ROMANO-BRITISH IRON-MAKING ON THE SEVERN ESTUARY LEVELS: TOWARD A METALLURGICAL LANDSCAPE

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At 15 main sites, and three supplementary ones, on or closely associated with the Holocene outcrop of the Severn Estuary Levels there is evidence for Romano-British iron-making in the form of various associations of ore, furnace lining, tap slag, furnace bottoms, and hammerscale. At one site ore-crushing platforms, stores of clay, and numerous shaft furnaces are known, and at another a probable bloom was found. The iron-making on the Levels occurred chiefly in the later Roman period and at several sites was on a scale sufficient to support an export market. Mines in the Forest of Dean supplied rich ores, which were widely distributed by land and water on both sides of the Severn within the wider Dean region. The evidence of charcoal associated with iron-making materials points to organized charcoal-burning using small roundwood cut from local, probably managed woodlands substantial in area. Throughout the period both the Iron Age simple bowl furnace and more technologically-advanced tappable furnaces were simultaneously in use. A set of 113 geochemical analyses of slags from the sites suggests that a wide variety of local clays were used to build furnaces, and that those of the simple bowl type were less efficient and more difficult to operate consistently than the tappable ones, probably chiefly shaft furnaces. Bowl furnaces were dug into the ground using mainly mattocks or entrenching tools, to judge from the casts of digging marks found on the undersides of furnace bottoms. The operation of the two kinds of furnace, and the processes occurring within them, appear on geochemical grounds to have differed in significant details. Blooms appear to have been purified at some of the smelting sites. The fate of iron marketed from the Severn Estuary Levels is so far unknown archaeologically.

INTRODUCTION

Iron is one of the commonest elements in the Earth's crust, occurring in a wide variety of mineral forms, from some of which the metal can be extracted by smelting. In the Roman age of iron, major, dispersed smelting industries were established in the Forest of Dean and the wider region (Jones and Mattingley 1990; Walters 1992; Meredith 2006), where hydrothermal goethite and haematite were worked; the Weald of Kent (Cleere and Crossley 1985; Jones and Mattingley 1990) with its rich resource of diagenetic sedimentary clay-ironstone (sideritic); and, to a possibly lesser extent, the Jurassic ridge of the East Midlands (Schrüfer-Kolb 2004) where other types of sedimentary ore abound.

It has become increasingly apparent (Allen and Fulford 1987; Allen 1988; Fulford *et al* 1992) that many Romano-British settlements, on or closely associated with the embanked Holocene estuarine alluvium of the Severn Estuary Levels, participated substantially in the Roman bloomery iron-smelting industry based on Forest of Dean rich ores. This paper is an attempt to consolidate, expand and review what is known of the industry in this part of the wider Dean area. Earlier collections and sites have been reassessed, new material and sites added, and a greatly increased body of more evenly spread and balanced geochemical data secured and assimilated. In this way it has become possible to glimpse many aspects of the Roman metallurgical landscape that depended on the Forest of Dean but which for the most part lay beyond its strict geographical bounds.

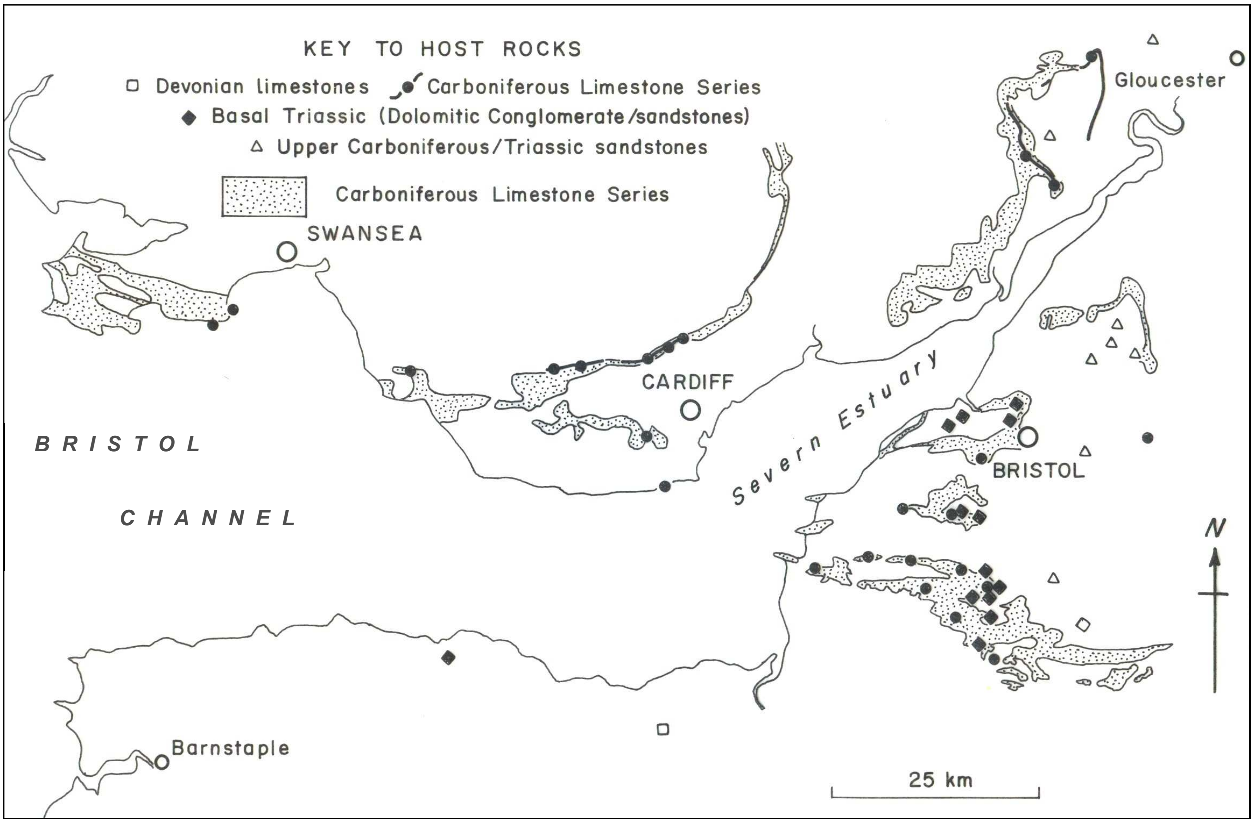

Figure 1. The Bristol Channel Orefield (based on Young and Thomas 1998).

THE BRISTOL CHANNEL OREFIELD

The iron ores smelted during the Roman period on the Severn Estuary Levels come from sources that lie in the Bristol Channel Orefield, and almost certainly largely or wholly from within the Forest of Dean. Figure 1 shows this extensive and important mineralized region, as mapped by Young and Thomas (1998), with minor revisions. With the Carboniferous Limestone Series as the chief mineralized formation, it ranges for 100 km or so from west Somerset and the Gower peninsula in the west, to the Mendips in the east, and to the Forest of Dean itself in the north. General accounts of the geology and economics of the ores, together in some cases with local details, can be found in Cantrill *et al* (1919), Sibly and Lloyd (1927), Dines (1956), Hart (1971), Slater and Highley (1976), Patrick and Polya (1993), Young and Thomas (1998) and Meredith (2006). Further local details appear in the sheet-memoirs of the Geological Survey for Devon and Somerset (Edmonds *et al* 1979, 1985; Edmonds and Williams 1985; Edwards 1999); the Mendip-Bristol-Tortworth area (Green and Welch 1965; Cave 1977; Kellaway and Welch 1993); and South Wales and the Forest of Dean (Strahan 1907; Trotter 1942; Squirrell and Downing 1969; Waters and Lawrence 1987; Wilson *et al* 199l). Gough (1930) and Alabaster (1982) have described the mines and minerals of Mendip, and Scott-Garrett (1959) and Wildgoose (1988) the important early mines at Lydney and probably Wigpool in the northern Forest. Meredith (2006) gives a valuable account of later mining and smelting activities in Dean. The iron ores hosted by Devonian sandstones and slates of the Somerset-Devon border (Edmonds *et al* 1979, 1985) are probably related to an earlier episode of mineralisation than that which created the Bristol Channel Orefield.

The evidence from dated smelting-sites and documentary sources shows that iron-mining in the Forest of Dean began in the Iron Age, was hugely intensified during the early Roman period (Walters 1992; Meredith 2006), picked up again in medieval times and was revived in the nineteenth and earlier twentieth centuries (Trotter 1942; Hart 1971; Meredith 2006). There was much nineteenth and early twentieth century iron-mining in the other parts of the region, especially industrialised South Wales, which also imported ores from Somerset. Where the Roman mines lay

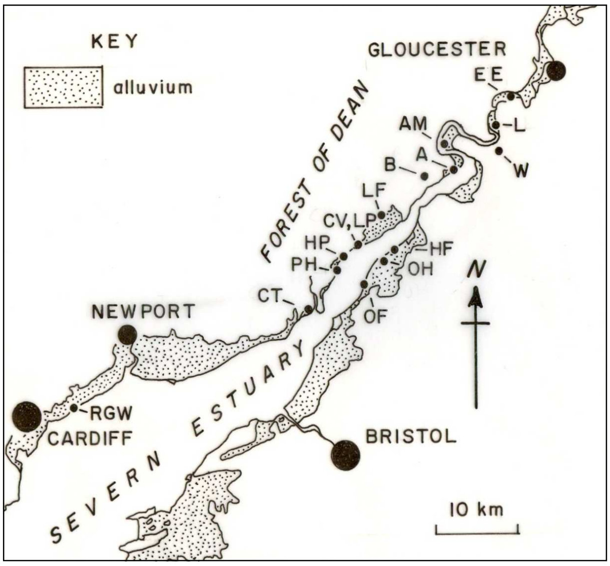

Figure 2. The Severn Estuary Levels, showing the sites mentioned in the text. Key to west-bank sites: A – Awre (Whitescourt); B – Blakeney (Millend Lane); LF – Lydney Park Farm; CV – Chesters villa; LP – Ley Pill (Woolaston); HP – Horse Pill, beach and cliff; PH – Pill House; CT – Chepstow (Thornwell Farm); RGW – Rumney Great Wharf. Key to east-bank sites: EE – Elmore (Windmill Hill); L -Longney, A-C; W – Whitminster (Packthorne Farm); HF – Hills Flats, with Severn House and Dayhouse Farms; OH – Oldbury (Home Farm); OF – Oldbury Flats.

in Dean remains largely unresolved. The Ordnance Survey (1991) map of Roman Britain confidently identifies five sites, but Walters (1992) is rightly much more cautious. While it is likely that a number of mines were worked, the only fully proven example is at the religious complex in Lydney Park in the east (Wheeler and Wheeler 1932; Scott-Garrett, 1959).

Probably because the mines are now exhausted and abandoned, making the assembly of relevant evidence difficult, the minerogenesis of the Bristol Channel Orefield is poorly understood. On stratigaphical grounds, however, the mineralisation cannot be earlier than late Triassic, and has even been assigned a Tertiary date. The ores at the Taff Wells-Llanharry subfield west of Cardiff, mined until 1978, are considered on the basis of detailed work to be low-temperature chemical precipitates from waters that leached iron from Triassic beds above (Gayer and Criddle 1970; Rankin and Criddle 1985). There is no known evidence on which to reject this general view for the orefield overall, although there unquestionably are some replacement ores.

The ore-bodies are closely related geologically and geographically with the pre-Triassic, regional landscape unconformity and palaeokarst that developed following the Permo-Carboniferous earth movements in southern Britain. They are chiefly precipitates hosted in voids which range from joints, bedding surfaces and major faults, largely in sandstone and similar formations (Lower and Upper Carboniferous, Triassic), to large solutional cavities, mainly in carbonate rocks (Devonian, Lower Carboniferous, Triassic), especially in the case of locally dolomitised Carboniferous examples and the basal Triassic Dolomitic Conglomerate (Figure 1).

The ores, divided between goethite (FeO(OH), orange-brown streak) and haematite (Fe_2O_3, red streak), occur in five main facies: massive, botryoidal, stalctitic, layered and earthy or powdery (ochres). Commonly more than one facies can be found in any given lump of ore. The massive ores are dense, compact and very finely granular. Botryoidal ores display surfaces formed of small, mutually interfering spheroidal aggregations beneath which are radiating sets of acicular crystals. The stalactitic ores are formed of closely spaced, irregular, parallel columns a few to several millimetres across composed of radiaxial, acicular crystals. Haematitic ochres range from thin, bright red coatings on botryoidal and stalactitic facies to large masses with a microcrystalline, powdery to a more firm texture, known and marketed as the pigment reddle. Goethite ochres occur mainly in microcrystalline masses. Disseminated very finely crystalline quartz and other impurities are often present. The layered facies is the most complex. It consists of millimetre-scale layers of massive ore, mainly goethite, interspersed with more porous but still comparatively hard ochreous material with a little very finely crystalline quartz. The iron ores of the Bristol Channel Orefield have long been understood to be of a high or very high grade, with even the ochres containing few impurities, a view confirmed by recent chemical work (Young and Thomas 1998). Disseminated quartz is least in evidence in the Forest of Dean. More coarsely

Table 1. Summary of contexts of iron-making sites.

