The possible water-powered bloomery at Goscote (Rushall), Walsall, West Midlands

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ABSTRACT: Bloomery slag deposits at Goscote (Rushall), West Midlands, have been known since the 1960s, corresponding with archive references to late-medieval and 16th-century iron working, the latter probably water powered. Recent sampling has provided slags which can be compared with those examined by Morton and Wingrove. The new samples were made up of one third tap slag, the rest without distinct morphology. Examination indicated the use of coal-measures ore to produce steel rather than iron, but it cannot be proved that the operation was water powered.

Introduction

Water-powered bloomeries form an important but poorly-studied late-medieval iron production technology. While historical sources indicate that late-medieval blooms were substantially larger than early-medieval ones, the exact impact of water power is not well understood (Bayley *et al* 2008). Was water power used for bellows or hammers, or both? If water power was used to drive bellows, did this have an impact on smelting conditions, such as temperature? An examination of the slag and a fragment of bloom from a possible water-powered bloomery at Goscote provides the opportunity to explore the contribution that archaeometallurgy might make to a better understanding of water-powered bloomeries.

The bloomery at Goscote (Rushall)

Historical sources show that iron smelting took place in the Walsall area from at least the beginning of the 14th century (Greenslade 1976) and that a bloomery was in operation at Goscote in 1576 (Dilworth 1976, 93). Unfortunately, no further details about the bloomery (including whether or not it was water-powered) are provided by historical sources. Unpublished excavations undertaken by G R Morton and the Walsall Archaeological Society in 1964 identified a substantial heap of bloomery slag (NGR SK 0219 0128; Black Country Historic Environment Record 2615) adjacent to the Fordbrook, a tributary of the river Tame. While the results of the 1964 excavation were not published, analyses of the slag and ore were included in several papers by Morton and Wingrove (1969-70; 1972) on medieval slags and water-powered bloomeries. Recent archaeological recording by Richard Cherrington of Benchmark Archaeology (funded by Severn Trent Water), during the construction of a pipeline at Goscote (SK 0222 0130), provided another opportunity to examine the slag from this site. Unfortunately, neither the 1964 nor the recent excavations have provided any information about the sorts of furnaces employed. Morton and Wingrove referred to the site as Rushall and did not use the name Goscote, nevertheless, a consideration of the map references shows that Goscote and Rushall are the same site.

Visual examination of the slag

During the construction of the sewer pipeline at SK 0222

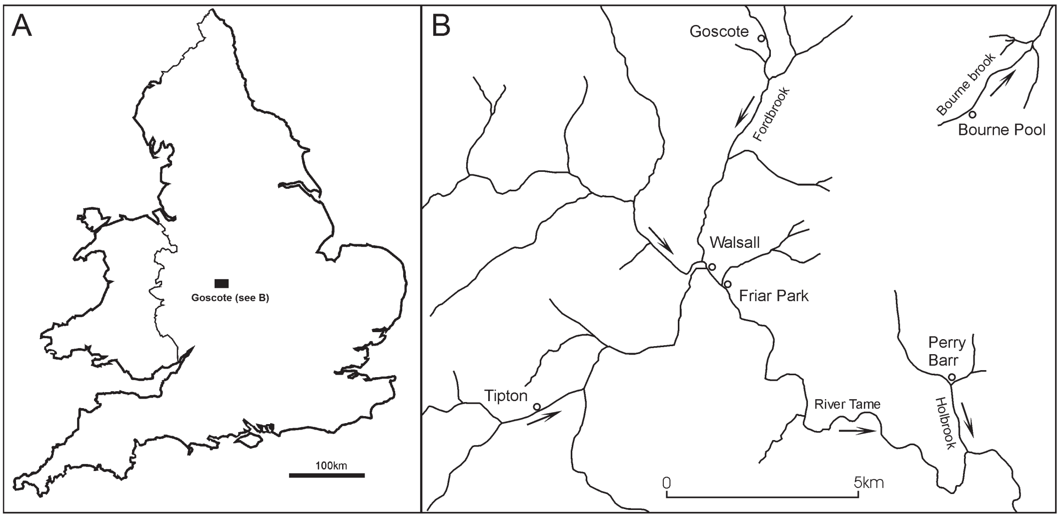

Figure 1: Map showing part of the course of the River Tame, some of its tributaries and associated bloomeries (after Dilworth 1976)

