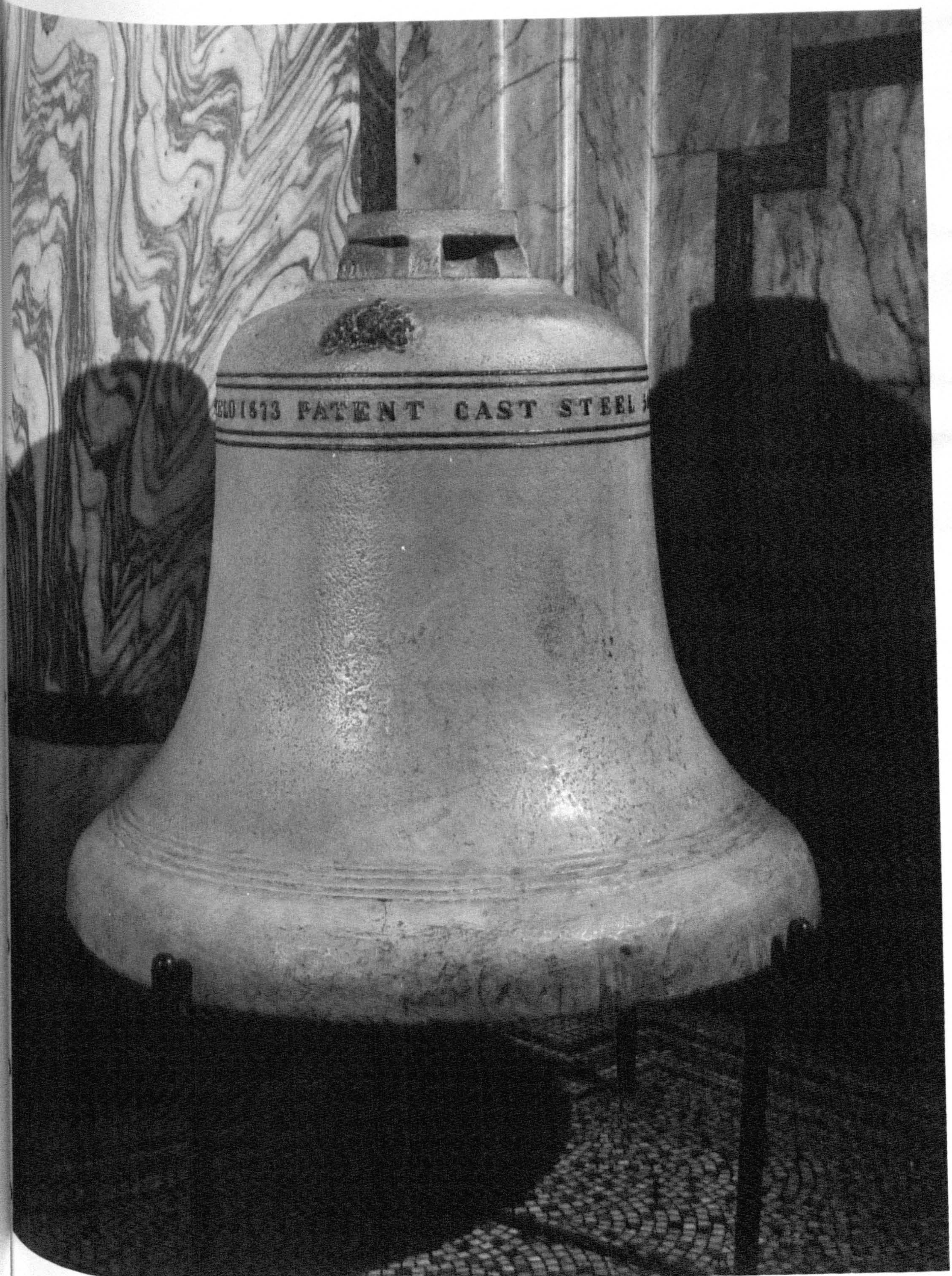

PATENT CAST STEEL

FIGURE 34

FIGURE 34 RECIPES FOR STEEL

This is a reproduction of a document preserved in the Doncaster Archives.

It provides mixes for three different "tempers" of steel, at 1.50%, 1.16% and 0.75% carbon. The "Warner's Carburising Iron" was nothing more than a pure White Cast Iron, containing, it would seem, about 3.4% carbon. The note at the bottom with regard to the necessity for adding Spiegeleisen is of interest; since the Spiegeleisen usually contained about 10% to 12% manganese such an addition would cover 0.030% or so sulphur in the melt, which in normal Sheffield practice should have been adequate. The final comment on the document indicates that Daniel Doncaster and Sons were willing to provide made up mixes of the type indicated for file steel, with 32 lb. bar iron to 17 lb. white iron with 1 lb. Spiegeleisen for 10/0d. per cwt. This particular comment, from its position in the file, would seem to come from the period 1880 to 1890, but it is known they were carrying on the same sort of business until the years just after the Second World War.

RECIPES

FOR

THREE MAIN OR STANDARD TEMPERS OF STEEL,

From which any intermediate tempers can afterwards be arrived at.

No. 1 FOR SAW FILES, &c.,

CONTAINING 1·50 % CARBON.

29 lbs. Swedish Bar Iron
20 " Warner's Carbonizing Iron.
1 " Speigel eisen.

No. 2 for TOOL STEEL for TURNING, &c.,

CONTAINING 1·16 % OF CARBON.

File 33 lb
— 17 lb W

34 lbs. Swedish Bar Iron.
15 " Warner's Carbonizing Iron. Certain
1 " Speigel eisen.

No. 3 FOR SAWS, TABLE KNIVES, &c.,

CONTAINING 0·75 % OF CARBON.

40 lbs. Swedish Bar Iron.
9 " Warner's Carbonizing Iron.
1 " Speigel eisen.

The Speigel is added for the purpose of neutralizing the sulphur, every part of which requires 7 parts of Manganese to neutralize it.

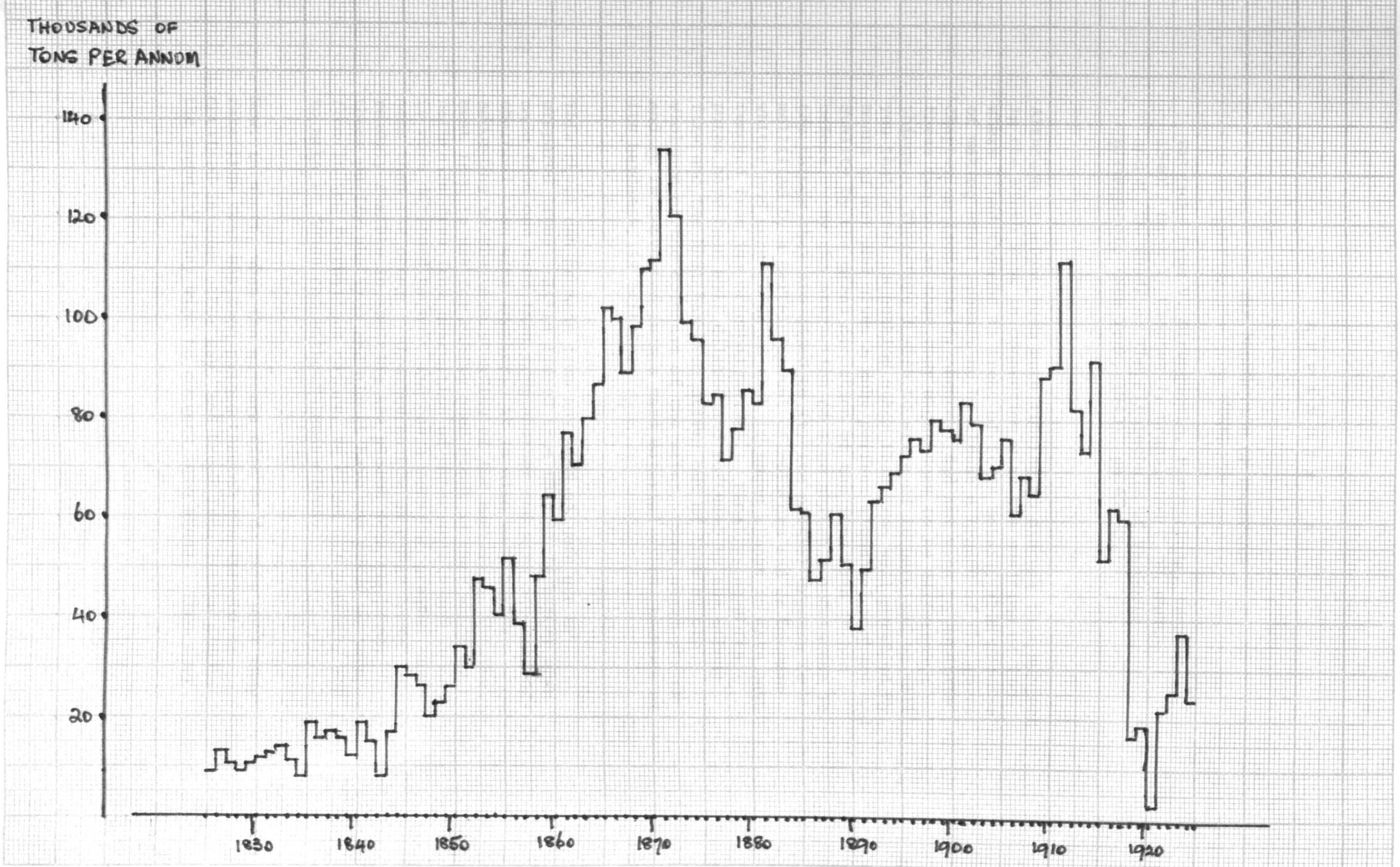
D. Doncaster & Sons 10/- per lb

FIGURE 35

FIGURE 35 THE PATTERN OF PRODUCTION LEVEL BY THE CRUCIBLE AND CEMENTATION PROCESSES IN THE SHEFFIELD AREA

The basis for the derivation of this plot is given in detail in Appendix YY.

It is in no way to be considered as a definitive pattern since there are no substantive figures available. It is, however, a reasonable interpretation of existing evidence and indicates the trends which can be perceived.


THOUSANDS OF
TONS PER ANNUM
140
120
100
80
60
40
20
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920

A P P E N D I X   A

THE PRODUCTION OF BRESCIAN STEEL

Extracts from V. Birunguccio, Pirotèchnia, (Venice, 1540), Book 1, Chapter 7, translated C. S. Smith and M. T. Gnudi as The Pirotechnia of Vanoccio Birunguccio (New York, 1943), pp.67-70.

Although it might seem more fitting to discuss this subject in the Ninth Book in connection with the smelting of iron where I had thought to treat of it in detail, this process of making steel appears to be almost a branch of the above chapter on iron itself; hence I did not wish to separate these two so far that they might seem to be different things. Therefore I wish to write of it here and to tell you that steel is nothing other than iron well purified by means of art and given a more perfect elemental mixture and quality by the great decoction of the fire than it had before. By the attraction of some suitable substances in the things that are added to it, its natural dryness is mollified by a certain amount of moisture and it becomes whiter and more dense so that it seems almost to have been removed from its original nature. Finally, when its pores have been well dilated and softened by the strong fire and the heat has been driven out of them by the violence of the coldness of the water, these pores shrink and it is converted into a hard material which, because of its hardness, is brittle.

This steel can be made from any kind of iron ore or prepared iron. It is indeed true that it is better when made from one kind than from another and with one kind of charcoal than with another; it is also made better according to the understanding of the masters. Yet the best iron to use for making good steel is that which by nature is free from corruption of other metals and hence is more disposed to melt and has a somewhat greater hardness than the other. Crushed marble or other rocks readily fusible in smelting are placed with the iron; these purify the iron and almost have the power to take from it its ferruginous nature, to close its porosity and to make it dense and without laminations.

Now, in short, when the masters wish to do this work they take iron that has been passed through the furnace or obtained in some other way, and break into little pieces the quantity they wish to convert into steel. Then they place in front of the tuyere of the forge a round receptacle, half a braccio or more in diameter, made of one-third of clay and two-thirds of charcoal dust, well pounded together with a sledge hammer, well mixed, and then moistened with as much water as will make the mass hold together when it is pressed in the hand. And when this receptacle has been made like a cupelling hearth but deeper, the tuyere is attached to the middle so that its nose is somewhat inclined downwards in order that the blast may strike in the middle of the receptacle. Then all the empty space is filled with charcoal and around it is made a circle of stones or other soft rocks which hold up the broken iron and the charcoal that is also placed on top; thus it is covered and a heap of charcoal made. When the masters see that all is afire and well heated, especially the receptacle, they begin to work the bellows more and to add some of that iron in small pieces mixed with saline marble, crushed slag, or other fusible and nonearthy stones. Melting it with such a composition they fill up the receptacle little by little as far as desired.

Having previously made under the forge hammer three or four blooms weighing thirty to forty pounds each of the same iron, they put these while hot into this bath of molten iron. This bath is called 'the art of iron'* by the masters of the art. They keep it in this melted material with a hot fire for four or six hours, often stirring it up with a stick as cooks stir food. Thus they keep it and turn it again and again so that all the solid iron may take into its pores those subtle substances that are found in the melted iron, by whose virtue the coarse substances that are in the bloom are consumed and expanded, and all of them become soft and pasty. When the masters observe this they judge that the subtle virtue has penetrated fully within; and they make sure of it by testing, taking out one of the masses and bringing it under a forge hammer to beat it out, and then, throwing it into water while it is as hot as possible, they temper it;

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* It is suggested there is here a misprint; larte di ferro could well be latte di ferro, which would then be translated as 'milk of iron'.

and when it has been tempered* they break it and look to see whether every little part has changed its nature and is entirely free inside from every layer of iron. When they find it has arrived at the desired point of perfection they take out the lumps with a large pair of tongs or by the ends left on them and they cut each one in six or eight pieces. Then they return them to the same bath to heat again and they add some more crushed marble and iron for melting in order to refresh and enlarge the bath and also to replace what the fire has consumed. Furthermore, by dipping that which is to become steel in this bath, it is better refined. Thus at last, when these pieces are very hot, they are taken out piece by piece with a pair of tongs, carried to be drawn out under the forge hammer, and made into bars as you see. After this, while they are still very hot and almost of a white colour because of the heat, in order that the heat may be quickly quenched they are suddenly thrown into a current of water that is as cold as possible, of which a reservoir has been made.

In this way the steel takes on that hardness which is commonly called temper; and thus it is transformed into a material that scarcely resembles what it was before it was tempered. For then it resembled only a lump of lead or wax, and in this way it is made so hard that it surpasses almost every other hard thing. It also becomes very white, much more so than is the nature of the iron in it; indeed it is almost like silver. The kind that has a white, very fine, and fixed grain is the best. The kinds I have heard of that are highly praised are that of Flanders and, in Italy, that of Valcamonica in the Brescian district. Outside Christendom the Damascan is praised and the Chormanian, the Azziminan, and that of the Agiambans. I do not know how these people obtain it or whether they make it, although I was told that they have no other steel than ours. They say that they file it, knead it with a certain meal, make little cakes of it, and feed these to the geese. They collect the dung of the geese when they wish, shrink it with fire and convert it into steel. I do not much believe this, but I think that whatever they do is by virtue of the tempering, if not by the virtue of the iron itself.

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* The word 'tempering' refers to what would now be called quenching and not as we now understand it to a reheating after quenching.

APPENDIX B

EARLY CEMENTATION STEELMAKING

Extracts from R. Plot, The Natural History of Staffordshire (Oxford, 1686), pp.374-375.

At the tile house at Bromley in the parish of Kingswinford one John Heydon hardens whole barrs of iron quite through, i.e. he makes them into steel, which he does not out of English, but Spanish or Swedish barrs, here called bullet iron, the manner thus. He has a round oven built of brick, not unlike those used by bakers at the top, having a grate in the bottom near the middle about a foot and a half wide, where he lays the coal: on each side whereof and at the end beyond it he lays his iron enclosed in coffins made of Amblecot clay to keep it from melting; the coffins being proportioned to the bars of iron, which are broken into lengths, or between three and four and four and five foot long; the longest being placed at the end of the oven and the shortest on each side; each coffin containing about half a tun of iron. When the fire is put to it, it is constantly tended day and night till the operation is performed, which according to the goodness or badness of the coal is done in a longer or shorter time, sometimes in three days and three nights, othertimes in four and not under a weeks time, the critical minute in which the operation is finisht being the great secret of the art of making iron into steel. Which when done, they cut it into narrower barrs, about half an inch over and then break it into short pieces of an inch or two inches long, called gadds, whereby the buyer may see whether it be good or bad (for there may be both in the same barr) otherwise they care not to buy it. And this is the method they proceed in here to make steel which seem somewhat agreeable to the practice in Aristotle's time, it then being performed by frequent ignition as it is now by a long one.

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Which additions of so many various materials beside heating the iron for superficial hardening makes me suspect that there must be some other applications for the central hardening or making of steel beside what John Heydon was willing to impart, it being evident that heating of iron only and letting it cool in the fire does rather soften it than harden it, as we plainly see in the annealing of wyer and other irons; which often heated and suffered to coole in the fire as it does out of itself (provided it be not hammered) will therefore be much softened.

A P P E N D I X C

THE NATURE OF IRON AND STEEL

Extracts from G. Jars, Voyages Métallurgiques, Vol.1 (Lyons, 1774), pp.21-22. Translation by the author.

It appears to be well founded that iron and steel are but one and the same metal and one becomes more convinced during the course of this work that one is but a modification of the other. There is no iron ore from which one cannot draw forth steel and there is no iron which one cannot convert into steel or any steel which cannot be made into iron again. Steel is nothing more than iron surcharged with phlogiston.

Monsieur de Reaumur regarded white cast iron as 'steel too steely'; he could have said this equally of all the crude cast irons. He was right to the extent that molten cast iron in general contains more phlogiston than is required in the hardest steel and this is proved since, despite the dissipation of the inflammable principle which makes itself evident in the reduction of crude iron on the open fire, there remains sufficient if one wishes to produce steel. But the great doctor should have added that the steel too steely was also very impure.

One will find in this volume an example which confirms this opinion; it is of a white cast iron from which one can easily obtain either steel or iron, because it is necessary to roast it and reheat it to dissipate its superabundance of phlogiston before working it to iron.

We have seen that in the smelting of iron ore we can obtain crude iron, which is very fragile and brittle, or ductile iron or steel and that this depends on the conduct of the fire, since whilst the quality of the ore has some considerable influence, it should not be considered other than as rendering the operations easy or difficult to those working it. Such a consideration is by no means the point of this dissertation, which has as its aim the establishment of those physical principles whose application cannot but be useful.

We shall actually see that in the refining of the crude iron we can, by suitable conduct of the heating, obtain from it either iron and steel, but also in this operation will take on the good quality or the bad quality of the crude iron which one has used.

APPENDIX D

THE PRODUCTION OF STEEL BY REFINING CAST IRON

Extracts from G. Jars, 'Voyages Métallurgiques', Vol.1 (Lyons, 1774), pp.22-24. Translation by the author.

The object of the refining operation on pig iron is to achieve the separation of the earthy matter which has remained in the metal from the first smelting. If one wishes to obtain iron, one seeks not to preserve in it the superabundance of phlogiston which is contained in it. If, on the contrary, the aim is to make steel, one must have both these objects in mind. We shall go on to see how we should proceed in the one case and the other.

The disposition of the hearth and the position of the tuyere are both essential features on which the whole operation depends. If one wishes to obtain iron, the hearth is made larger than for steel; one covers the bottom with coarse charcoal dust, hammer scale and slag and only a slight inclination is given to the tuyere. It is necessary that the air only plays on the surface of the iron. To obtain steel the charcoal dust and the slag are put into the bottom of the hearth but the tuyere is, with advantage, more steeply inclined, so that the air goes deeper; better still, the tuyere is placed nearer the hearth so that the air impinges within the material and keeps it continually agitated. A fixed inclination cannot be prescribed, since this is regulated by the quality of the iron. One cannot arrive at exactitude here or find the most advantageous position except by experience.

The hearth is filled up with charcoal, the crude iron is placed on top and at the height of the upper part of the tuyere. It is necessary to heat it up moderately slowly since if the heating is too fierce the pig iron will run through and will not bring itself to the point of separation of the earthy matter; this way one will obtain a white iron, very hard and very brittle, which is contrary to the proposed aim.

It is not necessary therefore to give a heat greater than that capable of melting the earthy matter which, being more fusible than the iron, becomes very thin and runs easily, whilst the metal remains pasty and much less fluid. From here we arrive at the point where the molten iron falls, drop by drop, into a state of fusion, the molecules of iron, being the more heavy, reuniting in the bottom of the hearth in a single mass, whilst the earths, which are in a state of complete fusion, escape in some measure from the pores of the iron to form a bath of slag around the mass; when they are present in quantity they combine with those rising from the iron, thus facilitating their separation. One can well imagine that, with this iron introduced slowly into the current of air from the bellows, the sulphureous particles, if there are any within, escape, as does the superabundance of phlogiston; the dissipation of this is achieved by stirring the iron as it forms and exposing its surface in all parts to the blast from the blower. One might call this process 'liquation', a term used in metallurgy to describe the separation of silver and lead with copper; in effect, these three metals being brought together at a temperature capable of melting the lead and not the copper, the former melts and entrains the silver, with which it has an affinity. Here it is the earthy matter which is more fluid than the iron and it can be brought into perfect fusion whilst the metal is not given any more fluidity than that which is sufficient to allow the earthy matter to escape.

But when one wishes to produce steel, much small charcoal is put on the hearth together with moistened charcoal dust so that it will be more adherent, as well as the light slag. The tuyere is more deeply inclined; melting is forced from the beginning so that the iron drips into the hearth and is kept there, in the molten condition and not pasty as in the previous operation, by the blast from the bellows which blows swiftly across the charcoal and makes channels through it. The bath is always covered with slag which is not run off. In this way one can see that an attempt is made to maintain phlogiston and to control its dissipation. The iron rests on charcoal in immediate contact with it below; it collects within the bed and is covered by the fluid retaining slag. Here the separation of the earthy matter is achieved by the force of the fire, since the material is constantly agitated by the blast and the earthy molecules meet the slag, with which they have much affinity, there locking together and becoming one body. But it is inevitable that there are also particles of metal which become slag, so that there is a greater loss than when iron is produced; in this case one does not recover much more than half the crude iron in the steel, whilst in the first case one generally obtains two thirds in the iron.

In the measure in which the steel is purged from the earthy matter, it resists the effect of the fire more and becomes harder; when it has acquired a sufficient consistency to be cut and to support the blow of the hammer, the operation is finished and it is pulled out.

APPENDIX E

THE NATURE OF IRON AND STEEL

Extracts from J. Black, Lectures on the Elements of Chemistry (Edinburgh, 1803), pp.498-504

When we try to dissolve fusible iron in acids we find it more difficult to dissolve it and there is an incomparably greater quantity of plumbago left from it than from tough iron. You know that plumbago is principally composed of carbon or carbonaceous matter; but there is besides often some sulphur or some phosphorus. The change of fusible iron into malleable iron appears therefore to depend chiefly on the destruction of the plumbago or the greater part of it. And it is easy to show in what manner this happens in the refinement of iron. Dr. Beddoes has endeavoured to explain how it happens in Mr. Cort's process and he has explained it in some measure but assumes a principle which I cannot admit.

The principle assumed by Dr. Beddoes and the French chemists is that the unrefined fusible iron, besides containing a quantity of carbon also contains iron in the state of an oxyd, and that the oxygen of this ill-reduced iron acts on the carbon and produces the increase of heat and the intumescence or fermentation and the eruption of elastic fluid and of flame. But it always appears to me inconceivable that there should be present in fusible iron at the same time, while it flows white hot from the great furnace, both an abundance of carbon and an oxyd of iron, without acting on one another originally, especially in the grey iron, which most abounds in carbon.

There is no occasion for having recourse to so unwarrantable a supposition. It is evident that the effect of a great part of Mr. Cort's process is to calcine a part of the iron in the first place. While the workman is busily employed in stirring it over from one side of its bed to the other, separating it into small parts, and mixing the whole carefully together, a quantity of the iron (to which air is admitted all the while) must be calcined or oxydated; he then increases the heat a little to make the oxygen of this calcined iron act on the carbon of the uncalcined. This increases the heat in the iron and produces the fermentation or formation of carbonic acid gas which, while it rises, carries some carbon with it - and hence the blue flame. The nicety of this operation depends on knowing how far to carry the calcination of part of the iron that there may be enough of oxygen to consume the whole of the carbon. If more iron than enough be calcined, it is so much lost.

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The very best kinds of refined, or bar iron, are very strong and tough when cold and bear to be bent backwards and forwards very much before they break and they are also very malleable when hot. Sweden is remarkable for producing iron, from some of its ores, of this very best quality. But the greater number of iron ores do not produce iron so good, though it be good enough for common uses.

The blacksmiths distinguish the common kinds of iron into two varieties, of which however there are many degrees. These two varieties they give the names of red short iron and cold short iron. The red short is tough and flexible when cold and works very well when strongly heated but if underheated it is brittle under the hammer; and as there are many varieties, the smiths make trials at first to learn how the iron is best wrought. The cold short iron, if cooled slowly after being heated, proves quite brittle when cold, especially thick bars of it, and acquires flexibility by being plunged red hot into cold water, but is always deficient in it. In its brittle state it breaks so as to show facets or plates remarkably large in the surfaces of the fracture.

Professor Bergmann made a great number of experiments to learn the causes of these different qualities of iron and he thought he had discovered the cause of cold shortness, ascribing it to the presence of a metal which he called siderum. But this has been found to be a mistake; Mayer showed that it is a phosphate of iron. Mr. Cort's process removes or prevents this bad quality.

When a piece of tough hammered iron is broken by bending, it is found to be fibrous; but if the same piece be kept red hot for some time and again broken, the fibrous appearance is almost gone. It would seem that it gets it by the action of the hammer and that iron consists of malleable infusible stuff mixed with a remainder of fusible iron. Such a mass, when heated red hot, must work under the hammer like a paste in the kneading, the fluid part being squeezed along between the ductile parts like so much grease. Perhaps this is the source of that shining or glowing skin which it gets in the welding heat, which enables two pieces to be struck together by the force of blows.

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I must in the next place give some account of steel, which is iron in a different state and possessed of properties by which it is much better adapted to serve some of our purposes than tough iron is.

Steel is refined iron intimately combined with a small quantity of pure carbonaceous matter or the carbon of the French chemists.

Slender bars of iron are put into a crucible and covered with charcoal dust rammed close round them. The crucible is luted and set in a furnace, where it is exposed to a strong red heat for some hours. When the iron is taken out its surface is frequently found rough and blistered; this I believe is owing to pushing the operation a little too far. It is now converted into steel and considerably increased in weight.

At Newcastle and other places in England, they have furnaces for this purpose, in which large quantities are made. These have the form of a large oven or arch, terminating in a vent at the top. The floor of this oven is flat and level. Immediately under the middle of this floor there is a long arched fireplace with grates, which runs quite across from one side to the other, so as to have two doors for putting in fuel from the outside of the building. A number of vents or flues pass from the fire place to different parts of the floor of the oven and throw up their flame into it so as to heat all parts of it equally. In the oven itself there are two large and long cases or boxes, built of a good fire stone and in these boxes the bars of iron are regularly stratified with charcoal dust, ten or twelve tons of iron at once, and all is covered with bed sand. The heat is continued five or six days and nights without intermission. And it requires as long a time for the furnace to cool again, before the steel can be taken out and the boxes filled with fresh bars of iron.

This process is a cementation and the carbonaceous matter must be introduced into the iron in the form of heavy inflammable air. You must recollect the experiment of Mr. Morveau, in which he exposed a diamond to intense heat, shut up in a small cavity in tough iron. The diamond vanished and the iron around it was converted into steel. These facts show plainly what happens. The charcoal, or carbon in substance, combines with the metal.

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The qualities of steel, by which it differs from iron, are,

1 It is more fusible. Tough iron cannot be melted in the most violent fires of common furnaces. It only becomes soft, but never fluid. But steel can be melted perfectly in crucibles, if exposed to the most violent heats of common furnaces.

2 In its solid state, steel is more rigid and hard than iron, nor can it be so much softened by heat, without losing its tenacity and flying in pieces under the hammer. It requires therefore more care and attention to forge it well than to forge iron.

3 Steel is much more readily broken by bending it than tough iron. It does not bear to be so much bent backwards and forwards. When a bar of it is broken the surface of it is quite different from that of iron. A bar of tough iron shows by its fracture that it is composed of fibres, the surface of the fracture being very rough, with the ragged ends of them. But steel, when broken, shows that it is composed of very small grains, of a plated structure; and presents a whitish grey surface, much more plain than that of the broken iron.

The most useful qualities by which steel excels iron are the strong cohesion of its parts and the extraordinary hardness it acquires when made red hot and suddenly cooled. It is thus made so hard as not only to cut iron with ease, but steel itself in its softer state.

This excessive hardness is attended with perfect rigidity and inflexibility, which makes such hard steel in some measure brittle. Files, which are hardened to this degree, can be broken by a fall. But the artists temper this hardness more or less, to fit the steel for different purposes.

This is done by heating the hard steel again. If its surface be made clean by grinding or polishing, then, when it is heated again, it will acquire a straw colour, which will gradually proceed to a fully gold colour, with ruddy purple streaks, which afterwards become full purple, violet and deep blue. These colours direct the artist in what state he shall arrest the temper, by dipping the steel into water or grease. The first yellow appearance fits it for the edges of chisels and punches, which are to be employed upon iron itself; the full gold colour or the beginning of the purple fits it for chisels which are to be employed on softer metals; a little more purple fits it for common edge tools; and the violet or blue fits it for watch springs. When clouds of dingy yellow are appearing among this blue, it is becoming too soft.

It would be a very desirable thing to combine this extreme hardness of steel with the toughness and tenacity of iron. The only way we can do this is by welding them together. It is thus our edge tools are made. A bit of steel is welded to the iron on that side of the plate or bar which is to be worked to an edge.

APPENDIX F

EARLY CEMENTATION STEELMAKING

Extracts from Mathurin Jousse, La Fidelle Ouverture de l'Art du Serrurier (1627), as translated by C. S. Smith, Sources for the History of the Science of Steel (Chicago, 1968), pp.51-52.

There are two kinds of Piedmont steel, made by different processes. One is artificial and the other is a natural steel produced from a good ore, but it is the latter which usually has tears and overheated spots and a coarse grain of a pale colour, and which is very difficult to weld. The artificial steel is the more common variety. It is made of small pieces of iron, which are placed in alternate layers with specially prepared crushed charcoal in a large crucible or specially-made fire-resistant pot, which has a lid and is covered in such a way that no fumes can escape. Subsequently this pot is placed in a kiln in which lime is burned or tiles, brick or earthen ware are fired or, better still, in a specially made furnace which is used for no other purpose.

This steel is of good quality provided that it has been refined twice and that the charcoal with which it was refined was freshly made shortly before it was employed. Note that not just any charcoal is suitable; do not go wrong here. The crucible must be exposed to a violent fire for two days and two nights, the longer the better, provided that it admits no air. This steel is good for working the earth and to steel-face hammers and other tools used for forcible and violent work. Under certain circumstances, it is also used for cutting tools, when it is thoroughly refined and properly quenched.

APPENDIX G

THE MANUFACTURE OF NATURAL STEEL

Extracts giving a translation of an account by Swedenborgius, undated, as printed in A. Rees, *Cyclopaedia* (London, 1819) as part of the article entitled 'The Tilting of Steel' (not paginated).

The ore from which the crude iron to be converted into steel is obtained, is of a good kind; it is black, friable, and composed of many small grains: it produces very tough iron. The conversion into steel is made upon a forge-hearth, something smaller than that commonly used for converting cast-iron into malleable iron: the sides and bottom are made of cast-iron; the tuire is placed with very little inclination on one of the side-plates; the breadth of the fire-place is fourteen inches, its length is greater; the lower part of the tuire is six inches and a half above the bottom: in the interior part of the fire-place, there is an oblong opening for the flowing of the superfluous scoria.

The workmen first put scoria on the bottom, then charcoal and powder of charcoal and upon these the cast-iron, run or cut into small pieces. They cover the iron with more charcoal, and excite the fire. When the pieces of iron are of a red white, and before they begin to melt, they stop the bellows, and carry the mass under a large hammer, where they break it into pieces of three or four pounds each: the pieces are again brought to the hearth, and laid within reach of the workman, who plunges some of them into the fire and covers them with coal. The bellows are made to blow slowly till the iron is liquified, when the fire is increased; and when the fusion has been long enough continued, the scoria is allowed to flow out, and at that time the iron hardens. The workman adds more of the piece of crude iron, which he treats in the same manner, and so on a third and fourth time, till he obtains a mass of steel of about a hundred pounds, which is generally done in about four hours. This mass is carried to the hammer, where it is forged and cut into four pieces, which are further beat into square bars four or five feet long. When the steel is thus forged, it is thrown into water, that it may be easily broken, for it is yet crude and coarse-grained. The steel is then broken in pieces, and carried to another hearth, similar to the former. These pieces are laid regularly in the fire-place, first two parallel, upon which seven or eight others are placed across; then a third row across the second in such a manner that there is a space left between those of the same row; the whole is then covered with charcoal and the fire is excited. In about half or three quarters of an hour the pieces are made hot enough, and are then taken from the fire one by one, to the hammer, to be forged into little bars from half a foot to two feet long, and while hot are thrown into water to be hardened. Of these pieces, sixteen or twenty are put together, so as to make a bundle, which is heated and welded, and afterwards forged into bars four inches* thick, which are then broken into pieces of convenient length for use.

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* This seems very large.

A P P E N D I X   H

THE MANUFACTURE OF NATURAL STEEL

Extracts from F. Korb and T. Turner, 'The Manufacture of Styrian Open Hearth Steel',*
<u>Journal of the South Staffordshire Institute of Iron and Steel Works Managers</u> (1889-90), pp.6-10

The pig iron,** having been broken into pieces of a suitable size, is now ready for the open hearth charcoal fining process. We may remind the members of this Institute that charcoal open-hearths were regularly used in England for the production of wrought iron from pig iron, until Cort patented the puddling process just over 100 years ago. Since that invention charcoal hearths have only been used in this country for producing metal of special quality, but doubtless a number of our members will recollect the use of charcoal fineries in this district, and the process has only been abandoned in connection with the South Wales trade since the extended application of Siemens steel. Under the varying circumstances of the different iron producing districts of the world, numerous modifications of a universally adopted principle naturally originated, though the chemical changes in each case were very similar. These changes are, of course, well understood, and do not essentially differ from those taking place in the puddling process, except that the impurities present are more completely removed, while the waste, and the cost of fuel and labour, are considerably greater. Professor Tunner has given a very complete account of the older open-hearth

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* The title is somewhat confusing since the author's reference to Open Hearth steel throughout refers to the charcoal finery. This should not be confused with normal Open Hearth steelmaking, here referred to as the Siemens process.

** Four analyses of Styrian white cast iron are quoted earlier, one from the makers, one from Dr. Percy and two from Professor Greenwood. The overall figures are as follows :

C	2.93-3.81
Si	0.11-0.37
Mn	0.71-1.02
S	0.016-0.030
P	0.020-0.066

processes, and this has been largely quoted by Dr. Percy in his classical *Iron and Steel*. We do not propose therefore to describe the reactions of the refining process at any great length, and much detail on our part will be all the more unnecessary, as we are fortunately able to show specimens of the materials used in the various stages of the manufacture, a large model of the furnace, the actual tools used by the workmen, and original drawings of the works themselves.

These works for the production of open-hearth raw steel are distributed along the sides of rivers in the Styrian Alps, each small works being at a slope or fall of the river capable of developing about 50 horse-power. It would be inconvenient to describe details connected with numerous small works; we have therefore chosen as an example the Warschenhofer-Zerrenhammer in Kleinreifling, Styria. These are shown in plan in Fig.1, while the sectional elevation of various portions is shown in Figs.2, 3 and 4. *

The necessary power for the hammer is obtained by means of a breast waterwheel, substantially built of larch wood. Its outer diameter is 3.5 metres, it has 25 curved paddles, and makes 25 revolutions per minute. There are five cams on the axles for working the hammer (a tail helve), hence there are 125 blows per minute. The hammer weighs 310 kilos (6 cwt.), the lift is .47 metre, and this requires nearly 50 horse-power. The blast used in the process is obtained by means of a powerful turbine and blower, from which it passes to a regulator, all of which are shown on the plan. There are two Zerren fires in the works which are indicated on the plan by A and B respectively. In the first of these (A) there is still to be seen a very ancient arrangement, standing under a stone chimney, and which is used for heating the blast. The second hearth was originally of the same pattern, but the chimney requiring to be renewed was pulled down, and a closed hearth with heater was built instead; a large old boiler now acts as chimney. The external view of such a hearth is shown in Fig.5 and it will be seen that the size and sectional area of the chimney is very large indeed when compared with the small hearths with which they are connected. The object of this is to prevent the escape of glowing sparks, since the Styrian houses are built partly of wood, and are covered with wooden tiles, so that without special care a conflagration might easily take place.

* Figs. 1 and 2 have not been located.