Site	Geological context	Archaeological context
West bank		
Awre (Whitescourt) (SO 705073, BGS Sheet 234)	Awre & Rumney Fmns, Third Terrace, Lias, beach	Natural exposures
Lydney Park Farm (S0 624018, BGS Sheet 233)	First Terrace	Excavations, plough soil
Ley Pill (ST 597985, BGS Sheet 250)	First Terrace	Natural exposures
Horse Pill (ST 580973), beach and cliff (ST 584976, BGS Sheet 250)	Wentlooge and Rumney Fmns, Second Terrace, Trias	Plough soil, natural exposures, beach and cliff
Pill House (ST 569957, BGS Sheet 250)	Wentlooge and Rumney Fmns, Second Terrace, Trias	Natural exposures
Rumney Great Wharf (ST 244783, BGS Sheet 263)	Wentlooge Formation	Natural exposures, beach, excavations
East bank		
Elmore (Windmill Hill) (ST 787163, BGS Sheet 234)	Wentlooge Formation	Plough soil
Longney C (ST 755133, BGS Sheet 234)	Wentlooge Formation	Plough soil
Longney A (*c* ST 759131, BGS Sheet 234)	Wentlooge Formation, Second Terrace	Plough soil
Longney B (ST 758129, BGS Sheet 234)	Wentlooge Formation	Plough soil
Arlingham (SO 695110, BGS Sheet 234)	Wentlooge Formation	Plough soil
Whitminster (Packthorne Farm) (SO 764098, BGS Sheet 234)	Trias, First Terrace	Plough soil
Hills Flats with Severn House and Dayhouse Farms (ST 6297, 6397, 633977, 632975; BGS Sheet 250)	Wentlooge Formation	Plough soil, excavations, beach
Oldbury (Home Farm) (ST 626963, BGS Sheet 250)	Wentlooge Formation	Plough soil
Oldbury Flats (ST 6093, 6193, 602936; BGS Sheet 250)	Wentlooge, Awre & Northwick Formations	Natural exposures, beach, excavations
Supplementary sites closely associated with the Levels		
Millend Lane, Blakeney (SO 672068, BGS Sheet 234)	Raglan Marl Group (Lower Old Red Sandstone)	Excavations
Chesters villa (ST 597986, BGS Sheet 250)	First Terrace	Excavations, plough soil
Thornwell Farm, Chepstow (ST 539919, BGS Sheet 2250)	Lower Drybrook Sst., Drybrook Lst. (Carboniferous Limestone Series)	Excavations

crystalline quartz in vugs often accompanies ores in Somerset, Mendip and South Wales.

CONTEXTS AND PRESERVATION

The reassessment below of Romano-British iron-making on the Severn Estuary Levels is based on material from six main sites on the west bank of the estuary and nine on the eastern shores (Figure 2, Table 1). Of the west-bank localities, four lie wholly or partly on the outcrop of the Holocene estuarine alluvium. Two are sited on the Pleistocene First Terrace of the Severn a short distance from the Holocene outcrop. Seven east-bank sites occur on the Holocene outcrop, one is partly on the Second Terrace, and another, within a stone's throw of the Holocene deposits, is located on the First Terrace. Also considered is evidence reported from three supplementary sites closely associated with the Levels, of which the most important is the Chesters villa. Although none occur on the Holocene outcrop, all lie close to the estuary and overlook these deposits from a short distance away.

Geologically, the contexts of these sites (Table 1) are mainly provided by Holocene estuarine sediments (Allen 1987; 2000, 2001, 2005; Yates *et al* 2001; Allen and Rae 1987; Walker *et al* 2002; Brown 2006; Jordan 2006). All but the last one or two millennia of Holocene time are represented by the estuary-wide Wentlooge Formation, the accumulation of which, under the impact of an unsteadily rising sea level, continued on the wetland margins of the estuary until these were embanked mainly in either Roman or medieval times. The topmost few metres of this unit consist of sandy-clayey-silts which were settled and exploited agriculturally after the embanking. Also widely recognised throughout the Severn Estuary are three post-embanking silt units: the Rumney, Awre and Northwick Formations (Allen 1987; Allen and Rae 1987). These underlie the few active salt marshes that remain in the area, have erosional relationships to older deposits, and testify to significant medium-term coastal change (eg Allen and Fulford 1996). The Rumney Formation appears to be of chiefly early-modern inception, but seems locally to have a very similar medieval precursor. The Awre Formation dates, after an erosional episode, from the later part of the nineteenth century and the Northwick Formation, also following erosion, from the early-middle years of the twentieth. These formations are also important for understanding the iron-making sites.

Several sites lie directly on, or are closely associated with, one of the Pleistocene river terraces of the Severn (Table 1). The age of these is difficult to establish, but is generally thought to increase with altitude. The terrace sediments include sandy clays, clayey sands, clayey-pebbly sands, clean sands and sandy gravels, with an overall thickness up to several metres locally (Wills 1938; Welch and Trotter 1961). Typically, the sand component is angular to rounded and medium- to very coarse-grained.

The solid geology figures at some sites (Trotter 1942; Welch and Trotter 1961). A thick series of dark red, coarse-textured mudrocks with occasional thin sandstones and concretionary limestones (calcretes) make up the Raglan Marl Group of the Lower Old Red Sandstone (Devonian). Lower Carboniferous rocks are represented by the Lower Drybrook Sandstone, a reddish to yellowish, medium- to very coarse-grained rock characterised by well-rounded quartz grains, followed by the Drybook Limestone, a locally dolomitised, mainly oolitic limestone. The latter is among the locally iron-mineralised formations of the Forest of Dean. The main Triassic unit in the area is the Mercia Mudstone Group, a series of bright red, coarse-textured mudrocks with occasional, thin, muddy sandstones. The Lias consists of grey, fossiliferous, fine-textured mudrocks with frequent thin limestones (cementstones).

The archaeological contexts of the sites are fourfold: excavations (two kinds), plough soils, natural exposures and intertidal beaches (Table 1). About one-third of the sites involve more than one context.

Archaeological excavations have furnished evidence for iron-making at Lydney Park Farm (with other contexts), Rumney Great Wharf (with other contexts), Oldbury Flats (with other contexts), Blakeney (Millend Lane), Chesters villa and Thornwell Farm. The material described from Severn House Farm (Hills Flats) comes from spoil dug without archaeological intervention during a mechanical excavation for a substantial wildlife pond sited on the estuarine alluvium.

Field-walked plough soils form an important context for the evidence, especially on the east bank of the estuary. Here the embanked Holocene silts were extensively and lengthily cultivated during medieval times, as witness the widespread survival even today of bold ridge-and-furrow (eg Allen 1990, 1992). Cultivation, now intensive and by machine, has resumed in many places since the Second World War. Although arable farming on the Severn Estuary Levels has revealed many Romano-British sites, an important limitation has proved to be damage to artefacts. Pottery in particular has been subject to such comminution that the sherds available in the soil are little larger than postage-stamps. The more delicate furnace linings and even slags appear also to have suffered some damage and reduction.

Table 2. Occurrence of iron ore at sites on the Severn Estuary Levels. Footnotes: 1 = one piece of 356.2 g; 2 = burnt to magnetite (?furnace waste); 3 = excludes two specimens of fragile reddle due to loss.

Site	Goethite		Haematite		total wt. (g)	av. wt. (g)
	no.	wt (g)	no.	wt (g)		
Awre (Whitescourt)	3	423.5	1	10.0	433.5[1]	108.4
Lydney Park Farm	2	31.2	-	-	31.2	15.6
Ley Pill	-	-	-	-	-	-
Horse Pill, beach, cliff	10	928.8	-	-	928.8	92.9
Pill House	21	936.6	2	17.8	954.4	41.5
Rumney Great Wharf	2	31.8	-	-	31.8	15.9
Elmore (Windmill Hill)	-	-	-	-	-	-
Longney C	1	9.0	-	-	9.0	9.0
Longney A	1	225.7	-	-	225.7	225.7
Longney B	-	-	-	-	-	-
Arlingham	-	-	-	-	-	-
Whitminster (Packthorne Farm)	-	-	-	-	-	-
Hills Flats, Severn House & Dayhouse Farms	14	826.0	3	136.0	962.0	56.6
Oldbury (Home Farm)	1[2]	17.6	-	-	17.6	17.6
Oldbury Flats	6	2085.5	28	1202.1[3]	3287.6	38.2

At several sites artefacts can be collected from natural exposures of the Pleistocene and Holocene deposits outcropping along the margins of the estuary (Table 1). At Ley Pill (Woolaston) the archaeological sediment is in a primary context sandwiched between undisturbed gravels of the First Terrace and later disturbed gravels and alluvial silts. The only other primary stratified contexts now evident in natural exposures are ditches and pits cut in the uppermost Wentlooge Formation at Rumney Great Wharf, and ditches and a palaeochannel incised into these beds at Oldbury Flats. Secondary stratified contexts are provided by natural exposures of the Rumney and Awre Formations at Horse Pill, by the Rumney Formation at Pill House, and by all three post-embanking units at Oldbury Flats. The archaeological material tends to be concentrated at or near the erosional bases of these units.

In a similar manner to the famous Romano-British site of Meols on the retreating coast of the north Wirrall (Griffiths *et al* 2007), the modern intertidal beaches of the Severn Estuary afford major archaeological contexts in the area. As explained earlier (Allen and Fulford 1987, 1992; Allen 1998, 1999), artefacts have been transposed because of erosion from both primary contexts exposed along the shore and from exposed secondary stratified contexts in the post-embanking formations described. These various stratified contexts, combined with the modern beaches, comprise a sort of 'archaeological cascade' in which, as the marshy shores of the estuary repeatedly retreated and readvanced in response to regime change on a centennial scale, artefacts were repeatedly released from stratified contexts only to become buried again when newer and younger deposits grew up. At Rumney Great Wharf, for example, there are post-medieval sand

Table 3. Occurrence of iron ore at sites on the Severn Estuary Levels. Footnotes: 1 = present as coatings of powdery haematite on some specimens; 2 = burnt to magnetite (?furnace waste); 3 = present as small lumps of reddle.

Site	**Botryoidal**	**Stalactitic**	**Facies (no.)**			
			massive	**layered**	**earthy**	**total**
Awre (Whitescourt)	2	1	1	-	-	4
Lydney Park Farm	1	1	-	-	-	2
Ley Pill	-	-	-	-	-	-
Horse Pill, beach, Ccliff	3	3	4	-	-	10
Pill House	14	3	4	2	presemt[1]	23
Rumney Great Wharf	-	1	1	-	present[1]	2
Elmore (Windmill Hill)	-	-	-	-	-	-
Longney C	-	-	1	-	-	1
Longney A	-	-	1	-	-	1
Longney B	-	-	-	-	-	-
Arlingham	-	-	-	-	-	-
Whitminster (Packthorne Farm)	-	-	-	-	-	-
Hills Flats, Severn House & Dayhouse Farms	8	3	4	2	present[1]	17
Oldbury (Home Farm)	1[2]	-	-	-	-	1
Oldbury Flats	31	18	35	1	3[1,3]	88

layers that yield recycled prehistoric, Romano-British and medieval pottery and other occupation debris. The consequences for interpretation are several. The wave and tidal currents that affect the estuarine beaches disperse, fragment, abrade and sort by size, density and shape the artefacts released. Assemblages consequently become biased, the smaller, more fragile and softer items having been preferentially reduced in proportion or removed. As an example, microscopic artefacts, such as hammerscale, often found in primary contexts, are generally no longer recoverable under these circumstances.

Given this range of contexts, and the fact that the slags are essentially glasses with a chemistry akin to the geologist's basic-ultrabasic igneous rocks, it is not surprising that the preservation of iron-making debris is very variable. Washing of sediments from some stratified contexts has revealed microscopic iron-making debris, supplementing the evidence provided by macroscopic material. Slag lumps in primary contexts commonly have more or less thick coatings of post-depositional, orange, limonitic material and, if relatively vesicular, can be rotted, making them unsuitable for chemical analysis. The same limonitic material, however, cements together the finer-grained dumped waste, occasional lumps of which survive transposition onto the less exposed beaches, allowing microscopic residues to be retrieved. Stirring by waves and tidal currents on the beaches generally cleans slag lumps of any limonitic coatings, revealing their original form, as is especially the case on the relatively exposed pocket beaches at Rumney Great Wharf.