0130 just over 40kg of slag were recovered (Fig 1). Much of the slag lacked any clearly recognisable diagnostic morphology; however, a third of the material comprised a form of tap slag with a distinctive porous internal texture (Fig 2). The porosity, which is fine and evenly distributed, matches descriptions of 'honeycomb' slag from water-powered bloomeries (Tylecote 1960, 455; Vernon *et al* 1998, 77). Most of the samples have the usual black colour of bloomery slags; however, parts of three samples were grey or green and glassy. Scanning the slag assemblage with a magnet identified a lump of bloomery iron (Fig 3).

Scientific examination of the slag

Eight samples of slag and the bloom fragment were sectioned and prepared for scientific examination and analysis: these comprised three samples of non-diagnostic slag (samples 1–3), one fragment of dense tap slag (sample 4), four fragments of 'honeycomb' tap slag (samples 5–8), and one fragment of bloom (sample 9). The samples were embedded in resin and were polished using standard metallographic procedures to allow an examination of their microstructure and determination of their chemical composition. The microstructures of the polished samples were recorded using a back-scattered electron detector attached to the scanning electron microscope. This provides grey-scale images in which the brightness of different regions is proportional to their average atomic number. The chemical composition was determined using an energy-dispersive X-ray spectrometer attached to the scanning electron microscope. A series of analyses (each typically of 0.4mm^2) was taken to obtain data representative of each slag sample as a whole. Where appropriate, usually because of differences in microstructure and composition,

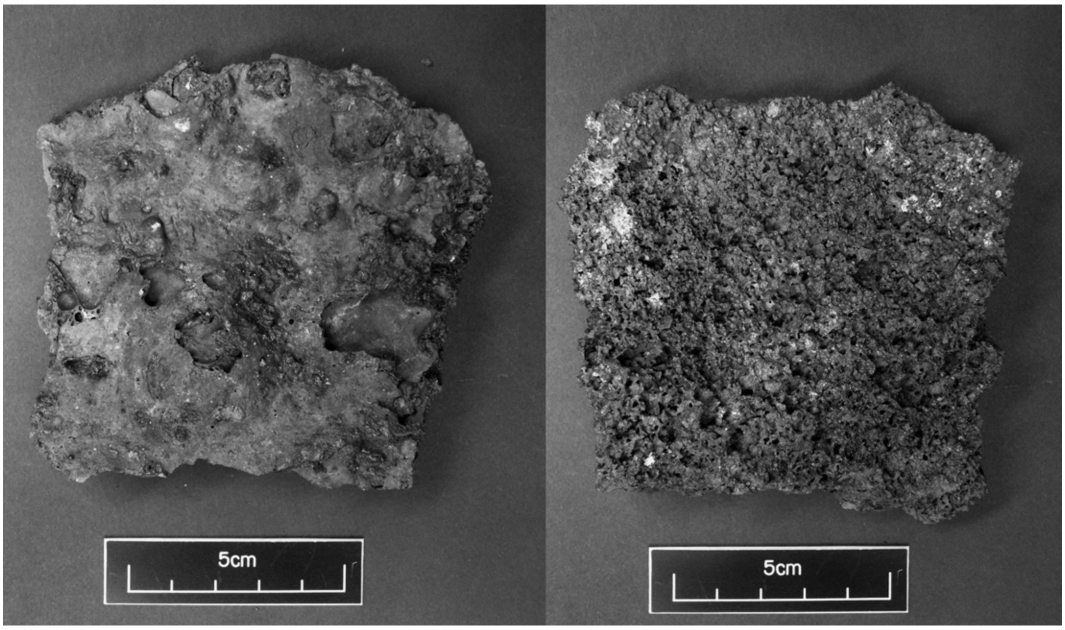

Figure 2: Fragment of 'honeycomb' tap slag from Goscote (Rushall). Left = upper smooth surface. Right = fracture surface showing highly porous 'honeycomb' texture.