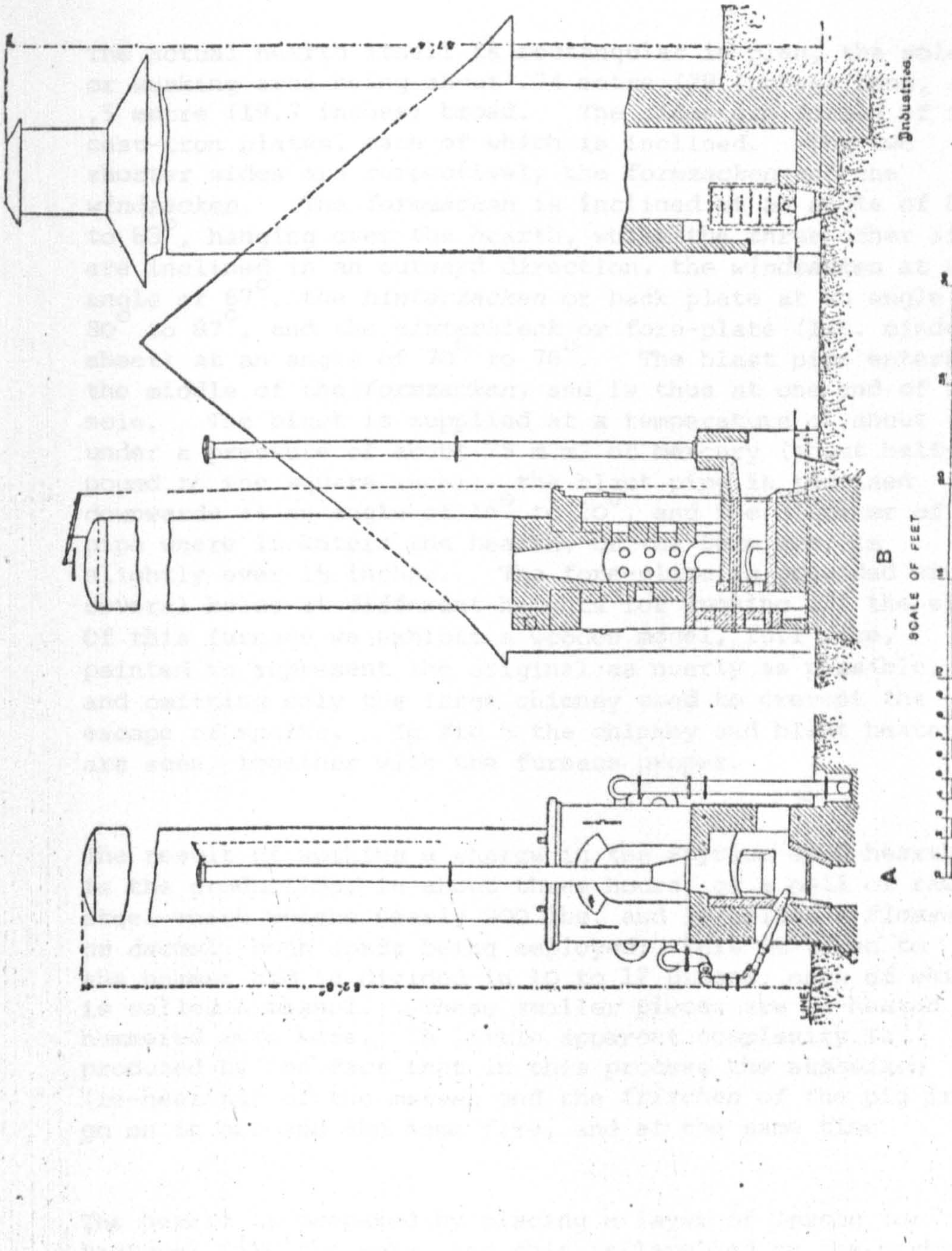


FIG. 4.

FIG. 3.

These high and wide chimneys are characteristic of such works and impart to them a most ancient and picturesque appearance.

The actual hearth itself is rectangular in plan, the sole or working area being about .74 metre (29 inches) long, and .5 metre (19.7 inches) broad. The sides are formed of four cast-iron plates, each of which is inclined. The two shorter sides are respectively the *formzacken* and the *windzacken*. The *formzacken* is inclined at an angle of 80° to 85°, hanging over the hearth, while the three other sides are inclined in an outward direction, the *windzacken* at an angle of 67°, the *hinterzacken* or back plate at an angle of 80° to 87°, and the *sinterblech* or fore-plate (lit. cinder sheet) at an angle of 70° to 76°. The blast pipe enters in the middle of the *formzacken,* and is thus at one end of the sole. The blast is supplied at a temperature of about 160°C under a pressure of about 25 m.m. of mercury (about half-a-pound to the square inch); the blast pipe is inclined downwards at an angle of 15° to 20°, and the diameter of the pipe where it enters the hearth, or the form eye, is slightly over 1½ inches. The fore-plate is provided with several holes at different heights for running off the slag. Of this furnace we exhibit a wooden model, full size, painted to represent the original as nearly as possible, and omitting only the large chimney used to prevent the escape of sparks. In Fig.5 the chimney and blast heater are seen, together with the furnace proper.

The result of working a charge in the Styrian open-hearth is the production, in about three hours, of a ball of raw steel which weighs nearly 200 lbs. and is called a *flossel* or *dachel,* both words being employed; this is taken to the hammer and is divided in 10 to 12 pieces, each of which is called a *massel.* These smaller pieces are re-heated and hammered into bars. A little apparent complexity is produced by the fact that in this process the *ausheizen* (re-heating) of the *massel* and the *frischen* of the pig iron go on in one and the same fire, and at the same time.

The hearth is prepared by placing a layer of *losche* (or brasque) into the sole, and this is levelled by the workman who stamps it with his wooden-soled shoes. A shovelful of hammer slag is then spread over, and the hearth filled with *losche* nearly to the form, a small groove being made under the form, and finally the charcoal is put on. The working begins with the heating of the *massel* from the last operation,

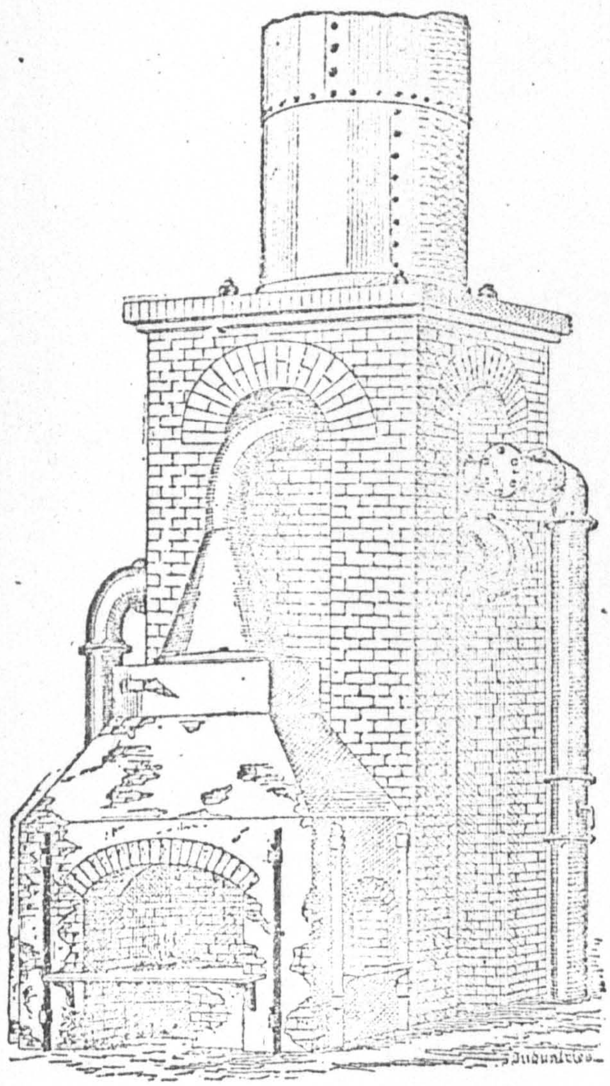


FIG. 5.—GENERAL VIEW OF STYRIAN OPEN-HEARTH.

each of which weighs about 16 to 20 lbs., and three of them being placed in the fire at once. After being heated and hammered into bars the raw steel is taken, while still red hot, and hardened by being thrown into a tank through which a stream of cold water constantly runs. In the meantime part of the pig iron has already been introduced in the form of a pile or sheaf of plates *(flossengarbe)*, each of about 1½ to 2 inches in thickness, and weighing together 60 kilos (132 lbs.). The pile, formed as described, is held by a pair of large tongs, an actual pair of which we exhibit, which rest on the side of the hearth and are balanced by weights hung on their shanks outside. These tongs retain the cast iron in the desired position on the wind side, above the charcoal, where it is very gradually heated. It is then moved to the other end of the furnace (towards the *windform)* and during this period both metal and charcoal are freely sprinkled with slag. Towards the end of the heating period, and when there are only two *massel* in the fire, the second *flossengarbe* which weighs 40 kilos (88 lbs.) is placed, as before, on the wind side. When the heating period is finished the first pile is held over the twyer, and as soon as the whole of this cast iron has melted down, the second pile, which in the meantime has been moved nearer the *windform,* is treated in the same manner. As soon as the pig iron has melted down it is essential that the temperature should be lowered as quickly as possible. For this purpose the slag is tapped off into a tank of water, the blast is reduced, and a shovelful of wet slag is thrown into the hearth. From the above it will be seen that decarburization, due to the combined action of the blast and the oxidising slags present, has proceeded very nearly as far as is desired at the end of the melting down stage. The raw steel should now be in the form of a lump, the top of which is some two inches below the twyer. The lump after being lifted in the hearth and cooled for 15 to 30 minutes so as to attain the proper temperature, is taken to the hammer and divided in 10 or 12 *massel,* as before described.

The charge of pig iron weighs about 2 cwt. and the operation lasts 3 hours; the production is some 7 cwt. per day of 12 hours. The loss of metal is about 10 per cent, and the consumption of soft (pine wood) charcoal necessary to produce 2 cwt. of raw steel is 1.87 hectolitre, or nearly 55 bushels. (For further details of this part of the process see Dr. Percy, *Steel and Iron,* pp.783-6). It is obvious that by slight modifications in the details of manipulation any kind of metal, ranging from the very softest and purest wrought iron to the hardest tool steel, can be produced in the Styrian charcoal open-hearth at the will of the operator.

The following illustrates the composition of Styrian *Heerdfrisch-stahl* produced as we have described : -

Carbon	from 0.899 to 1.141
Silicon	0.020
Phosphorus	0.019
Sulphur	0.005
Manganese	0.043
Cobalt and Nickel	traces
Copper	0.004
	0.990

If from the total amount of the elements other than iron we subtract the amount of carbon present, it will be found that the total impurities, apart from a little slag mechanically intermingled, does not exceed 0.091 per cent. Doubtless to this very exceptional purity many of the excellent properties of Styrian steel are due, particularly the readiness with which even those varieties which contain much carbon can be safely and easily welded.

It was formerly the custom to carefully assort the steel after hardening in water as previously described, and the metal was then cemented by heating with charcoal, and afterwards re-heated and welded into shear steel. To the excellence of such metal Dr. Percy refers (*Iron and Steel,* p.786).

The assorting of the raw steel previous to cementation was conducted as follows. The *massel* coming directly from the open-hearth was drawn, that is tilted, into a bar, and while still red hot thrown into cold water. The hardened steel was then broken up into short pieces and the fracture examined. Open-hearth steel, high in carbon, then usually shows very fine cracks in the angles of the bar; at those places where the bar is separated by a crack it shows concentric rings, with the various colours which may be seen on the surface of a tool during tempering, beginning with a light straw colour, and running back to a dark blue. Softer parts of the bar appear lighter in colour, and are much less affected by the hardening process; hence an experienced man is able to assort this hardened steel very exactly according to its content of carbon. By thus assorting the raw steel, and afterwards cementing it, a splendid material can be produced, but practically this method is more and more giving way to others. The cementation process has the disadvantage of a very great consumption of charcoal, and entails considerable waste; in the subsequent welding also the steel becomes a little softer at each re-heating. Further, though this cemented steel had splendid properties which have in the past rendered it so famous in Europe, it was still not perfectly homogeneous. To overcome this difficulty, therefore, the usual method in Styria at the present time is to assort the raw steel exactly as described for cementation, and the selected steel is then melted in crucibles and cast, so as to ensure perfect uniformity without at the same time reducing the content of carbon during the operation.

APPENDIX I

A SUMMARY OF THE WORK OF REAUMUR ON THE CEMENTATION OF IRON

Extracts from W. Lewis, The Mineral and Chemical History of Iron, Vol.v, Folios 107, 109, 111 and 113. Manuscript dated 1775-80, in Cardiff Public Library. Reference MS. 3.250.

The most perfect steel is prepared from the toughest and strongest forged iron, by surrounding it with inflammable substances and exposing it in a closed vessel to a strong fire. A variety of inflammable substances and compositions of them with one another and earthy and saline bodies have been used by the workmen for this purpose. Monsieur de Reaumur has entered into a particular examination of the several ingredients already made use of and of others analogous to them, both separately and combined together in order to discover the real effects of each and to determine the most successful composition. Forged iron, cemented with earthy matters alone, acquired none of the properties of steel; instead of being hardened it became sensibly softer both to the file and to the hammer .... Quicklime, sand and calcined bones made the iron somewhat softer than potters earth and elixated wood ashes .... Forged iron, surrounded with gypsum, melted into a mass of the figure of the bottom of the crucible; when the heat was insufficient for its fusion it was reduced to friable scales .... Powdered glass made the iron a little harder but did not give it the qualities of steel. Some have had a high opinion of the juices of certain plants, particularly that of garlic. Different earthy matters were therefore imbibed largely with this juice but the quality of the iron did not seem to be altered by it. Nor did earthy matters impregnated with oils and fats seem to have any effect. Salts used by themselves or along with earths divided the fibres of the soft iron but without disposing it to assume a granulated texture or become hard by quenching. From a mixture of soap and earths, the soap melted and fell to the bottom and changed the lower part of the iron into steel of a very bad kind. Charcoal, soot and old shoes burnt yielded each a hard and fine steel, but which for the most part was difficult to work when forged remained full of cracks. They all required a pretty long continued fire; the charcoal seemed to act the most slowly of the three. Horn, much esteemed by some of the makers of steel, seemed to have considerably less effect than soot. Wood ashes changed very little of the iron .... horse dung and the dung of poultry had the same effect as wood ashes. Pigeons dung gave a fine steel but intractable, that is, being forged hot fell into pieces under the hammer.

Pitcoal acted speedily on the iron, greatly diminished its volume, corroded it, made a hard fine but intractable steel. It appeared from these experiments that several of the above substances would be proper ingredients in composition for making steel but that some required additions to moderate and others to increase the activity. Different salts were mixed with charcoal and with a mixture of charcoal, soot and ashes. Fixt alkalies seemed to accelerate the change; but the steel was almost always hard to forge, full of cracks and could not be welded. Some other salts seemed rather to impede than promote the effect of the inflammable ingredients: such was borax. It was remarkable of some salts that the steel produced by them was not durable: forged and tempered once it had a fine grain but on a second forging and tempering it had scarcely any grain at all; this effect however was not constant, for steel prepared with the same salts sometimes retained its grain. These salts were sal ammoniac, sandiver, vitriol and fixt nitre. Charcoal moistened with aqua fortis into a paste gave a steel which bore only one tempering; forged and quenched a second time it returned to iron. Of all the saline substances made trial of sea salt answered the best, for making a fine hard steel which forged well and did not grow weaker in being worked. The foregoing experiments point out charcoal, soot, wood ashes and sea salt as the proper materials for changing iron into steel. By combining these ingredients in various proportions and trying them on different kinds of irons, it appeared that with the best iron a composition of eight parts of soot, four of powdered charcoal, four ashes and three or somewhat less of sea salt gave the finest and hardest steel; that for irons of inferior quality the activity of the composition may be diminished by increasing the ashes to eight parts and lessening the soot to four; that this last composition may be employed also for the best iron giving as good a steel as the first but requiring a considerably longer time; that these two compositions may be considered as the extremes; that they may be exceeded a little without danger but that it is always safest to keep within them, an increase of the inflammable ingredients making the steel too hard to work and an increase of the earthy making the change too slow; that there are irons which with the weakest of the compositions yield an intractable steel and afford a forgeable one by means of an additional quantity of earth but that it is not advisable to attempt the making of steel from any iron that requires this corrective.

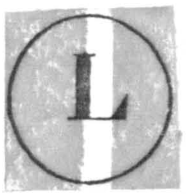
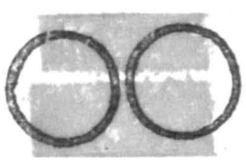
* * * * * * * *

Such is the substance of the numerous experiments of Mr. de Reaumur. Some of them I have repeated with the same event; the two compositions in particular which he fixes upon as the best I have often tried and found to succeed perfectly. I have obtained also with charcoal alone a steel which did not seem to be inferior in quality to that prepared with either of the compositions. The effect of soot does not appear to differ materially from that of charcoal, nor do the wood ashes seem to be of any other use than to divide and moderate the activity of the inflammable ingredient. A composition of powdered charcoal with a proper quantity of sand does not appear to stand much in need of any kind of addition and these, as I have been informed, are the ingredients made use of at some of our works where excellent steel is made.

APPENDIX J

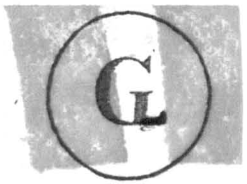
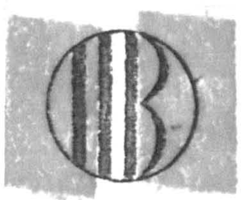
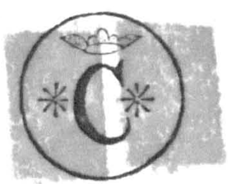
SWEDISH IRON STAMPS QUOTED IN EIGHTEENTH CENTURY STEELMAKING RECORDS

A compilation of information derived in the main from the late Torsten Berg, Esq., Bo Molander, Esq. of Stockholm and Jernkontorets Bibliotek

Stamp	English Name	Forge	County (Lan)	Founded	Closed	Permitted Annual Skippund	Production (Tons)
	Hoop L	Leufsta	Uppsala	1566	1926	6000	800
	PL	Akerby	Uppsala	1646	About 1875	2000	267
	W and Crowns	Stromsberg or Vessland	Uppsala	1643	1920	1650	220
	Double Bullet	Osterby	Uppsala	1545	1941	2600	347

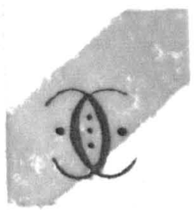
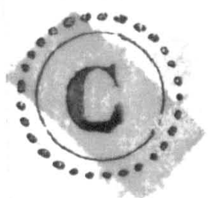
.... continued

APPENDIX J
(continued)

Stamp	English Name	Forge	County (Lan)	Founded	Closed	Permitted Annual Skippund	Production (Tons)
	GL	Gimo Forge	Uppsala	1627	1918	1500	200
	Steinbuck	Harg	Stockholm	1668	About 1930	3000	400
	Gridiron	Vattholma	Uppsala	1552	1905	1400	187
	C and Crown	Elfkarleo	Uppsala	1659	Still operating but no longer making iron	1850	247

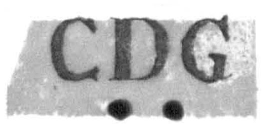
.... continued

APPENDIX J
(continued)

Stamp	English Name	Forge	County (Lan)	Founded	Closed	Permitted Annual Skippund	Production (Tons)
	Circle G	Gammelbo	Orebro	Before 1683	About 1870	2050	273
	Double C	Borgvik	Wermsland	About 1627	About 1925	2216	297
	Circle C	Elfsbacka	Wermsland	1642	1893	3266	435
	Crown and Anchor	Iggesund	Gefleborg	1685	Still operating but no longer making iron	1230	164

.... continued

A P P E N D I X J
(continued)

Stamp	English Name	Forge	County (Lan)	Founded	Closed	Permitted Annual Skippund	Production (Tons)
	PS	Nyfors and Korslangan	Kopparberg	1681	1899	2050	273
	AOK	Gysinge	Gefleborg	1701	1927	3200	628
	CDG*	Ullfors	Uppsala	1630	1925	1450	194

* It seems that the forge adopted the 'W and Crown' mark about 1760-63.

Footnote - see following page.

A P P E N D I X J
(continued)

Footnote

For the information on PS, CDG and AOK brands, I am indebted to Miss Karin Hullberg of Jernkontorets Bibliotek in Stockholm. The stamp mark for the AOK is redrawn from 'Sveriges Jern Bruks Langd', 1777, of which a photocopy was kindly provided by Mr. Bo Molander; that for CDG from a similar document dated 1787 provided by Miss Hullberg and the remainder from the 'Stampelbok' for 1845, previously held by Marsh Brothers and recently deposited with the Local History Collection of Sheffield City Libraries by Mr. G. L. Willan. The permitted annual production figures relate, where possible, to the eighteenth century; otherwise the 1845 figures are included. Discrepancies between these figures and those quoted in the attached extract from an American report of 1867 may be accounted for by extensions to the forges (for example, Elfkarleo in 1853, Stromsberg by the absorption of Ullfors, and so on).

A P P E N D I X J
(continued)

To supplement the information so far provided on the Swedish iron stamps, it appears useful to reproduce the abridged list given as an appendix to

<u>The Production of Iron and Steel in its Economic and Social Relations</u>

being the Report of the United States Commissioners on the Paris Universal Exhibition of 1867, edited by Abram S. Hewitt and published by the Government Printing Office, Washington, 1868.

Also appended is a copy of a notice issued in June 1864 which indicates that Hoop L iron was subject to counterfeiting operations, necessitating extra precautions being taken by the Concessionaires.

It may also be of interest to note that a recent example of other use of Hoop L has come to light in a Tompion turret clock illustrated in <u>Antiquarian Horology</u>, Vol.VIII, No.2, p.172 (quoted in T. Berg and D. F. Nettall, 'Iron Marks on Turret Clocks', <u>Antiquarian Horology</u>, Winter 1976, pp.78-81).

Mark.	Name of works.	Post Office.	Annual production in tons.	Principal ores.
	PROVINCE OF NORRBOTTEN.			
S: B:	Gellivore	Råneå	300	Gellivare.
	PROVINCE OF WESTERBOTTEN.			
HR RH	Hörnefors	Umnea	1,100	From middle of Sweden.
ICP	Olofsfors	Nordmaling	300	Id.
RI AB	Robertsfors	Ånäsen	600	Id.
FSL	Säfvare	Umnea	180	
	PROVINCE OF WESTER NORRLAND.			
CNF	Björkå	Nyland	150	From Lenaberg, Norberg, and Utö.
	Forsse	Nyland	1,400	Id.
	Graninge			
	Sollefteå			
×B×	Galtström	Sundsvall	380	From Utö, Bispberg, etc.
TG	Gideå	Örnsköldsvik	350	
ER	Gåhlsjö	Nyland	170	From Lenaberg, Norberg and Utö.
L-ö	Lögdö	Sundswall	175	From Stochenström, Utö, etc.
MF PD	Matfors	Id.	200	
	Norafors	Id.	175	From Staf.
NG	Sörfors, etc.	Id.	600	From Roslag.
TH	Torpshammar	Id.	[illegible]	
L	W[illegible]	Hernösand	340	
ALP	Åviken	Sundswall	130	

Mark.	Name of works.	Post Office.	Annual production in tons.	Principal ores.
	PROVINCE OF GEFLEBORG.			
SM	Andersfors	Hudiksvall	150	
P	Axmar	Gefle	1,100	From Utö, Enkärn, etc.
B E	Forsbacka, (for steel)	Gefle	850	From Tuna, Hartberg, etc.
HG	Gamelstilla	Thorsåker	430	From Bispberg, Norberg, and Thorsåker.
IPC O	Grönsinka	Gysinge	440	From Norberg, etc.
B	Gysinge	Id	940	From Dannemora.
HG E: P: HP VP CP RP TP	Hammarby; Kungsfors and Uhrfors; Hofors; Montros; Robertsholm	Thorsåker	2,300	From Bispberg, Norberg, and Thorsåker.
DE & C:o	Högbo and Sandviken	Gefle		From Bispberg and Thorsåker.
R W-n CR	(For gun-barrels.) Kiblafors (For steel.)	Söderhamn	1,100	From Hammarim and Norberg.
S DC	Ljusne	Id	430	From Norberg, Utö, Striberg, Dannemora, etc.
ST LB	Långvind	Id	680	From Wigelsbo, Utö, and Herräng.
	Mackmyra	Gefle	370	
CB M	Orkelbo	Id	1,500	From Vintjern.
T BM	Oslättfors	Id	600	From Bispberg, etc.
	Ström	Hudikswall	720	From Östanberg, etc.
S v.	Svabensverk	Falun	550	From Vintjern.
	Tolffors	Gefle	260	From Bispberg.
WB	Woxna	Bollnäs	630	From G[illegible]ås and Sörskog.

Mark.	Name of works.	Post Office.	Annual production in tons.	Principal ores.
	PROVINCE OF UPSALA.			
C	Elfkarleö	Tierp	430	From Dannemora.
G	Gimo	Upsala	280	Id.
L	Leufsta	Tierp	700	Id.
W	Strömsberg	Id	450	Id.
S	Söderfors	Id	850	Id.
IIB	Wattholma	Upsala	255	Id.
OO	Österby	Id	1,500	Id.
	PROVINCE OF STOCKHOLM.			
F	Forsmark	Tierp	520	From Dannemora.
S	Skebo	Norrtelje	830	Id.
	Harg	Östhammar	430	Id.
G GG	Rånäs	Stockholm	230	Id.
	PROVINCE OF STORA KOPPARBERG.			
K B	Avesta	Avesta	180	
DF D: L:	Dalfors	Gagnef	470	From Hamsari, Sörskog, and Gymås.
D	Dådran	Falun	350	From Vinjern and Skinnaräng.
HSC	Fredriksberg	Gagnef	1,100	From Byberg and Grängesberg.
FH	Fredshammar	Mora	770	From Åhl, etc.
SL SI	Farudal	Gagnef	650	From Åhl and Harmsarf.
GD WS LK G LG F	Garpenberg	Avesta	860	From Bispberg and Lång vik, etc.
HOS	Gravendal	Gagnef	1,100	From Grängesberg.
G GH	Grängshammar	Säter	1,100	From Gräsberg, etc.
P LW	Hagge	Suedjebacken	1,400	From Grängesberg.
T F	Horndal	Avesta	510	From Bispberg, etc.
K Mf	Kloster	Hedemora	940	From Rällingsberg.

Mark.	Name of works.	Post Office.	Annual production in tons.	Principal ores.
R×R, PS, PS	Kloten and Granbult	Köping or Ramsberg	980	From Grängesberg, Lomberg, and Ramsberg.
WF, KÅ, KB, E	Korså and Svartnäs	Falun	1,600	From Vintjern and Skinnaräng.
	Larsbo	Smedjebacken	600	From Ostanberg, Norberg.
L/B, N, SN, LX	Limå and Noraå	Gagnef / Falun	920	From Tuna Hästberg.
	Lindesnaes	Gagnef	1,500	From Gräsberg.
L, LÖF, T	Snöå		900	From Sommarberg, etc.
CBW, LW, JL	Ludvika	Smedjebocken	1,600	From Ivike, Främmundberg, Finnås and Håksberg.
EXD	Långö	Mora	270	
ME, AW, M:bo	Malingsbo	Wik	510	From Grängesberg, etc.
NXB, NB	Norn	Hedemora	280	From Bipsberg.
N.S., K: O:, OS	Norså and Olofsfors	Smedjebocken	230	
	Nybhammar	Id	1,600	From Grängesberg and Ivike.
	Siljansfors	Mora	280	From Sörskog, etc.
NV, DU	Stjernsund	Hedemora	280	From Bispberg and Norberg.
TW, ULF, GRU	Thurbo and Wikmansbyttan (Cast steel.)	Hedemora	760	From Bispberg and Norberg
	PROVINCE OF WESTERÅS.			
B	Baggå	Köping	470	From Gräsberg and Nyberg.
S	Berntshammar	Id	410	
WF	Bjurfors	Norberg	270	From Norberg.
E·B	Engelsberg	Id	320	Id.
L, L	Fagersta	Id	1,200	Id.
CVH, FERNA, BH	Ferna	Köping	1,700	From Gräsberg, Nyberg, and Grängesberg.

Mark.	Name of works.	Post Office.	Annual production in tons.	Principal ores.
GBR, HH, KH	Gislarbo	Köping	900	From Riddarhytta.
CN	Hallstahammar	Strömsholm	450	
HF, PB, N	Högfors and Persbo	Norberg	250	From Norberg.
	Jäder	Arboga	280	
SP, GH	Karmansbo, etc	Köping	1,300	From Norberg and Grängesberg.
KI, BC, LLC, LL	Kolsva	Köping	1,200	From Stripa, etc.
RB	Ramnäs	Westerås	940	From Östanberg, etc.
IA	Seglingsberg	Id	430	From Norberg.
VR	Skattmansö	Enköping	260	
SG	Skinnskatteberg	Köping	680	From Billsjö and Norberg.
Sh	Surahammar	Westerås	1,400	From Norberg.
BK SVANÅ	Svanå	Id	760	Id.
T	Trångfors	Strömsholm	190	
IW	Uttersberg	Köping	340	From Gräsberg, Tyskgrafva, etc.
HH, L	Westanfors	Norberg	190	From Norberg.
	Wirsbo	Westerås	430	
	PROVINCE OF ÖREBRO.			
GK, GK	Aspa	Askersund	490	From Nora.
BFW, BF, BFC, PPS	Bofors	Carlskoga	1,000	From Persberg and Nora.
	Bohr	Lindesberg	160	From Lomberg, etc.
	Bredsjö	Nora	170	From Ösjöberg, Gröndal, etc.
GR	Brefven	Kilsmo W. S. B.	350	From Nora and Lanna.
FCK	Bångsmedjen	Nya Kopparberg	140	From Lomberg, etc.

Mark.	Name of works.	Post Office.	Annual production in tons.	Principal ores.
K	Degerfors Ö	Åtorp	150	From Dalkarlsberg and Striberg.
WC H	Degerfors N	Begerfors N. W. S. B.	850	From Persberg, Dalkarlsberg, Striberg, & Viker.
K	Elfstorp	Nora	720	From Högborn.
P.F.	Frötuna	Arboga	390	
E D; L G; W; D; R (Common marks.)	Gammelbo (Company of Gammelbo.)	Ramsberg	270	From Ramsberg and Pershytta.
	Finnåker	Arboga	1,050	
	Grönbo	Id	220	
	Ramsbytta	Nora	120	
G B	Garphyttan	Örebro	260	From Pershytta and Mografva, etc.
HH AH	Gryn	Pålsboda W. S. B.	1,020	From Nora.
V	Haddebo Ö	Id	210	Id.
PW; B S	Haddebo N	Id	290	Id.
	Hammarby	Nora	1,000	From Hagby, Lerberg, etc.
MF; WE	Hasselfors	Hasselfors N. W. S. B.	600	From Dalkarlsberg, Striberg and Viker.
HS LS1; C; H C	Hellefors	Grythyttehed	2,810	From Lomberg and Svartvik, etc.
NE	Högfors	Nya Kopparberg	120	Id.
S×L; LS	Lassåna	Laxå W. S. B.	430	From Nora.
HSH	Laxå	Id	850	From Dalkarlsberg, Striberg, and Viker.
	Petersfors	Nora	150	From Jernboås.
A	Ramsberg	Ramsberg	150	From Stråssa and Blanka.
PV	Ramshytta	Id	140	Id.
K·	Rockesholm	Nora	260	From Skärhytta and Högborn.
D S R	Rockhammar	Arboga	1,050	From Stripa, Mossgnefva, etc.
	Sikfors	Grythyttehed	150	From Finnberg, etc.
CWS Mn	Skogaholm	Pålsboda W.S.B	510	From Nora.
03	Skyttberg	Hallsberg W. S. B.	800	Fr[illegible] Nora.

Mark.	Name of works.	Post Office.	Annual production in tons.	Principal ores.
HK E SH	Stjernfors	Nya Kopparberg	470	From Lomberg and Svartvik, etc.
BC C	Svartå	Svartå N.W.S.B	700	From Dalkarlsberg, Striberg, Viker, & Persberg.
TC L	Walåsen	Carlskoga	360	Id.
NL G; LH	Willingsberg	Örebro	500	Id.
C	Wrethammar	Ramsberg	130	From Stråssa and Blanka.
HW	Åbyhammar	Arboga	170	
PROVINCE OF SKARABORG.				
SF; HM	Forsvik	Karlsborg	300	From Nora
DB; A	Fredriksfors	Wassbacken	270	Id.
V; V	Lagerfors	Moholm W.S.B.	300	Id.
B H V	Ribbingsfors	Mariestad	350	Id.
VH; DS	Skagersholm	Finnerödja W. S. B.	430	Id.
PROVINCE OF CARLSTAD.				
F W	Ackhärn	Christinehamn	550	From Filipstad.
	Bada Ö	Sunne	150	Id.
IK	Björneborg and Jonsbol	Christinehamn	1,000	From Persberg, Dalkarlsberg, Streberg, & Viker.
ADL; BGG	Borgvik and Brunsberg	Carlstad	2,000	From Persberg.
GF	Brattfors, etc.	Id	850	Id.
K; SH	Charlottenberg	Arvika	400	From Persberg and Nora.
OPS	Dömle	Carlstad	470	From Filipstad.
	Edsvalla	Id	940	Id.
BFS; G G	Elfsbacka	Carlstad	1,280	From Nordmark and Finsbytta.
P N; B R	Fredros	Arvika	425	
CBE; I B C	Glasfors	Ökne	340	
AM	Gustafström	Grythyttehed	550	From Persberg, Björnböjde, Fagerberg, and Långvan.
CN; AJ & C; 7 I S	Helybodafors	Arvika	160	

Mark.	Name of works.	Post Office.	Annual production in tons.	Principal ores.
K:	Håkanbol	Åtorp	230	From Dalkarlsberg.
CH KB, D^x S, BE	Högfors	Sunne	630	
UvA	Kolsäter	Ökne	210	
J.S. OPS/C	Krontorp	Christinehamn	370	
RF, GF, IE, UF.	Lennartsfors	Ökne	800	
LP GE	Lesjöfors	Filipstad	1, 200	From Långban and Persberg.
NM JCA/CGO	Lethafors	Råda	220	
K: P.G	Lidefors Ö	Åtorp	150	From Dalkarlsberg and Striberg.
K: OL	Lidefors N	Id	160	Id.
S.H LNS	Lindfors	Carlstad	850	From Persberg.
OAS MM	Löfstaholm	Sunne	280	
MFS	Mitandersfors	Id	200	
OK MB	Mölnbacka	Carlstad	850	From Persberg.
GL Nm	Nielsdam	Christinehamn	280	
INN	Noreborg	Arvika	140	
HK N	Norum	Carlstad	150	
Ö	Qvarntorp	Id	170	
IGG	Ransäter Ö	Id	160	
F EF	Ransäter M	Id	180	
HK CCG	Ransäter N	Id	160	
RD RH GS	Rottnedal	Sunne	640	
6 LD 6	Rämen or Liljendal	Filipstad	680	From Långban, Persberg, and Filipstad.
IL Ł W CLG SB	Storfors	Christinehamn	1, 530	From Persberg and Nykroppa.
HK	Stömned	Carlstad	260	
CÜ ÜG	[illegible]vaneholm	Åmål	[illegible]	From Filipstad.

Mark.	Name of works.	Post Office.	Annual production in tons.	Principal ores.
WR RF	Sälboda	Arvika	1, 230	From Persberg.
Æ	Thorsby	Sunne	630	
~ Æ, LB ÆB, G.F ØF W.F	Uddeholm	Råda	4, 300	From Taberg, Nordmark, Persberg and Långban.
OPS	Wassgårda	Christinehamn	230	
Ł	Wägsjöfors	Sunne	170	

PROVINCE OF ELFSBORG.

Mark.	Name of works.	Post Office.	Annual production in tons.	Principal ores.
BF	Bäckefors	Åmål	1, 520	From Persberg.
CD LF	Christinedal	Id	460	
IGE, AL GM	Forsbacka	Id	390	
KB	Kollerö	Uddevalla	700	
V	Upperad	Wenersborg	320	

PROVINCE OF NYKÖPING.

Mark.	Name of works.	Post Office.	Annual production in tons.	Principal ores.
F	Forssa	Katrineholm W.S.B.	260	
Z	Forssjö	Id	310	From Skalunda, etc.
K	Krämbol	Id	230	
Ny	Nyby	Thorshälla	340	
	Nyköping	Nyköping	630	
	Skepsta (steel)	[illegible]lunda W. S. B.	350	
	Smedstorp	Malmköping	170	From Staf.
GS/W	Virå	Norrköping	260	

PROVINCE OF ÖSTERGÖTLAND.

Mark.	Name of works.	Post Office.	Annual production in tons.	Principal ores.
B R	Borggård	Tjellmo	260	
I∘B	Borkhult	Söderköping	190	From Utö, etc

Notice to the Consumers of Swedish (L) Steel Iron.

It having come to our knowledge, as the Sole Contractors for the Swedish (L) Steel Iron, that the above named mark is frequently impressed upon inferior qualities of Steel Iron, and sold as the well known and much esteemed Dannemora (L) Iron, and being determined to adopt every practicable mode of protecting the fair trader in, and consumer of, the above named Iron, *we give this public notice*, that no Swedish (L) Iron manufactured since 1st January last, or which will be hereafter manufactured, will be sold or delivered by us without the additional mark | LEUFSTA |, (the name of the Works in Sweden where the (L) Iron is manufactured,) being impressed thereon, such additional mark having been adopted by us for the further protection of the public and ourselves.

HINDE & GLADSTONE.

LONDON: *June*, 1864.

APPENDIX K

CONCERNING THE WROUGHT IRON USED FOR MAKING BLISTER STEEL

Extracts from Bengt Qvist Andersson, Anmarkingnar Samlade pa Resan i England Aren 1766 och 1767, Folios 156-161. Manuscript in Jernkontorets Bibliotek, Stockholm. Translation by courtesy of the late Torsten Berg, Esq.

The selection of the iron in England is given the closest attention, not only on account of the quality of the steel which may be produced from it but with due consideration given to the greater or lesser ease with which it may be processed. Consequently, if iron which can be converted to steel of satisfactory quality, but nevertheless does not produce this result consistently, such that part of the whole charge or part of one and the same bar are cemented to good steel whereas other parts have not been completely converted, then this iron is considered as useless as raw material for steel. If the iron requires several days longer time for its cementation than other tried kinds, it is rejected even though it produces good steel. Although practically all known makes of wrought iron have been investigated in England in this way, nobody has so far succeeded in making blister steel with a combination of all the desired properties from any kind of wrought iron other than the Walloon iron made from Dannemora in Sweden. Biscayan iron, converted to steel, has given the result that barely half of the five tons of bars, after several days of cementation more than the usual time, had become steel, and this, in any case, was soft and brittle. Six tons of Siberian iron, after being subjected to the same trial, turned out even worse. The part of it which finally became converted to steel consisted of 'open grains like spelter' (this is what the steelmaker at the furnace told me himself). Amongst the other trials made by this man, according to what he told me, was one on Siberian iron 'worked on the cross' (drawn down broadside) which had turned out quite well. However, since this did not always happen, it was probably not due to any basic quality in the iron itself, but rather to an occasional chance selection of a piece of iron of exceptional quality within the batch.