Table 4. Charcoal by wood species found in association with iron-making debris on the Severn Estuary Levels. Footnotes: 1 = Millend Lane, Blakeney (Barber and Holbrook 2000); 2 = Chesters Villa (Fulford and Allen 1992); 3 = Rumney Great Wharf (Fulford et al *1994); 4 = Oldbury Flats (Allen and Fulford 1992).*

Species	**MLB[1]**	**CV[2]**	**RGW[3]**	**OF[4]**
Alder (*Alnus* sp.)	x	x	-	x
Ash (*Fraxinus excelsior*)	x	-	-	-
Birch (*Betula*)	x	-	-	x
Cf. chestnut (*Castanea* sp.)	x	-		-
Elm (*Ulmus* sp.)	x	-	x	-
Gorse/broom (*Ulex/Cytisus*)	-	x	-	x
Guelder rose (*Viburnum opulus*)	x	-	-	-
Hawthorn (*Crataegus monogyna*)	x	-	-	-
Hazel (*Corylus avellana*)	x	x	x	x
Holly (*Ilex aquifolium*)	x	-	-	-
Maple (*Acer campestre*)	x	-	x	x
Oak (*Quercus*)	x	x	x	x
Poplar/willow (*Populus/Salix*)	x	-	-	x
Prunus group	-	x	-	x
Rosaceae Pomidea	x	-	-	-
Spindle (*Euonymous europeaeus*)	x	x	-	-

ORES

Pieces of ore are known in very variable amounts from more than half of the main sites listed in Table 1. Slag is occasionally found to have trapped small fragments of ore ('fines'), notably at Elmore (Windmill Hill) and Longney A, where very few or no discrete lumps of ore are known. Goethite dominates over haematite (Table 2) and all of the facies described above are represented (Table 3), botryoidal forms being more common than either massive or stalactitic varieties. A little reddle occurs in the main primary context exposed on the marsh cliff at Oldbury Flats and is also known from Chesters villa. The ores are for the most part free from disseminated, very finely crystalline quartz, which points toward the Forest of Dean as the source area.

The larger assemblages include one or two lumps weighing a few hundred grams, suggesting that they were part of an unsorted supply of ore direct from the mines. Most lumps, however, lie in roughly the range of 10-50 g, the size (walnut) that seems to have been preferred for smelting, implying a process of on-site beneficiation. Fulford and Allen (1992) recorded from the semi-industrial site at Chesters villa a number of rimmed settings of stout, horizontal stone slabs that could have been used, among other purposes, for crushing ore. The large amounts of ore found here, chiefly goethite but including reddle, ranged from small chips to lumps weighing as much as 1.93 kg. What could have been goethite ore was reported from Thornwell Farm (Hughes 1996) but, curiously, only slag and furnace lining were recorded from the substantial iron-making site at Blakeney (Barber and Holbrook 2000).

FUELS

Evidence for the use of charcoal can be found at most Romano-British sites on the Severn Estuary Levels and it is clear at many that coal, perhaps chiefly from the Forest of Dean, was also exploited. Charcoal was probably the fuel

Table 5. Occurrence of furnace lining at sites on the Severn Estuary Levels.

Site	Slag-free lining			Fused lining		Lining with slag	
	no.	total wt. (kg)	av. wt. (kg)	no.	total wt. (kg)	no.	total wt. (kg)
Awre (Whitescourt)	16	0.548	0.034	8	0.179	33	5.909
Lydney Park Farm	-	-	-	-	-	-	-
Ley Pill	14	0.334	0.024	-	-	-	-
Horse Pill, beach, cliff	-	-	-	1	0.014	2	0.176
Pill House	1	0.045	0.045	2	0.021	-	-
Rumney Great Wharf	20	0.505	0.025	6	0.177	19	4.174
Elmore (Windmill Hill)	2	0.036	0.018	-	-	-	-
Longney C	2	0.189	0.095	-	-	1	0.031
Longney A	3	0.084	0.025	-	-	-	-
Longney B	-	-	-	-	-	-	-
Arlingham	-	-	-	2	0.055	-	-
Whitminster (Packthorne Farm)	-	-	-	-	-	2	0.219
Hills Flats, Severn House & Dayhouse Farms	24	0.432	0.018	-	-	7	0.418
Oldbury (Home Farm)	8	0.090	0.011	-	-	1	0.173
Oldbury Flats	8	1.379	0.172	-	-	-	-

employed metallurgically as well as domestically. Except perhaps to preheat furnaces or fire-up charges, coal is unlikely to have been used for iron-smelting, because of the presence of volatiles, lowering the temperature that could be achieved, and deleterious sulphur.

Perhaps the firmest evidence for the use of charcoal in iron-smelting is afforded by lumps of slag that had entrapped small fragments of the fuel (see below). These have been found at Awre, Ley Pill, Rumney Great Wharf, Longney C, Longney A and Oldbury Flats. Fragments of coal trapped in slag at Awre, Horse Pill and Hills Flats (Severn House Farm) suggest that here this fuel was burned as a preliminary to smelting (see below).

The composition of charcoal associated with iron-making debris is known from four sites on or linked with the Severn Estuary Levels (Table 4), the evidence pointing to a single, distinctive tradition of fuel production. The site at Blakeney (Millend Lane) lies on the steep, dissected northeastern slopes of the Forest of Dean. Here the charcoal is dominated by small roundwood probably drawn from short-rotation coppices (Barber and Holbrook 2000). These could have been situated both on the slopes with locally sandy soils, as suggested by the presence of gorse/broom, and in the moist stream valleys. At the Chesters villa (Fulford and Allen 1992) further downstream, the fuel is dominated by small roundwood branches up to 18 years old which are likely to have come from managed woodlands in the hills of the Forest nearby to the west and also from wetlands along the estuary margins. The presence of spindle, preferring calcareous soils, is compatible with a nearby wooded outcrop of the Carboniferous Limestone Series. Small roundwood, probably sourced mainly from the embanked wetland, was also used for charcoal at Rumney Great Wharf (Fulford *et al*. 1994). Spindle occurs again here, but is perhaps more likely to have come from woods sited on the outcrop of the calcareous Lias (Lower Jurassic) than the more distant Carboniferous Limestone Series. The presence of gorse/broom points to the nearby presence of acid, well-drained soils, perhaps developed on the extensive outcrop of river terrace gravels at Cardiff to the west or a

Pleistocene fluvioglacial deposit to the north. The evidence from Oldbury Flats (Allen and Fulford 1992), the only site with analysed charcoal on the east bank of the estuary, again demonstrates the use of small roundwood, up to 16 years old in this case, either opportunistically gathered or from managed woodlands.

FURNACE-LINING AND FURNACES

With most sites yielding one sort or another, three varieties of furnace lining are recognised at Romano-British sites on the Severn Estuary Levels: slag-free lining, fused lining, and lining with adhering slag (Table 5). Furnace lining consists of clayey material which, as part of the structure of a furnace, was affected by the heat of smelting.

Slag-free lining occurs at most sites. It consists of flat to curved pieces of hard, brick-like, baked clay which display a cross-sectional sequence of colours and textures explicable in terms of the response of the parent material to the temperature gradient created in the walls of a smelting furnace. Typically, the baked clay is seen to grade from orange-red or cherry red (*c* 500°-700°C) to dark red, and then to dark purplish-grey with scattered spheroidal vesicles, and finally to an opaque (other than occasionally in thin-section), purplish-black or black, highly vesicular glass (*c* 1100°-1300°C) with a dull to bright, uneven surface ablated by the intensely hot furnace gases. These surfaces frequently display sub-parallel streaks and drips, pointing to loss of material that had become soft and viscous. The sloughed material would have become incorporated into the furnace charge. Less commonly, the baking sequence points to a more reducing environment, ranging from pale grey clay to dark grey, slightly vesicular clay, and finally to black, highly vesicular glass, again with a surface marked by streaks or drips. Thin-sections reveal that any quartz sand present once vesicles have begun to appear is filled with fine hair-cracks. A thickness of between about one and five centimetres is generally sufficient to reveal these baking sequences. The furnace walls as a whole, however, are likely to have been much thicker (*c* 20 cm) than the few centimeters registered by the baking sequence and, except at the site of a furnace, the much thicker but less-affected, and therefore softer, outermost clay is almost never seen.

The affected clayey material, varying from site to site, ranges from sand-free silty-clay, to slightly-moderately sandy silty-clay, to abundantly sandy silty-clay occasionally with quartz granules and even a few pebbles of sandstone, quartzite or vein-quartz (Table 6). As with much pottery, a coarse temper was often deliberately added where it was conveniently available, in order to reduce shrinkage and improve heat resistance. At sites on the Holocene outcrop (Table 1), such as Hills Flats, Oldbury (Home Farm) and Oldbury Flats, the sandiest varieties tend to be conspicuously absent or rare. Sandy clays dominate at sites such as Awre (Whitescourt) and Longney, lying on or very near Pleistocene river terrace deposits. There are, however, exceptions. The site at Rumney Great Wharf, lying well within the Holocene outcrop, is dominated by lining formed from abundantly sandy silty-clay and commonly is pebbly, while that at Ley Pill, on the First Terrace, yields only lining of silty-clay. While it is unlikely that the clays and other materials used to build furnaces were procured other than locally, they were not necessarily obtained from the immediate environment of a site.

The name *fused lining* is applied to discrete, generally spheroidal masses a few centimetres across of purplish-black to black, highly vesicular, glassy material with a dull to bright, slightly lumpy surface. These bodies are the least widespread and common of the varieties distinguished in Table 5. They are considered to represent clayey material that either melted and then sloughed off the inner walls of furnaces or lumps deliberately included in the furnace charge (see below). Their dark colour, opaqueness, and uniformly glassy surfaces distinguishes them from the small masses of fuel-ash slag occasionally found.

Lining with adhering slag is found at almost half of the sites on the Severn Estuary Levels, but is generally less abundant than the slag-free form (Table 5). This third variety of lining combines most of a baking sequence of clayey material, as reported above, but with an attached substantial quantity of fayalitic slag. The baking sequences are similar to those described, except for the highly vesicular, glassy stage,

Table 6. Composition of furnace lining at sites on the Severn Estuary Levels.

Site	**Silty-clay**		**Slightly-moderately sandy-silty-clay**		**Abundantly sandy-silty-clay**	
	no.	**no. %**	**no.**	**no. %**	**no.**	**no. %**
Awre (Whitescourt)	-	-	32	65.3	17	34.7
Lydney Park Farm	-	-	-	-	-	-
Ley Pill	14	100.0	-	-	-	-
Horse Pill, beach, cliff	-	-	2	100.0	-	-
Pill House	1	100.0	-	-	-	-
Rumney Great Wharf	14	35.9	3	7.7	22	56.4
Elmore (Windmill Hill)	-	-	1	50.0	1	50.0
Longney C	1	33.3	-	-	2	66.7
Longney A	-	-	2	66.7	1	33.3
Longney B	-	-	-	-	-	-
Arlingham	-	-	-	-	-	-
Whitminster (Packthorne Farm)	-	-	2	100.0	-	-
Hills Flats, Severn House & Dayhouse Farms	25	80.6	4	12.9	2	6.5
Oldbury (Home Farm)	6	66.7	3	33.3	-	-
Oldbury Flats	5	62.5	3	37.5	-	-

which tends to be only weakly developed. Typically, the attached slag is pillulous, with numerous irregular vesicles and larger internal cavities. It mainly occurs as (downward-)sloping masses, as if support from below had been partly lost or weakened, and in some cases as large, pendulous, drip-like blobs.

The larger pieces of furnace lining afford some insight into the size and shape of the various furnaces used for iron-making on the Severn Estuary Levels, for direct archaeological evidence of these structures is known only from the supplementary site of the Chesters villa (Fulford and Allen 1992). Excavations here uncovered the basal portions of what appeared to be numerous shaft furnaces (Coghlan 1956; Cleere 1972; Tyelcote 1986; Schrüfer-Kolb 2004), but seemingly not of the sunken type from the Iron Age as described by Hall (2008). Lining curved in a single direction can be inferred to have come from a cylindrical furnace or from one that included a cylindrical section, that is, from some type of shaft furnace. Where lining is curved in two directions at right-angles, the furnaces may be supposed to have had a curved or even partly domed upper part (slag-free lining) or a bowl-shaped lower part (lining with attached slag). Some type of bowl furnace is implied, either the simple, non-slag-tappable bowl furnace, or the slag-tappable developed bowl furnace (Tylecote 1986). The measured diameters of these curves are, of course, true only of particular positions within a furnace, and are not necessarily typical of the structure as a whole.