Figure 3: The bloom fragment (sample 9).

samples have been divided into sub-samples (*eg* a, b or c). In addition, a large number of spot analyses (each typically 3μm in diameter) were taken to obtain data on the composition of individual mineral phases.

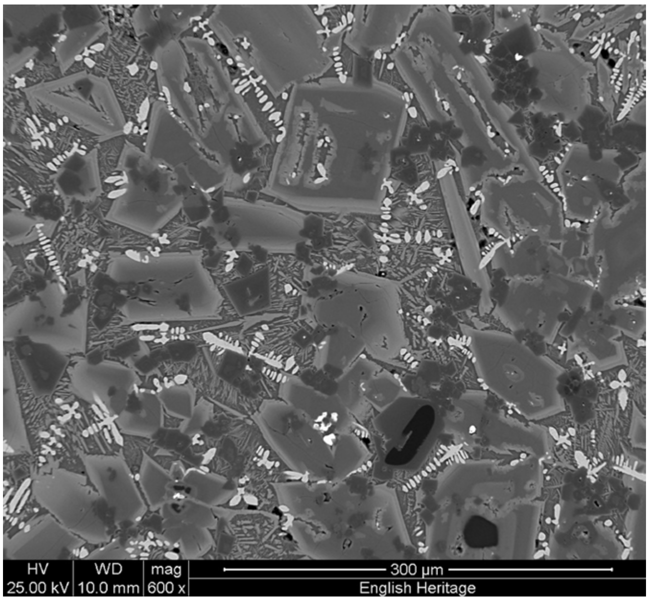

Figure 4: SEM image of sample 8a showing the presence of several phases within a glassy matrix. The bright dendrites are wüstite, the light to medium grey large crystals are olivines and the smaller darker grey crystals are spinels. The glassy matrix also contains very small olivine crystals.

The average chemical compositions of the black slag samples (Table 1) are all broadly similar to each other and to Morton and Wingrove's published analysis of slag from Rushall (Morton and Wingrove 1969–70; 1972). The black slags have microstructures that reflect their chemical compositions: they are dominated by olivines and spinels, with smaller proportions of wüstite and a glassy matrix (Fig 4). Olivines are silicate minerals with the formula M_2SiO_4, where the M represents a range of divalent cations (Fe, Mg, Ca, Mn, etc). The best known olivine in iron-smelting slag is fayalite (Fe_2SiO_4) although a small proportion of the iron is often replaced by other cations. Spinels are oxide minerals with the formula AB_2O_4 where A and B are, respectively, divalent and trivalent cations. The classic spinel is $MgAl_2O_4$ but iron-smelting slags more commonly contain $FeAl_2O_4$ (hercynite). Wüstite is an oxide of iron which approximates to FeO. The microstructure and chemical composition of the

Table 1: Average chemical analysis (wt%, SEM-EDS) of selected Goscote slag samples, plus the average value reported by Morton and Wingrove (1969–70).

No.	Type	Colour	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
1	ND	black	0.1	11.8	12.4	28.7	0.3	0.1	2.0	5.1	0.5	1.3	37.7
2	ND	black	0.2	8.2	12.1	29.4	0.3	<0.1	2.3	7.5	0.6	1.3	38.0
3a	ND	black	0.2	8.3	11.7	27.9	0.3	0.1	2.3	7.4	0.5	1.3	40.0
4	DTS	black	0.1	4.8	9.3	31.9	0.4	<0.1	1.9	6.4	0.4	1.0	43.7
5	HTS	black	0.2	7.7	12.9	29.6	0.3	<0.1	2.9	7.6	0.6	1.5	36.8
6	HTS	black	0.2	5.9	12.0	28.5	0.3	<0.1	2.7	6.4	0.6	1.4	41.9
7	HTS	black	0.2	7.9	13.5	27.6	0.3	<0.1	2.4	6.5	0.5	1.4	39.5
8a	HTS	black	0.2	7.7	15.3	28.2	0.3	0.1	2.7	7.4	0.5	1.2	36.4
9	BLM	black	0.2	4.0	11.9	27.8	0.4	0.2	2.9	10.0	0.5	1.3	40.6
M&W		1969–70	nr	5.7	12.6	26.9	0.8	0.04	nr	6.4	nr	1.0	43.9
3b	ND	green	0.2	11.5	19.1	45.2	<0.1	<0.1	3.5	12.8	0.9	2.3	4.5
8b	HTS	green-grey	0.3	8.5	17.9	54.5	<0.1	0.2	4.3	11.5	0.7	1.4	0.6
1b	ND	grey	0.5	1.6	24.1	59.7	0.2	<0.1	8.1	0.4	0.9	<0.1	4.5
3c	ND	grey	0.3	2.1	26.3	59.4	0.2	<0.1	4.7	0.4	1.0	<0.1	5.5