Experiments with the use of both Russian and English iron for the making of blister steel have been made several times at Newcastle, with the result that, in spite of the longer time taken before these kinds could be converted to steel, it was found that one end of the bar often consisted of practically nothing but iron when the other was steel. In addition, the product always lacked 'body' (strength and density).

At the steel furnace at Newcastle upon Tyne I saw a kind of American iron which was to be tried for steelmaking, but it seemed to be of very poor quality; it was full of cracks and slivers and altogether very badly forged. Swedish iron generally has such a good reputation in England that the blacksmiths there will not undertake certain difficult work if they cannot select Swedish iron for it. They also say that Swedish iron is superior to all other in regard to the specific gravity. For certain purposes, nevertheless, Spanish iron is regarded with considerable confidence, although not for steelmaking.

The characteristics that guide English steelmakers in their selection of good iron for conversion and the properties they demand it to have are as follows :

1. It must have so-called 'close grains', that is a clean dense grained fracture, free from iron fibres. Consequently iron that is fibrous ('tough iron') is not in demand, because it requires longer time for conversion to steel than the other kind and it can still hardly ever become uniformly hard steel.

2. The finer and more uniform the grain is, as shown by the fracture, the better the iron is considered to be; vice versa, an iron consisting of coarse grains ('open grains') is supposed to be of inferior quality.

3. The iron that can be converted in the shortest time is held to be the best, but it is even better if ...

4. It comes from the furnace covered by many small and closely spaced blisters.

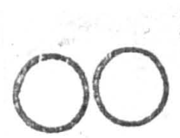
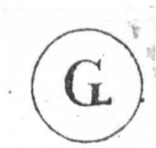
5. Some steelmakers value a steel more highly which has a coarse fracture when it leaves the furnace and before it has been drawn down than a steel with a finer fracture. Steelworkers prefer steel free from

porosities such as are generally indicated by the presence of large blisters on the outside.

At Newcastle, Swalwell and Blackermill the following stamps are nowadays the ones most sought after, namely :

It is also considered important that the iron is forged to heavy sections, such as 2½" to 3" wide by ½" thick, or 1½" square.

The above mentioned stamps also have a good reputation in Sheffield and Birmingham, as well as the following:

On the other hand, 'CDG' and 'AOK' no longer retain their former high standing. The steelmaker said about these stamps 'their substance is burnt away'. This statement, which is very often heard at the steel furnaces in England, practically always refers to iron showing fibres in the fracture, which they do not like.

A P P E N D I X   L

RAW MATERIALS FOR CEMENTATION STEELMAKING

Extracts from F. le Play, 'Mémoire sur la Fabrication de l'Acier en Yorkshire', Annales des Mines, 4me. Serie, Tome III (1843), pp.602-613. Translation by the author.

A judicious choice of raw materials is what matters most in the success of cementation steelworks. The most perfect working cannot remedy defects present in the iron which is to be used. In this respect, the manufacturers, possessing all the necessary information from innumerable trials carried out on a large scale over two centuries by so many workers in the same area and devoted to the manufacture of the same products, have for a long time demonstrated the various qualities which distinguish the kinds of iron used in Yorkshire.

Difficulty in Establishing the Rules for the Choice of Cementation Iron

The knowledge which the workers daily put to profit in the practice of their art and which alone could serve as a complete basis for the working of steel cannot at this time be considered within the domain of science. Among the (603)
obstacles which the savant has to conquer in this field of study I would particularly point out the following :

The artists of all classes and in all countries are, in general, little disposed to communicate to others the results of their experience; among the bulk of the industrialists of Yorkshire this attitude is the established one. Moreover, some of the manufacturers who do show liberal intentions in this respect are themselves rarely in a position to give enlightenment on the operations which they only direct for commercial profit and of which they leave the technical direction to simple workmen. These latter are truly the metallurgists of Yorkshire and it is only among them that one can gather the elements of steelmaking. But there, as elsewhere, there is barely a common language between the workman and the savant; it is, for example, extremely difficult to determine in many cases what qualities a workman means when he says that an iron has 'body', is 'sound', 'strong', 'tough', etc; all of these, however, are expressions which have a very precise meaning and which distinguish properties which are perfectly clear to the workman handling the iron. What increases the difficulty in this sort of study is that the expressions

do not always have the same significance to two different workers attached to two different branches of the steel trade. Finally, to arrive at a result worthy of confidence, it is necessary to know how to guard against the inexact observations of the workmen, to guard against the exaggeration with which they regard the importance of certain properties, essential perhaps for the speciality they produce, but entirely secondary for the steel industry as a (604)
whole.

On the other hand, the questions raised concerning the choice of iron used in the cementation steelworks are extremely complex and it would not be possible to deal with all the details involved within the simple framework of a simple report; I shall confine myself, therefore, to show briefly the facts which long research and a number of favourable circumstances have already allowed me to record.

Classification and Current Prices of Iron used in Yorkshire

The starting point for all studies relative to the qualities of steel iron should be a comparison of the commercial values of these irons. It is far from the whole truth, as can be seen from an overall consideration, that the market price should be an absolute means of classification for every important property, but it forms, if one can express it that way, the most precise common yardstick which one can use to appreciate among the different irons the useful properties. I have put together in the following table the results which I have gathered together on this subject in Yorkshire in 1836 and 1842 and which I owe to the goodwill of people well placed to know the commerce relating to iron in Hull and in Sheffield as well as the situation with regard to the Swedish, Norwegian and Russian forges which provide these markets.

The manufacturers of Yorkshire in addition work irons produced in England by very varied methods but which, with one exception only, all permit of the simultaneous use of coal and wood charcoal. These irons, of which (605)
the quality has improved in recent years, compete with the lowest grades of Swedish iron, but they are only used for a few purposes.

APPENDIX L
continued - 3

CURRENT PRICES OF SWEDISH, NORWEGIAN, RUSSIAN AND ENGLISH IRONS USED IN THE YORKSHIRE STEELWORKS

Swedish and Norwegian Forges		
Lofsta and Carlholm (Upsala)	£35. 0. 0.	per ton
Gimo and Ranas (Upsala)	£31. 0. 0.	
Osterby (Upsala)	£30. 0. 0.	
Forssmark (Stockholm)	£28. 0. 0.	
Stromsberg and Ullforss (Upsala)	£28. 0. 0.	
Gysinge (Gefleborg)	£27. 0. 0.	
Wattholma (Upsala)	£26. 0. 0.	
Hargs (Stockholm)	£26. 0. 0.	
Shebo and Ortala (Fahlu)	£25. 0. 0.	
Oster Rusoer (Nadenaes)	£24.10. 0.	
Elfkarleo (Upsala)	£21. 0. 0.	
Sorforss (West Norrland)	£21. 0. 0.	
Hedaker (Westeras)	£18.10. 0.	
Backaforss (Elfsborg)	£18.10. 0.	
Soderforss (Upsala)	£18. 0. 0.	
Norberg (Gefleborg)	£17.10. 0.	
Hedwigforss (Gefleborg)	£17.10. 0.	
Dadran (Fahlu)	£16.10. 0.	
Rishyttan (Fahlu)	£16. 0. 0.	
Catherineberg (Gefleborg)	£15.10. 0.	
Thurbo and Wikmanshyttan (Fahlu)	£15.10. 0.	
Awesta (Fahlu)	£15. 0. 0.	
Ludwika (Fahlu)	£15. 0. 0.	
Swana (Westeras)	£15. 0. 0.	
Amoth (Gefleborg)	£15. 0. 0.	
Strombacka and Swabenswerk (Gefleborg)	£15. 0. 0.	
Tjarnes Nedre and Robertsholm (Gefleborg)	£15. 0. 0.	
Hamarby (Gefleborg)	£15. 0. 0.	
Storforss (Carlstadt)	£15. 0. 0.	
Quarntorp (Carlstadt)	£15. 0. 0.	(606)
Friedricsberg (Carlstadt)	£14.10. 0.	
Fagersta (Westeras)	£14.10. 0.	
Sikforss (Orebro)	£14.10. 0.	
Melderstein (Norrbotten)	£14.10. 0.	
Snoa. Anderforss, Ericforss (Fahlu)	£14.10. 0.	
Spjutback (Carlstadt)	£13. 0. 0.	
Larsansjo(Westeras)	£13. 0. 0.	
Russian Forges		
Nijni-Taguilsk (Perm)	£19. 0. 0.	
Katav-Ivanovsk (Orenbourg)	£17.10. 0.	
Jourzen-Ivanovsk (Orenbourg)	£14.10. 0.	
Neviansk (Perm)	£14.10. 0.	

English Forges

Bagbarrow, Sparkbridge, Nibthwaite (Lancashire)	£17. 0. 0.
Lowmoor (Yorkshire)	£16. 0. 0.
Tividale (Staffordshire)	£15.10. 0.
Bowling (Yorkshire)	£15. 0. 0.

Physical Properties of Steel Iron

All the irons from the North which are sought by the manufacturers of cementation steel are distinguished by their grainy structure, compact and with a brilliant blue-grey colour somewhat resembling that of zinc. One sees most often in the transverse section of a bar all the features of a very pronounced lamellar structure and very rarely that of a fibrous structure. In this latter case, when nicked cold, instead of breaking with
an almost flat fracture, it tears away in fibres (607)
composed of a number of superimposed plates. The surface of these plates is a slightly silvery matt white colour; their edges, when distorted after breaking cold, present a silky gleam similar to that given, under the same conditions, by the fracture of refined copper. It is extremely difficult to break the bars cold, even when heavily nicked with a steel chisel.

Qualities Sought in Iron for the Manufacture of Steel

The essential property of these irons is that they give, by suitable working, a product having in the highest degree the useful properties of steel, that is to say they are capable of taking on a high hardness on heat treatment and a vivid brilliance on polishing, welding easily, showing high resilience and being capable of reheating many times without resuming the ordinary qualities of wrought iron. This essential property appears to me to be closely tied to the nature of the ores from which the iron is made, for on going back to the origin of the irons classified as the highest grades in this respect, I have established that they all come from a very limited number of beds of iron ore.

The quality of the fabricated articles, that is to say the property they have of bring more or less hard, sharp, polished, resilient, and so on, measures in this way the grade of the raw materials and, in part, their commercial value. One can imagine that this should be so since, on the one hand, the cost of the fabrication of the steel object remains constant, regardless of the nature of the iron and, on the other hand, the selling price of the object increases with the perfection of the raw material from which it is made. This property, which I propose
to call 'Steely predisposition'* distinguishes the irons (608)
previously mentioned from the bulk of the merchant irons of Europe and finds itself developed to its highest degree in the premier grades from Sweden, Norway and Russia.

A second and most important property is the regularity of distribution of all the elements within the body of the iron. The defects given by the lack of this quality show themselves during the successive working operations on the steel and in a more or less prompt manner, according to the quality of the iron and the nature of the working. The most general and decisive symptom is that given by the raw bars after they have undergone cementation. These bars should preserve their former shape, their surfaces perhaps covered with many small lumps which appear to be caused by the action of a gas which is developed in the body of the iron when it has acquired a certain degree of softness in the cementation furnace;** but it is essential that these kinds of blisters shall have very small dimensions (less than $\frac{1}{8}$") and shall be distributed uniformly over all the flat surfaces of the bars. Large blisters and, above all, large fissures distributed irregularly over the bars are a sure symptom of lack of uniformity. The workers often characterise this defect in different ways, saying that the iron 'lacks body' or is 'sick'.

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* The actual words are 'propension aciereuse", the property described would appear to be that generally referred to as 'body'.

** It was not until some 35 years later that Dr. Percy proved that the blisters were formed by the action of carbon on the slag stringers just below the surface of the iron, the carbon monoxide pressure being capable of raising the metal surface into the blisters.

This property is not perhaps independent of the nature of the iron ore, for it is developed to different degrees in irons derived from different ores but made by the same methods. It (609)
is always much more easy to show that the smallest differences in metallurgical treatment of identical ores are sufficient to establish pronounced differences in this respect in the quality of irons.

The enormous differences in price which exist between the best grades of Swedish, Norwegian and Russian iron appear to depend above all on defects in uniformity and when one follows with care the manipulations carried out on raw cemented steel in various shops one is not slow to understand why the workers pay some importance to this particular property. Experience shows that the walls of the major cracks formed during cementation can only be brought together with extreme difficulty under the influence of the forging operations to which the steel is submitted before putting it into service. Very often, in the same areas as these cracks, there are irregular segregations which are shown up by the presence of grey or black stains which the workers designate as 'flaws'. These flaws, which cannot be seen on the surface of the forged bar, nor on the rough finished articles (cutting tools, files and so on) are brought to light by the final operations (polishing or machining) so that one does not recognise the advisability of rejecting the object until one has carried out all the labour involved in its manufacture at a total loss. These exist in certain qualities of iron which possess the 'steely disposition'
to a high degree but which give steel which is flawed in such (610)
a manner that the amount rejected is at least one third of the sum total of the product. One imagines that the losses in material and labour involved in these rejections would markedly cheapen the raw material, even though the unrejected products occupy the same rank as those of the most highly prized grades. The English irons which are now employed in Yorkshire ordinarily recommend themselves on account of their uniformity; it is on these grounds that the steelworks seek them for certain applications, although under the heading of 'steely disposition' they lie below the more common grades of Swedish and Russian irons.

I repeat that this property plays a most important part in the grading of steel iron. Many facts, carefully collected with regard to the several grades which I have followed on a comparative basis through a multitude of successive operations, have permitted me to affirm that this single cause establishes a difference of 30% in the prices of these grades although in other respects they show themselves entirely identical.

Among the other properties which the workers seek among the steel irons I would single out again uniformity of texture. The workers have often indicated as equally good for the manufacture of steel those bars which show a single structure, be it sub-lamellar, coarse grained or even fine grained with traces of fibrous structure, but it is of advantage if each particular structure persists throughout the whole length of the bar. Experience proves that, in the contrary case, the different parts of the bar take on differing degrees of
cementation during conversion into steel, from which it (611)
follows that, in order to give a certain level of homogeneity to the steel subsequently it is necessary to use a more prolonged forging operation and, as a result, very considerable expense.

I shall have occasion many times in the following part of this report, and particularly in the second part, to return to these properties of irons and to postulate the cause of the enormous differences in price which exist between the various grades.

Shape and Dimensions of Cementation Bars

The bars of steel iron, apart from some exceptional cases, always have a flat form which, for a given cross sectional area, lends itself much better than a square or round form to the progress of cementation. The bars should always have a sufficiently large section so that the quantity of iron contained in the chests may be as great as possible; one does not depart from this rule except for very special manufacturers. The section of the bars rarely goes below 1 sq. in; often it rises to 3 sq. in. The thickness ordinarily varies between $^{5}/16$" and $^{13}/16$" and the width between 2¼" and 5½".

Cementation Mixture Employed in Yorkshire

Many workers have assured me that the complex cementation mixtures indicated in most of the works which deal with steel manufacture and also in English technologies have never been generally employed. In their opinion, the bizarre recipes given on this subject, as well as the alleged fluxes necessary for the melting of steel have
often been given with the aim of putting one off the scent (612)

of the real difficulties of steelmaking. The only reagent which I have seen charged with the iron in the cementation chests is crushed wood charcoal, part in the powdered condition and part in small pieces, the largest of which rarely exceeds a volume of 1/8 cu. in.

This charcoal is made from the branches and small debris arising from the woods used for timber within a radius of 20 miles from Sheffield; the dominant species is the oak. In the state in which it arrives at the works, the charcoal is already in quite small pieces and weighs around 20 lb. per cu. ft; it costs on average £2. 3. 6d per ton. It has often been tried, without success, to use the calcined charcoal from a previous operation as cementation medium; ordinarily, one may diminish the expense slightly without appreciably altering the carburising properties of the medium by mixing a fourth part of calcined charcoal with the new charcoal.

Coal Employed in Heating the Furnaces

Coal is the sole fuel used in Yorkshire, be it for the cementation or for the other branches of steel working.

One seeks, for preference, the very gassy coals which agglomerate in the hearth without fusion or puffing up. A mixture of fines and the small pieces remaining after sorting out the lumps is used. This mixture, after transport rarely exceeding 5 miles, costs from 8/0d to 9/0d per ton, according to the position of the works and the choice of the coal. One can use, if absolutely
necessary, fine coal of inferior quality which does not (613)
cost more than 4/0d per ton delivered to the works, but the conduct of the operation is then unduly complicated without corresponding benefit; the economy obtained will be more than balanced by the much greater length of operation and troubles caused by irregularities in the steel. These kinds of coal, abundant in Yorkshire, are only used for the heating of steam boilers.

A P P E N D I X   M

SWEDISH IRON FOR STEELMAKING

Extracts from J. L. Robsahm, Dagbok over en Resa i England Aren 1761, Folios 9-10, 12-13 and 20.
Manuscript in the Kungliga Bibliotek, Stockholm.
Translation by the courtesy of the late
Torsten Berg, Esq.

22nd May 1761: (Folios 9 and 10)

I met an Englishman by the name of Johan Hodgson from Newcastle-upon-Tyne - Hodgson in the Close, concerned in Iron Foundries. When he learned I came from Sweden, he immediately started to talk to me about Oregrund Iron, lamenting that the supplies were very limited and the price very high. I asked him which stamp he would prefer to have. He replied that for Sheffield wares he preferred the stamp

from Akerby as the foremost. It always cost him £2 more per ton than the 'double bullet' from Osterby, which according to him was considered to be the second best,

or 'Crown and W' from Vessland he liked very much and wished that he could obtain more of it. I said that we would talk more of this when I saw him in Newcastle.

As far as the much talked about 'cast steel' was concerned, he told me that it was only suitable for razors, that nevertheless had often to be sharpened, either on a stone or on a strop. It gave a uniform and good edge, but not lasting. Therefore it was not suitable for penknives or scissors and the consumption was, therefore, not large.

(In the evening he dined with Mr. Joseph Sykes at Hull): (Folios 12 and 13)

Our next conversation concerned the iron trade and he told me that for the past five years he had held contracts covering many of the best Roslagie or Oregrund stamps, some at 61 daler and some at 70 daler, which in due course had been sold to the steelworks in England at £20 to £22 per ton.[1] When Osterby Forge had been sold to Mr. Grill in 1757, the contract with Mrs. de Geer was cancelled and Mr. Sykes had lost £2000. This showed very clearly the very considerable profit that England has made from this trade. From such an excellent and genuine commodity as the Oregrund iron not a single bar would leave the country until converted into steel. The market for such steel would always be there, since without it the steel fabricating industry of Sheffield would have to shut down.

Mr. Sykes also told me that the new contracts for the next five years had now been concluded with the most important Oregrund stamps and the entire production of these would now be divided between certain merchants in London, Hull and Bristol. This will cause irreparable harm to our country because the result will be that foreigners will acquire the iron so necessary for them with so little gain to the owners of the forges and for our country, whereas a double profit could be made if the iron was converted into steel in Sweden.

The stamp

from the province of Warmland was according to Mr. Sykes not as good as formerly and this also applied to the stamp

from the same province. In reply to my question he told

1 In 1761 the rate of exchange varied from 68 to 76 daler to the £ sterling. The price in Gothenberg would be per skippund, there being 7.5 skippund per ton of 2240 lb. Thus the price in Gothenberg would have been between £6 and £8 per ton. Shipping costs and duty had to be added, but quite clearly Mr. Sykes was doing a very profitable business. The Sykes family quite simply dominated the imports of steel iron to Sheffield for 150 years.

me that the former was mainly used for agricultural implements and the latter for various parts for wagons and carriages and for horse shoes and horse shoe nails because it is a harder kind of iron which stands more wear.

2nd June 1761: At Swalwell (Folio 20)

From the bar iron forge I went to a number of anchor forges, now mostly used for forging chain links to make up a chain for the requirements of the Admiralty. Each link was three feet long and four inches thick. In one of the forges an anchor of 40 hundredweight was being made. I was also told that anchors weighing 70 hundredweight were made there. The bar iron used for this purpose must be the best Swedish and they dare not rely on Russian, Spanish or American iron in case it be cold short. The stamps from Iggesund and from Harg

were used for welding anchors. Pitcoal was used for the heating and the forging carried out by hand, for which ten or twelve workmen, working together at one time, are employed. First the shank was welded up and the ring fitted; then the arms were welded on, one at a time.

From the anchor forge I went to a number of workshops equipped for the making of black iron forgings, where shovels, mattocks and hoes were made. The latter two are implements used in America for cultivating the ground instead of ploughs. For all these articles the stamp 'C and Crown'

from Elfkarleo Forge was used. Spades, mattocks and hoes were all steeled to half the length. The steel was placed between two pieces of iron and the package then forged to its final shape.

APPENDIX N

THE CEMENTATION FURNACE AND ITS USE

Extracts from A. Rees, Cyclopaedia (London, 1819), as given in the article entitled 'The Tilting of Steel' (not paginated)

The conversion of iron into steel is performed in a furnace, hence called a converting furnace. The external building is a large and tall cone, similar to a glass-house, within which one or two large crucibles, called pots, are placed, and surrounded by flues in a manner best calculated to communicate a constant and regular heat to every part of them. In these pots the iron bars are placed, being stratified in pulverized charcoal, and the pots are covered over with sand to exclude the external air.

A more perfect idea of the converting furnace will be had by referring to *Plate VII of Iron Manufacture,**which contains a horizontal plan and two vertical sections of one of the furnaces used in the neighbourhood of Sheffield, with two pots for containing the iron. In all the figures, the same letters of reference denote the same parts. CC is the external cone, built of brick of stone work; its diameter at the base varies in different furnaces, according to the size of the pots it contains; its extreme height from the ground to its vertex should not be less than forty or fifty feet to cause a proper draught. To create a sufficient heat for the process, the top of the cone usually terminates with a cylindric chimney of some feet in height. The conical form of the external building is by no means essential; any form will operate in the same manner, if it is of a proper height: some are in practice built nearly in the shape of the small end of an egg, with a round chimney upon the top. The lower part of the cone is built square or octangular, as is the plan of *Fig.3*. The sides are carried up until they meet the cone, giving the furnace the appearance of a cone cut to a square or octangular prism at its base, and exhibiting the parabola where every side intersects the cone.

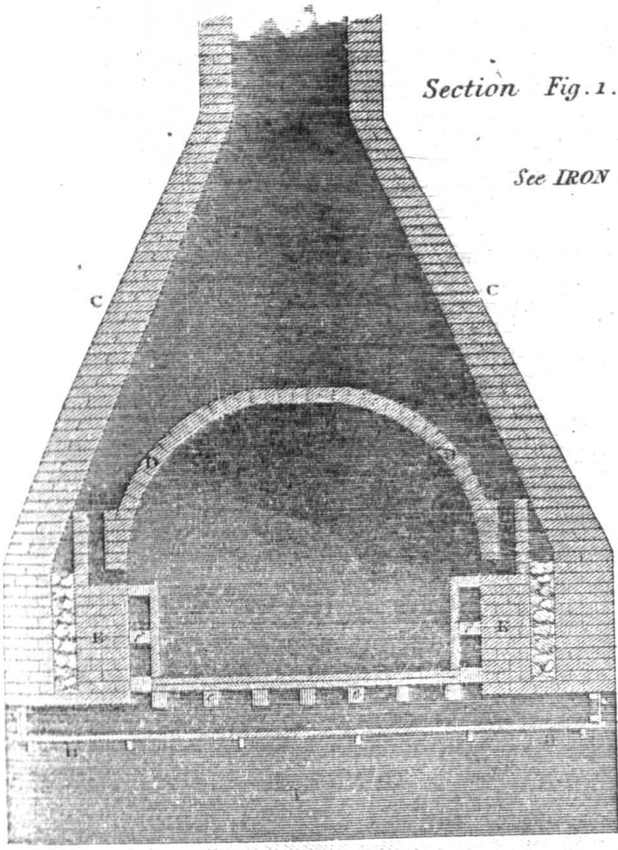
The conical building contains within it a smaller furnace, called the vault, built of fire-brick or stone, which will withstand the action of a most intense heat, without cracking or vitrification. DD in the section is the dome of the vault, and EE its upright sides, the space between which, and the wall of the external building, is filled up with rubbish and sand. The vault, as is shewn in the plan, is always four-sided, that it may contain the pots which receive the iron bars to be converted. AB represent the

* Actually marked "Plate III"

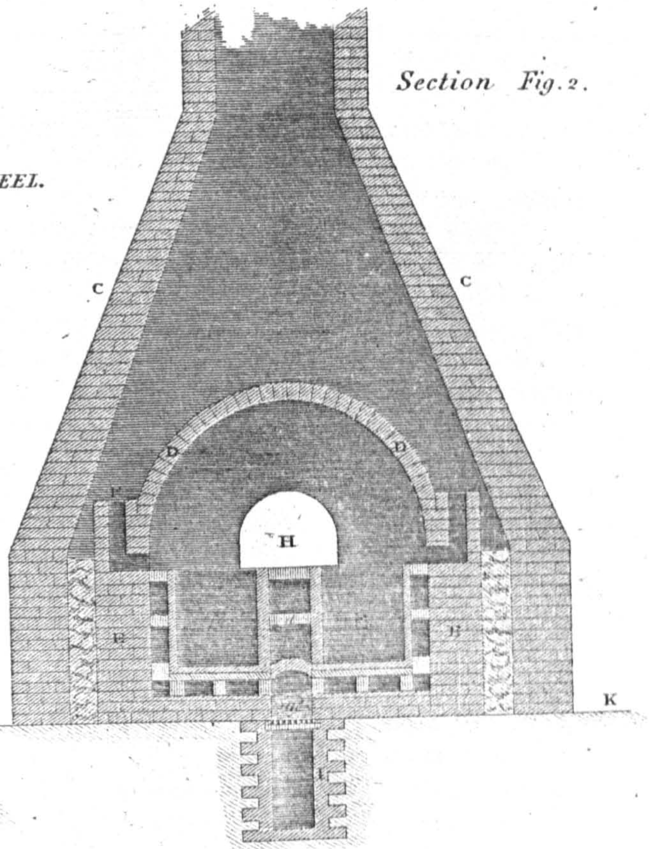
STEEL CONVERTING FURNACE.

Section Fig. 1.

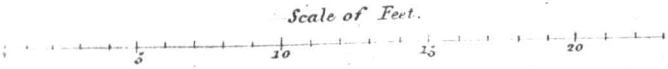
See IRON and STEEL.



Section Fig. 2.



Scale of Feet.



Plan Fig. 3.

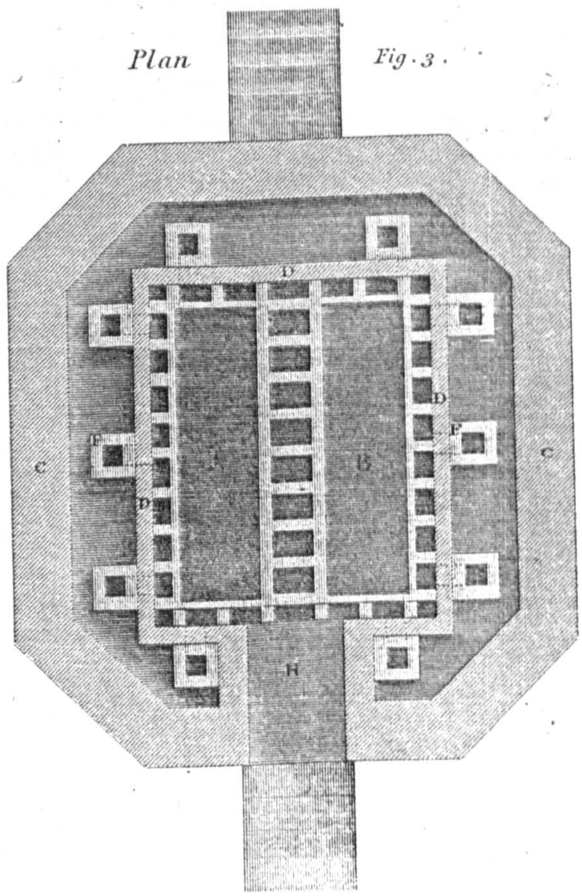
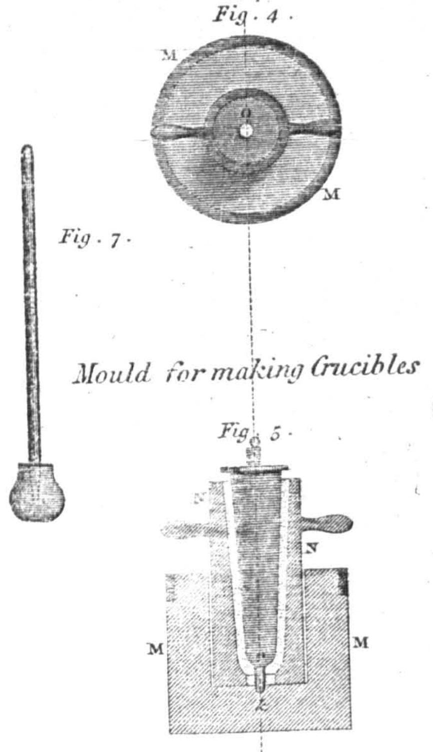


Fig. 4. Fig. 7. Fig. 6.

Mould for making Crucibles

Fig. 5.



Published as the Act directs, 1812, by Longman, Hurst, Rees, Orme & Brown, Paternoster Row.

Engraved by W. Lowry.

two pots, built of fire-stone, each ten feet long, three feet deep, and two feet nine inches wide; the space between them is twelve inches wide; and directly beneath it is the fire-grate. The pots are supported by a number of detached courses of fire-brick, as shewn at *ee (Fig.1)* which leave spaces between them, called flues, to conduct the flame under the pots; in the same manner, the sides of the pots are supported from the vertical walls of the vault, and from each other, by a few detached stones, *(f, fig.1)* placed so that they may intercept as little as possible of the heat from the contents of the pots. The adjacent sides of the pots are supported from one another by small piers of stone-work, which are also perforated, as shewn at *d (fig.2)* to give passage to the flame. The bottoms of the pots are built of a double course of brick-work, about six inches thick; the sides nearest together are built of a single course of stone, about five inches in thickness; and the other parts of the pots are single courses about three inches, the sides not requiring so much strength, because they have less heat and pressure to resist.

The vault has ten flues or short chimneys, FF, rising from it; two on each side, to carry off the smoke into the great cone, shewn in the plan 3, communicating with each side, and two at each end.

In the front of the furnace, at H, an aperture is made through the external building, and another corresponding in the wall of the vault; these openings form the door, at which a man enters the vault to put in or take out the iron; but when the furnace is lighted, these doors are closed by fire-bricks luted with fire-clay. Each pot has also small openings in its end through which the ends of two or three of the bars are left projecting in such a manner, that by only removing one loose brick from the external building, the bars can be drawn out without disturbing the process, to examine the progress of the conversion from time to time: these are called the tap-holes; they should be placed in the centre of the pots, that a fair and equable judgment may be formed from their result of the rest of its contents.

ab, in the elevation, is the fire-grate, formed of bars laid over the ash-pit, I, which must have a free communication with the open air, that it may convey a current of fresh air to supply the combustion. The ash-pit should also have steps down to it, that the attendant to the furnace may get down to examine by the light, whether the fire upon the whole length of the grate is equally fierce; and if any part appear dull, he uses a long iron hook to thrust up between the bars and open a passage for the air. The fire-place is open at both ends and has no doors. The fire-grate is laid nearly on a level with the floor of the warehouse, before the furnace, and the fireman always keeps a heap of coals piled up before the apertures at its ends, so as to close the opening. This forms a very simple and effective door; and when the furnace requires a fresh supply of fuel, a portion of the heap of coals is shoved in by a sort of hoe, and the heap renewed, to stop any air from entering into the furnace, except that which has passed upwards through the ignited fuel, and by that means contributed to the combustion.

The fire-stones that compose all those parts of the furnace which are exposed to the action of the heat, are first hewn nearly to size, and finished by grinding two surfaces together so that they make very perfect and close joints: when laid together, they are cemented with well-tempered fire-clay mixed up very thin with water. The fire-clay which answers best for this purpose, is that brought from Stourbridge, in Staffordshire, and is the same of which the celebrated Stourbridge crucibles are composed; but very good fire-clay for the purpose is procured from Birkin-lane, near Chesterfield. When the furnace has been once burnt, this clay becomes equally hard with the stone, and is less liable to fly or vitrify in an intense heat, than any other known cement.

The process of charging the furnace with iron for conversion is conducted as follows. The bars of iron are first cut to the length of the pot; and for this purpose an anvil is placed at such a distance from the wall of the building that the distance from the edge of a cold chissel wedged into the eye of the anvil, to the wall, will be just the length of the pots. One workman places the end of a bar against the wall, and lays the other end across the edge of the chissel, whilst another with a sledge-hammer strikes upon the bar till it is cut half through; then it is turned the other side upwards, and the end cut completely off. By this gauge the bars are all cut to one length, and a man enters through the door in the vault, to dispose of them in the pots: he is provided with a basket of fine pulverized charcoal, a sieve and a shovel. An iron plate is put into the furnace, and lays over the space between the two pots to form the floor, upon which the man stands while at work. He commences his operations by sifting a layer of charcoal over the bottom of the pot, about half an inch thick, and he is careful in using the sieve to lay the charcoal of an even thickness in every part; but if it should not be carefully done, he levels it with the shovel. The workman on the outside now introduces the bars into the furnace through a hole, made by taking out a brick in the wall, just over the end of one of the pots, and the workman within deposits them upon the stratum of charcoal in the bottom of the pot, arranging them parallel to each other, and leaving an interval of about an inch between each bar. When the bottom of the pot is in this manner covered with iron bars, charcoal is again sifted upon them, and levelled with the shovel, to fill up the intermediate spaces between the bars, and to cover them about an inch thick: another layer of bars is then introduced into the furnace, placed upon the charcoal, and in its turn covered over with a stratum of charcoal; and in this manner the pot is filled to within two inches of the top. A layer of the sand which is found in the bottom of grindstone troughs, is then spread three or four inches thick upon the whole, to cover the pots up close, and prevent the access of the common air and flame. In placing the successive layers of bars in the pot, it is proper that each should be laid over the space between two of the bars in the layer beneath, because each bar will then be surrounded by a greater thickness of charcoal, than it would if they were laid directly over each other. Two or three of the bars should be left somewhat longer than the rest, and their ends should project through the trial-holes in the ends of the pots, and sand rammed round them in the holes to keep out the air.

The pots being both filled and covered up with the sand and rammed down, the holes for introducing the bars are closed by a brick or fire-stone, and luted with fire-clay. The apertures through the outer wall opposite the ends of the trial-holes are also stopped and luted. The iron plate upon which the man stood is now removed, and the doors in the vault closed up by bricks set with fire-clay; next, the opening in the external building is shut up, and the furnace is charged ready for lighting.

The furnace is kindled by lighted wood placed on the fire-grate, then a few coals are thrown in, and when well lighted, the quantity is increased; the heat thus generated rarefies the air contained in the vault and in the great cone; and being thus rendered of less specific gravity than the external air, it rises up in the cone, and a fresh supply rushes in through the bars of the grate, to restore the equilibrium. By going through the fire, this air parts with its oxygen and excites the combustion, and becoming heated, rises up the chimney, and causes a very strong draught of air to enter the fire.

At first kindling, the fuel is supplied in small quantities, that the heat in the furnace may be gradually increased, and not endanger the cracking of the stones: in a few hours time the quantity of fuel is increased, so as to produce the full heat, which is to be maintained as equally as possible throughout the whole process. The fuel, which is pit-coal, is introduced at both ends of the grate, through small arches in the wall, which are in a line and on a level with the fire-grate, a quantity of coals being always left before the end of the arch to stop it up, and prevent any air getting into the furnace, without passing through the grate. Part of these coals is forced into the furnace, as before mentioned, when it requires a supply of fuel, which is generally at intervals of about half an hour each. The fireman frequently examines the appearance of the under side of the fire-grate, and judges from it the state of the fire; he improves it where necessary, as before described, by thrusting a hook up between the bars to make way for the air.

The flame arising from the ignited fuel upon the grate partly proceeds upwards between the pots, and heats them by that means; it then strikes the roof of the vault, and is reverberated down upon the pots, and escapes through the six flues or chimnies in the vault. The draught also draws the flame from the grate under the pots, and round the outside and ends. The principal object in this stage of the process is to maintain the same degree of heat in every part of the pot, that every bar may be equally converted in the same space of time. The roof of the vault must be built of very good stone (none being better than from Roches quarry, in Ashover) to withstand the great heat exerted upon it; it is customary to build them very thin, and cover the outside with a small thickness of dry sand to keep them tight, in case of a stone cracking.

In this way the fire is kept up in as equable a manner as possible until the iron is supposed to have imbibed a sufficient portion of carbon from the charcoal to render it fit for its intended purpose: in this circumstance, the manufacturer regulates his judgment by his experience of former processes. About the time that he supposes the conversion to be sufficiently advanced, one of the trial-bars is drawn out from the pot, and by comparing the size of the blisters raised upon its surface with another bar which is known to be sufficiently carbonated, an idea is formed of the state of the furnace, and accordingly the fire is, at the proper time, discontinued, and the furnace is suffered to cool. Some manufacturers proceed to make experiment of the trial-bar by hardening and tempering it, so as to prove to a certainty the degree of its conversion, the blisters being found in some degree fallacious; for their size depends as much upon the degree of heat to which the bar has been exposed, as upon its carbonization, and shew the rapidity with which the conversion has been carried on, rather than its actual state.

The time which the iron is required to be in the process of cementation depends upon a variety of concurring circumstances. 1. The degree of carbonization required to form a steel of the proper quality; this varies with the use the steel is to be applied to. 2. The heat it is subjected to. 3. The nature of the iron employed in the process. The combinations of these circumstances are so numerous that nothing but long experience can determine the proper duration of the process.