The site at Awre afforded much lining suggestive of shaft furnaces. Two large fragments in particular yielded internal diameters of *c* 18 cm and *c* 22 cm respectively. These values are somewhat smaller than the diameters of many excavated tall shaft furnaces (eg Tylecote and Owles 1961; Fulford and Allen 1992; Schrüfer-Kolb 2004). A large piece of lining from Ley Pill had the form of the flat floor of a furnace, probably of the shaft type, where it joined part of the vertical wall. The lower parts of bowl furnaces are indicated by fragments of lining from

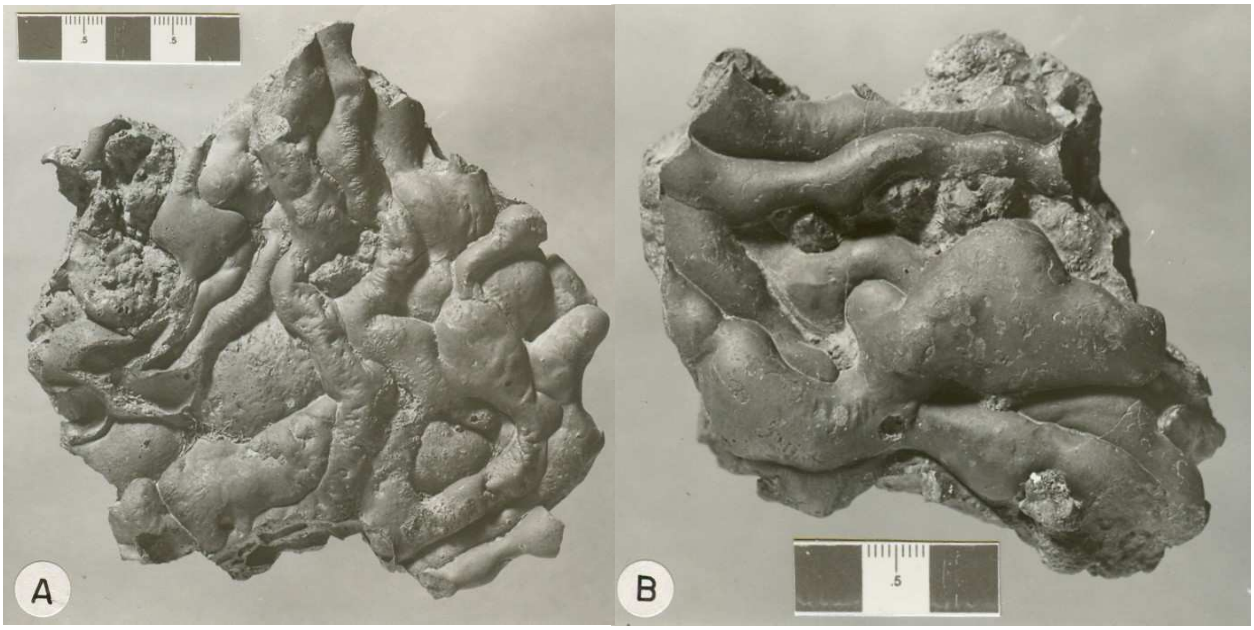

Figure 3. Representative tap slags (upper surfaces). A- Ley Pill. B - Oldbury Flats.

Awre and Rumney Great Wharf. Horizontal diameters measured *c* 23-28 cm and vertical ones between *c* 16 cm and *c* 21 cm. Also from Awre came a large fragment with a glassy, vesicular surface curved in one direction only that yielded an internal diameter of only *c* 9 cm, suggestive of a short, narrow chimney fitted to a furnace top.

The ability to tap slag from many shaft furnaces and developed bowl furnace allowed these furnaces to be relined with clay and used for more than one smelting. Multiple baking-sequences were recorded from furnaces at the Chesters villa (Fulford and Allen 1992) and from many furnaces excavated on the Jurassic Ridge in the East Midlands (Schrüfer-Kolb 2004). On the Severn Estuary Levels, lining with double baking-sequences has been found at Awre, Hills Flats (Dayhouse Farm) and Oldbury (Home Farm).

The compression of the airflow over the top of a furnace, the upward increase in velocity from ground level within the atmospheric boundary-layer, and gas buoyancy within the furnace combine to create a 'chimney effect' and allowed shaft furnaces built in the open to be blown largely if not wholly by natural draught (eg Juleff 1996). A bellows-driven forced draught may have been needed only during the earliest stages of a smelt, when the charge was being set alight and raised to the desired temperature. The use of a forced draught was essential, however, in the case of the much less elevated and possibly more open bowl furnaces. The archaeological evidence for the use of forced draughts takes the form mainly of finds of conical clay *tuyères* and of pieces of furnace lining that mould these devices. One such fragment of lining occurred at Oldbury Flats and a second was recorded from Chesters villa (Fulford and Allen 1992).

TAP SLAGS AND FURNACE BOTTOMS

Tap slags

In the absence of the remains of furnaces *in situ*, the firmest proof of iron-making at an archaeological site is the presence of dense, iron-rich tap slags with a trace-element content similar to average shale. This latter aspect of the chemistry of tap slags is important, at least in southwestern Britain, where commercial copper-smelting at widely scattered sites during the eighteenth and nineteenth centuries using the double sulphide with iron (eg Day 1973; Noall 1985; Hughes 2000) produced tap slags which, morphologically and in terms of bulk chemistry, are essentially indistinguishable from their iron-making cousins (eg Allen and Fulford 1990). These slags, containing significantly elevated levels of copper, occur not only at the sites of copper smelting, but became dispersed through use for hardcore and architecturally and in agriculture for soil improvement.

Table 7. Distribution and abundance of tap slag and furnace bottoms at sites on the Severn Estuary Levels.

Site	Tap Slag			Furnace bottoms			Tap slag relative to all slags (wt. %)
	no.	av. wt. (kg)	total wt. (kg)	no.	av. wt. (kg)	total wt. (kg)	
Awre (Whitescourt)	25	0.159	3.965	128	0.562	71.926	5.2
Lydney Park Farm	15	0.055	0.818	1	0.699	0.699	53.9
Ley Pill	42	0.138	5.799	6	0.304	1.822	76.1
Horse Pill, beach, cliff	20	0.020	0.395	5	0.561	2.806	12.3
Pill House	53	0.030	1.589	1	0.445	0.445	78.1
Rumney Great Wharf	-	-	-	58	0.422	24.471	0.0
Elmore (Windmill Hill)	49	0.035	1.694	3	0.429	1.288	56.8
Longney C	30	0.032	0.954	1	2.083	2.083	31.4
Longney A	40	0.102	4.090	3	1.183	3.549	77.6
Longney B	9	0.178	1.602	-	-	-	100.0
Arlingham	22	0.068	1.493	2	0.149	0.298	83.4
Whitminster (Packthorne Farm)	4	0.049	0.195	-	-	-	100.0
Hills Flats, Severn House & Dayhouse Farms	44	0.048	2.131	51	0.356	18.142	10.5
Oldbury (Home Farm)	9	0.044	0.400	11	0.226	2.481	13.9
Oldbury Flats	64	0.092	5.918	19	0.470	8.928	39.9

Tap slags, chiefly from the bloomery iron-making process, have often been described (Sperl 1980; Bachmann 1982; McDonnell 1983; Crew 1995; Bayley *et al* 2001; Schrüfer-Kolb 2004) and examples from the Severn Estuary Levels prove to be typical. These residues are recorded from all but one of the sites shown in Figure 2 and at many localities are extremely abundant (Table 7), greatly outweighing slag furnace bottoms ((see below).

Morphologically, tap slags are characterized by a ropy top (Figure 3) and an underside that moulds the particular surface over which the liquid slag had flowed and frozen after its release from the furnace. The ropiness, resembling features seen on some lavas, consists of smooth, irregularly-arranged to sub-parallel, finger-like shapes which typically conceal a rounded vesicle of a similar form but lesser size within their interiors. These large 'fingers' seem to have arisen as hot and comparatively liquid slag repeatedly broke through the hardening crust that formed as the uppermost layers of the flowing mass began to freeze. Occasionally, single fingers of slag are found, which presumably represent material that had burst forward from the leading edge of a flow. Some lumps of tap slag take the form of flat sheets no more than 5-10 mm thick with a smooth to irregular underside, the unusual thinness, coupled with the low relief of the upper surface, suggesting that the slag from which they formed was at a high temperature and extremely fluid. Typically, the lumps are a few centimetres thick, however, and appear to have chilled on an uneven surface of soil, elements of which are occasionally trapped by the slag. It is not uncommon to find small fragments of charcoal, iron ore and even pieces of older slag preserved on the undersides of lumps. The undersides of some lumps preserve the form of narrow, V- or U-shaped channels, evidently cut into the ground to guide the flowing slag from the furnace to some convenient collecting hollow. The structure of the largest masses of tap slag show that they arose as the molten residues from one smelting after

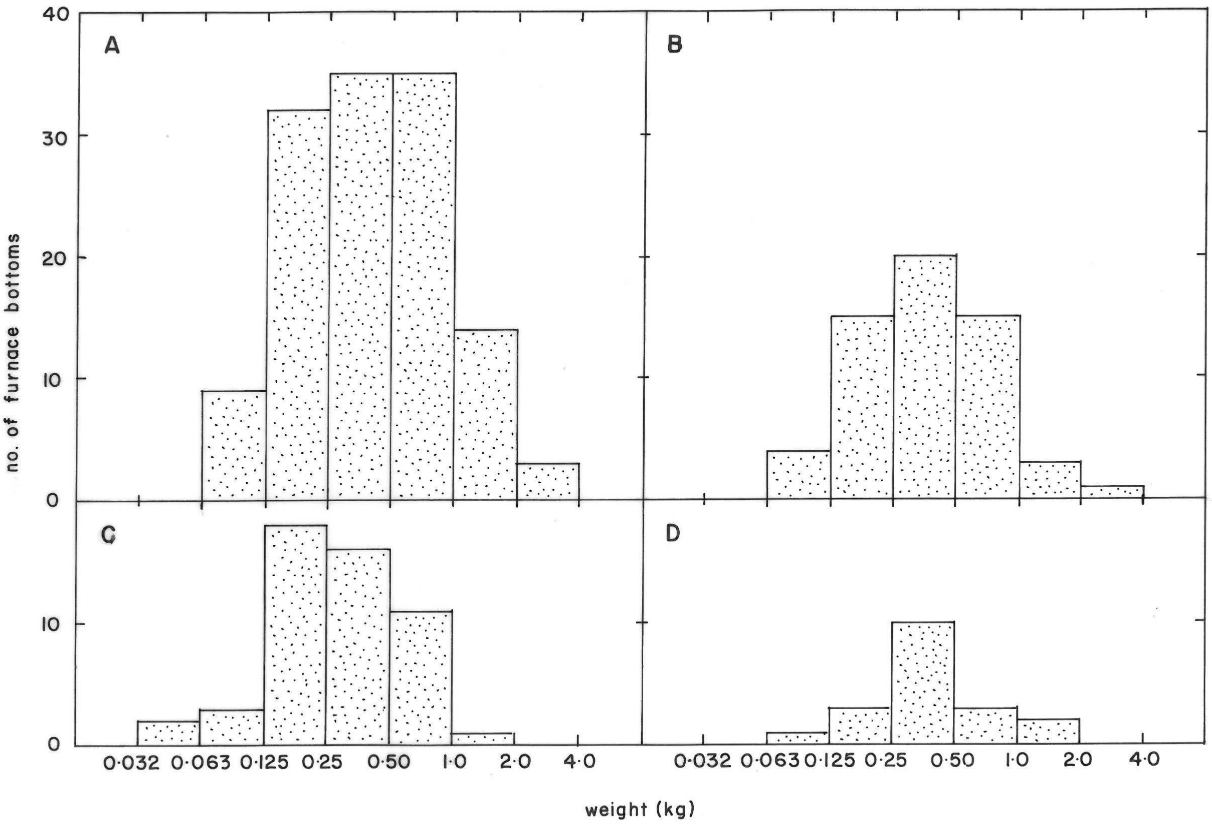

Figure 4. Weight-frequency-distributions of furnace bottoms. A - Awre (Whitescourt); B - Rumney Great Wharf; C - Hills Flats with Dayhouse and Severn House Farm; D - Oldbury Flats.

another were allowed to accumulate at the same sunken place. Masses weighing up to 17.6 kg were recorded from the Chesters villa on the west bank (Fulford and Allen 1992).

Tap slags from the Severn Estuary Levels are dense, dark grey to greenish-black in colour and streak, and with a generally very low to low content of almost invariably very small vesicles (excepting the fingers). Broken surfaces reveal the slags to be glass-like but with evidence for a variable crystalline component, as illustrated by Sperl (1980) and Bachmann (1982). X-ray diffraction analyses of the crystalline phase (Allen and Fulford 1987) in 12 samples from six sites revealed the presence of wüstite (FeO, 10-79%) and fayalite ($2FeO.SiO_2$, 10-96%), together with very occasional traces of quartz, presumably a contaminant from the ground. No traces of ore or other minerals were found.