Note: ND = non-diagnostic slag, DTS = dense tap slag, HTS = honeycomb tap slag, BLM = (slag inclusions in) bloom, nr = not reported

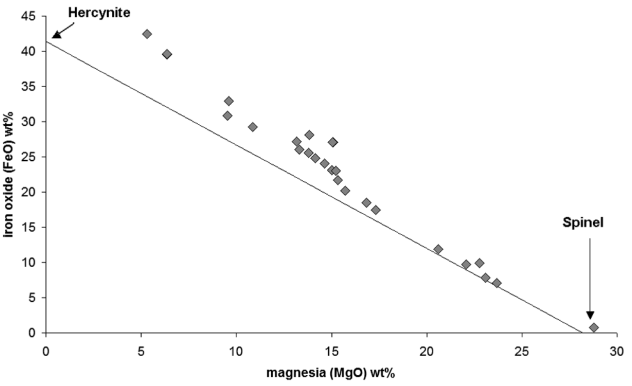

Figure 5: Proportions of magnesium and iron in spinels (hercynite = $FeAl_2O_4$; spinel = $MgAl_2O_4$).

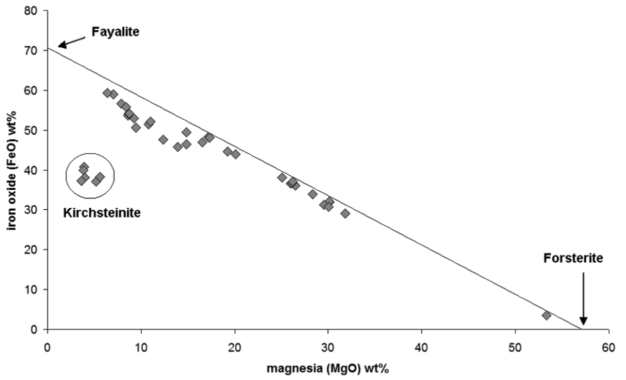

Figure 6: Proportions of magnesium and iron in olivines (forsterite = Mg_2SiO_4; fayalite = Fe_2SiO_4; kirchsteinite = $CaFeSiO_4$).

Goscote (Rushall) slags examined here conform closely to samples reported by Morton and Wingrove (1972). Small differences of detail are detectable but could easily be a reflection of developments in analytical techniques over the last 40 years.

One of the most striking aspects of the Goscote (Rushall) slags is the abundance of spinels (Fig 4). Spinels were identified in their slags by Morton and Wingrove who suggested that they were hercynite ($FeAl_2O_4$) with no magnesium (Morton and Wingrove 1972, 480). However, the analysis of the present samples showed that they all contained substantial proportions of magnesium (Fig 5). Most spinels showed roughly equal atomic proportions of iron and magnesium (spinel-hercynite solid solution, although all contain a slight excess of iron suggesting that some iron is present as Fe_2O_3, *cf* Richards and White 1954a; 1954b). The spinels are often zoned with magnesium-rich cores and increased concentrations of iron oxide at the outer edges, as can be seen in Figure 4.

The slags also contain olivine crystals as large laths hundreds of micrometres wide and several millimetres in length, as lozenge-shaped crystals (50–200μm across, Fig 4) and as fine laths and dendrites within the glassy matrix. The larger olivine crystals display complex chemical zoning. The proportions of iron, magnesium and calcium show considerable variation (Fig 6). The centre of the larger olivine crystals are magnesium-rich and, in a few cases, approximate to forsterite (Mg_2SiO_4). While the margins of these olivine crystals usually show much lower magnesium concentrations and a rise in the iron concentration, the composition is never truly fayalite (Fig 6). The outer areas of a few of the larger olivine crystals also show the presence of a calcium-rich olivine approximating to kirchsteinite ($CaFeSiO_4$).