In general terms it may be observed that a short period will produce a steel very soft and tenacious, which, when properly treated, will possess elasticity as its most striking property, and is therefore very proper for springs, wire-drawing, and other purposes requiring ductility, but without the hardness requisite for edge-tools. The period of cementation for such steel varies in different manufactories, from four to six days and nights.

Steel which requires more hardness, but at the same time sufficient tenacity to resist sudden shocks, such as the edge-tools for working wood are subject to, must be cemented a longer time. This, which is mostly tilted into shear steel, is cemented six, seven or eight days, according to the heat and the quality of iron employed. The steel employed for fabricating tools for cutting metals and other hard substances being but small in demand compared with the others, is not cemented a longer time, but is returned into the furnace at the next charge, along with a charge of iron, and cemented again with fresh charcoal: this is termed double converted steel. But for some few purposes, such as the turning and boring of cast-iron, the steel is converted three times: in this state it becomes so hard and brittle as to be totally unfit for any purpose requiring tenacity, or for any cutting edge which is less than an angle of 70 degrees, or it would be continually breaking.

The heat which is requisite for the process, must be as great as to give the iron nearly a welding heat, but if carried farther, will endanger melting the bars when the process has proceeded some time; an accident which has frequently occurred through the inattention of the fireman. It is observed by manufacturers, that the carbonization proceeds quicker when the heat is greatest, and for this reason the duration of the process varies in different furnaces, in some measure from their construction, in urging a greater heat, and this depends chiefly upon the height of the chimney, and the draught it occasions.

When the conversion is supposed to be complete, the furnace is suffered to cool, until a man can conveniently enter the furnace, to take out the bars and remaining charcoal, and prepare the furnace for a new charge. The bars which are brought out are (from being covered with blisters upon the surface) termed blistered steel.

On examination of the fracture of a blistered bar, it is found full of internal cracks, which are generally parallel to the flat side of the bar: some of them are larger than others and extend the parts of the bar sufficiently to raise numerous protuberances or blisters upon its surface. These cracks have every appearance of being opened by the expansive force of some gas generated in the iron during the process, but what the nature of this gas is, still remains to be investigated. It seems to arise from the body of the iron itself, by the crack being within the solid substance of the bar. The fracture of the blistered steel is exceedingly irregular, of a white colour, like frosted silver, and appears like an irregular crystallization; but the facets exhibited are larger in proportion as the cementation has been longer continued, and from this reason they are larger towards the surface of the bar than in its centre.

The furnace above described is of that kind which is esteemed the best for the process, and is most generally employed in and about the neighbourhood of Sheffield in Yorkshire, where the manufacture of steel is carried on in a larger scale than in any other part of England. The furnaces used at Newcastle, which is another seat of this trade, are very similar.

The charge consists of twelve tons, each pot containing six tons of iron; and it is necessary that all the bars converted at one process be of the same size, or the smaller ones would be thoroughly converted before the others had taken up a sufficient dose of carbon. This large quantity of a single article is more than the trade of some manufacturers will dispose of, they therefore employ smaller furnaces, which contain only eight tons, and such are generally constructed but with one pot ten feet in length, three feet broad, and two feet deep: the fire-place is directly beneath the pot, twenty inches wide, and flues are carried round it on both sides and ends: the vault and chimney of such a furnace are the same as the double pot. It is found by experience that the small furnaces consume somewhat more fuel in proportion to the quantity of iron they convert, than the large ones, because the heat loss in the beginning and end of the process, and that transmitted through the walls of the building, is the same in both instances.

All cemented steel in its raw state, after it is taken from the converting furnace, is called blistered steel; because the surfaces of the bars are covered with blisters, and on breaking a bar it is found to be full of cavities withinside, which seem to have been opened by some gas generated in the iron when in the process of cementation, and to have raised the surface into blisters, which are hollow within. In this state the steel is not fit for any purpose, because of these numerous cavities, and from the great disposition it has to break with the most irregular and rugged fracture imaginable. To render it sound and tenacious, it must be well hammered while at a moderate heat.

APPENDIX O

CONCERNING THE DRAWING DOWN AND ROLLING OF BLISTER STEEL

Extracts from Bengt Qvist Andersson, Anmarkingnar Samlade pa Resan i England Aren 1766 och 1767, Folios 170-174. Manuscript in Jernkontorets Bibliotek, Stockholm. Translation by courtesy of the late Torsten Berg, Esq.

As I have said before, the grading of the steel is not carried out with any great degree of care at the English cementation furnaces. If it is noticed, when the steel is withdrawn, that an occasional bar has not been fully converted, which is shown by the lack of blisters on the outside, it is put aside and goes into the furnace again with the next charge. The steel-maker also carries out some inspection of the bar iron when it is being charged, as also has been noted previously.

The steel is sold, just as it comes from the furnaces with the blisters on it, not only at the furnace itself, but also through the trade, both inside the country and abroad. It is actually sold under the name of 'blister steel'. Craftsmen who work in steel very often come to the furnace to buy blister steel, which in Sheffield, Rotherham and Birmingham is mainly offered at auctions, with the size of the lots determined by agreement with the buyers, to one ton, half a ton, or only a few hundredweights (each equal to a centner of 120 lb.). The buyers draw the iron down under a trip hammer or, alternatively, it is rolled and slit to the sizes best suited to the general requirements. The steelworks owners themselves generally have some part of their production drawn down or rolled and slit. The steel which is drawn down to heavier rods, either under the trip hammer or between rolls and slitting discs, is called 'faggot steel' but that which is forged to quite fine gauges, such as 'instrument steel' for which purpose the best quality steel should preferably be selected, is called 'Gad steel'. This is sometimes packed in so-called 'half barrels' (barrels or tubs containing 126 lb.) but is now more commonly shipped in 'bundles'.

For the drawing down of steel to the ordinary gauges a lump sum of £4. 6. 8d. is paid per ton of 20 cwt. of 120 lb. each. Of this amount, the owner of the trip hammer keeps £2.11. 8d for himself and pays £1.15. 0d to the so-called 'overseer' (foreman) who has to pay for the coal and wages out of it. Repairs to the hammer and other similar expenses are the responsibilities of the owner. The steel that is rolled and slit in the mill costs only £2 per ton for the processing in the mill but is not considered to be so good as the other and is not so much in demand. Consequently it sells for two shillings less per hundredweight. The trip hammer used for the drawing down of the lighter gauges of steel rods only weighs 40 lb. and is so fast that it makes nearly 400 blows per minute.

English cutlers prefer to purchase blister steel as it comes from the furnace and to take care of the drawing down themselves. Although the forges take every precaution to ensure that the steel during the reheating is not subjected to too high a temperature and that the forging is completed in as few heats as possible, the aforementioned cutlers do not trust them completely on this. They cannot tolerate that the steel reaches more than welding heat, at least not many times.

If certain defects appear during the drawing down, they are generally repaired by welding in the usual manner. The cutlers, however, prefer to cut off the piece of bar which contains the defective parts. All such stumps are then collected and can be sold to the crucible steel manufacturers.

There are, however, very many cutlers, as well as other workers in iron and steel, who pay little attention to the real quality of their raw material, as long as it has the property of being easy to work. The livelihood of these people is based on the making of fabricated wares for export. Their general trend of thought is to achieve large sales at reasonable prices but the inherent quality of the products is given scant consideration. They are not, therefore, very particular in selecting the raw material for them.

APPENDIX P

CONCERNING THE MANUFACTURE OF SHEAR STEEL FROM BLISTER STEEL

Extracts from Bengt Qvist Andersson, Anmarkingnar Samlade pa Resan i England Aren 1766 och 1767, Folios 180-182.
Manuscript in Jernkontorets Bibliotek, Stockholm.
Translation by courtesy of the late Torsten Berg, Esq.

Bertram, a steelmaker from Germany who has come to Blacker Mills* ironworks, some 21 miles from Newcastle upon Tyne, has undertaken the manufacture of shear steel from blister steel, according to the method used in Styria. The product is known as 'German steel', which name includes all steel made in finery of similar hearths and which was formerly entirely indispensible to the English and was sold at twice the price of blister steel. Nowadays it is not so much in demand since the art of handling blister steel has now been learned, so that it can be used for practically all the purposes for which German steel was previously employed. Some genuine German steel, however, is still consumed in England. In addition, the shear steel made at Blackhall Mill is also used to some extent by the cutlers in Sheffield and is known as Newcastle steel. It is sold for £50 to £55 per ton, which is the usual price for German steel in England nowadays. These prices do vary somewhat from one stamp to another, depending on their reputation.

The production of shear steel is carried out in practically the same way as in Styria by making up bundles of hard and soft steel bars which are repeatedly welded, folded together, and drawn down under the hammer. It is also made by putting together bundles of hard steel and soft iron, a method much used in Germany.

Six kinds of shear steel are particularly sought after, namely :

1 Razor steel
2 Single Shear
3 Double Shear
4 Double Spur
5 Double Spur and Single Star
6 Double Spur and Double Star

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* Blackhall Mill, actually about 12 miles from Newcastle (see Appendix W).

APPENDIX P
continued - 2

The types of steel are marked with the stamps indicated by the names. Spur steel sells for £54 to £55 per ton in Sheffield and is mainly used for table knives and tools of an inferior kind.

APPENDIX Q

THE EARLIEST CEMENTATION STEEL

Extracts from F. M. Ress, 'Zur Fruhgeschichte der Zementstahl Herstellung', Stahl und Eisen, Vol.75 (1955), pp.978-982. Translation by courtesy of Otto Hirston, Esq.

For the production of cementation steel an 'open flame' furnace was required, together with the cementation chests. The furnace was constructed of ordinary brickwork with an inner refractory lining. The cementation chests were produced of refractory material only and were held together with iron reinforcements. Paulus Hannibal from Nuremberg produced the refractory material, which he compounded from a mixture of 50% clay, 50% sand and he then added 10% horse droppings and subsequently fired the mixture. Lime or mortar were avoided. The furnace was sunk into the ground up to the charging door to avoid heat losses. The outer wall of the furnace arch was held together with strong iron bars and brackets. The chests had to be kept shorter than one and a half ells;[1] otherwise they suffered damage, as was experienced in the Nuremberg Works in 1601 when cementation steel was first produced. For the cementation of iron only carbon or charcoal from beech wood could be used. The charcoal was first granulated and had to be quite dry, since the drier it was the less it shrank in the fire; charcoal from fir trees was no use since it shrank early in the process. Only good and clean iron could be used in the chests and then a good steel could be achieved by cementation, comparable to 'kern und stanger stahl'.[2]

First, charcoal was charged into the chests one finger thick; then iron bars were charged side by side without them touching each other, neither should the bars touch the walls or bottom of the chests. Enough charcoal was spread on top of the first layer of iron bars so that the bars were covered. Then followed another layer of iron bars. This was repeated until the chest was full and there was only a space of one finger thickness from the top of the chest.

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1 This is taken to be about three feet; the ell was a very variable sort of measurement, however.

2 W. Lewis, 'The Mineral and Chemical History of Iron', Manuscript MS 3.250 in the Cardiff Public Library, c.1780, Vol.iv, p.227, refers to 'German steel - one kind called Heart and Club', used for cutters for cutting iron ... does not lose its temper by reheating ...'. It seems likely that this is the same material as 'kern und stanger' steel.

This space was again filled with charcoal. The charcoal had to be compacted as far as possible to avoid shrinking. Finally a lid was placed on to the chest and the joints were made tight with clay. Therefore no air could penetrate the chests, or otherwise the atmosphere would burn both the charcoal as well as the iron.

The chests were placed into the open flame furnace and, after charging, they were spaced approximately one and a half inches from one another so that during cementation the flames could penetrate and heat the chests strongly; they were therefore built up in three layers above each other in a staggered pattern. The door of the furnace was then closed with two layers of firebricks and sealed so that no heat could escape from the furnace. Then a small fire was laid through a stoke hole or ash hole in the furnace; according to the time of year it would be made with four to six logs and would burn for four to six hours. After this initial heating, the temperature was gradually increased so that the interior of the furnace became incandescent. The furnaceman had to follow special regulations during the running of the furnace. He adjusted the draught by means of valves or air holes. The heat was kept up for three days and three nights; then the furnaceman closed the ash hole with bricks and sealed the joints with clay, so that no fresh draught could get into contact with the chests, since particularly in winter they might crack due to the too rapid cooling. The air holes remained open, however. Only after six or seven hours could the furnaceman gradually supply air through the ash hole and the following day he gradually removed the outer layer of bricks from the furnace door so that finally, after three days of gradual cooling, the chests could be emptied; this means that each chest was opened inside the furnace and the steel removed. Damaged chests could not be used again. The refractory material of these chests, however, could be granulated and used again for the fabrication of new chests.

A P P E N D I X   R

STEELMAKING IN ENGLAND, 1692

Extracts from Erik Odhelius, Dagbok, Folios 174-175.
Manuscript in the Kungliga Bibliotek, Stockholm.
Translation by courtesy of the late Torsten Berg, Esq.

Some steel is made in England of Swedish iron but most of it is brought from Styria and Carinthia via Venice or Genoa. The ships that each year sail from these places to Holland and England always carry a quantity of iron as part of their cargo and those that trade only with Spain always find English ships there, for instance in Cadiz, to which this commodity may be transferred. Other steel, required for other purposes, is obtained partly from Dantzig and partly from Schmalkalden, Solingen and other German towns via Collen and Holland. Occasionally some Swedish steel is also bought, but not very often, because the artisans demand the particular kinds of steel to which they are accustomed, for example, English steel for files and rasps, Styrian steel for knives, Collen steel for surgical instruments, and so on. Due to the fact that Swedish steel of the kind that the artisans know best has never been imported to any extent it is at a disadvantage. Until the unknown steel equals the familiar brands with regard to quality, dimensions, the weight of the bundles, the packing in kegs and in all other respects and until it has been carefully tried out, perhaps to begin with by surreptitiously including some of it with well established stamps, it has no chance.

Most of the steel used in England is a kind of German steel called bundle steel* which is sold for 30 to 36 shillings a hundredweight of 112 lb., the so called 'gad' steel from Collen sold for ....** and Styria steel for 44 to 45 shillings, but that made in England in Staffordshire and Yorkshire generally sells for 26 to 30 shillings per hundredweight.

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*   Presumably the same as the Sheffield 'faggott' steel.

** There is a bad edge to the folio at this point and a few words are unrecognisable in the photocopy provided.

The same steel is made in Sheffield in Yorkshire and at Bromley in Staffordshire, but using Spanish iron or the Swedish iron called 'bullet iron'. It is made in small quantities at a time, one to one and a half tons in small furnaces. The iron, five feet in length, is placed in the so called 'coffins' together with the necessary charcoal and ashes and fired for eight days, more or less, according to the quality of the coal, after which it is removed and drawn out to bars half an inch square and broken off to gads, two inches long, so that the purchaser can inspect it.

A P P E N D I X S

STEELMAKING AT WINLATON, 1701

Extracts from Winlaton Council Instruction No. 39, 4th November 1701. Manuscript in Northumberland Record Office

When the steelmaker shall want iron to sett the furnace, the ironkeeper is to lett him pick out the sorts appoyntes to make steele which must allways be kept in the great pitt in the new iron warehouse. The steelmaster is to pick for sound iron and that which is free from rust. But the ironkeeper is to reserve sizes to answer what the service doth otherwise require.

One trusty person is to see the iron weighed ... When the steelmaker hath cutt the iron in lengths and cutt off all raw ends and faulty plates he is to return to the iron keeper the remains so cutt off to be subtracted from the totall delivered. He is to debit thus :

> AB Steelmaker. Dr. to six tons two hundred and two quarters and fifteen pound of L and G iron and being conversion 1 (the next conversion to be No.2 and so on without beginning again).

When the steel is made and drawn at the furnace ... must go and see the same weighed, first taking directions how to dispose of the same.

That which is for the mill, to be rowled or slitt, must be charged to the clerk of the mill under the style of raw steel.

That which shall be for the forge to draw so debit the Forgeman; that which shall be for the Naylkeeper, debit the Naylkeeper.

That which shall be for shipping off must be all the full lengths cut not broake which must be committed to the hands of the treasurer.

And all conversions must be thus balanced.

In case that the wast in rowling and slitting be above one twentieth part and the wast in rowling be above one fortyeth part it shall be specially examined into that there hath been no fraudulent practices.

And the forgemen are not to have no steele of a second conversion till such time as they have completed the steele they are upon and the same ballances.

In case the forgemen shall in the fine double steele wast above 11 lb. in 120 lb. or shall in the common faggott steele wast above 4 lb. in 120 lb. it is to be specially examined into butt both sorts are oft done with less wast.

All rod steels you must put 30 lb. in each bundle.

All faggott steels you must put 60 lb. or 120 lb. in the ffaggott as the steele will best fall out.

APPENDIX T

STEELMAKING AT WINLATON, 1701

Extracts from Winlaton Council Instruction No.41, 11th December 1701. Manuscript in Northumberland Record Office

1 The iron which is to make raw steele to be shipped off must be cutt into yard lengths of 34" so that three lengths may be the length of the pott.

2 For the steele to draw, the steele to cut or wrought up by yourselves I leave the length to your own discretion.

3 Steele must be made of the best Orgroond iron, all raw ends cutt off, all flawed or cracky parts layd by or cutt off.

4 In the cutting the iron at the shears the steelmaker is with a prickhammer to make a prick hole near the end of every bar that shall prove extraordly soft so the end it may be distinguished when made into steele.

5 If any pitch be upon the iron designed for steele, it must be burnt off; if clay it must be washed or beat off; if any rust it must be all beat off but all care in the world must be taken to keep the steel iron from rust or dirt.

6 In setting the furnace the steelmaker must take care to putt the smallest iron and sett it the aside the potts heat least.

7 Be sure to take care to cover the potts with such sand as shall be found best to preserve the steele from the flame.

8 Let all possible care be taken, in bringing up the fire to a heat without any neglect or ommission and that care be taken in heating the end of the potts equal to the middle, which will not be without abundance of care in keeping the fire to a good heat at each end.

A P P E N D I X U

STEELMAKING AT SWALWELL, 1761

Extracts from J. L. Robsahm, Dagbok over en Resa i England Aren 1761, Folios 20-23.
Manuscript in the Kungliga Bibliotek, Stockholm.
Translation by courtesy of the late Torsten Berg, Esq.

I then went to the steel furnace which was not in operation, which gave me a good opportunity of studying it, although I was not allowed to stay very long inside. It was built entirely of brick ... *(and he goes on to compare it with a furnace in Sweden)* ... there were only two pots for the steel and only one opening at each end of the furnace for the firing. There were also more flues on each side of the fireplaces through which the flames could sweep round the pots than in the Swedish furnace. I could not see any other difference. All the information about the actual cementation process that I could get from my guide, in spite of asking many questions, was that after the iron bars have been cut to suit the length of the pots they are packed in them in charcoal breeze only. The breeze is left over from the charcoal used in the bar iron forge and if there is not sufficient then crushed charcoal is used. Each bar is carefully embedded in charcoal after which the pots are closed by masonry so that no flame can reach the iron or steel itself. All the large openings are closed also by masonry to conserve the heat so much the better. Then the fires are lit and kept going constantly for six or seven days, producing a uniform heat. On the sixth day, a bar called a 'tap-bar' is taken out to ascertain how far the cementation has proceeded. If the steel then is full of large and small blisters the process is complete, but it is, nevertheless, continued for two or three further charges of coal, after which the fires are put out and the furnace left to cool off. If the tap-bar is found to be insufficiently converted on the sixth day, the sampling is repeated on the seventh day and again until the steel is found to be fully converted. This is only indicated by the quantity of blisters.

To produce extra good and hard steel, that can be sold for 11d per pound (i.e. £102 a ton), the guide told me that from the best stamps of steel-iron, namely Leufsta and Akerby, certain bars are carefully selected - they are tested cold as well as hot - and if they stand up to the tests they are heated in charcoal fires and drawn down to small size bars. These are folded five times, welded together and then placed with other iron in a cementation furnace to be converted into steel. After conversion they are again heated in charcoal fires, folded, drawn down and again placed in the cementation furnace. After the second cementation and drawing down to a width of 1 inch (25mm) and a thickness of ¼ to ⅜ inch (6 to 10mm) the result is a steel that cuts glass. This account seems very likely because it is based on good grounds and my opinion was strengthened in the matter when I heard Mr. Hodgson say that he could very well make steel that would be as good as that which came from Germany but that he cannot sell it at a sufficiently high price because much labour is required and because the charcoal here is so expensive. This statement was made to me by Mr. Hodgson when he showed me his steel furnace.

He also showed me great quantities of his steel, which he called German Steel. It was stamped with two cloth shears and his name, because it is particularly suitable for shears and scissors and better than the German, otherwise he would not be able to sell it, due to its higher price. The steel was drawn down to long thin bars, just as my former guide had told me it would be.

Mr. Hodgson's steel furnace was built of dressed refractory stone instead of brick and had at the time of our visit been fired for six days and the next day the stoking was going to be discontinued. The whole charge consisted of Osterby iron because not a single bar of the Akerby or Leufsta stamps was available either in Hull or in London.

Notes

One or two interesting points arise here. Robsahm only mentions one furnace at Swalwell, whereas we know of two in action both before and after his visit. He may not have seen the second, since he was found to be too interested in certain items at Swalwell and was asked to remove himself from the premises shortly after he had viewed the furnace. On the other hand, it would be economically correct to have adjacent furnaces and, indeed, the plan of Swalwell of 1840* shows just this. Nevertheless, rather surprisingly, the two furnaces at this time are of different sizes; to judge by the circles on the plan, one was of the size expected (a 20-foot diameter cone would house a 10-12 ton furnace), whilst the other, with a 40-foot diameter cone, would indicate an adjacent furnace with a capacity of around 25 tons or even more. Is it possible, therefore, that Robsahm just happened to be on the site when the original furnace had been dismantled and was being rebuilt in a larger version?

The activities of Mr. Hodgson are intriguing. His headquarters were at the Close in Newcastle and he had a foundry and 'some steel furnaces'. It has been assumed that the furnace in the Close, worked by Bertram and later held by Hall, was now one of Hodgson's furnaces, since it seems to have been in the Close, or very near by. It is at least implied in the Robsahm diary that Hodgson worked the Derwentcote furnace. The making of German steel and the use of the double-cloth-shear mark, both the property of Bertram at Blackhall Mill only eight years previously, could well indicate that Hodgson was also working Blackhall Mill. In this case, Hodgson had gathered together the three properties and was, by 1761, the major steelmaker in the area after the Crowleys; since the three properties were all in the possession of the Cooksons in the early nineteenth century, it may well be that they inherited the Hodgson empire.

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* <u>Plan of Swalwell Town, Street and Manufactories</u>, (Watermark 1840), Gibson Collection No.69, Department of Palaeography, University of Durham.

APPENDIX V

STEELMAKING AT SWALWELL, 1765

Extracts from G. Jars, _Voyages Métallurgiques_,
Vol.1 (Lyons, 1774), pp.221-226.
Translation by the author

The blocks of masonry which make up the furnaces which are used for the cementation of iron appear to us to make a long square(1), the whole transversed by an iron grate almost at ground level, some twenty inches wide, with a cellar below. About sixteen inches above the grate space is provided on either side to construct the chests into which the iron is to be placed. To this end, there are ten supports built on either side; it is on these that the chests or crucibles which are to contain the iron are built; they are made from a sandstone resistant to fire, held together with clay introduced into the joints. The internal dimensions of the chests appear to be ten and a half feet long, two feet four inches wide and two feet six inches deep. The flame is able to circulate all round the sheets. Their sides are held by separate walls which give them all the solidity necessary to resist the weight of the iron and the violence and prolonged action of the fire. The chests and all the interior of the furnace are covered or closed under a vault which concentrates the heat; the smoke and flame is obliged to pass through eight side chimneys made to this end. The whole furnace is surrounded by a main chimney, made in brick and in the form of a sugar loaf.

The one and only iron which has been found fit for conversion into steel is Swedish iron. Several trials have been made with iron produced in England but never yet has there been obtained from it a steel of sufficiently good quality. Different Swedish irons are used; according to their different quality they give varying costs of steel, since they themselves have different values. The dimensions of the bars and strips(2) of

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(1) Of rectangular plan.

(2) Flat rectangular bars.

iron which are used are not always the same; some are square in section but more usually they are from an inch and a half to two and a half inches wide and from four to seven lines thick(1). The strips of iron are cut to the length of the chests. From five to thirteen tons(2) of iron are put in each chest, each ton being twenty one quintals(3) of one hundred and twelve English pounds. Thus at any one time, including both chests, a furnace will convert about ten tons of iron, or from twenty three to twenty eight thousand weight(4).

Only charcoal dust is used for the conversion of iron into steel and no use is made either of oil or salt additions. It has already been said that the chests or crucibles are made from cut sandstone. When it is desired to put the iron into chests, the workman chosen for this goes inside the furnace; the bars are passed to him through holes made in the ends; these are the same holes through which the flames will pass, but their outer ends are luted up during the firing. He takes a cement of charcoal dust, such as is obtained by passing through a coarse sieve, and after slightly moistening it makes a bed of it on the bottom of the chest, on which he puts a layer of strips of iron such as have already been described, usually cut to the length of the chest. Pieces of different length are also put in, such as are available, but they are always arranged so that they do not touch each other and are always separated by charcoal powder. The first layer is totally covered with a bed of half an inch in thickness of the same cement, on which is arranged a new layer of iron strips. This is continued successively until the chest is full. The last layer is covered with charcoal

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(1) Roughly from ⅜ to ⅝ inch thick.

(2) This presumably is an error; it must mean 6½ tons or 13 tons for both chests.

(3) Rather like a baker's dozen?

(4) Presumably 23,000 to 28,000 lb. or about 10½ to 12½ tons.

powder on which is laid a bed of sand to cover the whole surface, so as to concentrate the phlogiston in the interior of the chest so that the charcoal is not reduced to ashes by the firing. The sand is ordinary sand but it is moistened. If it is dry, it is necessary to wet it. It is well firmed; it is made into the shape of the back of an ass so that it rises above the sides of the chest, in such a way that in the centre it can be ten inches thick. When the iron is all in the chests, the furnace is prepared as follows before lighting up.

The iron bars making up the furnace grate, which are fixed into the masonry, are quite distant the one from the other and, in consequence, cannot hold the coal: other bars are therefore arranged on top of them the whole length of the grate or furnace. These are placed quite close to each other so as to retain the coal. After this a brick wall is built at each end of the grate so as to close the two large openings and to form in each place one of only ten inches high by seven or eight inches wide, at the level of the grate; these serve as doors to place the coal on the grate. They are closed with iron plates of the size of the opening; these are fixed on and then opened up every time it is required to attend to the fire and to rake it to remove the ashes, which has to be done every so often with the aid of very long iron rakes. The doors are also opened whenever it is necessary to put coal on the grate.

In the ordinary way fire is applied to the furnace on Monday evening and it is kept strongly heated until the following Saturday evening; this is the usual time necessary for the operation when there is only ten tons of iron in the furnace, so when the furnace contains twelve to thirteen tons the fire is kept in until the Sunday evening. But in order to be sure that the iron is well cemented, there are some furnaces where a small hole is arranged in one of the ends and also in each of the chests, so that a bar may be withdrawn to judge whether it is sufficiently cemented. Familiarity makes it such that the workman knows by its colour and by the blisters on its surface when the steel is at the point it should be. This practice of withdrawing the bars is not a general one.

Thus, after some five days and five nights at an uninterrupted heat, the iron having been considered to be entirely converted into steel, the brickwork made at each end of the furnace is demolished to open up the doors; to accelerate the cooling, the iron bars put on the grates to retain the coal are taken out and the coal falls into the cellar; the four holes (1) are also opened up, having been closed with temporary brickwork during the operation. Despite all this, it needs at least a week for the bars of steel to become entirely cold; they are never removed until they are so.

Then the same workman who put the bars into the chests enters again and passes them out through the same holes at the ends of the furnace and they are received by another workman outside. Two men are sufficient for the conduct of the operation: they are given four shillings per ton for their work(2). It is reported that from thirteen to eighteen 'fodders' of coal are burned in one campaign, each fodder weighing about sixteen quintals of one hundred and twelve pounds each and costing four shillings. It is observed that the iron suffers neither augmentation nor diminution in its weight on conversion into steel.

Very little steel is sold in the condition in which it comes out from the furnaces - blister steel, as it is called - its price being twenty six to twenty eight shillings per quintal of one hundred and twelve pounds(3). For general sale, it is submitted to a further simple operation, being forged under a hammer and the strips of iron (now steel, of course) being reduced to a square of seven or eight lines(4) of indeterminate length: they are finally allowed to cool in air without quenching in water. This operation, without doubt, has the object of closing up the pores, for the fracture of the steel as it comes from the furnace has very large facets and is similar to that of a very bad, brittle iron much more than that of steel. The grain is very different after it

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(1) It is not clear where these were.

(2) About 14/- per week, a very similar figure to that given by Angerstein in 1753.

(3) £26 to £28 per ton.

(4) About ⅝ inch.

has been forged; it then acquires that of common German steel. In this state it is known as 'common steel'. It is used to make files, saws, scissors, knives, etc. A great quantity is sent to several parts of England, above all to Sheffield and Birmingham(1). It is sold at thirty two shillings per quintal of one hundred and twelve pounds. As the ends of the bars converted into steel are usually flawed(2) and make less satisfactory steel, they are cut off for forging in faggots. This steel is called 'soft steel' and is used to weld on to the edges of tools such as are used for tilling the ground.

The steel obtained by cementation can be made more perfect by a second operation which converts it into German steel. It takes this name since it closely resembles it in texture and quality. They showed us a bar of steel made in Germany and sent through Holland as an example and the company making this type of steel here maintained that it had opened up a market in Germany in this way. To carry out this operation, the converted iron, as it comes from the cementation furnace, is made into bundles of eight, ten or twelve bars: these are heated in a coal fire, taking care from time to time to throw on to the bundle some dry powdered clay, in the same way that one throws on sand in the forge welding of iron, in order to conserve the heat and make the forge welding more easy. Experience has shown that clay is preferable to sand when the welding of steel is being considered but that sand is much better when welding iron. When the bundle is sufficiently hot, it is brought to the hammer for welding, drawing down and forging to the sizes one requires. It is not ordinarily made except to order, be it for England or abroad. The procedure is precisely the same as that used in Styria to make the best quality of steel(3).

Some forgers in England, to produce a superfine steel which on this account sells at twenty sols per pound(4)

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(1) 'Bermingham' in the original.

(2) It would now be termed 'roaky'.

(3) It did, of course, use blister steel as its raw material rather than the Styrian 'natural steel'.

(4) Probably around 10d, equivalent to about £90 per ton.

submit it to two other operations and throughout they use only charcoal as fuel: they reduce the cemented steel in the first place to German steel. They then cement the German steel in the same way as they do the iron and then again forge it in faggots, as described above, but in a charcoal fire.

To succeed in imitating the English and their procedures for the conversion of iron into steel, before setting up a large establishment, one must be assured by repeated trials of success, which depends essentially on the quality of the irons which one wishes to cement.

A P P E N D I X W

STEELMAKING AT BLACKHALL MILL ABOUT 1720

Extracts from H. Kalmeter, Dagbok ofver en 1718-1726 Foretagen Resa, Vol.1, Folios 349-350. Manuscript in the Kungliga Bibliotek, Stockholm. Translation by courtesy of the late Torsten Berg, Esq.

On September 1st I left Newcastle and travelled to Blackhall Mill, about 12 miles away, where, as previously stated, there is a steelworks belonging to Mr. Dan Hayford. The steel maker was a William Bertram who throughout the neighbourhood was considered to be a very good worker and a sober man. For this reason, and because he had previously been in Sweden and had taken his wife from there, I took the opportunity of asking him whether he would not like to return to that country and take charge of a steelworks there. This he was not unwilling to do and offered to bring other men with him, both from the steelworks and from the sword factory at Shotley Bridge.

The steel furnace contains two chests, each eight feet long, four feet wide and two feet deep. Between the chests, which as is well known are placed above a wind furnace and the fireplace itself, there is a space or flue where the flames from the fire enter certain smaller flues, located at the sides and ends of the chests and underneath them. There are three of these at the sides and two at each end and the fire thus heats the chests both from below and above and to achieve this the furnace is provided with a vault in the same way as a baking oven. Above the vault there is a chimney stack through which the smoke escapes.

Five English tons of bar iron are charged into each chest and it is generally estimated that 10 sacks of charcoal are required. To charge, heat, cool and empty the furnace takes four weeks, one for each operation. I was told there was no scaling loss and the men operating have to supply the same weight in steel as the weight of the bar iron charged. The charcoal used here is made of oak or beechwood. In this connection it should be observed that pitcoal, without doubt, is more suitable for making steel than charcoal, because it gives a much stronger heat, particularly when good, clean coal is used. For this reason the steelmaker asked if it would not pay to ship pitcoal to Sweden at least for mixing with the charcoal if not for the total firing of the furnace. This, however, would have to be tried experimentally.

Raw steel (blister steel from the furnace), since the price of Swedish iron had increased so much, was selling for £28 per ton, the Swedish iron costing £18 per ton. In the days when the Swedish iron sold for £14 per ton the steel was sold for £21 to £22 per ton. But if the raw steel is sheared and made into what they call 'German Steel', its price is some £12 more per ton, of which the owner gets £6 and the steelmaker £6. In this connection, it should be remembered that, if the first heating in the furnace does not produce the quality of steel desired, the process has to be repeated.

The steelmaker estimated that the owner's profit from one chest of steel amounted to £40.

A P P E N D I X X

TYPES OF STEEL

Extracts from W. Lewis, The Mineral and Chemical History of Iron, Vol.iv, Folios 225 and 227. Manuscript dated 1775-80, in Cardiff Public Library. Reference MS 3.250

Hayford steel, so called from the name of its first maker, is common steel doubled and forged together but converted higher than usual because it loses in forging. The softest of this kind of steel is called Sheerblade, and used for the large cloth sheers. The next, rather harder, marked with a sheer blade and star, may be employed for the same use. The third in hardness, called spur steel, makes penknives at Sheffield and the best razors ... The next, double spur ... The hardest of all, double spur and star: this is used chiefly for gravers: razors also are made of it, and fine scissors. These steels are made chiefly near Newcastle; Mr. Cockshutt makes them of late, but his are not in such repute; uncertain whether from their being really inferior or from their character not being yet established. All are made of the same Swedish iron, in the same furnace, and differ only in one being more converted than another ... they are examined and sorted after the operation.

Blistered steel is common steel as it comes from the furnace. What is very much blistered is hardest. Scythes are made of blistered steel welded to iron.

German steel ... one kind called heart and club used for cutting iron does not lose its temper by reheating, as the Hayford does, hence best for such tools as require to be often heated.... suspected to be made of wild steel. It is forged into bars and has the marks of the tilting hammer.

Wild German steel, from Tyrol or Stiria; in triangular ingots, broken, in pieces of 2, 3 and some of 8 - sand adhering to the bottom, and some bits of charcoal in the cavities -strikes fire copiously with common hard steel, not two pieces of it with one another ... is now harder, rawer, more of a reguline nature, less manageable than formerly, hence not used by workmen who used it before ... supposed to be once less melted than before. An excellent knife blade was formerly made of it. Used now only by Mr. Cockshutt for making tools to draw steel wire: other kinds of steel are too soft, gull or widen fast, and make the wire taper.

APPENDIX Y

SWEDISH IRON SUPPLIES FOR STEELMAKING

Extracts from L. E. Gruner and C. Lan, L'État Present de la Métallurgie du Fer en Angleterre (Paris, 1862), pp.789-790.
Translation by the author

In the past, long term contracts have provided Sheffield with almost a monopoly of the steelmaking irons from Sweden. For the last fifteen years, however, since the expiry of the old contracts, the tendency has more and more been towards a direct relationship between the Swedish producer and the English user. There has been a progressive elimination of the middle-man factors and a reduction in the length of term of the contracts. Today, whilst there are still to be found import houses in Hull and Sheffield, a good number of manufacturers could be quoted who provision themselves directly from Sweden on an annual requirement basis. The distinctly superior grades, five or six in number, are still the subject of agreements which do not expire for several years, but it seems doubtful whether these will be renewed. Of the two houses which have succeeded to the monopoly trade in these extra special grades previously held by Sykes and Company, the one in Hull, Wilkinson and Company, having taken over their share of the trade, does not have exclusive trade with the English buyers any more than with other customers; the other, Naylor, Vickers and Company in Sheffield, whilst engaged at the same time in both the iron trade and the manufacture of steel, will sell commercially at the same prices in Hull or in Stockholm to users in any country; the United States, for example, also receive Swedish irons bought through their agency.

In short, the commercial conditions which formerly worked to the same advantage to the English steelworks as they would have had by owning the mines and ironworks in Sweden are being, by degrees, worn away and are giving place to a free market which gives a different character to the Sheffield steel industry and tends towards an integration of effort to produce maximum economy.

APPENDIX Z

STEELMAKING IN SHEFFIELD IN 1765

Extracts from G. Jars, Voyages Métallurgiques, Vol.1 (Lyons, 1774), pp.256-258.
Translation by the author

In the town of Sheffield and its neighbourhood there is converted into steel a large quantity of iron. Many of the furnaces used are similar to those at Newcastle but they are smaller and convert less iron in them at a time than in the larger furnaces which are much less common than the first, probably because these cost less to construct; they are made on the same principles.

The furnaces consist of a brick vault, about 12 ft. long and 6 ft. wide and 7 ft. high in the middle. Some furnaces are larger or smaller. The iron fire grate on which the coal is placed is below ground under the middle of the vault. It is covered with large pieces of sandstone, resistant to fire, which form at the same time the bottom of the chest, pot or crucible which will contain the iron. On this base are built the sides of the crucible or chest with stone of the same kind as the base. Holes are made along the whole length of the grate which are made to come out inside the furnace between the sides of the chest and the vault. I judged that there were about six of the holes along each side so that the fire flames made at the grate were obliged to enter by these holes and envelop the whole of the chest, since the hearth and grate traversed the furnace for the whole length of the chest and flames were made each side. The flames gave themselves finally into the upper part in the middle of the vault where they went through a chimney flue.