Furnace bottoms: general character

Another kind of iron-rich slag commonly found on Romano-British archaeological sites takes the form of plano-convex to concavo-convex, cake-like masses weighing from a few tens of grams to a few kilograms. These have been divided between furnace bottoms and smithing-hearth bottoms (Sperl 1980; Bachmann 1982; McDonell 1983; Bayley *et al* 2001; Schrüfer-Kolb 2004), but the two are difficult to separate, unless they are examined in sliced form, and are likely to have been frequently misidentified (eg furnace bottoms for smithing-hearth bottoms). The two represent quite distinct processes. Furnace bottoms consist of slag that settled to the base of an iron-making furnace during a single smelt. If this was a tappable furnace with a depressed base, the cake-like mass is likely to display a 'handle' where the slag spilled over the narrow sill at the exit to the structure, as was seen at Chesters villa (Fulford and Allen 1992). No such handle will occur on slag cakes that froze against the ground at the

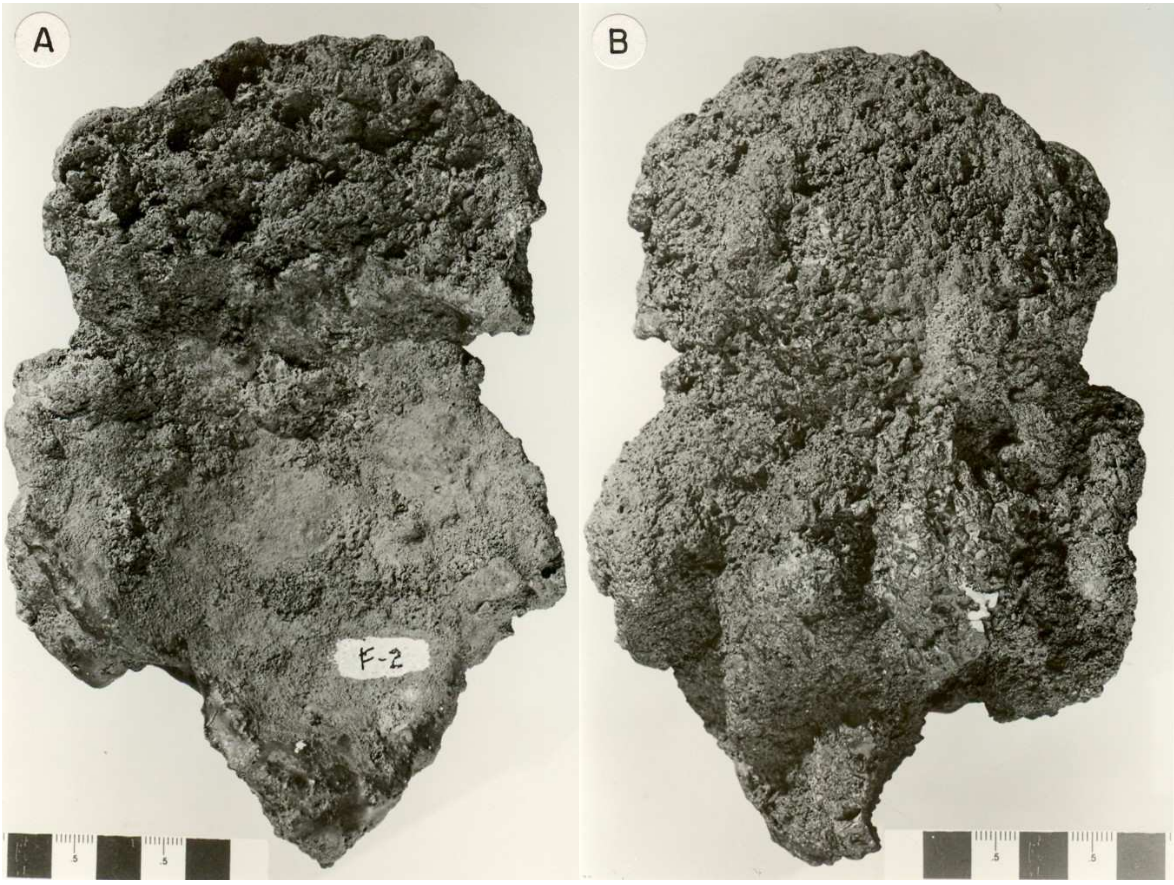

Figure 5. Representative furnace bottom, Awre (Whitescourt). A - upper surface. B - lower surface, showing the casts of marks made by digging tools.

bottoms of simple bowl furnaces that could not be tapped. Because furnace bottoms form as the result of a *single action* – an individual smelt – they show no internal stratification, although some properties may display a smooth gradation away from the contact with the ground. In contrast, a smithing-hearth bottom arises in stages *over a period of time* at the base of a repeatedly reactivated hearth used for bloom-refining or other heavy forge work. Consequently, they are stratified internally in some way through the variable development of such as vesicles and/or inclusions of ore and/or fuel. The slag cake interpreted by Bayley *et al* (2001, fig. 21) as a smithing-hearth bottom, for example, displays two layers, a lower one with abundant large vesicles and scattered inclusions, and a sharply defined, upper one with no inclusions and distinctly fewer and smaller vesicles.

Slag vesicles form in two ways and afford clues as to the thermal regimes in furnaces and hearths. Those produced by outgassing from the slag as it cooled while remaining liquid tend to be rounded, with concave, inward-facing surfaces, although not necessarily small and spheroidal. They indicate a slag at a comparatively high temperature, and consequently relatively low viscosity, such as could be tapped from the upper parts of the pool of slag that had sunk to the bottom of a furnace. Tap slags provide excellent examples of this type of gas vesicle, from the small, spheroidal ones typical of the main parts of the slag to the elongated but still rounded large ones within the surface 'fingers'. Relatively small, spheroidal vesicles are also commonly found in furnace bottoms, where they tend to be more abundant than in tap slags. Those that arose near the contact with the ground occasionally are elongated at right-angles to this contact, as if bubbles of gas were attempting to escape the gradual, inward-march from below of the concave freezing-front. The second origin of vesicles is through the incomplete agglomeration of pillules of relatively viscous, cooler slag as they sank down toward the bottom of a furnace or hearth and began to coalesce. Typically, these vesicles are large and irregular in form, with many convex inward-facing margins, an observation consistent with the lower temperatures to be found toward the floor of a furnace, below the fiercely heated regions where the smelting reaction takes place and slag is at its most liquid. The same kind of vesicle is also common in smithing-hearth bottoms, again suggestive of a comparatively low temperature.

A forced draught was required for most furnaces and certainly for all smithing hearths. Bayley *et al* (2001) suggest that the depression found on the upper surface of many slag cakes was shaped by the air blast from a downward-pointing *tuyère*. It is much more likely that the concavo-convex form typical of furnace bottoms - and also seen on smithing-hearth bottoms - simply records the substantial contraction of the slag as it chilled and lost exsolving gases.

Furnace bottoms have been identified at all but two sites on the Severn Estuary Levels, where they vary considerably in both absolute and relative abundance (Table 7). A total of 289 well-preserved examples were recorded, of which almost one-half came from a single site (Awre (Whitescourt)). They also range considerably in size, the smallest weighing just 38 g (Hills Flats) and the largest 3350 g (Awre (Whitescourt)). Weight frequency-distributions prepared for localities yielding sufficient furnaces bottoms suggest that the typical weight is site-specific (Figure 4, Table 7). The largest occur at Awre and the smallest at Hill, at about half the weight, with Rumney Great Wharf and Oldbury Flats falling in between. The furnace bottoms are dense and dark grey to greenish black on freshly broken surfaces, with hints of crystallinity. X-ray diffraction of the crystalline phase in nine furnace bottoms from five sites (Allen and Fulford 1987) showed

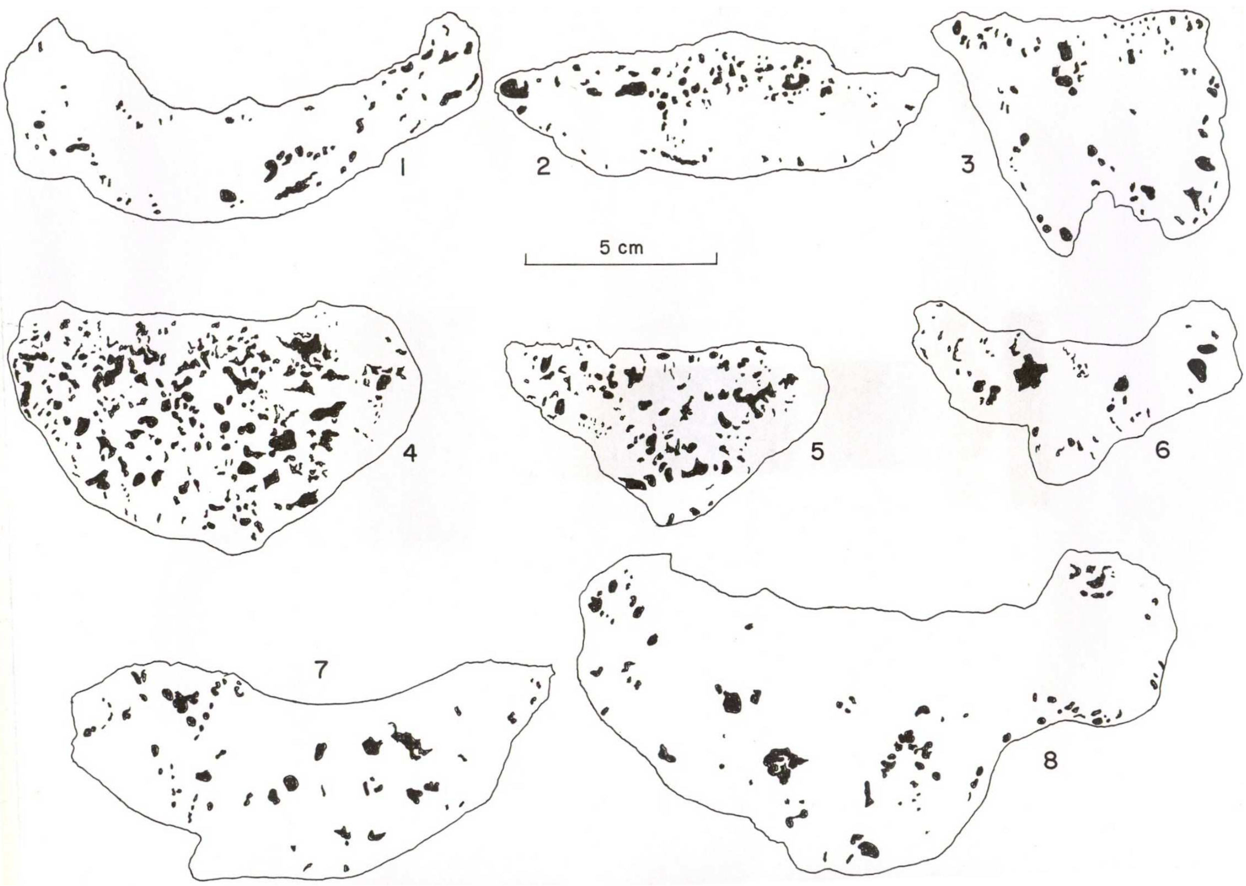

Figure 6. Cross-sectional profiles of sliced furnace bottoms. 1-3 - Awre (Whitescourt); 4-6 - Rumney Great Wharf; 7,8 - Oldbury flats. Note that only the larger vesicles have been depicted.

Table 8. Frequency of tool marks on the underside of furnace bottoms from the Severn Estuary Levels.

Site	No. of furnace bottoms	Frequency and character of tool marks					
		absent	vague	pointed	square-rounded	trapezoidal	rod-shaped
Awre (Whitescourt)	128	26	11	64	28	-	4
Lydney Park Farm	1	1	-	-	-	-	-
Ley Pill	6	4	1	1	-	-	-
Horse Pill, beach, cliff	5	2	-	3	-	-	1
Pill House	1	1	-	-	-	-	-
Rumney Great Wharf	58	11	6	23	10	3	7
Elmore (Windmill Hill)	3	2	1	-	-	-	-
Longney C	1	1	-	-	-	-	-
Longney A	3	3	-	-	-	-	-
Longney B	0	-	-	-	-	-	-
Arlingham	2	1	1	-	-	-	-
Whitminster (Packthorne Farm)	0	-	-	-	-	-	-
Hills Flats, Severn House & Dayhouse Farms	51	14	1	19	8	-	1
Oldbury (Home Farm)	11	6	1	2	2	-	2
Oldbury Flats	19	7	-	10	-	2	1

slightly less wüstite (9-78%) and fayalite (0-69%) than in tap slags. Generally subordinate amounts of goethite (?ore) were recorded from some samples, together with traces of quartz (?ground contaminant) and, in one sample, potassium feldspar.