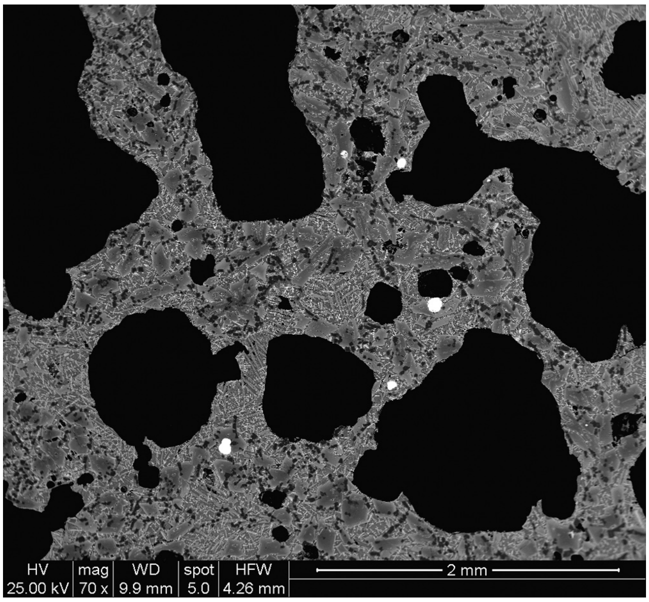

Figure 7: SEM image of sample 6. The dark areas are porosity within the slag, the brightest areas are metallic iron droplets.

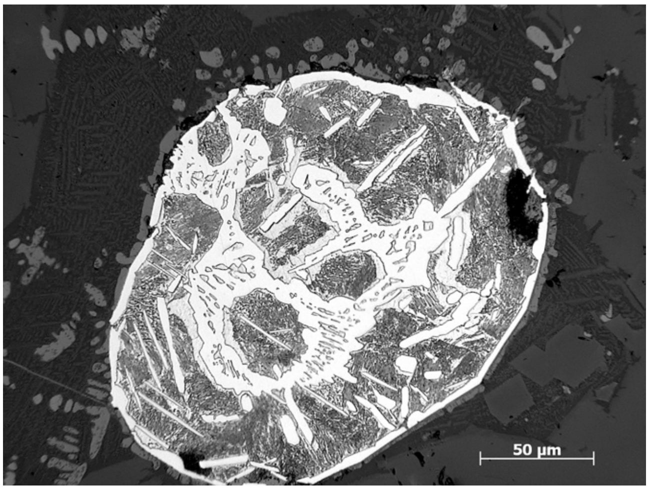

Figure 8: Optical microscope image of a metallic inclusion in sample 6 (etched with nital).

The black slags contain numerous metallic droplets (Fig 7) which were analysed and shown to be iron with no detectable silicon, phosphorus or sulphur. After

Figure 9: Optical microscope image of the bloom (sample 9) microstructure.

etching with nital the droplets revealed a hypereutectoid microstructure (Fig 8), suggesting that the metal produced was a high-carbon steel.

Portions of three of the Goscote (Rushall) slag samples contained regions of green or grey glassy slag up to 30mm across. These regions contained low proportions of iron oxide (lower section of Table 1) and contained only occasional fine olivine laths (usually approximating to forsterite). In two cases (samples 1b and 3c) the magnesium, calcium and manganese concentrations in the glassy regions are sufficiently low to indicate that they might derive from the vitrification of a clay-built furnace superstructure. In the other two cases (samples 3b and 8b) these elements are present at higher levels than any of the other samples. These regions have compositions which come close to those seen in early blast-furnace slags (Tylecote 1992, 96).

Scientific examination of the bloom

The bloom fragment was sectioned and a sample prepared for metallographic examination. In some regions this metal is dominated by pearlite (Fig 9) with some Widmanstätten ferrite especially at the outer edges. The carbon content appears to vary from close to nil to approximately 0.8wt%. On the whole the bloom fragment appears to have a slightly lower carbon content than the metal droplets within the slag.