They do not put more than four or five tons of iron at most into the furnace; a continual fire for five days is needed to convert the iron into steel.

The iron used is that from Sweden; it is known that no other is capable of making good steel. The iron is arranged in the chest with charcoal powder and the whole is covered with sand, as is the practice in Newcastle.

The cemented steel, which is also called blister steel, is taken to the hammer shop where the hammers are light and move very quickly. I have remarked that they heat the steel with coal which has been almost deprived of its bitumen. Since there is always a large fire on the hearth, care is taken to put the new coal on top of the pile so that it is relieved of its bitumen before arriving at the place where the steel is. The workman takes care in poking his fire not to allow the new coal to fall towards the tuyere. The degree of heat given to the blister steel is a full cherry red; if it is too hot it will break in pieces. The hammer is worked very quickly so that the steel can be drawn at this heat without having to go twice into the fire. It is thus drawn into square rods of four or five lines to the side. It is not quenched into water. This steel is sold and used in this state for all small articles.

Blister steel can be made more perfect by the following operation. They usually use the scrap pieces arising in the steelworks. They have furnaces built in fire clay bricks similar to those used for melting brass but much smaller and they receive their air from an underground passage. At the mouth which is square and at ground level there is a hole through the wall which rises to the base of a chimney. These furnaces hold only one crucible, 9-10" high and 6-7" in diameter. The steel is put into the crucible with a flux, which is kept secret, and the crucible is placed on a round brick placed on the grate. Coal, converted to coke, is placed around the crucible and fills the furnace; the fire is lit and the upper opening of the furnace is completely closed with a lid made of bricks bound with an iron edge; the flame goes through the chimney flue.

The crucible is five hours in the furnace before the steel is perfectly melted. Several operations then follow. There are square or octagonal moulds, made in two pieces in cast iron, put one against the other, and the steel is poured in at one end. I have seen the ingots of cast steel; they look like pig iron.

The steel is drawn down under the hammer, as is done with blister steel, but it is heated less strongly and with more care, because of the risk of breaking.

The object of this operation is to bring together closely the parts of which the steel is constituted so that there are no roaks in it at all, such as are seen in that coming from Germany and which it is held that cannot be prevented except by melting.

This steel is not in very general use; it is only used for those items requiring a fine polish. The best razors are made from it, several penknives, the best steel chains, the springs of watches and small watchmakers' files.

A P P E N D I X AA

STEELMAKING IN ENGLAND IN 1725

Extracts from H. Kalmeter, Relation om Engelska Bergwerken Aren 1725, Folios 111-116. Manuscript in Bergskollegi Arkiv, Stockholm. Translation by courtesy of the late Torsten Berg, Esq.

In the following I will talk about the steelworks and in Stourbridge there are two steel furnaces and quite a few around Birmingham as well as in other places in England. No English iron is converted into steel because it does not have the required strength. Neither have I found that, so far, any attempt has been made to try Russian iron, although some people consider it useless for this purpose. Therefore all steel in England is made of Swedish or Spanish iron, but the iron used is of two kinds, of which one is said to be tough and hard and is the best, because it has the highest degree of strength and fractures into long, whitish streaks or splinters. The Oregrund iron is of this kind and the stamps

are most in demand in England. Although the other Oregrund stamps are known at the steelworks and good steel is made from them, they are not as good as the aforementioned which are the only ones used to make German steel.

The second kind of iron is said to be tough and soft and does not possess as good strength as the former. Most of the Spanish iron is considered to be in this class. Properly speaking, three kinds of steel are made in England, of which the first is called 'blister steel' because in the furnaces it, so to speak, boils and covers itself with blisters and bubbles and in this state, and in whole lengths before being drawn down under the hammer, it is sold in Stourbridge and Bristol for 24 to 28 shillings per 120 lb. It is used for rough work, such as axes, hoes and so on. The next type of steel is 'faggot steel', which is blister steel drawn down under the hammer to thin, square bars and hardened. It is sold in bundles which have given its name and contain six bars each. The price is 28 or 32 or 40 shillings per 120 lb. and is used for all kinds of edge tools. If it is intended for scythes of various types, it is sold as small short bars broken off to the required length.

These two types of steel are made of Swedish or Spanish iron, the former being the ordinary Oregrund stamps or others.

The third kind is called 'German steel' which as has already been stated is made only from

iron and is drawn out to long thin bars, as this is also used for very fine edge tools, for example, razors and scissors and so on. The price in Stourbridge and Bristol is 40 shillings a hundredweight of 112 lb., instead of per 120 lb. as the other kinds are sold.

The converting furnace is an oblong wind furnace of whatever length one desires and contains two pots, one on each side with a distance of about two feet between them. They are now building in Stourbridge a furnace with three pots and two fireplaces, so that one pot stands in the middle and this will suffer most from the fire. The bottoms of the pots, which as well as the whole of the inside of the furnace are made from Stourbridge clay, rest on arches of clay or more correctly on arches of brick made from this clay. Between and below the pots and lengthwise in relation to the furnace, iron bars are placed, on which the coal is burned, so that the flames can sweep up through the furnace, which is covered by a vault about four to five feet above the bottoms of the pots. As the vaulted roof slopes down at the sides, the flames are forced downwards over the pots and for this purpose there are flues on all sides through which the draught pulls the flames and smoke out. Above the vault or the furnace proper there is a round chimney or dome. The pots or the furnace are, as I have said, of any length desired and here the pots were seven feet in one furnace and eight feet in the other. In Birmingham the furnace was longer. The widths of the pots can also be made as desired from two to three feet and the depth is made so that the top edge reaches the chest of a man standing on the bars of the firegrate where the coals are placed later. He can then fill the pot, receiving the iron bars that are to be converted from another man who passes them in through square holes in the furnace wall at the end of the pots. The bars are placed on edge with charcoal breeze packed well in between them and also between each layer of the iron. On top, good 'strong' sand is strewn, which fuses in the heat forming a crust, because the better the iron is sealed off from the atmosphere the better the steel will be.

The next thing to be observed during the steelmaking process is to keep the temperature moderate in the beginning, then increase it gradually and finally decrease it slowly. Towards the end, or when one knows the iron is converted, one must take care that it does not melt. In one of the aforementioned furnaces the charge is 3 tons and in the other 4 tons of iron; the firing takes 6 to 7 days, or even longer sometimes. The steelmaker must make sure that the thickest bars are in the location of the furnace where the draught is strongest. So that he may know when the iron has been converted he has two test bars in each pot, the ends of which stick out through the above mentioned square holes, of which there are two, one above the other. When he thinks the conversion is complete he pulls one of the bars with a pair of tongs and draws it down under the hammer. If the fracture still has iron in it, the heating is continued for two or three further firings or stokings and then the second test bar is pulled out to see if it is converted right through. To make sure that the tests are representative the test bars are of the thickest iron in the charge. There is no scaling loss in the process of conversion, rather the opposite. The increase in weight amounts to 13 or 14 lb. per ton. However, when the steel is drawn under the hammer, the loss is generally 100 lb. to the ton, although no allowance is made for any fixed loss. The firing is carried out with pitcoal, which is considered best and most suitable for this purpose. The conversion of one furnace charge requires 4 to 5 tons of coal. Around Stourbridge, not to mention other places where there are steelworks, there are many coalmines, so that coal can be bought very cheaply and it costs at the works eightpence a load (or about 2½ styfver* per 100 lb.)

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* The 'styfver' was a Swedish coin, of which there were 32 in one 'daler silver'.

At the mine the price of coal is 4 pence and the carriage costs 4 pence a horseload, which is estimated to be 300 lb. (or a little more than a skippund).*

It is said that iron or steel that has been lying for some time, for example for six months or more, is much softer and easier to forge than that which has just been fined or converted. Moreover, many are of the opinion that steel that has been twice converted and drawn down under the hammer is finer than that which has only been converted once and there was talk of making experiments with double conversion. The cost of making steel is reasonable enough, not above 15 to 16 shillings per ton of blister steel.

At Newcastle, to mention that place especially, German steel fetches some £19 more per ton than the blister steel. Of this the owner of the works gets £6 and the master or steel-maker £6.

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* The skippund was a Swedish measure of weight, there being 7.5 skippund per ton of 2240 lb. More precisely, the 'skippund stapelstadsvikt' was equivalent to 299.7 lb.

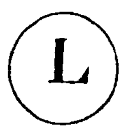
APPENDIX BB

STEELMAKING IN ENGLAND IN 1750

Extracts from S. Schroderstierna, Dagbok Rorande Handel, Naringar, Manufakturer, M.M., uti Holland, England, Frankrike, Tyskland och Danmark, 1748-1751, Folios 201-202 and 163. Manuscript in the Kungliga Bibliotek, Stockholm. Translation by courtesy of the late Torsten Berg, Esq.

Folios 201-202

There is only one steelworks in Birmingham and it belongs to a Mr. Willemoth. It consists of two cementation furnaces. Swedish bar iron is used for conversion to steel because it is the best for the purpose. Amongst the many kinds of iron tried and used for this application the stamps



have been found to be the best; the latter is considered equal to or even better than the former. English iron has been tried but found useless for steelmaking because it does not have, as the English say, enough 'body'.

Each furnace is charged with about five tons of either of the above mentioned kinds of Swedish iron. The heating goes on for about five days and a few days are then required for the cooling before the steel is removed. The bars are placed lengthwise in the furnace chests with a substance consisting of charcoal breeze, and probably also something else, packed between them, so that any one bar does not come into contact with any other. The firing is carried out with pitcoal, placed on grates of thick iron bars. The fireplace is located below the chests and the heat is distributed around them. After the iron has been converted into steel it is full of blisters, looking like the bubbles on boiling water. The converted steel is considered quite good and is used everywhere in the district.

The iron costs from £17 to £19 per ton and the steel made from it sells for £24 or £25. per ton. However, it should be noted that the iron is bought according to the light weight, each hundredweight equal to 112 lb. The steel on the other hand is sold according to the heavy weight, each hundredweight being equal to 120 lb., which makes a difference of 160 lb. per ton.

150 tons of iron a year are converted to steel at this works. The workers deny that any increase in weight takes place during the conversion.

On this occasion I was unable to obtain further information about the cementation process, as the steelmaker was very secretive about his art. Nevertheless, he was willing to disclose it to anybody interested for £10, but only on the condition that such a person would not start a steelworks within a certain distance of Birmingham.

Folio 163

At the Town Mill in Birmingham, owned by Sampson Lloyd II :

The steel which comes from the steel furnaces here in Birmingham is cemented Swedish iron of the stamps

It is sheared into short lengths, heated, rolled and slit in the same manner as for iron. It is sold at 25s. to 27s. per hundredweight of 120 lb. The lengths of ordinary iron for rolling and slitting are about 15 inches and are generally rolled to 4 ft. 6 ins. before slitting. It is thought that steel is treated in a similar way.

APPENDIX CC

STEELMAKING IN BIRMINGHAM IN 1770

Extracts from a letter from Robert Erskine to Robert Atkinson dated 11th October 1770. Original in the Archives and History Bureau, New Jersey Library, Newark, N.J., U.S.A.

Birmingham

Dear Sir,

At the steel work I mentioned in my last, I had an opportunity of seeing the inside of a furnace for converting Iron into Steel, which was building; The length was proportioned to that of a long bar of iron about 15 feet, and the breadth 8 or ten feet; This space was covered by a low arched roof of Brick, in the center of which was an hole about 7 inches square, which communicated with a chimney about 15 feet high. If you suppose four lines drawn the longest way at equal distances through the furnace they will divide it into five equal spaces, three of which, viz. the middle and two sides, are for building the Chists where the iron is converted, the other two are for the fewel which is put in at both ends - the middle space is built of solid brickwork, breast high, as likewise are the two at the sides, the two intermediate spaces which remain, are open to the ground and grated over for the purpose of holding the fewel - There are consequently three Chists for holding the iron, which are every way a brick thick. The bottom of the Chists are supported upon a number of rows of bricks, two bricks high and about six inches apart, that the fire may pass freely round the whole of the Chists. In these Chists the iron bars (with the materials for the conversion) are placed edgeways, so as not to touch each other and then covered up close (I suppose with bricks and mortar). The Chists are about three feet deep and 18 inches wide and hold about 8 tons. There is a space of about 8 inches between the outer chests and the wall of the furnace, that the heat may get round them. The iron is put in at holes in the wall at the top of the Chists, and taken out steel at opposite holes, all which holes, while the operation is performing, are stopt with bricks and mortar. The fire is kept up for six days, and then it is left to cool, to such a degree, that a person can go into the furnace and lift and push the steel bars out of the Chist. (Tho' this description may not be intelligible to another yet it will enable me to make a drawing if necessary). It is only Swedish iron that they here convert into steel.

Steel made of English iron will not weld, &c. To make cast steel it must be twice converted, or undergo a second operation similar to the above, there is a visible difference between the steel which has once, or twice, undergone the operation ...

... In the same bar, even of Swedish iron, there is often two different kinds of metal a white and a grayer kind. The white Mr. Bolton finds to his purpose to have chizzled out and have separated from the other. The science of knowing the different natures and properties of iron, is not to be acquired in a day, I must content myself with knowing as much of it in general as I can and the chief thing necessary seems to be, to know how to make good malleable iron, neither Red nor Cold Shot, and how to make the best pig iron to produce this kind.

... I have sent samples of Ores, Iron, different Steels, lime and furnace stone to Dr. Fordyce and am

Dear Sir,

Your most obliged hum. Sert.

Robert Erskine

P.S. One of the workmen at the Steel Manufactory affirmed positively from experience that the Steel acquired no addition of weight in Conversion, provided the iron was not rusty; if it was, then it acquired a small matter and blistered.

APPENDIX DD

SUGGESTED CEMENTATION MIXTURES

Compiled from Various British Patent Specifications

1 *Nathaniel Kimball, Patent No. 5263, A.D.1825*

'Take one ounce of sal ammonia, one ounce of borax, one ounce of alum, one quart of fine salt; put them in an iron or other metal vessel; stir them well together and heat them till the vessel is red hot and the same ceased to smoke; then, after it is cool, pulverise it to a dust. Afterwards take four quarts of strong soot, two quarts of pulverised burnt leather, two gills of burnt horse hoof, one pint of fine salt, one quart of vinegar and two quarts of urine; put them into an iron or other metal vessel, stir them well together to the consistence of mortar, then boil it down, stirring it well till it becomes perfectly dry like dust; then, after cooling it, take the first mentioned composition and sift it through a fine sieve, mixing it at the same time with the second composition. The mixture is then sifted on to the iron to be converted into steel ... the above proportions form a suitable quantity for converting one hundredweight of iron'.

2 *John Holland, Patent No. 12705, A.D.1849*

'Silkworm chrysallides, cocoons, silk, the silkworm and all its products and the refuse of the same may be used, preferably after being torrified or highly dried, but not carbonised, and then reduced to powder. Bars of malleable iron ... may be converted into steel by packing them together with the torrified substance and coal, coke or plumbago in powder, in alternate layers, in cases such as are used for cementation'.

3 *John Francois Jules Alexandrew Boulet (of La Chapelle, St. Denis near Paris), Patent No. 2174, A.D.1854*

'The compound cementing substance which I have devised for the more effectual and speedier conversion of any kind of iron into steel is a mixture of 'glucose' or other saccharine matter, of horn sawdust or horn shavings, of graves, or residue of animal fat, of dried blood and charcoal of any wood. These matters have to be pulverised or comminuted into as small portions as possible, if they are not already in a powdery state, and the whole has to be thoroughly mixed, so as to form one homogeneous mass. As to the proportions of the different articles, they have necessarily to be varied, according to the kind and size of the iron to be cemented'.

4 *Charles Pauvert (of Chateaurault, France), Patent No. 610, A.D.1857*

'I make a cement composed of the materials, and in or about the proportions following (by weight): 33 parts of finely divided charcoal, 33 parts of highly aluminous clay, 33 parts of carbonate of lime or wood ashes, 1 part carbonate of soda, 1 part of carbonate of potash'.

5 *Richard Archibald Brooman (A Communication from Job Johnson), A.D.1859. No.1591*

'A mixture of quicklime free from foreign matters, bone dust or baked bones finely divided, and charcoal, after being exposed to the atmosphere for one or more days, is to be interstratified with the articles of iron to be operated on in a cementing or converting furnace. Wire rods, plates and railway bars are among the articles which may advantageously be treated. The mixture may be used again after being exposed to the atmosphere in order to reabsorb carbonic acid'.

6 *John Henry Johnson (A Communication from Francois Auguste Dufey), A.D.1860. No.222*

'Charcoal dust, grease and fatty matters of all kinds, animal and vegetable, together with fish oils, saltpetre, horn or other azotised bodies, prussiate of potash, soot, sea salt, powdered slate and ores, burnt leather and black lead and other similar substances constitute the materials from which a choice may be made'.

7 *George Davies, Patent No. 2216, A.D.1860*

'Wrought iron may be converted into steel by means of gases produced by heating a mixture of equal parts of vegetable and animal matters ... Charcoal, soot or waste from oleaginous matters or from spinning cotton, flax or like substances may be mixed with woollen rags or waste flesh, horn, hide or similar refuse matters'.

8 *William Edward Newton, Patent No. 564, A.D.1861*

The abridgment reads as follows :

'The patentee claims for the cementation of iron and steel the employment of alkaline carbonates, particularly those of baryta and strontia, mixed with powdered charcoal. Under the heading of carbonates are included any other salts which, under the influence of heat and in contact with carbon and the nitrogen of the atmosphere, are capable of producing cyanides, which are in reality the cementing agents'.[1]

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(1) It should be noted that this theory, that nitrogen and cyanide were important, was current at the time, having been postulated by Christopher Binks.

Also see his patents No. 2695 and No. 2711 (A.D.1856) and No. 33 (A.D.1857).

APPENDIX EE

QUOTATION FOR STONE SLABS FOR CEMENTATION FURNACE CHESTS

From an original held in the Doncaster Archives, Sheffield

From: Albert Gillott,
Norfolk Quarries,
Grenoside,
Near Sheffield.

Manufacturer of Grindstones suitable for wet or dry grinding: for needles, hackle pins, hammers, springs and all engineers' purposes.

Pitching stones, rockies, sawing and planing - stock on hand.

Converting pot stones, ashlar, &c.

To: Messrs. D. Doncaster & Sons, Ltd. Nov.14th, 1940

The price of 1 Set of Pot Stones :

14 ft. 10 in. long)
5 ft. 10 in. deep) inside measurements

3 ft. 3 in. wide at bottom
3 ft. 6 in. wide at top

Sleepers 4 ft. 4 in. by 8 in. square

Bed Stones 4 ft. 4 in. long

Two tap holes comprising 4 stones 3'6" x 18" x 5" finished
4 stones 18" x 18" x 5" finished

is £135.10.0d. nett delivered all complete to your works.

(Signed) A. Gillott

APPENDIX FF

COLLECTED INFORMATION ON THE COST OF PRODUCING BLISTER STEEL BY THE CEMENTATION PROCESS

The earliest costs of producing blister steel which have been found in any detail come from the visit of Angerstein to Blackhall Mill in 1754.[1] Dealing with the production of 10 tons of steel, the following breakdown is given :

10 tons 160 lb. of iron[2]	£211.12. 0.
Coal	1.10. 0.
Wages for four weeks at 18/0d.	3.12. 0.
Including the bookkeeper	12. 0.
Interest on £200 building cost at 5% per annum for 4 weeks	16. 8.
Freight to Newcastle	5. 0.
	£218. 7. 8.
Selling price of steel	£260. 0. 0.
Profit	£41.10. 0.

or £498 per annum per furnace.

There is evidence, elsewhere, that this furnace had a capacity of 10 tons, so this presumably represents the costs for one heat on one of the largest furnaces operating at the time in the whole country. The costs per ton of steel produced may be set out as follows :

Iron	£21. 3. 3.
Coal	3. 0.
Wages	7. 2.
Bookkeeper	1. 2.
Interest	1. 8.
Freight	6.
	£21.16. 9.

1 R. Angerstein, Resa genom England 1753-1755, Vol.2, Folios 237-238. Manuscript held by Jernkontoret, Stockholm.

2 It will be noted that there is an extra 160 lb. of iron included; this must be considered as waste. There is, incidentally, no charge for the charcoal used.

APPENDIX FF
continued - 2

Excluding the cost of the iron but including the waste of iron, this gives a conversion cost of 16/6d. per ton, which is a low figure in comparison with most of what follows.

The Cutlers' Company records cover a period just subsequent to the Blackhall Mill evidence.[1] They are not uniformly explicit throughout the record and there are problems in the carry-over of costs from one period of management to another. There are, nevertheless, two periods for which production costs can be assessed with some assurance.

The initial period of just over three years under Joseph Ibberson, from 1759 to 1762, covered the sale of 128 tons 8 cwt. of steel, with 1 ton 4 cwt. left in stock when George Greaves took over. It is reasonable, therefore, to assume that the previous costs covered the production of 129 tons 12 cwt. of steel. On that basis, the following figures, which give a total conversion cost of £2. 8. 2d. per ton, may be evaluated :

		Total Cost	Cost per Ton
		£. s. d.	£. s. d.
Iron plus Carriage		2873.10. 8.	22. 3. 6.
Charcoal		8. 3. 0.	1. 3.
Coal		44.17. 6.	6.11.
Steelmaking:			
Labour	88.16. 0.		
Drinking	3. 2. 6.		
Sundries	4. 4. 9.		
Slitting	6. 0. 0.	102. 3. 3.	15. 9.
Repairs:			
Materials	31. 1. 5.		
New Pots	15.16. 9.	48.18. 2.	7. 3.
Expenses:			
Rent	35.18. 0.		
Taxes	2. 3. 2.		
Interest	72. 7. 0.		
Letters	19. 6.	110. 7. 8.	17. 0.
TOTAL COSTS		3186. 0. 3.	24.11. 8.
Profit Margin		212. 6.11.	1.12. 9.
SELLING VALUE		3398. 7. 2.	26. 4. 5.

1 Company of Cutlers in Hallamshire Archives, Volumes 47 and 48.

APPENDIX FF
continued - 3

The bulk of the material appears to have been sold at £27 per ton. The implications are, therefore, that :

(a) There were some other expenses not listed;

(b) There was some waste of iron not included:

or (c) There was less steel produced than has been computed from the records.

Since, however, such an error is only of the order of 3%, it does not materially affect the conclusions. It will be remembered that the furnace employed at this time had a capacity of only some 3¾ tons.

The second set of figures comes from the end of the Cutlers' Company 'adventure' since it is possible, by careful study of the accounts, to put together an assessment of the total conversion costs of the operations under Beely. The total disbursements of £344.10.11. for the period from March 1769 to August 1772 may be categorised in some detail, since the Day Book is very explicit; even such items as 'wheele barry trindle', 'baggin and pack thread', 'two basketts and two besoms' and 'paid Price Heptonstall re overcharge in Mr. Birk's time' are all faithfully recorded. Invariably every item listed as 'Jon. Makin for the Heat' is followed by 'Ale for the above heat', whilst each rebuild of the furnace (and there were four of these when the 'potts' were replaced) was accompanied by 'Ale at Furniss'. This custom was, of course, perpetuated in the later Sheffield custom of 'lowance' (that is to say, an allowance, paid in cash or in drink) provided for the crucible steelmakers in many establishments, right into the twentieth century. The costs for the production of a total of 260T. 11cwt. 11lb. of steel, excluding the basic cost of the iron, were as follows :

APPENDIX FF
continued - 4

	£. s. d.	Total Cost £. s. d.	Cost per Ton s. d.
Steel Production:			
Steelmaker	67.11.10.		
Ale provided	3.17. 0.	71. 8.10.	5. 5¼.
Charcoal		19. 2. 0.	1. 5½
Coal		120. 1. 8.	9. 2½.
Repairs, etc:			
Stone and New Pots	28. 3. 6.		
Sand	3. 1.11.		
Clay	8. 0.		
Pointing Slates	3.12. 6.		
Stays	3. 6. 6.		
Iron Plates	1. 2. 9.		
Extra Labour	8.18. 6.		
Wheel Barrow Repairs	7. 0.		
Mending Tools	2. 6. 6.		
Sundries	5.10.	51.13. 0.	3.11½.
Cartage:			
Freight on Iron	13.11.11.		
Letters	1. 9.		
Carriage on Steel	4. 7.	13.18. 3.	1. 0¼.
Charges:			
Interest	63. 0. 0.		
Rent	2. 4. 1.		
Land Tax	5. 3.		
Poor Assessment	1.14. 6.		
Constable Assessment	9. 0.		
Back Payment	14. 4.	68. 7. 2.	5. 3.
TOTAL		£344.10.11.	£1. 6. 5.

The furnace capacity at this time had been increased to about 7½ tons.

For this same period there is available some cost detail for an unspecified furnace in the Birmingham area from a Swedish report on steelmaking.[1] The information may be translated as follows :

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1 Bengt Qvist Andersson, Anmarkningar samlade pa Resan i England Aren 1766 och 1767, Folios 174-176. Manuscript in Jernkontorets Bibliotek, Stockholm.

For 12 to 16 campaigns in the year, depending on the size of furnace, the following is required :

132 tons of iron, in Birmingham £26 a ton	£3432. 0. 0.
528 cauldrons of coal at 9/0d.	237.15. 0.
2 ditto for the personal use of the two workers who are entitled to it	18. 0.
Wages for the steelmaker and his helper @ 24/0d. per week	62. 8. 0.
Repair of the furnace, charcoal breeze, candles and other contingencies	50. 0. 0.
TOTAL	£3783. 1. 0.

The 132 tons of steel are sold in Birmingham as they come from the furnace for £31 per ton; the yearly return from one furnace is thus £4092 and the profitability is consequently £308.19. 0d.

The costs per ton from the above information work out as follows :

Iron	£26. 0. 0.
Coal	1.19. 2.
Wages	9. 5.
Repairs, etc.	7. 6.
	£28.16. 1.

This gives a conversion cost of £2.16. 1. per ton of steel for a furnace whose capacity is somewhere between 8 and 11 tons per heat.

Details from the Swedish operations at Halstahammars Bruk in 1787[1] make an interesting comparison. The costs are quoted in 'skillings' and 'rundstycke' for the production of one 'skeppund stangjarn stapelstadtsvikt' of steel but these can be converted to the standard basis of comparison as follows :

	Cost per Skeppund s. r.	Cost per Ton £. s. d.
Labour for firing	5. 4.	4. 1.
Labour for repairs	4.	3.
Clean dust-free charcoal for firing	29. 4.	1. 2. 5½.
Birch charcoal, stamped to dust	2. 4.	1. 9½.
Ashes, to mix with cement	2.	1½.
Materials for repairs	3.	2.
Steelworks foreman	3. 7.	2. 9.
Use of furnace	3. 0.	2. 3½.
Coke baskets, brooms, casks	4.	3.
TOTAL	44. 8.	1.14. 2.

It is stated that these figures were mean values for the previous three year working period; the furnace is represented in one of the surviving drawings of furnaces designed by Sven Rinman and was a double furnace unit,

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1 C. Sahlin, 'Svenskt Stal', <u>Med Hammare och Fackla</u>, Vol. III (1931), pp.167-168. With regard to conversion of the Swedish units into English, I was informed by the late Torsten Berg that there were 7.5 skeppund to the English ton; with regard to the currency, there were 48 skillings to the Riksdaler and 12 rundstycke to the skilling. In 1787, £1 Sterling was equivalent to 4 Riksdaler and 4 skillings (or 196 skillings). The above conversions are based on these figures.

APPENDIX FF
continued - 7

each furnace containing two chests with 65 skeppund (817 tons) total weight of iron.[1]

The same document also gives the cost of forging :

	Cost per skeppund R. s. r.	Cost per ton £. s. d.
Labour for forging	11. 8.	8.11.
Labour for repairs	4. 6.	3. 5.
Charcoal	11. 0.	8. 5.
Steelworks foreman	3. 7.	2. 9.
Steel packers	1. 8.	1. 3.
Boxes	7. 6.	5. 9.
Attendants' wages	11.10.	9. 1.
Carriage	5.	4.
Materials for repairs	1. 8.	1. 3.
TOTAL	1. 5.10.	2. 1. 2.

This leads to a summary for the total cost of the bars:

Iron	6.24. 0.	11.18. 9.
Cementation	44. 8.	1.14. 2.
Forging	1. 5.10.	2. 1. 2.
Incidentals	19.10.	14. 6.
Waste, less scrap value	9.10.	7. 6.
TOTAL	9. 7. 4.	16.16. 1.

It will be noted that the price for iron in Sweden is at a much lower figure than that normally met in the English records. Indeed, it is stated to have been available in their own works at from 5 to 6½ Riksdaler per skeppund

1 The Rinman drawings are preserved in the Rinmanska Arkivet of the Techniska Museet in Stockholm.

(£9 to £12 per ton). Had the iron been charged at £26 per ton, as in England at this time, the forged bars would have cost £31 to £32 per ton. The enormous amounts of charcoal required for the cementation process must have been the determining factor which persuaded the Swedish authorities to concentrate on the production of iron, rather than make steel from a much smaller quantity of iron.

Between 1830 and 1836, Marsh Brothers in Sheffield extended their steelmaking activities by taking over the Navigation Works and building four cementation furnaces, two in 1830, one in 1835 and one in 1836. An account book has survived which gives detailed construction costs for the first two furnaces, and the same source gives the overall cost of the four furnaces as being £1538. 0. 6.[1] The same account book gives details of iron conversion from November 1830 to October 1837; unfortunately, the complete information enabling a detailed survey of costs to be made is only available for the two years 1834-35 and 1835-36. In the latter year, with 740 tons being converted from three furnaces, assuming the normal 16 heats per annum, it may be computed that the furnaces had a mean capacity of around 15 tons per heat. The costs may be tabulated as shown in Table B.

The best known source of production costs for the cementation process must be the report of Le Play, covering operations in a typical 18-ton furnace in Sheffield for the period 1836 to 1842.[2] The details per ton of blister steel are as follows :

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1 I was allowed to inspect this volume by kind permission of G. F. Willan, Esq. At my suggestion, this volume, together with the remainder of the surviving Marsh Brothers papers, has now been lodged with the Sheffield City Libraries Archives. Details of the costs may be found in Table A attached.

2 F. le Play, 'Mémoire sur la Fabrication de l'Acier en Yorkshire', Annales des Mines, 4me. Serie, Tome III (1843), pp.625-626.

Coal 0.6 tons @ 9/0d. per ton	5. 5.
Charcoal 0.075 tons @ 50/0d. per ton	3. 9.
Labour 2 days @ 3/0d. per day	6. 0.
Maintenance	2. 8.
Various general costs	2. 4.
Interest on capital	3. 0.
Profit	2.10.
TOTAL	£1. 6. 0d.

The higher cost of 28/0d. per ton is stated as being applicable to higher carbon material with a longer period in the furnace. The size of furnace is not indicated but, assuming a three week cycle and two men in attendance, a capacity of around 20 tons can be estimated.

In 1869, Henry Seebohm gave the following figures for cementation costs,[1] again expressed in terms of one ton of blister steel produced :

Coals	10. 0.
Wages	6. 0.
Charcoal	3. 6.
Rent and Taxes	1. 6.
Wear and Tear of Chests	1. 0.
Tools, etc.	1. 0.
	£1. 3. 0.
Add a margin for occasional losses on 'crozzled' or 'flushed' bars deteriorated in value, 'aired' bars requiring reconversion, sundry trade expenses, etc.	3. 0.
	£1. 6. 6.

The final set of figures covers the production for the year 1887 from the cementation furnaces of Seebohm and Dieckstahl.[2]

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1 H. Seebohm, On the Manufacture of Cast Steel (Sheffield, 1869), p.5. This was the text of a lecture given to the Sheffield Literary and Philosophical Society, 2nd March 1869, and was subsequently printed privately.

2 Seebohm and Dieckstahl Note Book, Sheffield City Libraries, Ref BDR 76.

APPENDIX FF
continued - 10

Special Costs

(Iron for cementation	2220 lb.)		
Charcoal @ £2.3.6. per ton	123 lb.	2. 4½.	
Coal @ 8.6d. per ton	1680 lb.	6. 4½.	
Labour @ 2.10½d. per day	2.03 days	5. 7½.	14. 4½.

General Costs

Industrial Capital: rent of works or interest on capital at 5%	3. 4.	
Floating Capital: interest at 6%	6½.	
Maintenance of plant: bricks, clay, iron for tools, labour of specialist workmen	2. 4½.	
Management and supervision: exercised without cost by head workman	Nil	
Miscellaneous costs: taxes, licences, carrying of letters, office costs, etc.	1. 6.	7. 9.
TOTAL		£1. 2. 1½.

Le Play states that the above figures apply to a works with three furnaces, which have not been fully occupied due to the rather depressed state of trade, but have produced 600 tons between them in the year. This represents about 12 heats per furnace in the year, with two men full time and a part time helper. The figures quoted also indicate a .9% gain in weight during cementation and a coal consumption of 0.75 tons per ton of steel. A consideration of the interest figures implies a capital cost of £2000 for the works with three furnaces and a stock and work in progress value of around £270.

A French report of 1862[1] indicates a cementation cost of 26/0 to 28/0d. per ton, itemised as follows, as being typical of the standard Sheffield practice:

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1 L. E. Gruner and C. Lan, L'État Present de la Metallurgie du Fer en Angleterre (Paris, 1862), p.796.

The size of furnaces is not given but the tonnage produced was some 700 tons, 70 tons of which had to be reconverted, giving a nett output of 630 tons. For this amount the following figures are applicable :

		Cost per ton
Converting Coal:		
Tinsley	£131.17. 3.	
Rothervale	96. 4. 5.	
	£228. 1. 8.	7. 3.
Charcoal:		
Tyson and Bradley	£73. 2. 6.	2. 4.
Wages:		
R. Townes	£91.10.10.	
J. Campbell	84.14. 4.	
	£176. 5. 2.	5. 7.
Rent, Rates and Taxes	£55. 0. 0.	1. 9.
Standard Costs:		
Carting		2. 0.
New Pots		8.
Tools, etc.		6.
TOTAL		£1. 0. 1.

In addition to the manufacturing costs, it is of value to quote the variations in costs of the bar iron. Since the product of the Leufsta forge in Sweden, the famous L iron, or 'Hoop L' as it became known, was used for well over two centuries, Table C gives the various prices in Sheffield quoted in a number of available records.

T A B L E   A

BUILDING COSTS FOR A PAIR OF CEMENTATION FURNACES ERECTED AT NAVIGATION WORKS BY MARSH BROTHERS IN 1830

(Abstracted from Account Book, now lodged in the Archive Division of Sheffield City Libraries)

The furnaces were probably of around 15 tons capacity each (7.5 tons per individual chest)

Excavating, leading rubbish, levelling yard	£40. 5. 8.
George Fox, foundation setting	£33. 3. 0.
Repairing bridges	£3.19. 3.
Foundation stone	£2. 1. 0.
Hair for plaster	10. 0.
Graham & Marshall, Wickersley. Coping for wall	£5. 6. 0.
Geo. Furniss. Ashlar for gates	£6. 0. 0.
Booth & Co. Bond iron	£1.10. 9.
Floor grate 2q.24lb. @ 10/- 7. 1.) 16 Bearers 7t.3q.14lb. @ 10/- 3.18. 9.)less 4 Plates 35t.2q. 0lb. @ 7/- 12. 8. 6.)5% 4 Door Frames 4t.2q.22lb. @ 7/6 1.15. 3.)	£17.11. 0.
Lead for chimneys, gutters, skylights, etc.	£15.18. 9.
Wm. Blagden for lime (37¾ cwt.)	£32.15. 0.
T. Mercer, Bole Hills, for a pair of warranted potts	£15. 0. 0.
Jane Booth of Grenoside for ditto	£17.17. 0.
Saml. Revill of Sheffield Park 24500 stock bricks @ 29/-	£35.10. 6.
Saml. Glave, Brickmaker 103150 stock bricks @ 29/-	£149.11. 4.
2700 palettes @ 36/-	£4.17. 2.
Jon^{n}. Goodison, Stannington, firebricks	£66. 0. 0.
John White, stone	£47.14. 7.
J. Stead, vaulting and other stone	£7. 0. 0.
J. Stead, extra stone	£13.17. 1.
G. Foster, sand	£7.14. 6.
Ashley, plasterer	£5.10. 6.
Jno. Chadwick, labourer	£6.13. 0.
Goulder, for sinking well	£10.17. 6.
Morley for putting down lead pump, etc.	£8. 7. 6.
Wm. Stringfellow, building lay by wall	£15.12.10.
Joel Buxton, contract builder	£152.17. 7.
I. & I. Woolhouse, ditto	£162. 5. 2.
James Mann, slater	£57. 5. 0.
Timmons, painter	£5.18. 8.
Mrs. Wilson, ale for rearing furnaces	£2.12. 6.
TOTAL	£951. 3.10.

.... continued

T A B L E   A
continued

Above furnaces, built in 1830		£951. 3.10.
February 1835	Extra furnace there	£139. 2. 6.
January 1837	Extra ditto, with Warehouse and Sheds	£447.14. 2.
TOTAL COST AT NAVIGATION WORKS		£1538. 0. 6.

TABLE B

CEMENTATION COSTS - NAVIGATION WORKS, 1834-36

	1834-35		1835-36		Mean
Tons, converted	583.75		740.10		
Coal used, tons	480.60		892.85		
Coal, tons per ton steel	0.823		1.206		1.035
	Total	Per ton	Total	Per ton	Per ton
Coal	£180. 4. 6.	6. 2.	£379. 9. 4.	10. 3.	8. 5.
Charcoal	41.11. 4.	1. 5.	52.10. 0.	1. 5.	1. 5.
Wages	171. 0. 0.	5.10.	234.18. 5.	6. 4.	6. 1.
Ground Rent	19.15. 0.	8.	19.15. 0.	6.	7.
Horse and Cart, Wear and Tear	78. 0. 0.	2. 8.	110. 0. 0.	2.11.	2.10.
Poor Rate			6.17. 6.	2.	1.
TOTAL	£490.10.10.	16. 9.	£803.10. 3.	£1. 1. 7.	19. 6.