In plan the furnace bottoms range from almost circular to oval or irregular and up to about twice as long as wide. In a subordinate number of cases, the upper surface combines a comparatively smooth, concave area - a free surface of once-liquid slag on which floated the occasional piece of fuel - with a portion, generally at either one end or forming a continuous encircling band round the edge, occluded by a mixture of charcoal, some unspent ore and orange-brown, post-depositional alteration products (Figure 5A). In most cases the upper surface is fully occluded by a variably thick mixture of these materials, which in some cases also preserves a little fuel-ash slag and the casts of straw and twigs and occasionally coal, perhaps fuel used to light the furnaces. Slicing reveals a normally concave-up top concealed beneath the occluding material. Typical profiles and vesicle abundances and distributions appear in Figure 6. Vesicles are readily picked out by rubbing a hard, white, cold-cream soap with a circular motion over the dampened sliced surface. The soap infills the vesicles, causing them to stand out against the dark slag.

Almost all the furnace bottoms recovered from the Severn Estuary Levels froze against the ground and not against a clay lining. The undersides consequently record the form of the base of the hollowed-out, but incompletely lined, ground surface, and occasionally reveal items that had either strayed into the hollow or been deliberately introduced. In addition to grains of sand or pebbles captured from the substrate, the former include fragments of charcoal, ore and, very occasionally, hammerscale (see below). The latter are fuel-ash slag, impressions of grass or straw and, very rarely, particles of coal.

Table 9. Frequency distribution of pointed marks on furnace bottoms from the Severn Estuary Levels.

No. marks per furnace bottom	Frequency (no.)	Frequency (%)
1	47	38.5
2	36	29.5
3	28	23.0
4	8	6.6
5	3	2.5
Totals	122	100.1

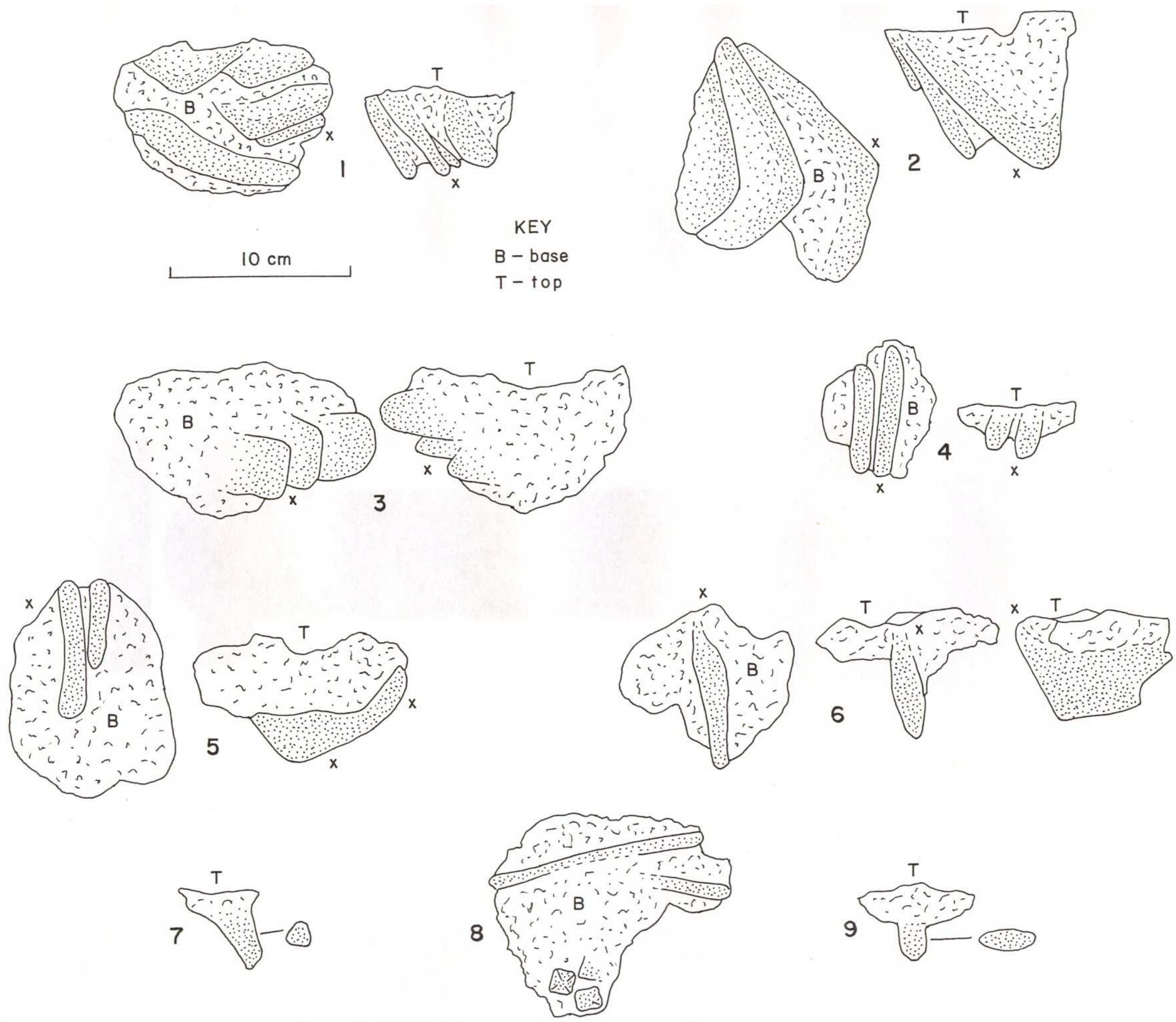

Figure 7. Types of toll marks preserved on furnace bottoms from the Severn Estuary Levels. 1,2 - pointed Awre; 3,4,5 - square-rounded, Rumney Great Wharf; 6 - trapezoidal, Oldbury Flats; 7 - triangular sectioned rod, Rumney Great Wharf; 8 - square-sectioned rod, Awre; 9 - oval-sectioned ?mattock, blade, Rumney great Wharf.

Furnace bottoms: tools marks

Of the total of 289 furnace bottoms recovered, the undersides of only 79 (27.3%) lacked casts of the marks left in the ground by the tools used to shape or probe the furnaces (Figure 5B). Such *tool marks* were found on the undersides of slag cakes from nine sites and, it should be emphasized, across the full range of weights. They are classified according to shape as *vagu*e, *pointed*, *square-rounded*, *trapezoidal* or *rod-shaped* (Table 8). At the more prolific sites, the proportion of slag cakes with the marks varies from *c* 50% to *c* 80%. As many as four or five marks, in some cases of more than one kind, are found on some furnace bottoms. Using the tops of the cakes as a presumed horizontal reference, the tools recorded by the casts seem to have been driven into the ground at angles mainly between 50°-70° from the horizontal. The attitudes of the rod-shaped casts, however, suggest generally steeper angles of entry.

A small number of tool marks are best classified as vague. While definite protuberances on the undersides of the slag cakes, and thus attributable to penetration of the ground by some kind of implement, they lack any clearly defined shape, perhaps because the tool used was moved about significantly before retraction.

Pointed tool marks (Figure 7.1, 2) are by far the most frequent (Tables 8, 9). The marks are triangular in appearance, with a more or less rounded tip, and an angle of *c* 60°-120° between the straight sides. They commonly cluster in roughly shingled, partly offset groups, an indication that the craftsman using the implement worked it through the ground from a single (probably standing) position. Tool marks of this shape probably record the use of military-style entrenching tools of the kind discussed and illustrated by Manning (1970). These implements had a triangular blade on one side of the handle-socket and a pick-blade on the other.

Less common are square, with blunt right-angled corners, to smoothly rounded tool marks 6-12 cm across (Table 8, Figure 7.3-5). On some furnace bottoms these also occur as roughly shingled sets. Trapezoidal tool marks (Figure 7.6) are much fewer (Table 8). They have bluntly rounded corners but sloping rather than parallel sides. Only the very largest of these various marks are likely to represent square to rounded spade-sheaths. Typically, as illustrated by Manning (1970, 1985), these latter are at least *c* 15 cm across. Most and possibly all tool marks of the square-rounded class from the Severn Estuary Levels can be attributed to the use of mattocks, with a generally roughly square adze-blade on one side of the head and an axe- or pick-blade on the other. Goodburn (1976) illustrates from Chedworth Roman villa a well-preserved example, with a square blade *c* 12 cm across with slightly rounded corners.

Roughly pointed oval, circular, square and even triangular cross-sectional forms have all been observed among the rod-shaped tool marks (Table 8). Like some of the other tool marks, they occur singly or in small clusters (Figure 7.7-9). The largest are the oval ones, reaching a maximum long diameter of *c* 3.5 cm. The smaller of these various tool marks, and their generally steep attitude, suggest that some implements were used not so much to excavate the furnaces as to probe their contents once smelting had begun.

A variety of implements are likely to be represented by the pointed class of tool mark. The smaller, and especially the steeply inclined and clustered, marks would seem to record the use of rods of a range of cross-sectional forms. At Awre (Whitescourt), for example, a fragment of slag was recovered that had clearly begun to congeal around a straight, square-section rod before being prised off. A fragment that partly preserved the shape of a similar rod was also found at Oldbury Flats. Manning (1985) records amongst metal-working tools a *c* 60 cm, round-sectioned Iron Age poker, the closest item in his extensive survey to some of the rods inferred from the Severn Estuary Levels. The larger, oval marks recorded from a number of sites were perhaps made by the worn ends of the pick-blades of entrenching tools or mattocks, for rods of this size of a realistic length would have been too heavy and cumbersome to have served as practical tools.

HAMMERSCALE

It is not uncommon on wet-sieving archaeological sediments from sites of metallurgical activity to find feebly to strongly magnetic, microscopic particles up to several millimetres in size called hammerscale (Starley 1995; Bayley *et al* 2001; Schrüfer-Kolb 2004). Substantial amounts of hammerscale were recovered from Awre (Whitescourt) (Allen 1986; Allen and Fulford 1987), Ley Pill (Allen and Fulford 1987) close to the Chesters villa (Allen and Fulford 1992), and from Hills Flats (Severn House Farm) (Allen and Fulford 1987). Lesser amounts were recorded from Elmore (Windmill Hill) (Allen and Fulford 1990b) and Oldbury (Home Farm) (Allen 1997). Traces of hammerscale were also detected at Rumney Great Wharf (Allen and Fulford 1987), subsequent to the first report (Allen and Fulford 1986). The hammerscale found at the supplementary site of Millend Lane (Blakeney) was not regarded as significant in amount (Barber and Holbrook 2000).

Hammerscale represents forging activities but, as recorded from the Severn Estuary Levels, varies considerably in appearance (Allen 1986; Allen and Fulford 1987; see also Sim 1998). One broad category takes the form of spherical to spheroidal or stout, scale-like particles with features indicating that they had either chilled in flight or after landing on the ground while still plastic or even liquid. These could be spatter, formed as slag was hammered from within or off the surfaces of portions of blooms undergoing refining. The particles of a second broad type are thin and scale-like, with blistery tops and vesicular undersides. Some preserve the shape of an angle, others show a pattern of fractures, and others again are marked by delicate, parallel, hammer-induced striae. These would seem to be composed of slag dislodged from the surface of a piece of iron as it was forged, either in the late stages of bloom refining or during the fabrication of an iron object. The type(s) of hammerscale found at Millend Lane (Blakeney) is unknown, but examples of both categories occurred at the other listed sites.

METALLIC IRON

It is very unusual to find substantial masses of raw metallic iron on Romano-British archaeological sites, but such evidence, although not in itself conclusive of the process, is strongly suggestive of iron-making there. Depending on the slag content, these lumps are either blooms from the first stage of the bloomery process or small billets produced as the result of the forging of blooms during the second, refining stage (Tylecote 1986; Sim 1998; Bayley *et al* 2001).

As well as ore, tap slag and a single furnace bottom, Lydney Park Farm yielded an irregular but roughly equidimensional, much corroded mass of metallic iron with slag weighing 0.528 kg. This is the only site on the Severn Estuary Levels to have afforded such material, although small scraps of the metal, probably indicative of the fabrication of iron objects rather than smelting or refining, are common.

WEST BANK SITES (Figure 2)

Awre (Whitescourt)

A considerable dump of Romano-British bloomery slags was detected at this riverside site, material from which has been reworked as the result of probably repeated coastal erosion into the much younger Rumney and Awre Formations exposed at the present coast and also on to the associated beach (Allen and Fulford 1987, 1990a). The date range of the pottery associated with the slag is from the second to the fourth centuries AD, with a bias toward the third and fourth. Iron-making on a semi-industrial scale, both smelting and bloom-refining, is clearly proved by the quantity of residues (established geophysically), and by the combination of ore, furnace lining, slags and hammerscale (Tables 2, 5, 7). The predominance of furnace bottoms over tap slags (Table 7) suggests that production was almost entirely by simple bowl furnaces. Occasionally, a tappable furnace was used, but whether this was a shaft or a developed bowl furnace only excavation here can hope to establish.