Discussion

The manufacture of iron using a direct process, that is one in which a malleable form of iron was made in a single stage in one (bloomery) furnace, was introduced into Britain during the early first millennium BC. During the next two millennia numerous variations on the basic process are found, but most furnaces were of a modest size, air was forced in using hand-operated bellows and the blooms formed were rarely large (<10kg). The historical records for medieval blooms, before the introduction of water power, indicate that they were typically 30lb (13kg) in weight (Schubert 1957, 140). However, a significant increase in bloom size occurred in the 14th century at the time that water power was applied to the bloomery process (Mott 1961). The early-15th-century accounts of the water-powered bloomery at Kyrkeknott, County Durham report that blooms of 195lb (86kg) weight were produced by that process (Lapsley 1899; Tylecote 1960, 457).

While it is clear that by the 16th century water power was used to power both bellows and hammers, the situation in the 14th and 15th centuries is much less clear. Most early references are equivocal and simply indicate that the bloomery process made use of water power. A significant area of uncertainty is the exact use that was made of the water power. Schubert (1957, 134–138) suggests that water power was first applied to the bellows (from the middle of the 14th century) and that it was only used to power a hammer at a later date. On the other hand, Mott suggested that the real 'value of a water-wheel [was] to operate a powerful hammer' (Mott 1961, 149) although it was also applied to bellows for smelting. Tylecote (1986, 142) argues that water power was initially applied to the hammer (which would require *c*6kW of power) and only later to the bellows (which required less than 1kW). The introduction of fulling mills (with water-powered hammers) pre-dated water-powered bloomeries and perhaps lends weight to the idea of water power being applied to hammers first and bellows later (*cf* Mott 1961).

The assemblage of slags from Goscote includes a distinctive form of porous tap slag with a honeycomb-like texture. Such slags have been reported from water-powered bloomery sites (*eg* Tylecote 1960) but have not previously been studied in detail. The porosity must be due to the formation of gas within the slag at a fairly late stage in the smelting process, when the slag was sufficiently fluid to allow gas bubbles to form but too viscous to allow them to escape. The scientific examination of the Goscote slag and bloom fragment suggests that this bloomery produced steel rather than iron blooms. One possible source of gas could be carbon dioxide formed due to reactions between the iron carbide in the steel bloom and the iron oxide (wüstite) in the slag.

Morton and Wingrove (1972) divided the medieval slags they analysed into two groups: the first in which rich iron ores (such as those from Cumbria or the Forest of Dean) had been used, and the second which made use of leaner ores, especially those associated with the Coal Measures. The Goscote slags have compositions which are consistent with the use of ores from the Coal Measures (*eg* high magnesium and aluminium content); however, slags with broadly similar compositions have been reported from sites where such ores would not have been readily available. It would also be wrong to link the chemical composition of the Goscote slags with the use of water power in the process. Slags with compositions similar to those from Goscote have been reported from late-Saxon smelting sites, such as West Runton (Tylecote 1962), where there is no suggestion of the use of water power.

Morton and Wingrove (1972, 483–6) used a comparison of Rushall ore and slag to argue that the slag could only have been made with the addition of a small proportion of lime. The present study confirms that the Goscote (Rushall) slags contain higher concentrations of both lime and magnesia than might be expected from the ore alone. Any definitive consideration of the use of a limestone flux in water-powered bloomeries, however, will depend on the availability of better data than is currently available. This should include a consideration of the nature of the ore, the furnace (including the extent to which it might contribute to the formation of slag), any fuel ash and possible limestone fluxes.

Conclusion

The application of water power to the bloomery smelting process from the 14th century to the 17th century is poorly understood, but occurs at the time when smelters started to produce much larger blooms. This technology may have helped to produce the increased quantities of iron used in late-medieval and post-medieval society. In addition, aspects of water-powered bloomery technology may have influenced the development and adoption of blast-furnace technology. The examination of the slag from Goscote makes a small contribution to our knowledge of water-powered bloomeries, and indicates that there is much more to be discovered.

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