T A B L E C

SHEFFIELD PRICES OF LEUFSTA
OR 'HOOP-L' IRON

Year	Source	Price per Ton
1701	SIR 2	£17.10. 0.
1714	SIR 4	£15.12. 6.
1715	"	£18. 0. 0.
1717	SIR 5	£26. 7. 6.
1718	"	£27.10. 0.
1719	"	£26.10. 0.
1720	"	£19.10. 0.
1721	"	£21. 0. 0.
1723	SIR 6	£17. 0. 0.
1724	"	£19. 2. 6.
1730	SIR 7	£18. 5. 0.
1735	"	£17. 0. 0.
1745	SIR 9	£16.10. 0.
1747	"	£16. 0. 0.
1749	"	£16. 0. 0.
1750	"	£18. 0. 0.
1751	SIR 10	£19.10. 0.
1753	"	£20. 0. 0.
1756	"	£20. 0. 0.
1759	"	£20.10. 0.
1760	SIR 11	£22. 0. 0.
1762	"	£22. 0. 0.
1765	"	£21. 5. 0.
1832	WD 634	£40. 0. 0.
1835	"	£35. 0. 0.
1840	Tyzack	£35. 0. 0.

Year	Source	Price per Ton
1842	Le Play	£35. 0. 0.
1844	Tyzack	£32. 0. 0.
1845	"	£32. 0. 0.
1848	Tyzack/SJC 41	£32. 0. 0.
1851	Tyzack	£32. 0. 0.
1852	"	£29. 0. 0.
1854	"	£36. 0. 0.
1855 (	"	£34. 0. 0.
(	LD 266	£36. 0. 0.
1857	Tyzack	£36. 0. 0.
1858	Tyzack/Doncaster	£34. 0. 0.
1859	Tyzack	£32. 0. 0.
1861	"	£32. 0. 0.
1863	Tyzack/Doncaster	£32. 0. 0.
1866	Doncaster	£23.10. 0.
1868	"	£19. 0. 0.
1870	"	£25. 0. 0.
1880	"	£23.10. 0.
1886	"	£20.10. 0.
1896	"	£20. 0. 0.
1902	"	£20.10. 0.
1906	"	£18.10. 0.
1911	"	£17.10. 0.
1914	"	£17.10. 0.
1915	"	£18.10. 0.
1916	"	£30. 0. 0.
1917	"	£36. 0. 0.
1918	"	£80. 0. 0.
1919	"	£54. 0. 0.
1922	"	£30. 0. 0.
1926	"	£28.10. 0.
1928	"	£28.10. 0.

Sources:

SIR 2-11 = Staveley Ironworks Records

WD 634 = Fowler Note Book

SJC 41 = Ebenezer Jackson Note Book

LD 266 = Brittain Accounts

(all above in Sheffield City Libraries)

Tyzack = Tyzack Purchase Ledger

Le Play = 1843 Report (Annales des Mines)

Doncaster = Daniel Doncaster Archives

A P P E N D I X   GG

THE MAKING OF COINING DIES IN CAST STEEL

Extracts from a letter from Matthew Boulton
to William Huntsman dated 6th July 1797.
Original in the Birmingham City Libraries,
Reference H3.241

I believe I have discovered one course why my Dies do not stand as well as is necessary for I observe that such as are steel'd with some Bars that are $1\frac{1}{2}$ Inch square do not stand as well as those w^{ch}. are made out of the $2\frac{1}{2}$ Inch by $1\frac{1}{2}$ In as the engraving of the first is made at the end of the Steel whereas those Dies made from the $2\frac{1}{2}$ Inch Steel the engraving is put upon the Edge of the Steel and not on the End of it.

In the one case the $1\frac{1}{2}$ In square is rounded by the hammer and then cut off in pieces about $2\frac{5}{8}$ long and a hoop of iron whielded round it. Whereas the large bars being $2\frac{1}{2}$ broad a piece of $1\frac{1}{2}$ is cut off it and then rounded by ye hammer and when forged into a die the edge of the bar becomes topmost. I have now not an ounce of your steel to work on and therefore I must beg of you to send me as soon as possible some bars $2\frac{1}{2}$ by $1\frac{1}{2}$ of as good a quality of dies as you can possibly make.

Our agent Mr. Southerns wrote me that he had seen you and that you had promised to send som Fryday next which I hope you will not fail to do. Mr. Southerns also mentioned that you could get some dies forged for me under your own direction. I must own I wish you would for I want more than my Smith can do. I have therefore sent you one of my Dies by Coach and wish you would get me 12 Doz forged exactly to the same height and diameter, they are about $2\frac{1}{2}$ in or $2\frac{5}{8}$ $diam^{r}$. and $1\frac{1}{2}$ In high in the cylindrical part and $2\frac{5}{8}$ from bottom to top. I beg you set a man instantly to forging and if he succeed I shall want a great number.

These dies are steeled quite through and take from $1\frac{1}{2}$ lb. to 1 lb. 10 oz. of steel. They are for striking penny pieces of the size I have sent with the die but as they are struck in Collars they require a very hard blow and if not steeled through the dies would sink in the middle. If the lower part was common blistered steel it might be tryed but I fear the Whielding it to Cast Steel would injure the quality.

APPENDIX HH

THE DISCOVERY OF CRUCIBLE STEEL

A Letter to the Editor of The Times from
Benjamin Huntsman II, dated 30th December 1864,
printed in the issue dated 3rd January 1865

Sir -

A correspondent in *The Times* of the 21st inst. has directed the attention of all who are interested in the invention of the art of manufacturing cast steel to a paragraph copied from the works of M. Broling, a Swede , who wrote either at the end of the last or the beginning of the present century. Your correspondent, after having described the opportunities for observation which Broling possessed during his residence in this country, and in Sheffield particularly, proceeds to contrast his history of the invention with that given by Le Play, who wrote many years later, and then ventures to assume, without any other authority, that the account which Le Play has given of Huntsman's invention is unworthy of credit, being at variance with the account of the same invention given by the Swedish author so many years before.

It is fortunate both for the character and reputation of Benjamin Huntsman that there are sufficient facts still in existence to enable me to give a contradiction to Broling's curious story. Francis Huntsman, now in his 80th year, the grandson of the inventor of cast steel, is living at Loversall, near Doncaster, and many of the circumstances connected with the originality of the invention are familiar to him, as he received them from his father and from others who were alive during the lifetime of his grandfather. The present Mr. Huntsman must have been at least 15 years old when Broling wrote, and if such a story had had currency at that time it is highly improbable that he would have remained in ignorance of it, but he has no recollection of ever having heard the name of Waller mentioned in connexion with the discovery of cast steel.

Your correspondent, quoting from Broling, says "that Huntsman, perceiving the pecuniary value of the invention for edge tools, and possessing the requisite means, erected works and began to melt on a large scale". This is at variance with the truth, and if Broling had taken the slightest trouble in attempting to verify the story given to him he would have discovered his mistake. Huntsman was not a rich manufacturer or possessed of riches, but a clockmaker living at Doncaster, whose attention had long been given to experiments on steel for the purpose of manufacturing springs for his clocks of a superior quality, and further with a view to improve the construction of the pendulum. His grandson possesses a clock made by him with the pendulum of cast steel, and several others may still be found in the neighbourhood. In the year 1742 he sold his small property in Doncaster, and resided at Handsworth, afterwards at Attercliffe, near Sheffield: at each of these places specimens of his early experiments both in making crucibles and melting steel have been at various times discovered. After he had perfected his invention an offer was made to him by others in Birmingham to enter into a partnership and to carry on a trade at that town. Huntsman went over there, accompanied by his servant, Thomas Hoult, who was living in the present century, but when he found that it was to be one of the stipulations of the partnership that he should teach six other persons the secret of his art he indignantly refused the offer made to him and returned home, and it is probable that it was shortly after this that his secret transpired in the manner told by Le Play and alluded to by your correspondent.

It is well known to all who are acquainted with the manufacture of cast steel that it is almost impossible for Waller to have manufactured rollers for rolling gold and silver lace, and that his name as an inventor should be forgotten in Sheffield. The difficulties to be overcome were too great to be concealed, for Huntsman not only manufactured his own crucibles out of a clay which he had taken great pains to discover, but made his own coke for the fuel to melt his steel.

Benjamin Huntsman's eccentricity of character, joined to his Quaker principles, may offer some explanation why he never claimed any merit in his invention. He appears to have been content with his success. He made no effort to turn his discovery to any great private advantage and when the Royal Society offered to make him one of their members he declined the honour. All this, added to his great benevolence to the poor in affording them gratuitously his widely known medical skill, is inconsistent with the character drawn of him by "Y" as the pirate of another man's invention.

I have the honour to remain, Sir, your obedient servant,

BENJAMIN HUNTSMAN

West Retford-hall, Dec.30, 1864

A P P E N D I X   II

THE MANUFACTURE OF CAST STEEL

Extracts from G. Broling, Anteckningar under en Resa i'England Aren 1797, 1798 och 1799, Vol.III (Stockholm, 1816), pp.24-70, 80-101 and 143-147

This translation was produced in part by Paul Widgren, Esq. (pp.24-42) and the remainder by Nils Bjorkenstam, Esq. who kindly checked the earlier part so as to give a uniformity of style. Thanks are also due to Jernkontoret in Stockholm for provision of negatives of the plates.

The first part of the account (pp.1-24) forms an introduction which has not been translated; neither have the contents of pp.70-79 (on the forging, hardening and annealing of cast steel) nor of pp.101-142 (on the manufacture of rolls from cast steel). The figures in parentheses within the text indicate the commencement of the text on each page in the original.

* * * * * *

MANUFACTURE OF CAST STEEL FROM BLISTER STEEL (24)

Apart from the specially designed building required, the manufacture of cast steel is based on three main factors: the highest quality of *STEEL*, which in itself should combine all the properties which are required to make it the best of its kind, a *CLAY* with the highest degree of fire resistance for the manufacture of the crucibles in which the above is to be melted, together with a *FUEL* (25)
sufficiently powerful and heat generating to attain the intense degree of heat necessary during the melting operation.

The size and scope of the building really depends on the estimate of the amount of the product that can be sold. In my description, handed over to 'Bruks Societeten', I could at the time only produce drawings exemplifying one such building which I had seen abroad. From these I shall now retain only two plates in order to give some idea of the size of such a building, where one can annually manufacture up to one hundred tons, and in addition describe that installation built by me here for a far smaller production, especially as it incorporates several activities within a limited space which are indispensable to the operations and which elsewhere abroad, where all the manufacturers give each other a more helpful hand, do not necessarily have to be in the vicinity of each other, as for example furnaces for coking of the coal, hammers for forging of the cast steel, places for crucible manufacture, and so on.

THE BUILDING FOR A CAST STEEL WORKS (26)

As regards the site for a cast steel plant, one should preferably choose a sloping location. In the case of my plant it was fortunate that a terrace, 8 feet in height, had previously been laid out, whereby some saving was achieved in the height of the building and thereby in the overall cost.

The next priority is to study carefully the nature of the ground, as the wall in which the chimney stacks are to run will contain more bricks than the other three walls put together and will thereby require a firm foundation if the building is not to settle differentially due to the different weights of walls, which would result in the development of cracks. I have endeavoured to prevent this by means of a 6 ft. wide and 10 ft. deep foundation wall of granite laid on a double bed of heavy timber grillage.

The need for a sloping site arises from the fact that an arch, 6-8 ft. high, must be built at that side of the building where the furnaces are to be installed (27) in order to achieve the strong draught required during melting. The length of this arch is determined by the number of furnaces, as square niches are arranged on one side of the arch to form ash bins underneath each furnace.

This arch is provided with a robust plate-iron door by means of which the draught can be regulated whilst melting is in progress.

A stone staircase leads up from the arch to the melting shop itself, the entrance to which is also provided with an iron door in order to avoid the risk of fire. It is evident that, for the same reason, the floor of the melting shop should be made of stone or better with bricks laid on end, as several holes will be made therein into which the cast steel crucibles can be lowered during casting, as further described later. Between casting, these holes are filled with suitable stones or, still better, with specially made cast-iron boxes, 9 inches long and 6 inches square at the upper end, provided with a base to which iron lugs are cast (28)
so that they may easily be lifted during casting. Furthermore, these lugs are located in a small hollow in the base itself, as is shown in fig.Q, plate 6.

The building itself (plate 3) is built of brick and is two storeys high. The upper room serves as storage space for materials and can in addition, as in my small plant, incorporate a cast-iron lathe for machining large pieces of iron and steel and for grinding and polishing rolls, and so on. In the attic above, shelves can be arranged for drying the crucibles.

A staircase leads up from the attic to the roof, at which point a small plate-covered trap door is provided as it is useful in many instances to have quick access to the roof, for example in order to carry out repairs or, as is required in some instances, to reduce or completely block the draught by means of a cover plate.

In foreign plants, where in most cases 12 furnaces are used, the melting shop is of a corresponding length, as is shown in plate 2. In plate 1 there is a clear (29)
survey of both the nature of the arch and of the operations during casting.

At my own plant, where neither the requirement nor the space have permitted a larger building, the melting shop is only 23 feet long and somewhat more than 20 feet wide.

Plate 4 shows the lay-out of this room.

A A A A A	5 cast steel furnaces.
B	The steam engine.
C	The boiler for same.
D	A furnace for coking coal provided with an ordinary forge hearth.
E	A cast-iron hammer for cast steel forging.
F	A portable hearth of cast-iron.
G	A furnace for drying and annealing crucibles.

I shall endeavour to give a description of these arrangements in the order in which they are required.

FURNACES FOR CAST STEEL MELTING (Plate 5) (30)

The convenience normally connected with the arrangement of crucible melting furnaces, with their openings on the same level as the floor in the melting shop, becomes a necessity when preparing cast steel. The advantages thereof are numerous. With this arrangement the furnace operator will be at the greatest distance from the fire he is to maintain, he can see whether the crucible is upright in the middle of the furnace, whether the cover is in the correct position, on which side coke is required and, finally, he can use his entire strength when lifting the crucible, as described later.

Each of these furnaces is 42 inches high and 12 inches square inside, the upper end being provided with a frame of cast iron, 1 inch thick, with an inner opening equal to that of the furnace and 20 inches square outside. These iron frames are particularly useful as, although the upper edges of the furnace are smooth to begin with, when new, after a time the joints, as well as small pieces of the bricks themselves, are worn away so that the furnace doors do not completely seal the opening and thereby permit a certain amount of air to force its way down into the furnace, thereby reducing the useful draught coming through the grate. (31)

In the rear wall of each furnace, 9 inches from its upper edge, a 6 inch square hole is made from which a horizontal chimney or flue is laid straight through the entire wall but in such a way that the hole leading outwards from the vertical chimney flue is only 18 square inches and can thus be completely sealed by means of an ordinary brick laid on its edge together with a little mortar. This opening is provided to enable pieces of brick and mortar which have fallen down the chimney to be scraped out by means of a suitable rake.

Two cast iron bars, 2 inches square, are cemented in at the lower end of the furnace. On these are laid 7 loose iron bars, 1 inch square, which constitute the grate itself. The significance of these bars lying loose, thus facilitating their removal when casting is to be carried out, will be explained later. (32)

Five furnaces with the above-mentioned dimensions are set in their own wall, which runs alongside the outside wall. One side of the arch is supported on this wall and under the grate are ash bins which go down to the floor, the front of which are left open, whereby each ash bin forms a niche 2 feet wide, 2'6" to 3 feet deep and 6 feet high, so that one can easily inspect and clean the grate as often as necessary.

The draught (pipes or) flues lead horizontally from the furnaces to the middle of the outer wall and

continue up this wall until they eventually converge at the base of the roof, from whence they lead vertically up through a chimney 16 to 20 feet high (33)
(pl.3, fig.1). To ensure a strong and steady draught, each furnace should be provided with its own chimney for the entire length and, in order to save bricks, at the base of the roof these should be positioned so close to each other that the intermediate wall is only one brick thick.

The furnaces themselves, the horizontal flues and the vertical chimneys to a height of 6 to 8 feet are lined with fireproof bricks. One does not need to incur the cost of continuing this lining farther since well-carbonized coal produces little flame. It is as well to point all the joints for the entire length with fireproof mortar as falling pieces must not melt in the horizontal flues, thereby complicating the cleaning of same.

The fireproof bricks used to line the furnaces should, as is the custom in England and also at the clay works in Skåne, be made of fired and unfired fireproof clay, whereby they become more compact and less brittle.
They are first ground on one side, either against one (34)
another or against a cast-iron slab, with sand. They are then cemented in by hand with the ground side facing outwards, as is the custom of chimney builders, and with a mortar of 2 parts fired clay or crushed fireproof brick and 1 part unfired fireproof clay (more or less, depending on whether the fireproof clay is greasy or pliable). The mortar should be as firm as possible and each stone must be wetted and well covered with mortar before being laid. The cementing or lining must be carried out with every possible care and attention as the joints are always the first to become defective since they can never be provided with that stability possessed by the stones already fired.

In addition, each furnace is provided with a lid (pl.6, A). This consists either of an iron frame, into which fireproof bricks are fitted and cemented fast, or of a thin cast iron box in which nails are cast at a distance of 2 inches from one another in such a way that their heads protrude 1½ inches; fire-
proof mortar is filled between these nails, incorpora- (35)

ting as many splinters of fireproof stone as possible. A hole of approximately 1 inch in diameter is provided in the middle of each lid through which one can observe the depletion of the coke during smelting. In addition, each lid is provided with two 12 to 15 inch high handles in order that it may be lifted on and off with ease without it becoming too hot.

CRUCIBLES

Externally these are approximately 13 inches high, 8 inches in diameter at the top and slightly conical in shape, with the base diameter 2 inches smaller than the top diameter. The wall thickness at the top is not quite 1 inch, below which it gradually increases to reach 1½ inches at the base, and the thickness of the base itself is 2 inches. This downward increase in wall thickness is of great importance with regard to the effect of the flux on the inner side as well as to the effect of the fire on the outer side, since the fire tends to exercise its strongest effect at a distance of 5 to 6 inches from the grate. (36)

The crucibles should not be placed directly on the grate as the strong penetrating draught, far from making the bars of the grate red hot, causes them to maintain a fairly low temperature and thus it becomes necessary to arrange for the base of the crucible to be at least 3 inches above the bars of the grate. For this purpose one may use small pedestals, 3 inches high, or whichever is more convenient in practice two small bases each 1½ inches thick, placed on top of each other, the diameter of which must not exceed that of the base of the crucible. The reason for this is that pieces of coke have a tendency to stick to the crucible as the coke, at this distance from the grate, always coheres, which constitutes a definite inconvenience when the crucible is used several times.

The lids of the crucibles should be of the same shape as the above-mentioned baseplates with the difference, however, that they are of the same size as the upper end of the crucibles. (37)

The way in which the crucibles themselves, as well as the lids and the base-plates, are manufactured will be described in detail later.

Normally two tools are used for the charging of steel and flux into the crucible.

THE CHARGING SHOVEL B (pl.6) is made of non-tinned iron-plate, 10 to 12 inches long, 5 to 6 inches wide and with 3 to 4 inch raised sides somewhat sloping towards the front. Four thin iron rods 2'6" to 3 ft. long are nailed fast to the shovel, two on each long side, in such a way that they may pivot on the nails. A square iron ring of the same shape as the shovel, but somewhat smaller, is nailed fast in the same manner at the top end and two handles are fitted to the shortest sides of the ring. From this it is easy to understand that, with the aid of these handles, either end of the shovel may be raised or lowered as required and thus the steel in the shovel can easily be charged into the crucible despite the intensity of the heat.

THE CHARGING FUNNEL C is used during charging of smaller pieces of steel or flux. It is also made of non-tinned (38)
iron-plate of approximately 2'6" in length, 4 inches at the upper end and 2 inches at the lower end, and is provided with a handle. When in use the lower end is first blocked with paper, after which the material to be charged into the crucible is poured into the funnel and, as the paper immediately burns through when the funnel is lowered into the crucible, the material is slowly discharged without the risk of spillage or inconvenience caused by the material falling from a greater height.

THE COKE BASKET D is a common household article in England, used for carrying coal. It can hold one and a half to two gallons*, is made of robust iron-plate

* This is given as 1.5 to 2.0 kappe; the kappa is virtually the same as a gallon, being $^1/32$ tunna or 4.56 litres; the gallon is 4.54 litres.

and is, in other respects, as shown on the drawing; it has a fixed handle for gripping with one hand and another smaller handle on the back plate for gripping with the other hand to enable easy emptying, and a foot with a somewhat slanting base so that the basket tilts slightly backwards when resting on the floor, thus preventing spillage when the basket is full of coke.

In addition, small wooden boxes E are used in which the weighed steel is stored and from which it is discharged, as required, into the charging shovel. (39)

Four types of tongs are also required during this handling for insertion and removal of the crucibles, removal of the lids, pouring of the steel, and so on.

THE LIFTING TONGS F are used to lift the crucibles in and out of the furnace; they have a double grip and must be robust at the lower end. The handles decrease in thickness towards the top and this decrease must be carefully worked out so that the tongs are neither too heavy nor too fragile. If the former were the case, an exceptionally strong man would be required to lift the crucible due to the awkward position and the intense heat. If the latter were the case, and the tongs should give way, both the melter himself and those around him would run a great risk of being injured. This operation is the most difficult in the entire handling and normally requires some experience before it can be performed without danger. Furthermore, as is known, 5 pounds can constitute quite a difference when lifting a weight with straight arms.

THE LID TONGS G are used for removal of the lids of the crucibles, either while the crucible is still standing in the furnace in order to check whether the steel has melted, when charging a new quantity of steel, and so on, or when the crucible has been lifted out for casting. It may seem that any type of tongs may be used for this purpose but, since one can never satisfactorily prevent the spillage of flux on the upper edge of the crucible during the various investigations required to check whether the steel has melted, it frequently happens that the lid sticks and exceptional strength is required to remove it.

THE CASTING TONGS H are common tongs such as those utilized in all foundries where round crucibles are used. They have two blades in the form of a semi-circle and which accurately fit the circumference of the crucible. Tongs such as these are commonly used in English Cast Steel Works when the melter alone casts from the crucible, but it appears to me both less dangerous and much easier to use casting tongs (41)
as shown in figure I where two workers each handle one side and can thereby carry out the casting in a much safer way.

THE MOULD K into which the steel is poured after melting is usually made of cast iron. Several shapes and sizes are used, depending on whether large or small ingots are required. It is thus possible to make it flat, as in figure L, round or square; however, the most common shape is octagonal with an appearance at the upper end as shown in the plan view and of the actual size in figure M. The moulds are approximately 30 inches long and comprise two parts which must be well matched so that the steel is unable to leak out which, apart from the loss, may also present actual danger and, for this reason, it is imperative to check that the mould is carefully fitted together at the base during assembly. To hold it together during the casting two iron rings are used which are either wedged fast (42)
or, still better, fixed with screws as is shown in figure K.

A further few simple tools are required during and after the melting; a *CLEARING HOOK N* for the removal, should the draught seem to be insufficient, of any small pieces of coke which may be stuck between the bars of the grate; common *FORGE TONGS* for the removal of the grates after casting has been completed; a 4 to 6 feet long *IRON BAR O* of thin round iron for checking whether the steel is molten and, in addition, an octagonal or an ordinary flat iron bar, to be used when the crucible is lifted out, partly for pushing the coke through the openings presented on either side of the crucible by the removal of the bars of the grate and partly for knocking off the slag formations which generally appear during melting on the sides of the furnaces just above the grate and which, if not removed between each melt, would finally prevent any draught.

After having briefly mentioned the mechanical tools I will now describe the chemical ingredients which are (43) required for the manufacture of cast steel; I refer to *THE FUEL* and *THE FLUX*.

Of all the combustible materials provided by nature for our comfort and the improvement of crafts, only one has been found that can provide the intense degree of heat required to melt a larger quantity of blister steel or forged iron in enclosed vessels, namely coal. However, in order to make it entirely suitable for this purpose, the coal must be improved by artificial means, that is, carbonized or made into coke.

The way in which carbonization is carried out, partly in the open field and partly in furnaces specially arranged for this purpose, will be described later.

Of the many kinds of coal with which a bountiful nature has provided Great Britain, two kinds in particular may be considered the best. These appear under the names of *CAKING COALS* and *SPLINT COALS*.

THE CAKING COALS undoubtedly take precedence as they have the characteristic of reaching a stage of half melting when burning whereby they coagulate so that even the smallest pieces, when carefully used, can be utilized. They generally contain less iron sulphide and, for this reason, are generally used for forging fires and, as a consequence, are often commercially referred to as *SMITH COALS*.

SPLINT COALS show no sign of melting when burning and are therefore mostly used in large pieces, since the smaller pieces and pulverized coal of this kind are of little use. On the other hand, they provide a stronger flame and are, for this reason, used mainly in reverberatory furnaces, steam engines and so on, where it is of more importance to take advantage of the stronger flames provided.

In order to ascertain to which kind of coal a specific

sample belongs, it is sufficient to put some finely crushed pieces in a red hot spoon. If they cake or (45)
stick together to form one piece they belong to the caking coal class, otherwise not.

For the purpose in question, or for processing to coke or carbonized coal to be used when melting cast steel, *CAKING COALS* should preferably be used. The purest kind should be chosen, that is, the one which contains the least iron sulphide or other foreign matter. They should be carbonized to a rather high degree in furnaces especially arranged for this purpose, and for this reason they also go under the name of *HARD COKES* so as to differentiate them from other types. This intense carbonization is necessary in order to make it lose, as far as possible, its characteristic of sticking together in the furnace as this results in the great inconvenience of the coke not sinking down consistently as it is consumed but leaving hollows through which the draught is channelled directly on to the sides of the crucible which may easily cause cracks or at least delay the melting of the steel, and this is always a loss.
It is also possible to use carbonized *SPLINT COALS* as (46)
these are always less subject to the inconvenience mentioned above but, from the opportunities I have had of trying this type of coke, I have found that a rather strong smell of sulphur has occurred and, in addition, it contained several pieces of slate, thus producing slag which adhered both to the crucible and to the sides of the furnace. These should be avoided as far as possible.

The reason carbonized coal generates such an intense degree of heat is the amount of pure coal it contains and the slowness with which it burns, enabling it to retain the same position over a longer period when used during melting whereas ordinary charcoal, when subjected to such a strong draught, is rapidly consumed and constantly changes its position, whereby no specific point on the surface of the crucible is ever subjected to a constant degree of heat for a long period. From experience it is known, for example, that if one continuously turns a large iron bar in the fiercest heat in a forging hearth, nearly
double the time is required to make it reach welding (47)
heat than if it lies still and is only occasionally turned slowly to enable another side to eventually face the blast.

There are two further reasons why charcoal cannot be used to advantage, even if it could produce the required heat. Through recent trials it is known that iron, steel and pig iron are variants of the same material and that the varying carbon content constitutes the difference. During several hours of continuous melting it would be difficult to prevent a material as light as charcoal from being blown into the crucible by the strong draught during the frequent removal of the lid and in this way the steel may become so contaminated by carbon that it becomes more or less similar to pig iron, and useless to the same extent.

Without doubt even the potash contained in the charcoal ash would severely attack the crucible in this intense heat and in conjunction with silica and alumina, of (48)
which the crucible is composed, would be turned into glass and thereby rather add to the destruction of the crucible.

The second material which chemistry must provide in the manufacture of cast steel is that which the English call *FLUX,* the purpose of which is to protect the steel from burning during the melting. We normally understand the word *FLUX* to mean all such materials which, during the smelting of various ores, promote other slow melting types of rock to flow more rapidly or to form a glass-like slag.

In large smelting plants various types of material are used as flux and these can rapidly produce a thin glass-like slag in which the metal particles sink without any difficulty and are prevented from burning. However, in order to judge the most suitable flux for a certain type of ore, it is necessary to know well those rock types accompanying this ore with regard to their condition in smelting heat and, furthermore, to know with what kind of additives they may be brought to melt or their all too rapid cutting nature may be (49)
reduced to that degree necessary for the keeping up and condition of the smelting furnaces. The only flux in question should only have the one property common to all glass, namely that of floating on top of the steel during the melting and, furthermore, it should be composed of such materials which do not attack the crucible too much.

It is of this type of flux that the English steel manufacturers make such a big secret, especially as they suggest that the various compositions thereof contribute to a greater or lesser degree towards the quality of the molten steel.

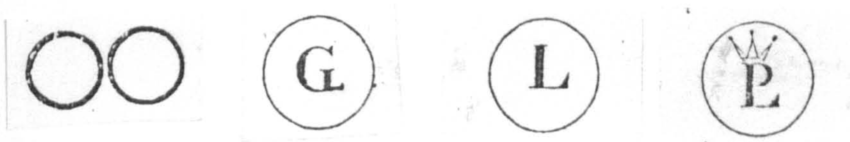
No metallurgist with any knowledge can, from this statement, allow himself to be misled to expect any other assistance from this additive than that which nature allows. All such materials which, in conjunction with each other, can be melted together into a fairly slow-melting glass, without incurring any damaging side effects, may be used. It seems, however, that the best composition of flux is that (50)
which, in addition, comprises those materials of which the crucible is made.

The flux I have used consisted of 2 parts of crushed crucibles well mixed with 1 part of burnt lime or chalk, to which I have sometimes added 1 part of crushed bottle glass in order to make it flow more easily.

The addition of flux, however, is not absolutely essential since the melting of the steel can well be carried out without it; this I have tried several times but it naturally leads to a greater loss by oxidation. If the admission of air were not more or less prevented by the lid remaining continuously in position, under the intense heat the steel inside would be turned into glowing scale (black iron protoxide) during several hours of annealing, and as this is one of the most cutting materials (which I have never succeeded in melting by itself without it cutting its way through the crucible within a ¼ of
an hour), the addition of flux would definitely (51)
be required to protect the crucible from this inconvenience, which it does to a certain extent.

The most important material used in the manufacture is *THE STEEL* which is to be used in the melting; this should have undergone double conversion in the cementation furnace.

Despite what the steel melter claims regarding the usefulness of the added flux, the quality of the cast steel depends mainly on the blister steel being used providing that the melting is carried out correctly; and the cast-steel manufacturer *HUNTSMAN*, who had a large factory in Attercliffe near the town of Sheffield in Yorkshire, was himself so convinced of this that for more than 30 years he never used any other types of iron than those with the four marks below*, which in England have the leading positions :



As evidence that *HUNTSMAN'S* steel owes its advantage (52)
to this reason, I must mention that, although he keeps his steel a penny a pound more expensive, the largest instrument manufacturers in London still use his cast steel. In addition, it is quite natural that other steel manufacturers, in whose factories I have seen broken off scissors, knives, forks, scythes, files, bayonets, and so on, being melted to cast steel, have no problems in finding outlets in a town where so many 'skeppund' of cast steel are processed annually to produce razors, scissors, pen knives, and the like, and in which case the difference in price is always considered to be of greater importance than the difference in quality.

Perhaps chemistry will one day reach perfection, whereby any type of iron may be used to produce a steel of the same quality as that from Osterby or Leufsta works, but until then I am convinced that there is no other secret in the art of cast-steel manufacture than to obtain the best iron, convert it
twice in the cementation furnace and, with due care (53)
and attention, melt it to cast steel.

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* These are the stamps from Osterby, Gimo, Leufsta and Akerby. For further details, please refer to Appendix J.

MELTING AND CASTING OF STEEL

In general, when a steel melting campaign is arranged, it is carried out as follows. The previous day, the steel, fluxes and so on are weighed out, coke is brought in, cut into pieces about the size of an egg and in the evening six crucibles are placed in the crucible stove. Of the six crucibles, seldom more than four, at the most five and, if all goes well, only three will be used, but as the work involved and the cost are the same, and it sometimes happens that all six are needed, it is always better to have them to hand.

A purpose made stove, shaped as shown in Fig.P, Plate 6, with grates in the bottom as well as on three sides, filled with burning coal, is inserted beneath the grate in the crucible furnace. This is made in the usual English manner*.

The purpose of this stove is to allow the crucibles,
placed in the crucible furnace itself, to be preheated (54)
slowly since they would crack if strongly heated. The coal, left unmoved, is only gradually consumed and will keep the fire alive until next morning.

As a rule, one starts operations early in the morning, in order to be able to finish so much sooner and not have to do the casting late in the evening. One melter, one workman and one boy hardly have time to manage more than three furnaces. The bars of the grate are put into these furnaces and on top of them, as accurately as possible one double or two single 'stands' are placed centrally. In spite of all their other advantages, carbonized coals are relatively difficult to ignite and it really requires some training to do this properly, so they will not burn unevenly or start to burn in three corners of the

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* The meaning of this is not clear.

furnace, while the fourth still is quite cold and so on. I want to describe the handiest manner in which this ignition is carried out. One shovel of burning charcoal is put on the grate and spread evenly on all sides. Some cold charcoal is put on top which, because of the strong (55) draught, even with the lid not yet on, immediately will catch fire. When all is under control and the fire is even all around, pieces of coke are gradually thrown in and this is continued until one sees that the coke is burning, which by no means will be as quickly as with charcoal. When this mass of coke, well ignited, has grown somewhat higher than the stands, this is to say about 4 inches above the grate, the small pieces of coke which at this stage cover the stands are carefully scraped off. The crucible is carefully taken out of the crucible furnace and put down into the cast steel furnace with the lifting tongs. The lid of the crucible is put on, a small amount of coke is put down slowly with a handshovel and as soon as this layer has started to glow, more is put on until the mass of coal is burning as far up as the upper level of the crucible.

Even the crucible is now red-hot all through. One could equally well put in both steel and flux before the crucible is put down, but when it, as has just been mentioned, is heated up whilst still empty, an experienced (56) eye immediately observes if the smallest sympton of a crack shows itself anywhere; the crucible, of course, cannot then be used but has to be lifted out in a manner which will be described later on. If, on the other hand, the crucible is without fault, a suitable piece of steel is carefully placed on the bottom. Thereafter, with the charging shovel a steel quantity of about 10 to 12 lbs., as much as it can hold at one time, is put in. Using the previously described charging funnel, about a "kvarter"* of the ready made flux is poured on top, however with such caution that none of it is dropped on the edge of the crucible and thus to prevent the lid

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* A "kvarter" was equivalent to 327ml or about 20 cubic inches. The weight of flux would be about 1½ lb.

getting stuck and giving difficulty in later removal. The lid of the crucible is then put on, the furnace filled with coke up to the base of the hole which leads from the furnace into the chimney, and at last the furnace-lid also is put on: now the draught really starts.

The procedure is the same for two other furnaces. At the end of 1 to 1½ hours, the level of the coke has
usually dropped down to the upper edge of the crucible (57)
so the lid can be removed. As a rule, the steel now has started to melt at the bottom, but has still not sunk low enough in the crucible to give space for the remaining part of the charge; for this another half hour will be necessary. Therefore some coke is again put in; and when it is burned down, the steel usually is nearly melted so that it is now possible to put in the remaining part. With the crowbar, the coal pieces are pushed down in the corners of the furnace especially at the inner wall, where they usually most quickly are burned; and one ensures that the crucible is standing quite vertically, because if it starts to bend over, this has to be corrected in time, otherwise it can easily crack and the melting can be unsuccessful. Fresh coke is added, but not quite as high as the first time and if, when this has burned down, one does not find the steel completely fluid, only small portions of coke are added at a time in order not to waste time and fuel unnecessarily and so that steel will not become too hot since in such case it is more disposed to become porous when cast.

While the melting is going on, one has frequently to (58)
go down into the cellar in order to ensure that everything is according to plan; whether the grate needs cleaning and so on. As soon as it has reached the stage where one thinks the steel in one or other of the crucibles has started to melt, one of the workers should stay in the cellar to see if any of the crucibles has been damaged, which immediately shows itself by sparks coming through the grate. This crucible immediately ought to be lifted in order to save as much of the molten or unmolten steel as possible.

When everything is running perfectly, the first crucible will be ready for casting after 3½ hours. When the steel is examined with the test rod and is found molten, the crucible lid is placed back again as well as the furnace lid; and it has to be left 8 to 10 minutes in order to gather heat, during which time the furnace operator is preparing himself to lift the crucible.

Anyone who has not had any opportunity to see such a melt
can hardly form an idea of the tremendous heat such a (59)
furnace now is holding. When the lid is removed, it is usually difficult to see the difference between the crucible and the coke around it; it is as if looking at the sun on a fine day in summer. The eye needs a few moments to get accustomed to it. However it is possible to modify this unpleasant feeling by quickly moving the hand with the fingers spread back and forth in front of the eyes and then it is reasonably possible to see the difference between the crucible and the coke. It is, therefore, not strange that the furnace operator needs to take some precautions in order to be able to lift the crucible with the necessary boldness and safety. Such precautions involve the fastening around his right leg of a pad made from six layers of coarse woollen material covered with an iron sheet and the protection of his hands with long wide bags made from canvas, which are soaked in water and well wrung out and tied above the elbows.

The two halves of the mould which so far have been lying with the inside parts facing downwards on the top of the above-mentioned stove (on which now and again a few
pieces of coal are thrown to produce smoke, the soot from (60)
which, as from birch bark, sticks on the metal) are now taken out and screwed together, and the mould is then put down in one of the above-mentioned holes in the floor of the casting room, placing it as near as possible in the vertical position; a small cover of clay or plate is placed upon it to prevent unwanted material from falling in and especially preventing condensation of humidity which could have disastrous consequences during teeming.

A hod with damp sand and a short iron plug of the same size at one end as the opening of the mould must also be ready for use.

I have just mentioned that the mould ought to be quite vertical. This is absolutely necessary, because if the running steel when pouring should first hit one or the other of the sides of the mould, it will immediately cool, stick and form a long, more or less slender strip, which might subsequently weld imperfectly to the steel
gradually running into the mould and then on forging (61)
produce flaws and holes which always bring trouble.