Lydney Park Farm

Field-walking yielded relatively little material from this complex of buildings, which were excavated in the 1950s but without subsequent publication by the excavator. Fitchett (1986), reviewing the excavator's surviving notes, concluded that the buildings, then by a waterside with hard-standing, formed part of a large villa that dated on the basis of pottery from the second/third century. The field evidence suggests that iron-making was taking place but on an unknown scale. There is ore, roughly equal weights of tap slag and furnace bottoms, and apparently an iron bloom, but no furnace lining (Tables 2, 5, 7). Both tappable and simple bowl furnaces appear to have been in use.

Ley Pill (Woolaston)

The Ley Pill site is a small dump of iron-making waste situated *c* 150 m from the semi-industrial tips associated with the Chesters villa of the second to fourth century (Allen and Fulford 1987; Fulford and Allen 1992). It has yielded tap slag, furnace bottoms, furnace lining and much hammerscale (Tables 5, 7), together with a few, badly weathered, Romano-British pottery sherds of otherwise indeterminate date. In the field a little ore was seen.

The use of tappable furnaces predominated at Ley Pill and bloom-refining also took place. Because no furnace bottoms were recovered from the villa's excavated industrial site, however, the dump at Ley Pill may represent a separate and perhaps earlier iron-making location at which simple bowl furnaces as well as tappable ones were used.

Horse Pill, beach and cliff

The materials and residues related to iron-making here come from primary as well as a range of secondary contexts (Allen and Fulford 1987; Walters 1992). They include ore, furnace lining, tap slag and furnace bottoms (Tables 2, 5, 7). Slag, first-century 'native' wares, and Romano-British pottery were reported from the cliff-top fields. Waterside contexts yielded a small amount of pottery ranging in date from the second to the fourth century. The scale of iron-making is unknown but the preponderance of furnace bottoms amongst the slags suggests mainly the use of simple bowl furnaces.

Pill House

At this complicated, riverside site, iron-making debris is transposed into the lowest two and also the uppermost of four debris horizons, each associated with an erosion surface, stacked within a thick sequence of the youngest Holocene sediments (Allen and Fulford 1987). No pottery was found in the lowermost horizon, with abundant ore and slag. The second and third horizons yielded pottery dating from the seventeenth to the nineteenth century. No medieval wares have ever been found at any level. Although the metallurgical debris is not distinguishable in appearance and chemical composition (see below) from proven Romano-British assemblages in the area, the lack of pottery of this date – other than a fragment of Samian ware loose nearby on the shore - leaves open the possibility that the smelting recorded is younger. Also left open is the possibility that the activity did not occur locally, as there is evidence for a landing place at the site, which would have allowed slag from a distance to have been shipped out. With the advent of the blast furnace, many Romano-British and medieval slag dumps scattered about in the Forest of Dean were apparently reworked at so-called 'cinder-mines' as a source of 'ore' for use in water-powered smelters sited on streams (Hart 1971; Meredith 2006).

The iron-making materials found are ores, furnace lining, tap slag and a furnace bottom (Tables 2, 5, 7). The scale of the activity is difficult to judge, but it would seem that, as at Awre, the use of tappable furnaces predominated where the iron-making took place.

Rumney Great Wharf

The Romano-British settlement at Rumney Great Wharf (Allen and Fulford 1986, 1987; Fulford *et al* 1994), equipped with at least one well, came progressively to light as the result of coastal erosion. It presents a range of both primary and secondary contexts (Table 1), both kinds having yielded materials related to iron-making, the secondary ones in considerable quantities. The associated pottery collections are substantial and dominated by third- and fourth-century wares, although some of the second century are recorded. A Romano-British date was obtained by thermoluminscence analysis from a large fragment of furnace lining.

Rumney Great Wharf is unique among known sites on the Severn Estuary Levels in having yielded no tap slag but only furnace bottoms (Table 7). There is also ore, charcoal, furnace lining and traces of hammerscale (Tables 2, 4, 5). No furnaces have so far been unearthed, but it seems likely that most of the settlement has now been eroded away. Production would seem to have been on a substantial scale but based entirely on simple bowl furnaces. Apparently blooms were also refined at the site.

EAST BANK SITES (Figure 2)

Elmore (Windmill Hill)

The substantial area yielding Romano-British occupation debris on the embanked estuarine alluvium at Elmore could be the site of an important minor settlement, as stone and ceramic walling and roofing materials have been found (Allen and Fulford 1990b). The associated pottery is chiefly of third-fourth century date, with a few items from the second century. Iron-making materials are present, including a little furnace lining, much tap slag and a few furnace bottoms (Tables 5, 7). The scale of production is hard to judge, but it seems clear that chiefly tappable furnaces were in use.

Longney C

Longney C is the smallest of a cluster of Romano-British sites located by field-walking on the outcrop of embanked alluvium next downstream from Elmore (Allen and Fulford 1990b). Only scraps of Romano-British pottery have so far been recovered. The iron-making materials are a little ore and furnace lining, much tap slag and a furnace bottom (Table 2, 5, 7). Both tappable and simple bowl furnaces were in use, but the scale of production is uncertain.

Longney A

This extensive site is the main one at Longney (Allen and Fulford 1990a) and could represent an important minor settlement. The abundant pottery dates the site chiefly to the third-fourth centuries, but there are also significant quantities of wares from the second century and possibly earlier. That iron-making was taking place is clear from the presence of ore, furnace lining, abundant tap slag and a few furnace bottoms (Tables 2, 5, 7). Tappable furnaces were chiefly in use. The scale of production was probably substantial.

Longney B

Longney B is a small area defined by field-walking a few hundred metres to the southwest of site A (Allen and Fulford 1990a). The pottery assemblage is of broadly the same date as that from A, but is significantly different in terms of the wares present, perhaps expressing a different function for this location. Iron-making materials are not abundant and restricted to tap slag (Table 7).

Arlingham

This site on the alluvium is known from an extensive spread of industrial wastes, building materials, bones and teeth and several pottery sherds suggesting the later Roman period (Allen 1990; Allen and Fulford 1990a). Iron-making is evidenced by the presence of furnace lining, much tap slag and a few furnace bottoms (Tables 5, 7). Production was perhaps limited to a small or modest scale, mainly using tappable furnaces.

Whitminster (Packthorne Farm)

Situated on sloping ground just off the alluvium, this is the only site known from the Severn Estuary Levels which, on the basis of pottery and a coin, is limited to the early Roman period (Allen and Fulford 1990a). It yields building materials, bones and teeth and industrial residues. The iron-making materials are restricted to a little furnace lining and tap slag (Tables 5, 7), and the scale of production could have been small.

Hills Flats with Severn House Farm and Dayhouse Farm

This complicated and prolific site, revealed partly by coastal erosion, presents both primary and secondary contexts (Table 1), all of which appear to relate to the same important minor settlement on the alluvium (Allen and Fulford 1987, 1996; Allen 1997). Some late Iron Age pottery is present but the assemblage as a whole emphasizes the third and fourth centuries, there being an indication that, perhaps in response to coastal erosion, the more seaward parts of the settled area were abandoned earliest.

Iron-making materials abound (Tables 2, 5, 7). They include ores, furnace lining (one piece with a double baking-sequence), tap slag, a preponderance of furnace bottoms, and hammerscale. Production is likely to have been at a substantial level, apparently with simple bowl furnaces chiefly in use.

Oldbury (Home Farm)

A substantial amount of Romano-British and some medieval occupation debris occurs on the alluvium at this site (Allen 1997). The second and early third centuries are moderately well represented by the pottery assemblage, but most of the wares belong to the interval from the mid-third to the mid-fourth centuries. Although there seems to have been medieval cross-estuary traffic in iron ore at Hill Pill (Allen 1996; Allen and Fulford 1996), the iron-making materials at Home Farm are considered on general and chemical (see below) grounds to be Romano-British (Tables 2, 5, 7). They are ore, furnace lining, tap slag, a preponderance of furnace bottoms, and hammerscale. Simple bowl furnaces seem chiefly to have been used at the site, but the scale of production of iron blooms and refined metal need not have been large.

Oldbury Flats

Coastal erosion and construction activities related to Oldbury Power Station have afforded through numerous contexts (Table 1) evidence for the presence on the alluvium of a substantial, dispersed Romano-British settlement that possessed at least one high-status building (Allen and Fulford 1987, 1992; Hume 1992; Allen and Rippon 1997; Allen and Davidson 2007). As at Hill, the abundant pottery points to the beginning of activity in the late Iron Age, but reveals that occupation was mainly during the third and fourth centuries, with some probable shifts in focus over time, probably in response to coastal movements.

Iron-making materials are very abundant (Tables 2, 4, 5, 7). They include ores, charcoal, furnace lining, tap slag and furnace bottoms. Charcoal was recovered and analysed (Table 4). To judge from the amounts of slag from the coastal contexts, and especially from the site of the silt ponds inland, the production of iron was on a semi-industrial scale and comparable to the level of activity at the Chesters villa (Fulford and Allen 1992) on the opposite bank of the estuary. As furnace bottoms and tap slag are roughly matched in abundance, tappable and simple bowl furnaces could have been used to similar extents.

SUPPLEMENTARY SITES (Figure 2)

Blakeney (Millend Lane)

Hardstanding, an oven, dumps, pits, ditches, worked stone, metalwork and a coin-hoard were recorded from this site in the valley of the Bideford Brook on the west bank of the estuary (Barker and Holbrook 2000). The emphasis of the substantial pottery assemblage is on the third and fourth centuries. Only a general description was published for the 424 kg of slag recovered. Tap slag, some preserving the shapes of small channels, and a little hammerscale are present, but neither furnace bottoms nor furnace remains are recorded. A considerable variety of small roundwood-charcoal is found (Table 4). The scale of the iron-making appears to have been considerable, and perhaps based exclusively on tappable furnaces.

Chesters villa

Associated with this west-bank residential site (Scott Garrett 1938) is an open-sided, padstone, industrial building and huge slag dump (Fulford and Allen 1992). Pottery from both the villa and the industrial building points to activity from the mid-third century to the end of the fourth. Geophysical survey, pit-sampling and excavation pointed to iron-making on a semi-industrial scale. The bases of numerous shaft furnaces, dumps of clay for furnace-making, and a number of crushing platforms were found, in addition to ores, furnace lining (one fragment with a *tuyère*-mould and double baking-sequence), a variety of tap slag and small roundwood-charcoal (Table 4). There is no evidence that simple bowl furnaces were ever used, in contrast to nearby Ley Pill. The scale of iron-production was estimated to be at least of the order of a few tonnes annually.

Thornwell Farm (Chepstow)

At Thornwell Farm lies a Romano-British farming settlement overlooking the River Wye from the west (Hughes 1996). The pottery assemblage of more than 10,000 sherds pointed to occupation from the early second century to the mid-fourth. The metal-working debris by its mode of

Table 10. reproducibility of major and minor elements in international standards and selected slags. Footnote: T = tap slag; B = furnace bottom.

Sample	**Composition, wt% (3σ, %)**						
	Na_2O	**MgO**	**Al_2O_3**	**SiO_2**	**K_2O**	**CaO**	**Fe_2O_3**
International standards							
GSP-1	2.80 (0.13)	0.97 (0.06)	15.54 (0.11)	67.62 (0.29)	5.52 (0.03)	2.13 (0.02)	4.29 (0.03)
G2	4.08 (0.11)	0.72 (0.04)	15.19 (0.17)	67.86 (0.33)	4.43 (0.04)	1.91 (0.02)	2.62 (0.02)
DRN	3.02 (0.12)	4.28 (0.12)	18.08 (0.11)	53.37 (0.27)	1.70 (0.02)	7.04 (0.07)	9.65 (0.10)
FER-1	0.35 (0.13)	0.31 (0.08)	0.56 (0.02)	16.77 (0.16)	0.02 (0.00)	3.26 (0.04)	75.13 (0.64)
Slags							
A983B	0.16 (0.25)	2.04 (0.29)	4.33 (0.08)	31.62 (0.20)	1.41 (0.01)	2.54 (0.03)	61.91 (0.33)
B1B	0.40 (0.24)	0.43 (0.08)	4.90 (0.11)	21.75 (0.23)	0.63 (0.01)	0.29 (0.01)	75.76 (0.66)
RGW322B	0.44 (0.11)	0.49 (0.06)	10.22 (0.36)	19.72 (0.31)	0.55 (0.01)	0.36 (0.03)	60.75 (0.13)
RGW490B	0.56 (0.27)	0.62 (0.03)	7.42 (0.16)	20.29 (0.24)	0.51 (0.01)	0.56 (0.02)	72.11 (0.62)
OF146T	0.22 (0.26)	1.21 (0.07)	2.00 (0.02)	12.50 (0.09)	0.68 (0.01)	1.04 (0.00)	91.38 (0.57)
OF299T	0.36 (0.09)	1.74 (0.12)	4.19 (0.06)	26.49 (0.19)	1.42 (0.01)	1.22 (0.01)	68.54 (0.24)
OF423T	0.35 (0.17)	1.19 (0.07)	3.05 (0.07)	17.52 (0.21)	0.63 (0.01)	1.66 (0.03)	80.42 (0.51)
OF441T	0.18 (0.14)	1.23 (0.11)	2.59 (0.05)	25.76 (0.18)	0.78 (0.02)	0.82 (0.02)	71.51 (0.41)
OF578T	0.26 (0.15)	1.28 (0.07)	2.70 (0.06)	15.76 (0.20)	0.57 (0.01)	1.21 (0.02)	84.53 (0.85)
OF323B	0.47 (0.16)	3.06 (0.07)	3.88 (0.07)	26.71 (0.15)	1.75 (0.01)	4.45 (0.03)	56.58 (0.36)
OF367B	0.10 (0.20)	1.36 (0.15)	1.13 (0.04)	8.14 (0.07)	0.31 (0.01)	0.52 (0.02)	91.5 (0.37)
OF508B	0.48 (0.27)	1.83 (0.07)	2.54 (0.04)	13.77 (0.19)	0.85 (0.01)	1.14 (0.03)	81.55 (0.91)
OF746B	0.28 (0.12)	2.08 (0.10)	2.38 (0.10)	18.89 (0.11)	0.36 (0.01)	1.78 (0.02)	73.97 (0.87)
OF1005B	0.29 (0.35)	2.11 (0.23)	1.82 (0.07)	9.41 (0.05)	0.33 (0.01)	0.52 (0.02)	90.34 (0.99)

Table 11. Reproducibility of selected trace-elements in sample DF470B. Footnotes: 1 = 11 results; 2 = ten results; 3 = four results.