Now when everything is in order, the casting is done; but before I describe this I cannot avoid making the remark, which is very often confirmed by experience, that the success of an undertaking frequently depends upon attention to slight and trifling details. Even those with considerable experience in making large metal castings with charcoal would probably not think it could involve any particular difficulty in lifting a crucible from the furnace since burned charcoal either is easily taken away or pushed away to give space for the tongs. But there is a great difference when using carbonized coal. These coke pieces are just like a lot of red hot bits of stone, which it is as fruitless to try to push aside as to remove them from the furnace on account of the large amount of them and the tremendous heat. During my stay in
Sheffield, I have many times seen crucibles of cast (62)
steel lifted and this type of cast being made, without finding anything particularly remarkable; but one day I happened to go down in the cellar to have a look at the coke which already had gone through this high degree of heat and I had scarcely come down when a multitude of sparks appeared below the grate of one of the furnaces. This unfortunate but immensely beautiful fireworks display always indicates that the crucible in that furnace has become cracked. The worker who was stationed there immediately shouted the news of this to the melter on the upper floor and he himself, in a hurry, pulled out four grate iron bars, two on each side of the bottom of the crucible, and so the coke immediately fell down and in a few seconds the furnace was empty, the crucible lifted and emptied. Everybody involved in practical enterprises must well be aware of the satisfaction with which an investigator may be told how to deal with a difficulty in a situation where previously he had not had any presentiment of such a trouble. I admit that,
from this moment on, I did not feel it was impracticable (63)

to establish such a plant and must add that during all my foreign visits nothing has surprised me as much as this simple manipulation. Perhaps somebody will wonder why I have attached so great importance to something which everyone ought to do in case of need; but unfortunately very few individuals have the innate fortune such that they may easily discover the simple solutions. Among the hundreds of experimental furnaces and reverberatory furnaces which I have seen erected and where unfixed grate iron bars are used, I never actually saw one until at an English cast steel works, where the ease with which it is possible to remove these iron bars from the ashpit during the melting is of such an advantage, not only when lifting the crucible but in putting the same or a new one down to a clean grate free from coke and so on.

When everything is ready for the pouring of the steel
into the moulds, two iron bars from the grate on either (64)
side of the bottom of the crucible are removed and three bars on which the crucible is standing remain. Most of the coke then falls down; the furnace lid is lifted and placed aside against the wall not to be in the way and should some cokes still remain in the furnace these are slowly pushed down with one of the iron crowbars; the crucible is then found totally free and is gripped with the lifting tongs, the melter grasps as low down on the tongs as possible in order to be able to lift the crucible easily over the opening of the furnace, bearing in mind that the stand at the base of the crucible is always stuck to it, following the crucible upwards.

The double-handed casting tongs, a little open, are placed on the floor close to the furnace in advance to put the crucible into them, two workers immediately gripping each end of the tongs, lifting them to the middle of the crucible and keeping it steady, while the melter lifts the crucible lid. The crucible is then brought to the edge of the mould and a third
worker moves away the flux with a wooden spatula (65)
previously charred, and the pouring is done slowly but with an even speed so no intervals occur, by which a "cold shut" would arise, which on subsequent forging would give shell and flaws. When all the

steel is poured, a handful of moistened sand is thrown upon it and the above-mentioned iron plug is pushed in to prevent the steel from rising in the mould, which it often shows a strong tendency to do.

If the pouring is done too quickly and the steel at the same time has been very hot, a totally opposite trouble occurs, the steel quickly filling the mould but sinking again, leaving a thin cylindrical crust which very often amounts to half the weight of the ingot and this crust cannot be used without remelting.

As soon as the crucible is empty, it is turned upside down
on the floor and, using a broad axe with a long handle, (66)
fig.R, pl.6, one hurriedly cuts away the agglomeration of coke and slag which has stuck around the bottom of the crucible (so it looks like fig.S, pl.6), whereupon the crucible as quickly as possible again is put down in the hole, so that the side which earlier faced the wall now is turned outwards, and the lid is put on.

While this is going on, the crusts of slag which have stuck to the sides of the furnace are pushed away with an iron crowbar; the iron grate bars, which had been removed, are put back again and immediately some shovels-ful of coke are put in which now, in the white hot furnace, quickly start to burn. The furnace is again filled to the upper edge of the crucible with coke and the steel is charged in the same way as before mentioned.

The same procedure is done with as many crucibles and furnaces as are in use during this day. Should a crucible crack, it is replaced by one of the crucibles from the heating furnace for the crucibles; in such a case, one sees to it that it has to be surrounded by
cold coke as soon as possible so the heat does not reach (67)
the crucible too quickly. Usually three melts are made each day in each crucible, when three furnaces are running. For these nine melts, you need about 6 barrels*

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* The Swedish barrel or "tunna" held 165 litres of 5.83 cu.ft. and would therefore hold about 90 lb. of coke. The coke consumption was, therefore, of the order of 4 lbs. for every lb. of steel cast.

of coke; a little more for the first ones as the furnaces are still cold and a little less for the last ones, together with half a barrel charcoal and a quarter barrel uncarbonized coal used to heat crucibles and moulds not included.

The first time a crucible is used, usually 20 lbs. steel is charged, second time 15 and third time only 10 or 12 lbs. as the sides of the crucible each time always are eroded somewhat. If all melts go well, about 130 lbs. a day will be obtained (from three furnaces).

The loss during the melt itself is relatively small and does not exceed ¼ lb. in every 20 lb. but, as a larger or smaller part from the upper end of the bar always has to be cut away as unsolid and flawy, the total loss will be bigger. As it so happens, the (68)
crucibles very often fail in service and the loss will be more considerable on account of unnecessarily burned coke, which will become more expensive to the extent to which ordinary coal rises in price.

As one usually puts the crucibles into the furnaces at 4 o'clock in the morning, the first 3 melts could be ready between 7 a.m. and 9 a.m. the following between 10 a.m. and 12 noon and the last ones between 1 p.m. and 3 p.m. Before the furnaces are hot enough, the first melts call for 3½ to 4 hours; the following ones 3 hours and the last ones very often not more than 2½, depending as well on the reduced quantity of steel charged.

The rest of the day is used to tidy the casting area, clean the furnaces from slag which has stuck to the sides, to cut, mark and weigh the obtained steel and so on. It is seldom possible to use a furnace more than 10 to 12 days before it is burned out and needs repair; the spoiled area does not, as a rule, go further up than 8 or 9 inches above the grate, where (69)
the heat has its strongest influence.

Then the fire bricks from this part of the lining are carefully removed and just as many new ones are put in their place in the same manner as when bricking the new furnace mentioned above.

The cut away bricks are carefully cleaned from slag and, after being crushed and mixed with 1/3 unfired clay, they are able to be used as bricks if no easier supply is to be found.

According to Mr. Mushet, it is possible to make cast steel of any degree of hardness wanted by adding charcoal powder to iron. Both in small scale and full scale experiments, it has proved quite successful to produce steel from a mixture of pig iron and bar iron and to cover changes in grade in pig iron by bigger or smaller additions of charcoal. I have had the opportunity to arrange many experiments on these lines and have no doubt that the very famous wiredrawing dies from Lyons can be imitated in this way; the citing of
these experiments would take too much space and, as I (70)
shortly may have a new opportunity to continue these experiments more widely, I will later on, in a separate paper, describe this procedure and the results thereof.

MAKING CRUCIBLES IN A METAL MOULD (80)

As it is of the greatest importance to have good crucibles which are of such a quality that they will not crack during a long period of fierce heating and stay intact without fusion when making cast steel, I will now describe the way they use in England to manufacture them.

The doubt which almost every nation has had as to their capability in producing cast steel is probably mostly due to the opinion commonly held in England that, other than clay which is dug at Stourbridge, there is no other clay found refractory enough for this purpose. The export of this clay, for this reason, has been prohibited, with relatively high fines imposed.

Half a mile from Stourbridge at a place called Deley* in Worcestershire, four miles from Dudley and about 9 miles from Wednesbury, the well known Stourbridge clay is dug. The layer of clay lies under a bed of coal at a depth of 20 fathoms (120 ft.), lying almost horizontally, and is not more than 3 ft. thick. It is followed for 120-140 ft. in the field, after which a new shaft is lowered because the raising of the clay becomes too difficult from the original shaft. This clay has a dark grey colour, feels dry and rough because it contains a fine-grained and fairly pure quartz and fine-grained white particles of mica without any trace of lime. From this, the famous firebricks known as *WHITE BRICKS* are made at the mine. In specially ordered dimensions, these bricks are sent all over the country to be used in glass manufactories, cast steel furnaces and so on. (81)

On account of the rigorous prohibition against the export of this clay, I could only get but a small amount of it for comparative tests; for my crucibles, therefore, I had to consider using some other kind of clay which could be obtained with less difficulty and at a lower cost.

Among the refractory clays imported from abroad for use in steel furnaces and glass manufactories, I have not found any which in heat resistance can be compared with that of the black-brown type imported from Rouen and normally known as "Black French Clay". This clay occurs in a good many shades, partly depending on the different clay pits from which it is taken, partly depending on the accuracy by which it has been separated from other neighbouring heat resistant kinds such as grey, bluish and white.** (82)

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* This location cannot now be identified despite the apparently clear details. It is thought that it could be a corruption of "Delph". Clay has been worked in the Delph area for centuries.

** This last, in Sweden, was apparently called "sugar refinery clay" since it was used to cover the sugar loaves at one stage during the process.

When using this clay in making crucibles, it is at first well cleaned from all intermixture from above-mentioned lighter clays and from straw and sticks which could have contaminated it during transport, and it is crushed in small pieces if it is hard, or cut with a knife if it is soft, in order to separate more easily any extraneous and harmful substances.

If, for example, the quantity of this cleaned clay (83)
amounts to one and a half barrels, half a barrel is taken from it and dried in the sun or in an oven, and one barrel is spread out on a tray (made from thick oak or birch planks, 2'6" to 2'9" square and with 6 inch standing ledges all around) or a similar one such as is generally used in mixing operations in clay manufactories.

The clay in the tray is made wet with water so that it is well soaked and it is thoroughly pounded several times a day with a large wooden pestle until it is shown to be so well mixed that a piece cut with a brass wire shows no different colours. This bulk of clay is then shovelled into a heap and is beaten and left until it becomes so firm that it can only be handled with much effort. Using a strong iron ring 1 inch high and 5 to 6 inches in diameter, now and again oiled to prevent the clay from sticking, small bricks or cakes from this lump are moulded, knocking them in with a mallet. Then these cakes are spaced out in a circle on a square or round wooden plate in
such a manner that the second layer of cakes will lie (84)
over the joints of the first layer and in this way many cakes may be accommodated in a small area and still have enough space to dry quickly. The wooden plates are put outside in the shade in a shed and are once a day moved about so as to get rid of all humidity as soon as possible.

When all the cakes of clay mentioned above are quite dry, they are placed in layers in the furnace (pl.8) together with carbonized coal; a layer of charcoal is, however, put at the bottom next above the grate irons, so that the coke will ignite evenly. Under the grate a small fire is made from wood and kept alive until it is obvious that the charcoal has caught fire. The furnace opening is plugged with bricks so that the draught becomes so strong that the cakes will reach a heat almost as high as that in the cast steel furnaces.

When the fire has burned out, all the cakes are found lying on the grate, mixed together with some carbonized coal, from which they have to be thoroughly separated (85)
during the withdrawal. These cakes are then crushed under a vertically rotating stone or pounded in an iron mortar (with a lever in the usual manner), sifted through a small-sized brass sieve and now called *POT-SHERD*, the principal ingredient in the crucible making.

The operations mentioned are specially necessary the first time crucibles are made because it is possible later on to use pieces from the used crucibles after they have been well cleaned from all flux and slag to produce more pot-sherd, and the more you can use of this old pot-sherd the more certain you are that the crucibles will not crack or shrink when used later on.

The dried, unfired clay prepared earlier is pounded and sieved in the same way.

PREPARING THE MIXTURE USED FOR CRUCIBLES

To 20 portions of pot-sherd 9 portions of unfired clay are used, which portions are measured with a can* and spread in layers upon the tray mentioned above, which before has been well cleaned. The mixture is well (86)
turned over so that the dry mass will be fairly evenly

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* The Swedish "kannor" was a measure equivalent to 2617 ml. Its actual size is not relevant here, however, since comparative volumes are quoted.

mixed before the water is added. For 58 cans of mixture, about 21 cans of water are usually needed which is gradually added during continuous mixing with the shovel. When all water is added, the mass is well pounded several times with the large wooden pestle, is shovelled into a heap, beaten again and covered with a wet cloth. This pounding is repeated once a day during 2 or 3 weeks. Should the mass during this time dry too much, more water is added in small quantities and then well pounded through.

When it has been well prepared in this way, it feels more ductile than it was originally and is now ready for crucible making, for which purpose the following moulds and tools are required, which are illustrated on pl.7.

A is a mould of cast iron,* the iron $1\frac{3}{4}$ to 2 inches thick, 16 inches high, 8 inches in diameter at the top and 6 inches at the bottom, fitted with two handles integral with the casting in order to be easily lifted. In the bottom of the mould is fixed a round, somewhat conical plug (87)
made from cast iron, B, with a round hole in the centre.

C is the so called core mould* by which the inner sides of the crucible are shaped. It is turned in a lathe from some hard kind of wood, for instance, white beech, pear or white beam, but preferably from lignum vitae. With the core, the thickness of the crucible is settled and thus can be made larger or smaller as wanted, but it always ought to have at the upper end a lap, bb, which will fill the mould exactly, to prevent any of the clay mixture forcing its way out. This core is fitted with an iron spike, c, somewhat pointed at the end, but higher

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* In Sheffield, the cast iron mould would have been termed the "flask" and the wooden core mould the "plug".

up it has a sufficient thickness so that it exactly fits the hole in the loose cast iron bottom, B. This provides the great advantage that the crucible has the same thickness all around.

D is a section through the three items just described together with a crucible left inside.

E shows the crucible made, F the lid of the (88)
crucible in horizontal level and in vertical section and G the bottom brick whereupon the crucible is placed in the furnace. H is a sturdy mallet of hard wood, I a square wooden tray. A cylinder, K, from birch wood is fitted to the upper side of the tray and has the same diameter as the bottom of the crucible.

CRUCIBLE MAKING

The iron plug, B, is placed on a sturdy block covered with a thick iron plate. The iron mould, A, is placed thereupon and, from the clay mixture made in the above-mentioned way, a lump of suitable size is taken; the best way of judging the size required is by weighing the first crucible as soon as it is made. This lump is kneaded on a sturdy table and at the same time formed by hand to a size so that the lower part of the crucible is nearly filled.

Three bent thin iron sheets of a size so that they together just cover the larger diameter section of the inner surface of the mould are well oiled and fitted in the mould, thereafter the lump mentioned is slowly dropped down into the mould.

With a round billet of wood shaped like the core, but with- (89)
out spike, a hole in the clay mixture is formed by a few light knocks with the mallet. The hole has to be accurately in the middle, which with some experience it is possible to arrange. In order to prevent the billet from sticking, it has to be repeatedly drawn up. This operation is carried out in order that the spike of the core to be used later will more readily find the hole in the bottom plug and not rub off too much of the oil smeared on the core, which might cause it to stick. If the core gets

stuck, the crucible will come up with it and it is then almost impossible to separate the crucible without destroying it.

When the core is installed, some heavy blows are beaten on it with the mallet and between every third and fourth blow it is turned around to ensure it will not get stuck. Finally, relatively heavy blows are given in order to get the clay, which does not have any way out, packed together without leaving bubbles or holes in any place.

The core is then carefully drawn upwards; the mould (90)
is lifted (the bottom plug, B, is left on the iron plate) and is placed on the wooden cylinder, K, upon which the moulded crucible will be standing, while the cast iron mould is slowly placed on the box. The thin iron sheets are carefully taken away and the crucible is placed bottom down on an even and smooth board which has to lie exactly horizontal, without which it may easily happen that the crucible gives way unevenly, will become misshapen and will crack.

Normally there is a stand outside fitted with a roof so that the stand is protected against sunshine and rain. Into the stand short boards are pushed, on which boards may be placed not more than 3 to 4 crucibles and leave room for easy handling. The crucible making preferably is arranged on a fine day in the spring or autumn; it is understood that if a crucible soon after being made is exposed to frost it will be totally destroyed. Likewise, a little
bit more caution is needed when doing this work on a (91)
very hot summer day because the crucibles then would dry unevenly.

When the crucibles have been standing bottom down overnight, they are next morning turned bottom up. The hole made in the bottom by the spike is closed with a piece of clay-mixture in this manner. The hole is widened with a knife which allows any oil to be scraped away. A conical wooden pin is dipped in water and turned around in the widened hole and a clay plug, which is somewhat longer than the thickness of the bottom, is inserted. After the bottom is made even, the crucible is turned over again and the plug on the inside is kneaded with the core shaped billet above mentioned. The crucible once again is turned bottom up and left standing this way 24 hours or more, until it gets as dry as it can in the fresh air, after which it is moved into a warm room.

The lids for the crucibles and the bottom bricks are made in a slightly tapered cast iron ring, either from the same mixture as crucibles are made from or from crushed fire proof bricks added with a third unfired fireproof clay and in the same manner as the clay bricks mentioned above. (92)

FIRING OF THE CRUCIBLES

After the crucibles have had time to dry right through, first in fresh air and then in a heated room or most commonly on the shelves above the crucible furnaces, they are placed bottom up upon their lids in the crucible furnace.

Pl.8, fig.1, shows a horizontal section of this furnace, fig.2 the profile of the same furnace and fig.3 a vertical section along the line ab in the fig.1.

This furnace can be made in different sizes depending on the quantity of crucibles needed. I have not made it bigger than to hold nine crucibles at the same time. It differs from common kilns in that when the crucibles are put in and the charging opening shut with a door (fabricated in the same way as doors used to cover cast (93) steel furnaces and smeared with clay), the furnaces are filled through the top opening, partly with previously used coke, which has fallen down in the ash pit on discharging cast steel crucibles, and partly with coke too small to use in melting cast steel mixed with one third of common charcoal. On the top, a few shovelsful of ignited charcoal are evenly spread so that the furnace slowly ignites itself and the fire goes down to the grate.

The opening at the top is closed with loose bricks, not luted with clay, so as to make it possible to remove them and to be able to control the fire so that it is

burning evenly. The opening to the ash pit is closed with a sturdy iron plate, drawn aside a little to let only so much air pass as is needed to keep the coal glowing slowly. The crucibles should not be fired too quickly since they will then be more disposed to cracks when heated in the cast steel furnace. The slower (94)
such a firing goes on the better. The crucibles are left cooling with the furnace and are not removed until they are absolutely cold or they can be left in the furnace until they are needed. If cast steel crucibles have been dried slowly and strongly, they can be used without firing but then much more care is necessary when heating up the furnace.

A separate firing may be made for the crucible lids and the bottom bricks to provide a sufficient supply, because they very often get broken. Even these may be used unfired if they are previously heated on the lids of the furnace. In this condition, however, they require a more careful handling.

CARBONIZATION OF COAL OR PREPARING COAL TO COKE

This kind of carbonization is carried out in several different ways :

1 When larger quantities are necessary as for (95)
iron ore smelting in blast furnaces, a charring-stack is made ready in this manner. The ground is levelled and well patted with clay and sand to give a rectangle 6 to 8 ft. wide and 14 to 16 ft. long depending on the size of the stack, which may contain from 40 to 100 tons of coal.* The biggest coal pieces are used in the lowest layer and they

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* There is obviously an error here. It could be that 40 to 100 "tunnor" are implied, which would give from 4½ to 11½ tons of coal. A calculation based on the stack size quoted, with the natural angle of rest, would only give 3½ to 4 tons.

are put up against each other with the most pointed part downwards in order to improve the draught at the bottom. Coming higher up, smaller pieces of coal could be used up to 3'6" - 4 ft. in height, leaving in several places small openings down to the bottom through which the stack is ignited with burning coal. As soon as it is obvious that the stack has started to burn, these openings are shut with small pieces of coal so the fire will spread at the bottom, after which it slowly goes upwards, until the whole stack finally gets totally burning. If the coal contains a lot of iron sulphide, the stack has to burn for a long time; if not, it is shut up with coal ash which is at first (96)
shovelled around the bottom and the sides and then on the top. Such a carbonization will take three to four days, depending on the size of the stack, which is then left to cool down for 12 to 14 days before it is pulled down.

2 When a smaller quantity of carbonized coal is required or if one requires some quickly, the coal only is put on the ground in the form of a triangular prism with a 3 to 4 foot side, still seeing to it that the largest coal pieces are placed nearest the ground. The coal pile is ignited in one of the ends and as soon as there is some coal being carbonized the still red hot coke pieces are pulled apart; they will die of their own accord, but the rest of the carbonization operation will go on. In this manner, however, no particularly well and evenly carbonized coke is produced.

3 For the melting of cast steel and other more particular needs, very well carbonized coals are required, which for that reason are called *HARD COKES;* the carbonization of these has to be more exact. This is only (97)
done in purpose built furnaces of the type of which pl.9, fig.1 shows a horizontal section and fig.2 a vertical section.

When using such a furnace, it is at first heated with wood in the same manner as in a

a baking oven until it gets red hot inside, after which one shovels coals into it, spreading them about 12 inches high all over the hearth and then builds a small wall made from loose bricks in the opening of the furnace to the identical height to prevent the coal from falling out. The red hot furnace will now slowly ignite all the coal which, when caking coals are used, conglomerates into a cake and is normally carbonized right through after 12 to 15 hours, without any other draught apart from that arising from the opening in the furnace. The distinctive sign of a total carbonization is nothing other than that all smoke and flames have ceased; the coals are then considered burned enough. Now the loose bricks in the
wall are taken away, after which the cokes (98)
are broken with an iron bar and raked out on the ground, where they die of their own accord.

As soon as the furnace is emptied, other coals are shovelled into it and the work goes on night and day until the needed quantity of coke is achieved.

Such a furnace, only 3 ft. in diameter and 1'6" high inside, I have installed in my small cast steel works and have found it fully adequate for the purpose. Because of the more free ingress of air, the top layer of coal has the best carbonization; the same I have found to be the case with bigger pieces of such cokes, which come from abroad, from which I conclude that they are carbonized in the same manner.

4 In another place, I have seen 6 furnaces shaped internally in the same way, only 4 ft. in diameter and 2 ft. high in a continuous wall (as fig.3 shows) without chimneys and
only with an 8 inch hole in the roof, where (99)
the smoke may issue. This hole is closed with a suitable lid when necessary. These furnaces are managed in the same way as the above mentioned.

5 If for some reason much more carbonized coal is needed, a brick furnace is erected, shaped almost in the same manner as a forge hearth with its chimney but with the difference that two hearths are built on each long side (fig.4) with one 4 ft. high dividing wall, lengthways between, and another crosswise between, so that these walls form a cross inside. These four fireplaces, shown in fig.5 in horizontal section, have a joint chimney and are each fitted with an iron door which can be raised or lowered to increase or reduce the draught and because the coals from time to time can be broken with an iron bar in order to get the bottom part well carbonized too, cokes of any wanted hardness can be obtained.

All these furnaces are erected in the open air, but the
carbonized coals ought to be kept under shelter to stay (100)
dry.

By all newly described ways of carbonization, the
volatile ingredients of the coals are lost. For this
reason *LORD DUNDONALD* invented a method to take care of
these during the very carbonization process and in 1781
was granted an exclusive licence lasting 20 years to
practise the invention. For this purpose he erected
18 to 20 brick built furnaces in one continuous row.
From each furnace chamber, a horizontal pipe was drawn
to a main horizontal flue 200 to 300 ft. long, also
made from bricks, and lying upon arches. This flue
ended in a water tank. The coals put in the furnace
were ignited and burned with as little draught as
possible, during which carbonization the coal tar
deposited in the chimney and ran down into the basin.
Average good coal will give 4 to 5 per cent of tar and
the best up to 8 or 10 per cent. This tar is said to
be so thick that 4 barrels give 3 barrels pitch. Some (101)
carbonated ammonia is also supposed to be obtained by
this type of carbonization.

REVERBERATORY STEEL FURNACE HEATED BY COAL (142)

As every cast steel works, which deserves to be called (143)
independent, should have its own steel furnace, I will
add a short description of such a one which, in consid-
eration of its size, seems to be very well suited for
this purpose.

I had the opportunity to see in London, in a big factory making carriage springs, such a furnace, no bigger than being capable of holding at any one time about 3½ tons of iron; such a cementation consumed about 20 barrels of coal*.

The chests and vaults of the furnace are built as usual of fire proof bricks, manufactured in the same place from fire proof clay and crushed used fire proof bricks, ground in a mill with a vertical millstone.

The chests are only just over 7 ft. in length (therefore the iron bars to be converted to steel must be cut in half), 18" wide and 27" deep. The bottoms of the chests are made from bricks put edgewise.

This steel furnace, illustrated in figs.1, 2, 3, pl.16,
has 2 chimneys which internally are 12 inches square and (144)
20 to 24 ft. high. In Yorkshire there are steel furnaces which have 4 chimneys, 2 at each end of the furnace.

Beneath the bottom of the chests there are eighteen flues, 4 inches square, alongside the chimney. The vault of the furnace is 20 inches at the highest place above the upper edge of the chests but is said to have dropped a little after being used for a long time.

The grate is situated 12 inches below the horizontal part of the flue. Five crosswise bars support the grate bars lying ¼ inch apart from each other.

The fireplace is 21 inches wide and 4'6" from the grate to the bottom of the ash pit.

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* This gives a total of just under two and a half tons of coal or about 15 cwt. coal per ton of steel.

Two vaulted walls, 8 inches thick, are built between the inner sides of the chests in order to give them strength and were, as usual in steel furnaces, badly damaged by the heat. Over the grate bars, where coal is put in, there are, at each end of the furnace,
vaults 10 to 12 inches wide and 12 inches high (145)
decreasing to a hole 6 inches high and in each of them is an inwards sloping iron plate, 1½" thick, whose inner part ends 3 or 4 inches above the grate. The way down to the ash pit consists of some stone steps, because this room usually is situated below the floor.

For better stability and strength, the furnace has two strong iron bands wedged together in the corners of the furnace and four buttresses on each side.

The holes, through which the test bars are taken out, are in the middle of the ends of the chests and there are two corresponding holes in the furnace wall through which the iron bars are pushed into the furnace when charging the furnace. Before charging the iron into the chests, the ash pit is cleaned fairly well, the grate bars are moved away and a small ladder is raised against one of the crosswise erected walls between the boxes.

Charcoal from ash trees, where thin twigs seemed to have been used in the carbonization and not very much
crushed, is spread out on the bottom of the chests 3 (146)
to 4 inches thick, where upon the iron bars, pushed through the holes mentioned above, are laid near one another on the flat side. Layers of charcoal powder, half inch thick, are laid between each layer of iron. This is continued until the boxes are almost filled, when everything is covered with some heat resistant sand earlier used for grinding mirrors. This sand is mixed with a lot of glasspowder and therefore is more useful to bind the sand mixture during the cementation process.

This sand is made slightly moist and is hand moulded to give a seal some six to eight inches thick in the middle.

When during charging the chests the testing holes have been reached, an iron bar is left in each hole, one end sticking out 12 to 15 inches. The hole around the bar is well filled with the sand mentioned above and moulded with an iron bar to make it air tight. Then (147)
coal is shovelled upon the grate and ignited.

The charging holes are always well filled with coal so they are almost closed except at the top where a small opening is left.

After the fire had been on 3½ days, one of the test bars was removed and observed still to have a small core of iron; the firing therefore was continued another half day then the other test bar was removed and this one was well carbonized right through.

This cementation had thus lasted only 4 days which seems to be a short time, but steel for carriage springs does not need to be so very high in carbon content and, furthermore, their coal highly surpasses our fuels which are charcoal or wood.

The making of blister steel is so well described by Bergsradet* *RINMAN* and so well known in our parts that further information is quite unnecessary.

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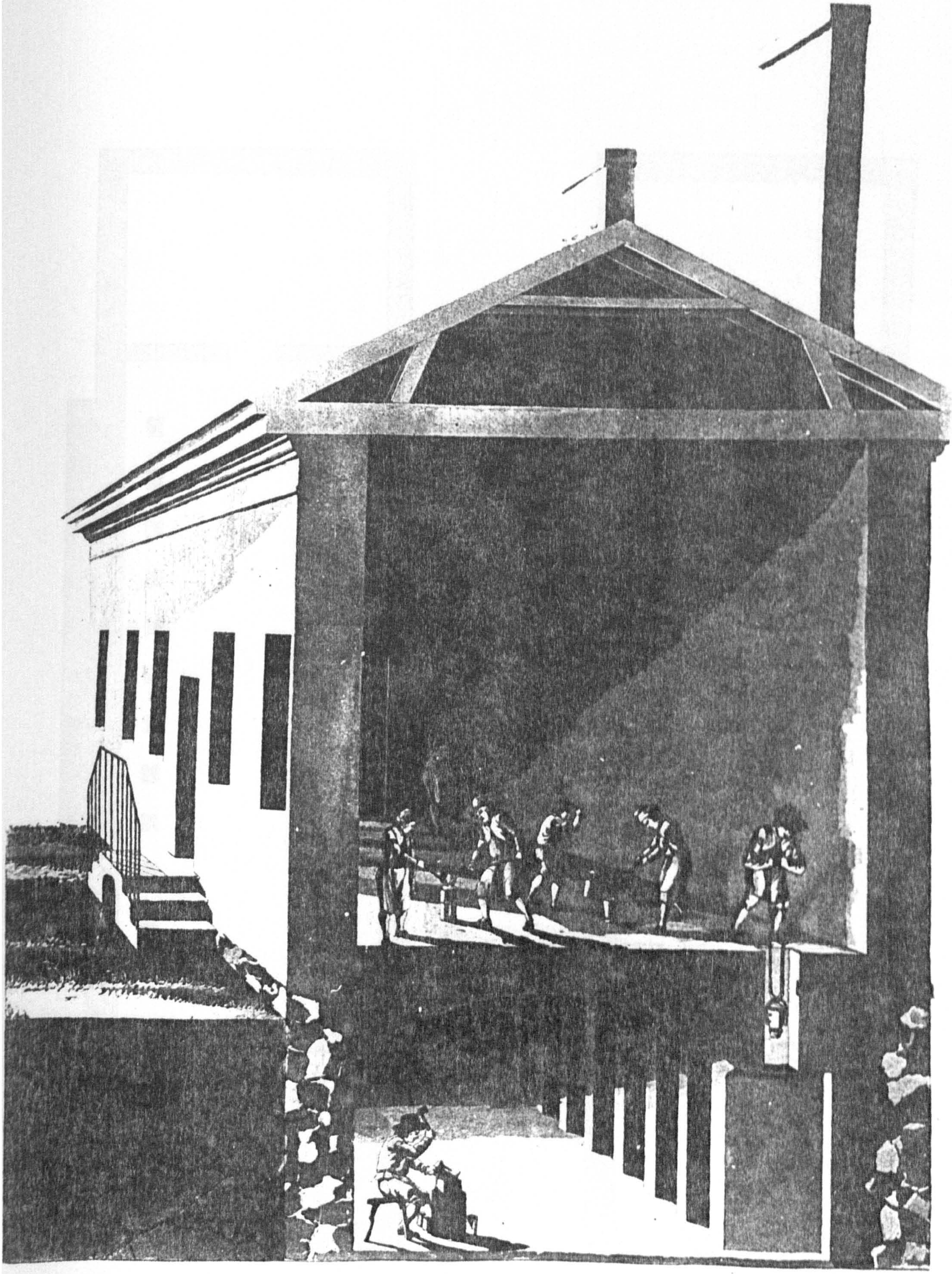
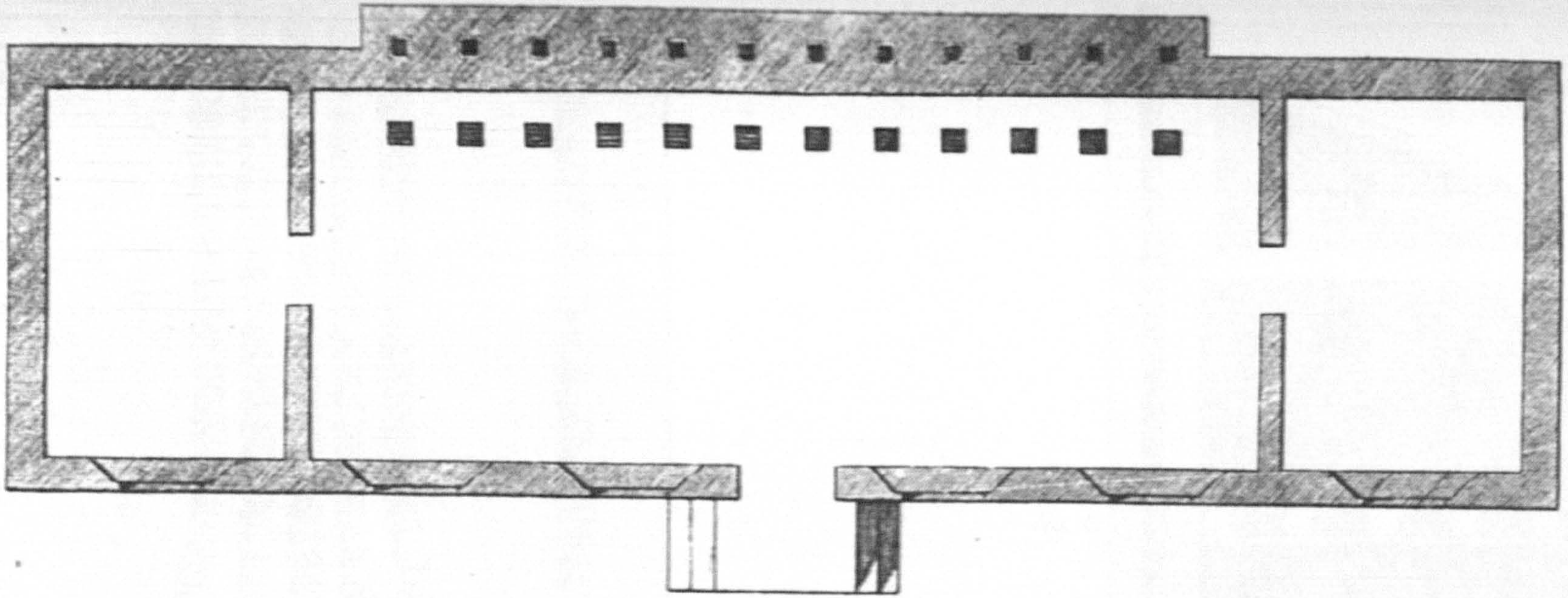
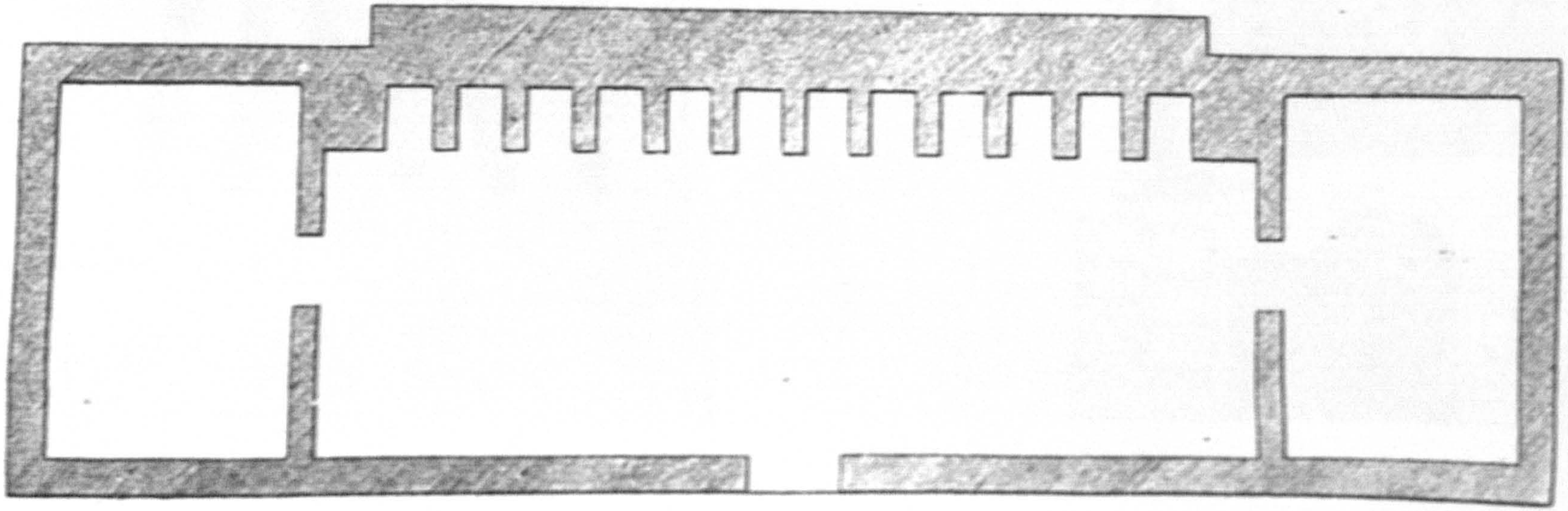
* Member of the Board of Bergskollegium, which administered the Swedish iron industry at that time.

Pl. 1







Pl. 3.

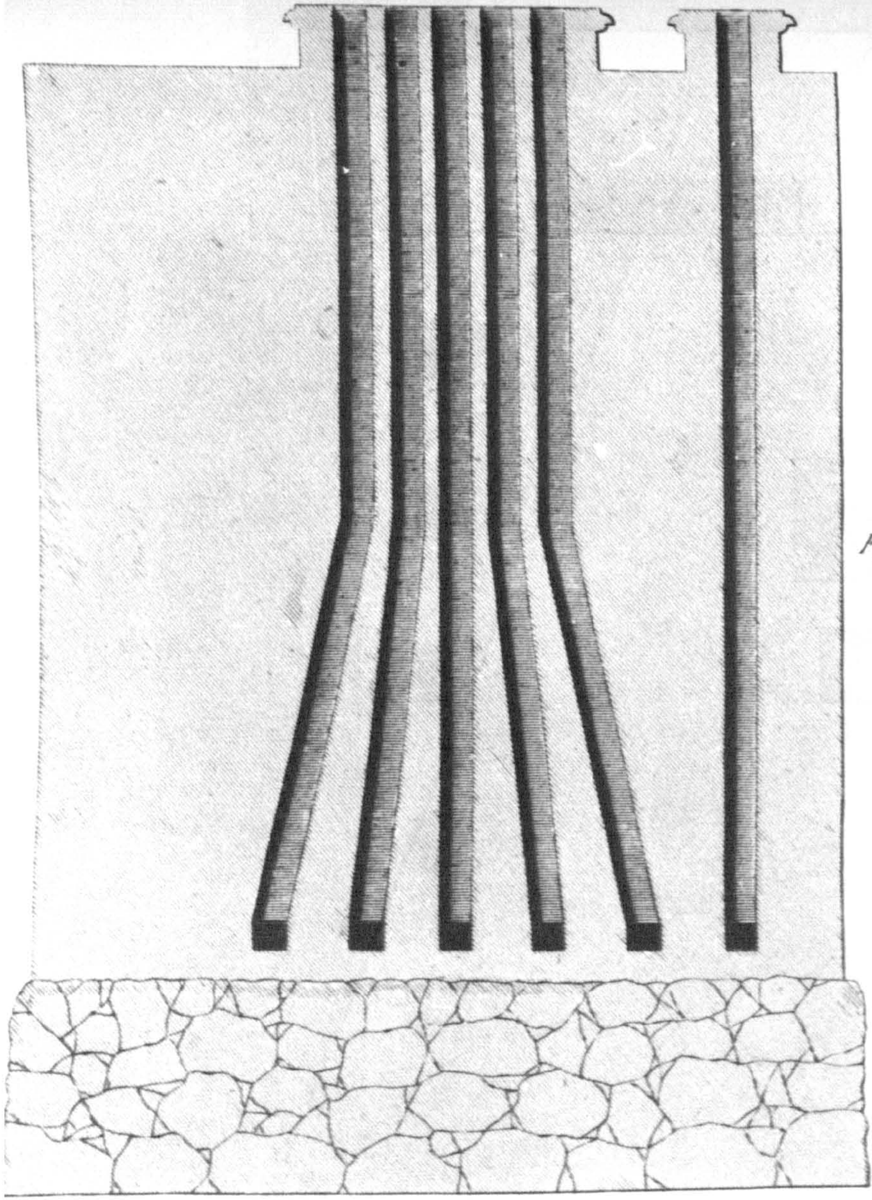


Fig. 1.

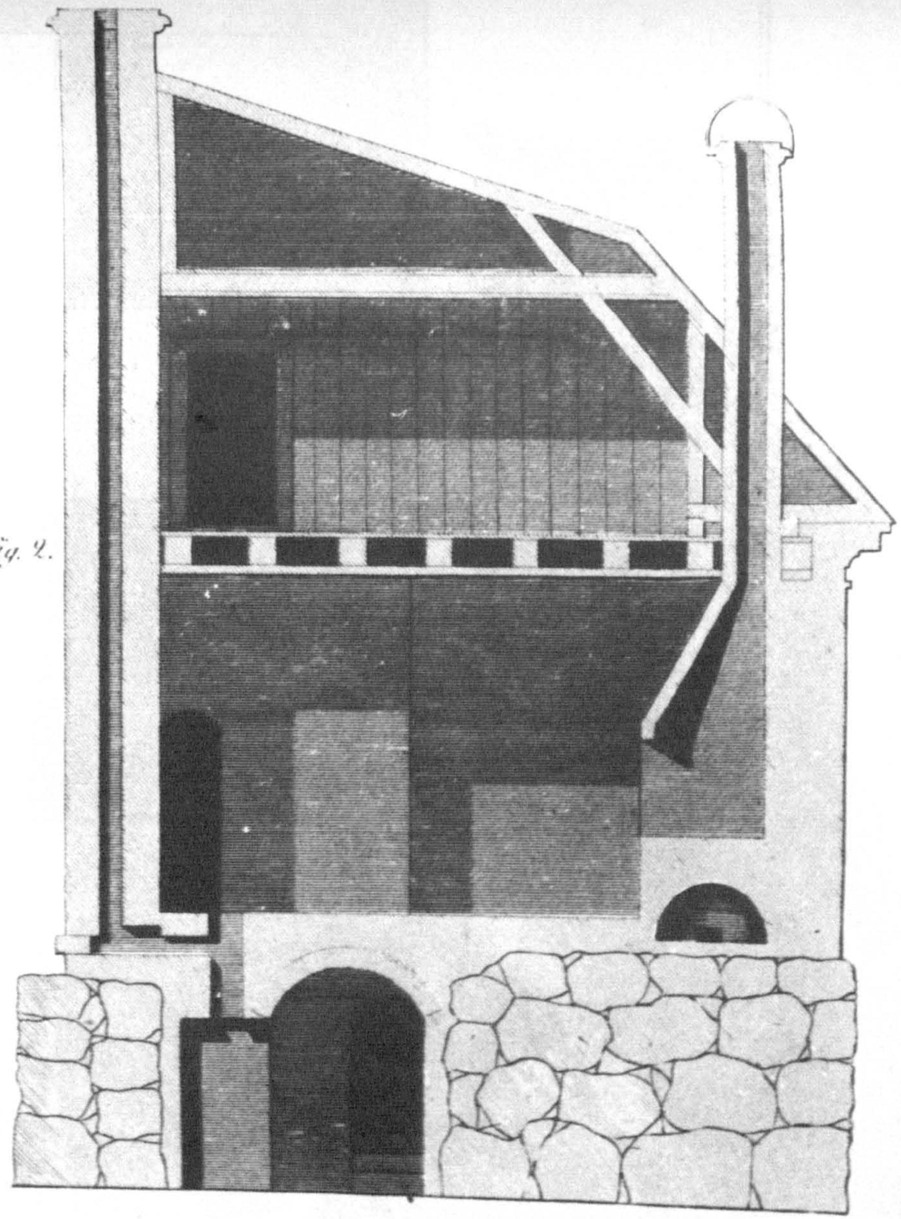


Fig. 2.

1 6 12

PL. 4.

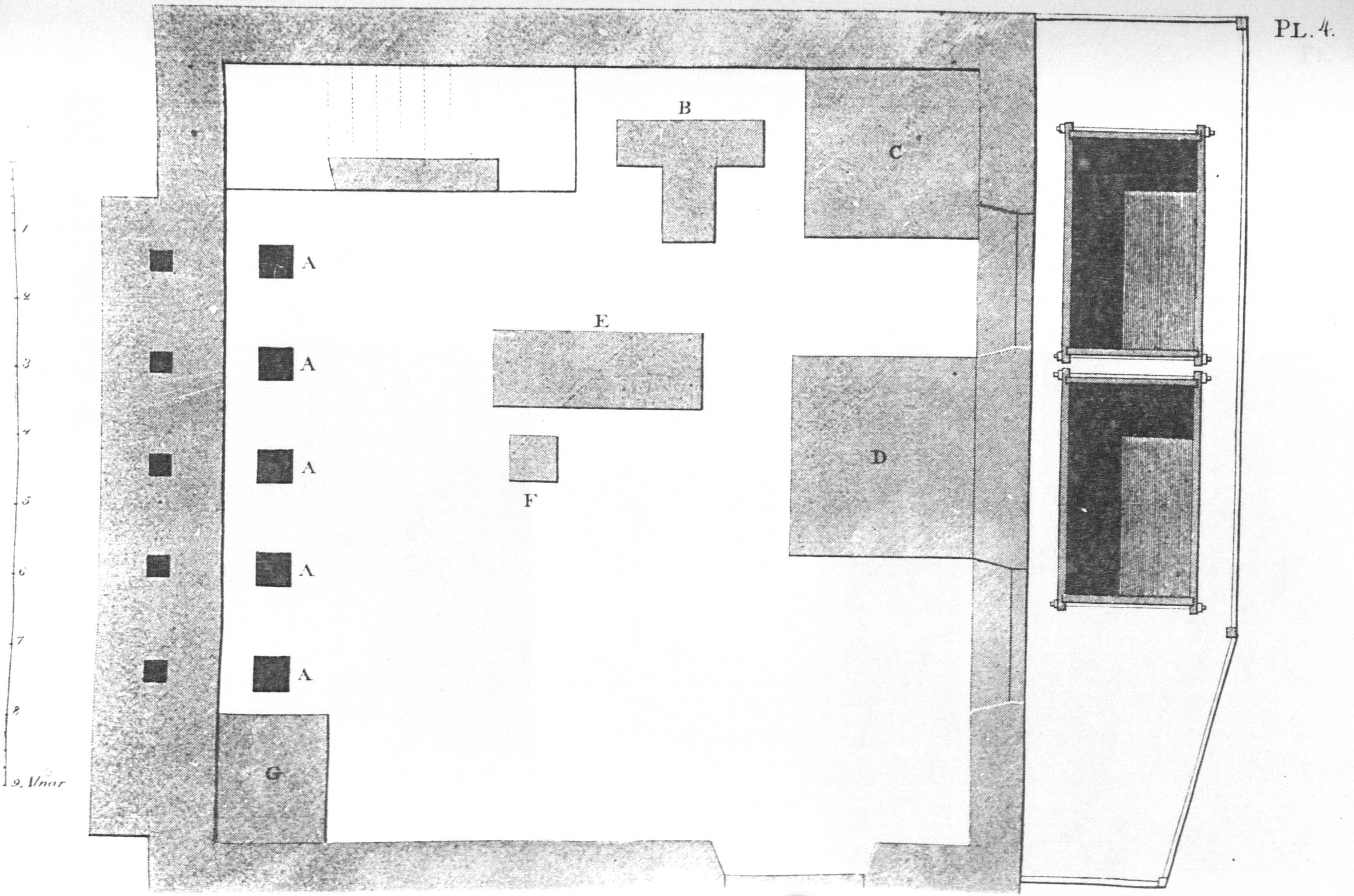


Fig. 1.

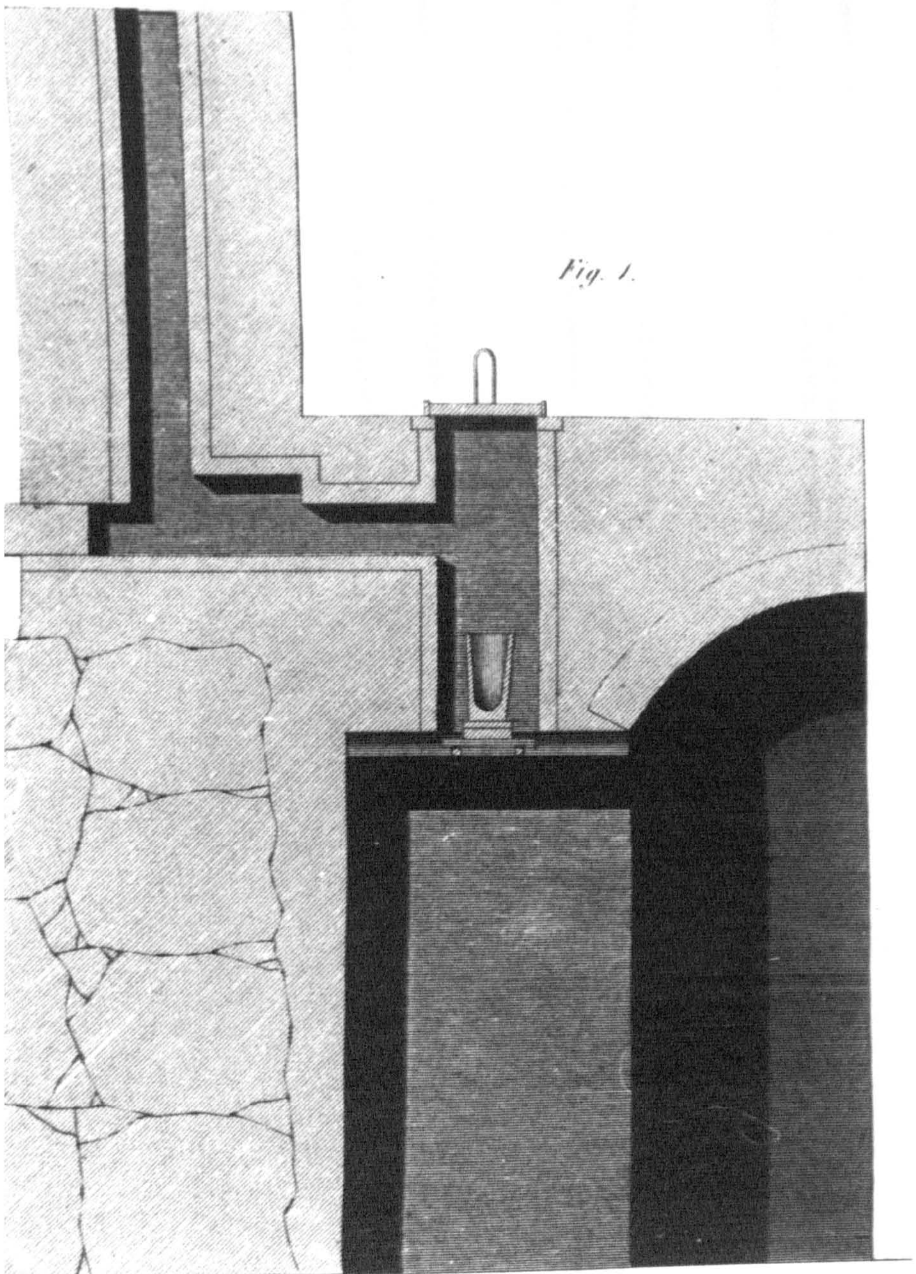
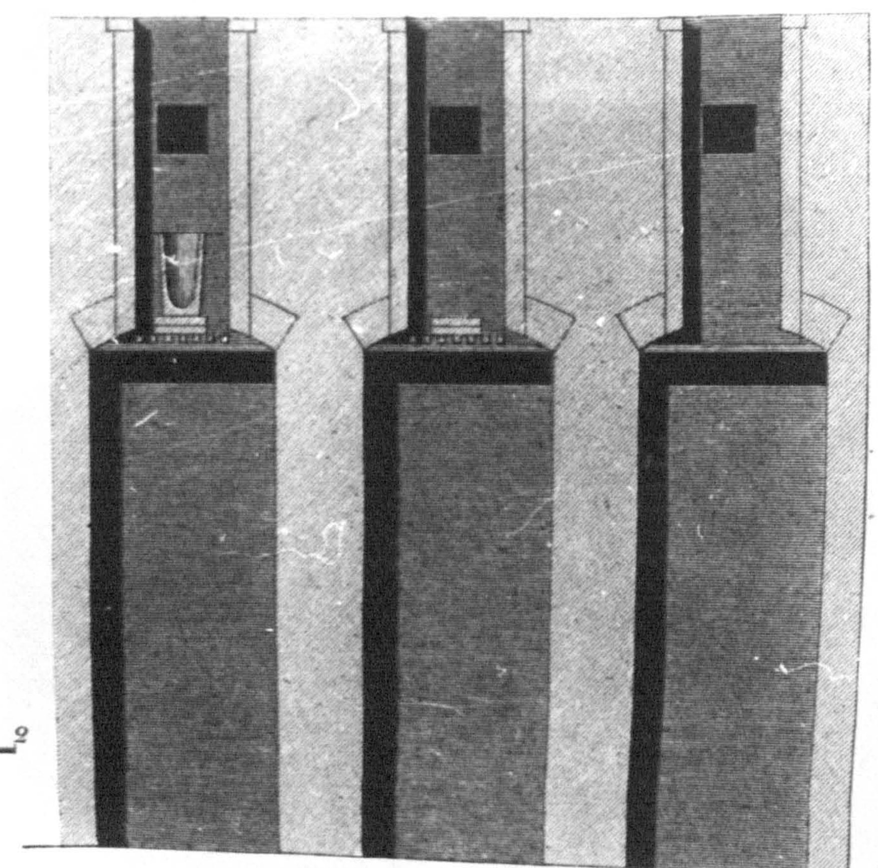
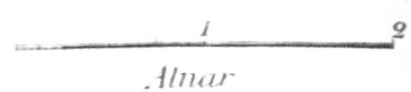
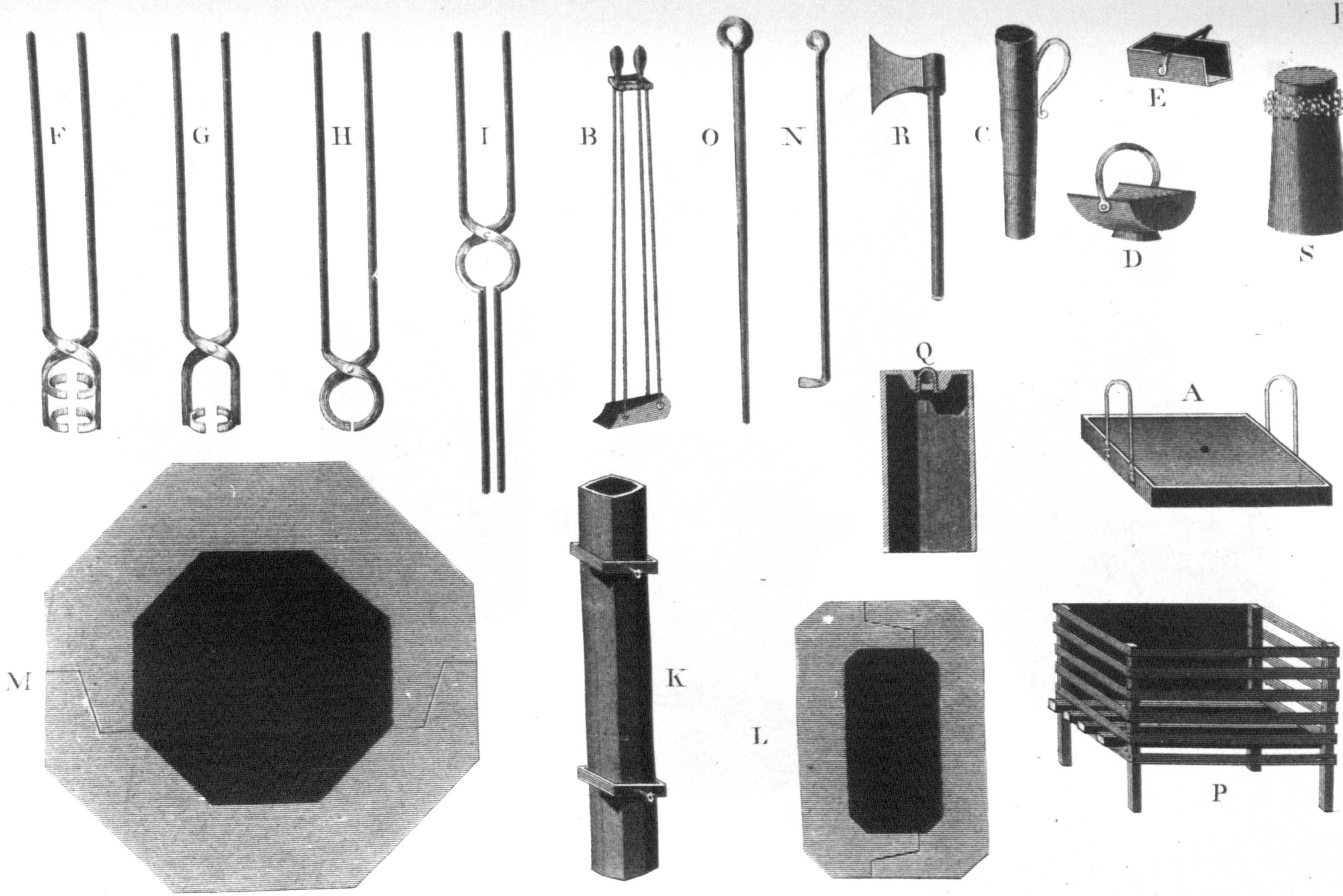


Fig. 2.



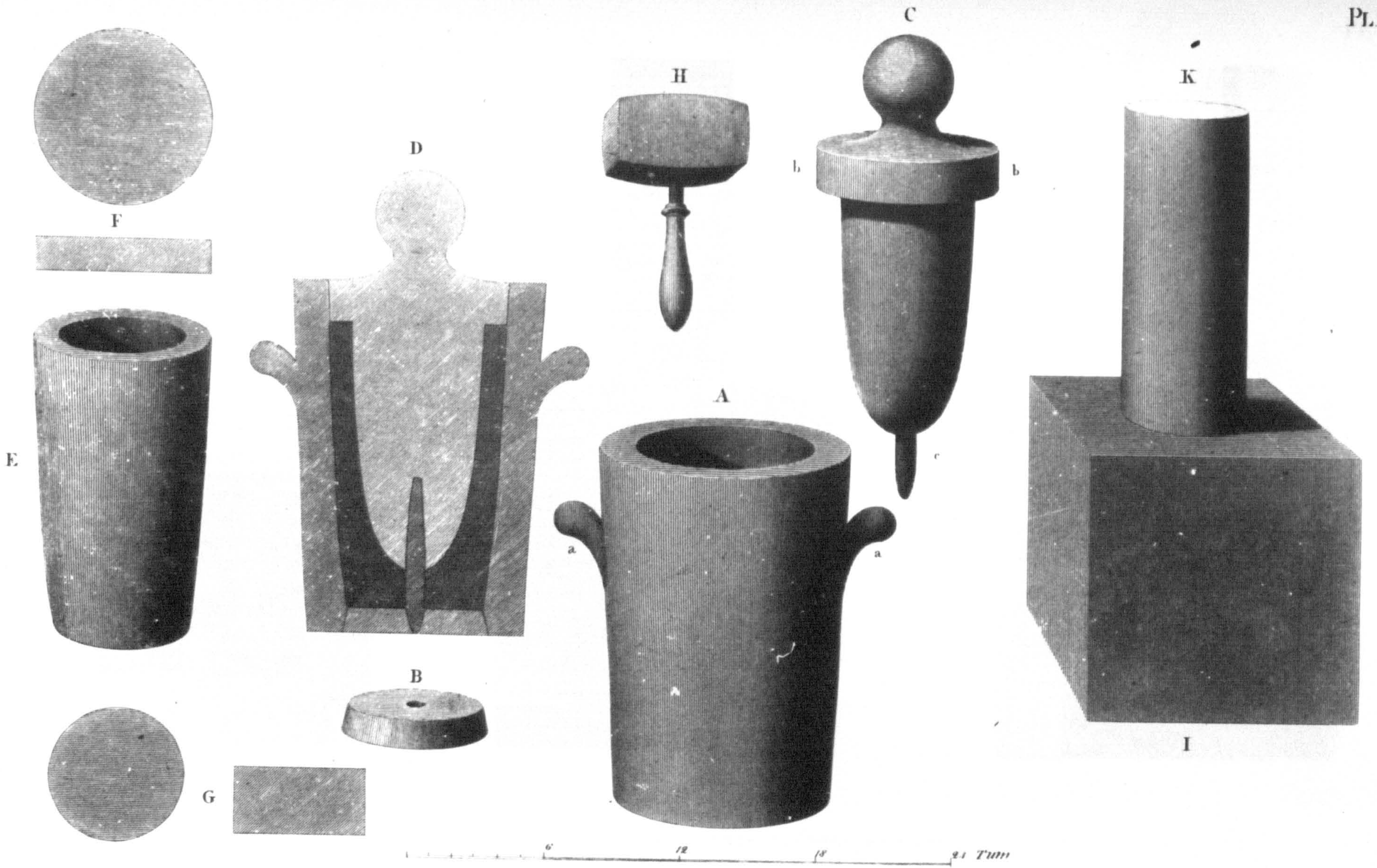


Pl. 6.



C.A.B. Sc.

Pl. 7.



PL. 8.

Fig. 1.

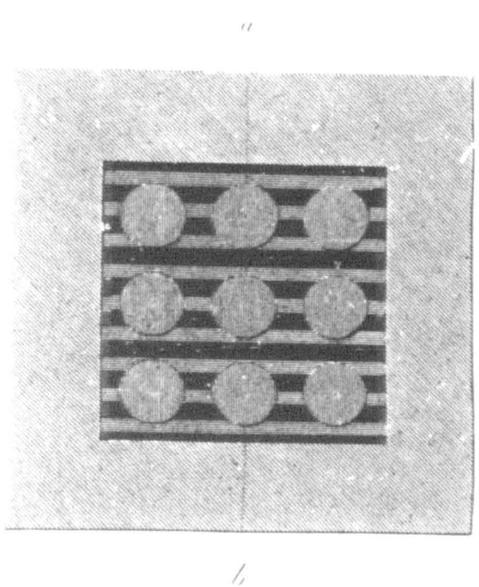


Fig. 2.

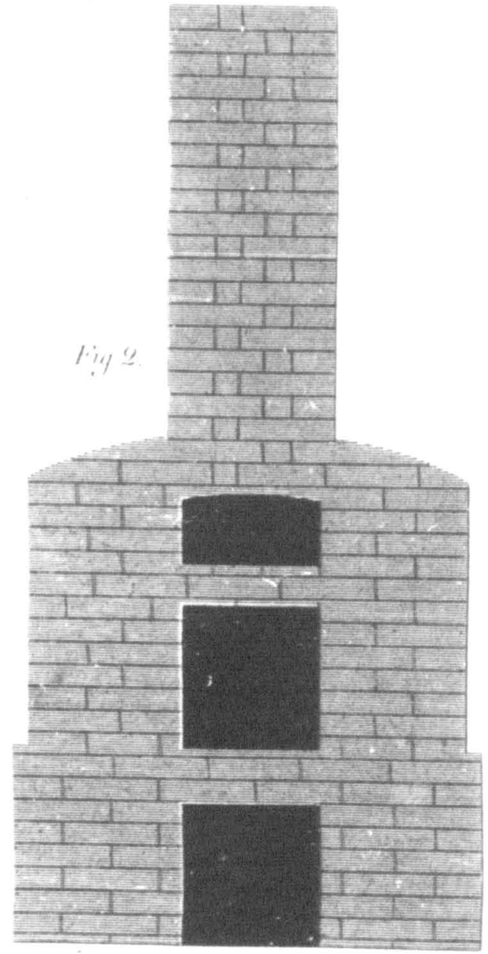
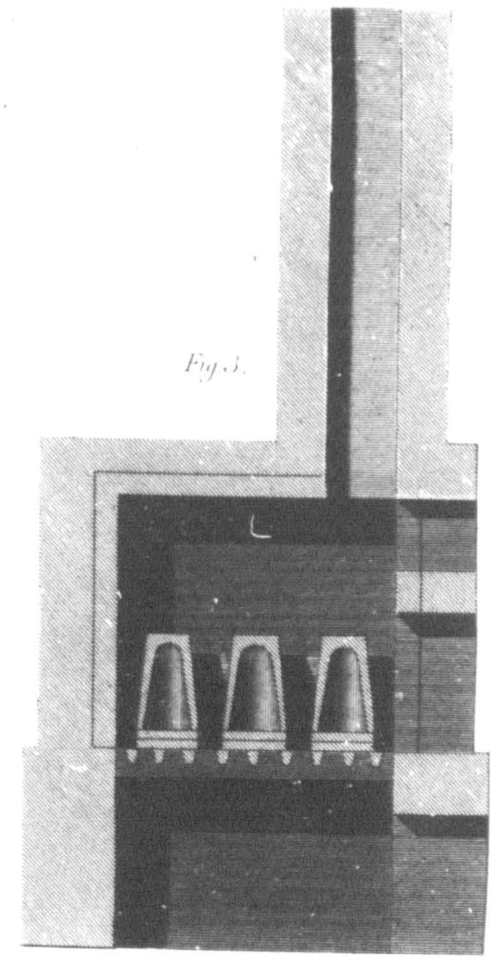
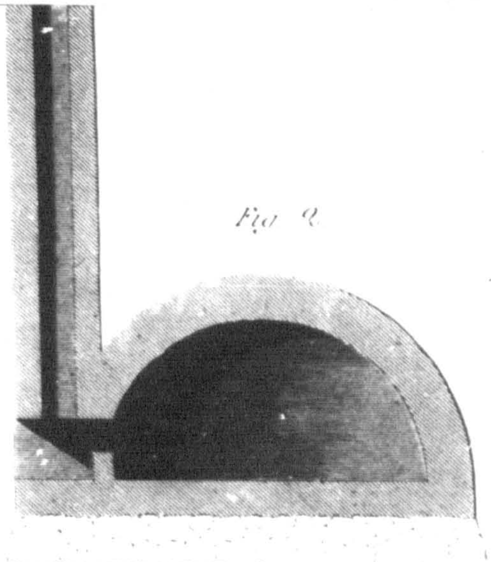


Fig. 3.



Pl. 9.

Fig. 2.



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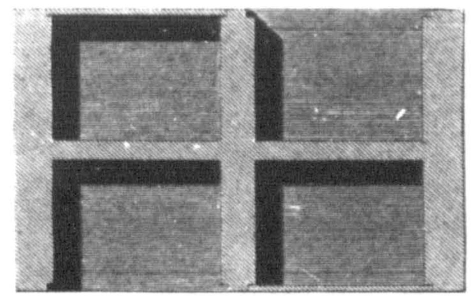


Fig. 4.

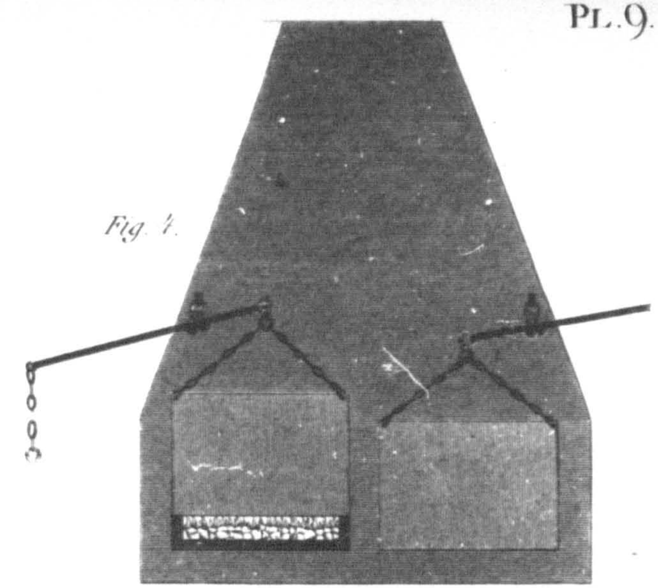


Fig. 1.

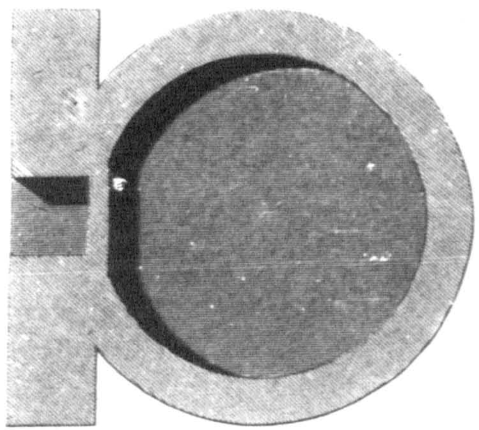
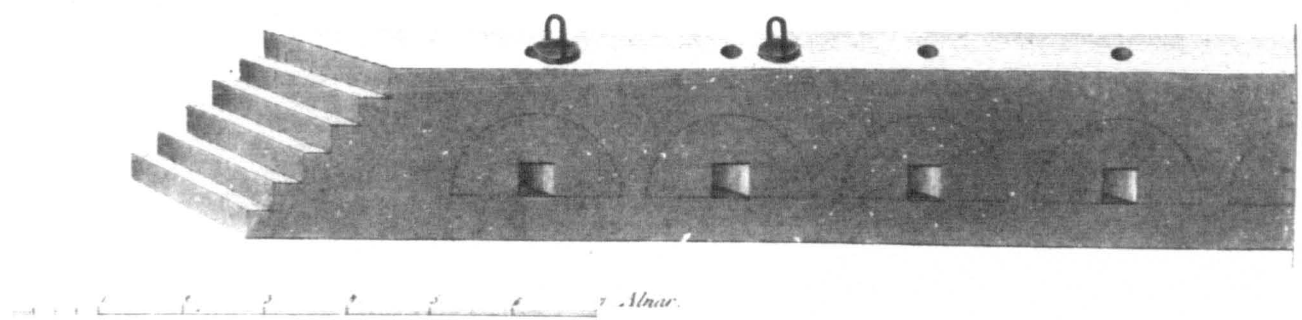


Fig. 3.



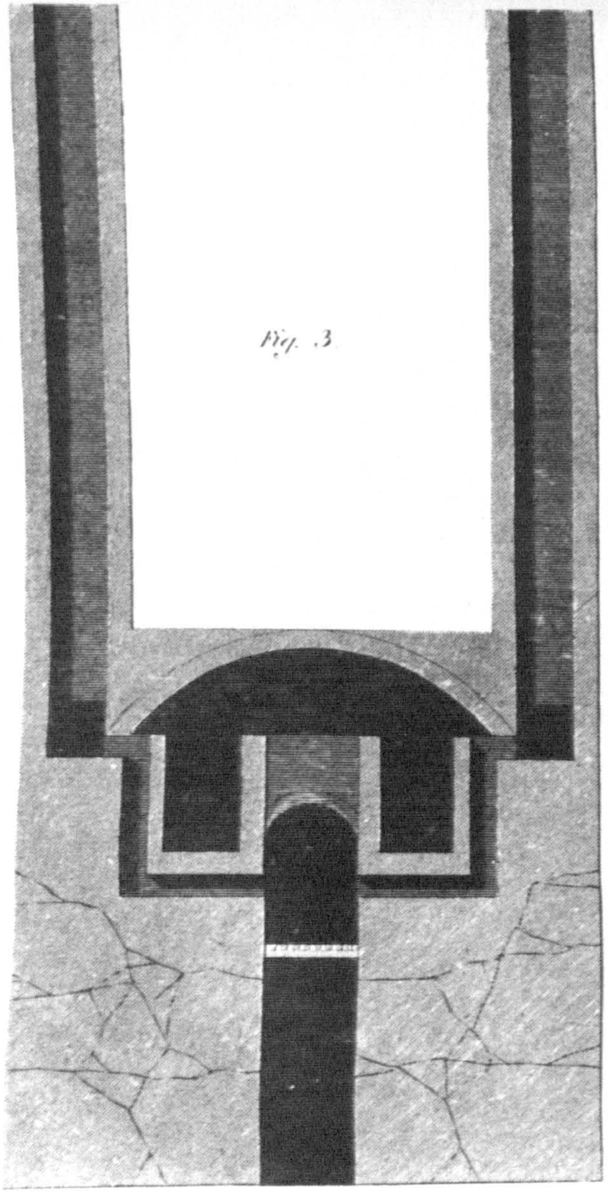


Fig. 3

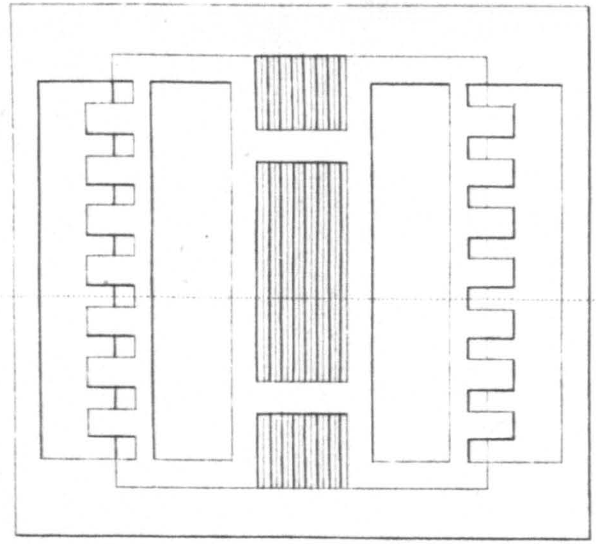


Fig. 1

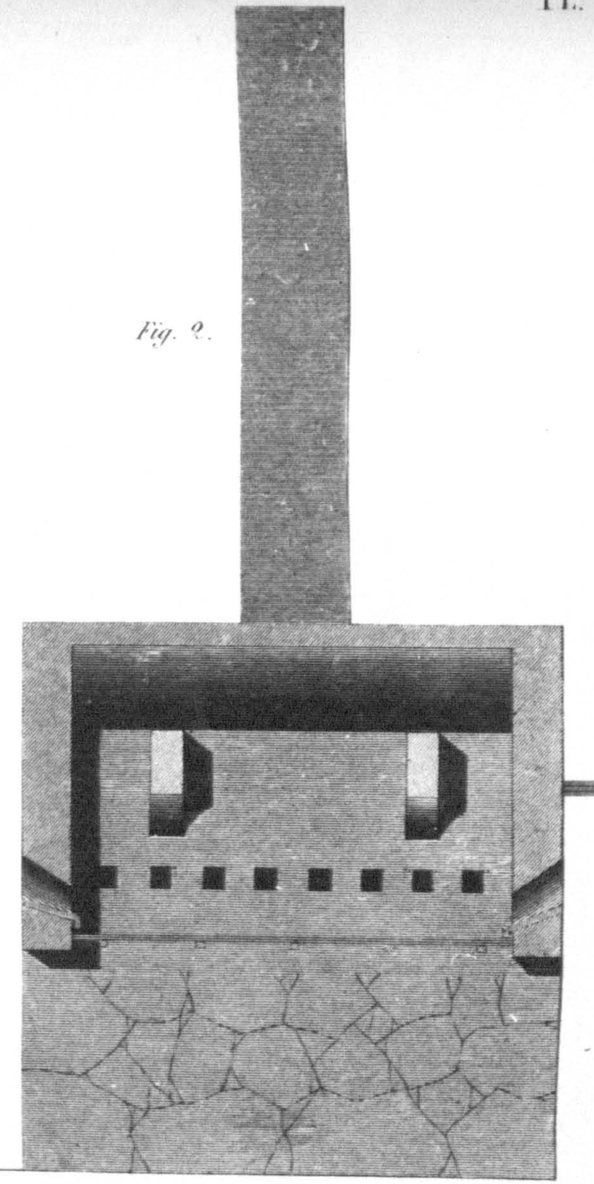


Fig. 2