Composition, ppm (3σ, ppm)					
Cu	Zn	Rb	Sr	Y	Zr
55 (16.5)[1]	12.5 (13.9)[2]	8.3 (4.5)[3]	147 (12.6)[1]	10.9 (4.9)[1]	77.9 (29.1)[1]

occurrence suggested low-level activity areas near rather than within the settlement. Tap slag and pieces of a smithing-hearth bottom, together with possible ores, are present. There is unspecified wood charcoal.

SLAG GEOCHEMISTRY: INTRODUCTION

Purpose

Geochemical analyses of smelting slags, yielding data on major-, minor- and trace-element compositions, have the potential to (1) assist in the overall characterization of these materials, (2) discriminate between sites with different sources of ore, fuel and clay for furnaces, and (3) discriminate between different processes (including their relative efficiency).

Sample preparation and analytical method

Examples of slags from the above sites were selected on the basis of their freshness and, in the case of furnace bottoms, their representation of the size-range available. As far as possible, equal

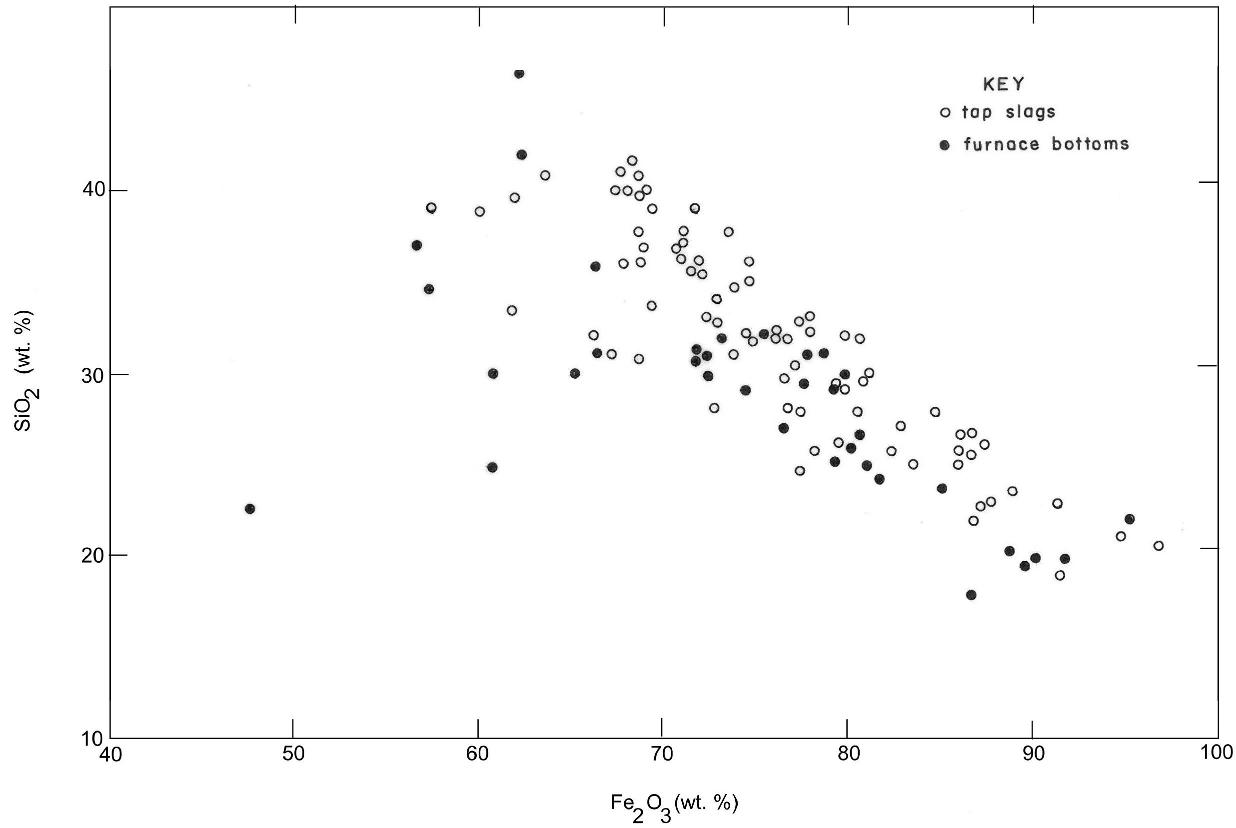

Figure 8. SiO_2 as a function of Fe_2O_3 for tap slags and furnace bottoms from all sites (values not adjusted for loss on ignition).

or near-equal numbers of furnace bottoms and tap slag were chosen, but some sites yield few or no bottoms and one has no tap slag. Samples were cleaned and soaked in repeated changes of water for several days, in order to remove any trace of salt (many sites are intertidal or nearly so). After slicing, a sub-sample for analysis was removed from all but the outermost parts of each slice, and then dried, crushed and ground in agate. Trace elements were analysed on pressed powder pellets. Analysis for major and minor elements was carried out on fusion beads made using a lithium tetraborate flux as a dilutant, samples and flux having been dried at 110^{o}C overnight. All analyses were carried out using a Phillips PW 1480 x-ray fluorescence spectrometer with a dual anode Sc/Mo 100Kv x-ray tube.

Appendix A gives in terms of oxides the major- and minor-element compositions of the slags, including the loss on ignition. The elements which proved to be of particular interest are the alkali metals Na and K (Group 1), the alkaline earths Mg and Ca (Group 2), and Al, Si and Fe. A suite of trace-elements was also measured (V, Cr, Co, Ni, Cu, Zn, Pb, Rb, Sr, Y, Zr), but of these only the period-four elements copper and zinc, and the period-five elements rubidium, strontium, yttrium and zirconium are thought of present interest (Appendix B).

Reproducibility

Four international chemical standards were run during the analytical programme and each was analysed ten times. In Table 10 can be found the reproducibility of the major and minor elements of particular interest in terms of these standards, the results appearing in the form of values for the mean composition and three standard deviations (3σ). Fourteen slag samples were similarly reanalysed several times (Table 10). One slag sample was reanalyzed 11 times in order to establish the reproducibility of the trace-element composition (Table 11).

These results are of a sufficient quality as to suggest that the general data (Appendix A) can be used with confidence to explore similarities and differences between the sites and types of slag.

Apparent similarities and differences in terms of trace-elements (Appendix B) must be viewed perhaps less confidently.

Data analysis

Chemical analysis yields results as percentage compositions or as parts per million, that is, relatively in the form of a closed number system. Since as one component goes up in proportion others must come down, spurious correlations and associations can arise when the assessment of chemical data is limited to raw proportions only, although some recent authors continue to use them (eg Paynter 2006). This problem can be circumvented, however, by the use of ratios between components, calculated on the basis of either the full composition or an appropriate sub-composition (Buccianti *et al* 2006). A choice of kinds of ratio is available, but all are absolute quantities which can be handled using classical statistics.

Four ratios calculated on the oxides of major and minor elements (Appendix A) proved of particular interest. These are the total alkali-metal oxides (Na_20+K_2O) relative to alumina (Al_2O_3) (hereinafter TA/Al), the total alkaline-earth oxides (MgO+CaO) relative to alumina (TAE/Al), the alkali-metals relative to the alkaline-earth metals (TA/TAE), and the ratio of iron oxide, Fe_2O_3, relative to silica, SiO_2 (Fe/Si). Three ratios were selected using the trace-elements (Appendix B): Zn/Cu, Sr/Rb and Zr/Y. In interpreting these various ratios, it needs to be remembered that the measurement error in a sum is additive and that in a quotient is approximately the difference of the errors of the terms (Topping 1955).

MAJOR AND MINOR ELEMENTS

General values

Two different 'reference sets' of rather consistent analyses are available (Appendix A). At the supplementary site of Chesters villa, where only taps slags are recorded, the mean composition, unadjusted for losses on ignition, is Na_2O=0.26 %, MgO=1.71%, Al_2O_3=4.42%, SiO_2=22.82%, K_2O=1.61%, CaO=1.88% and Fe_2O_3=70.56%. Yielding only furnace bottoms, Rumney Great

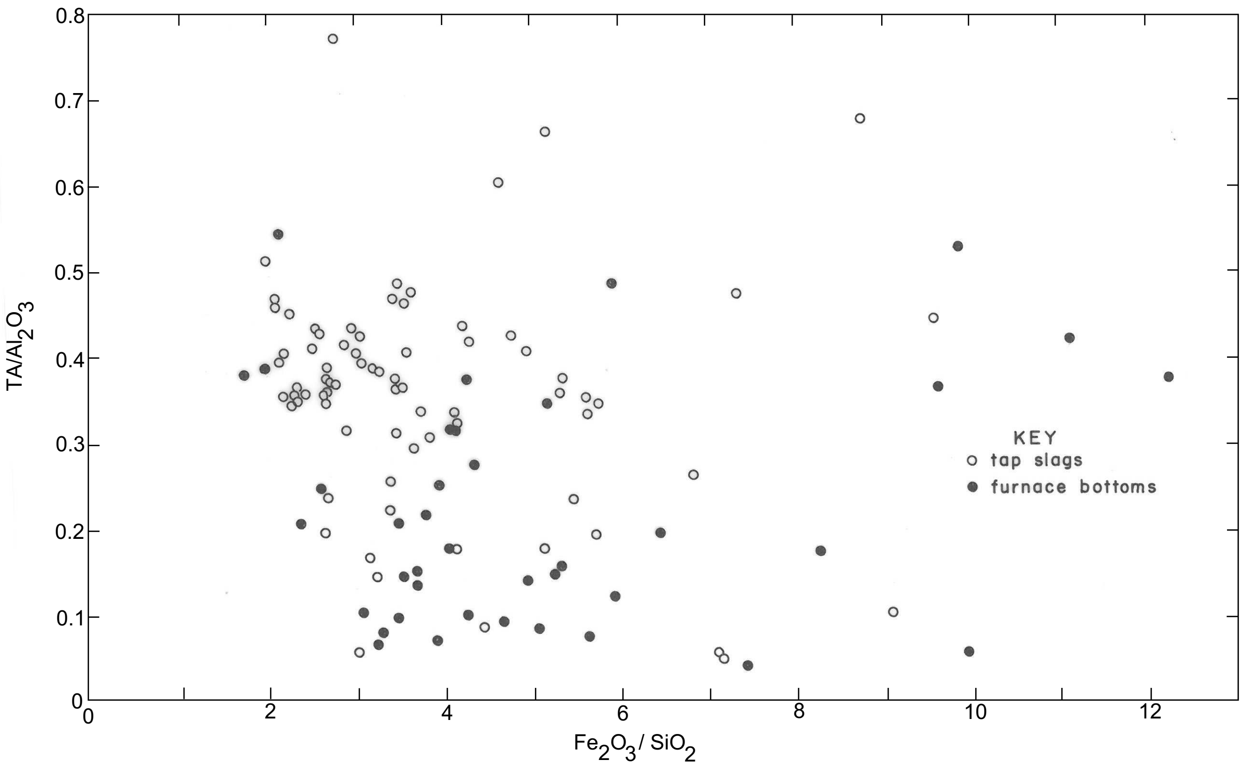

Figure 9. The ratio TA/Al_2O_3 as a function of the ratio FE_2O_3/SiO_2 for tap slags and furnace bottoms from all sites.

Table 12. Major– and minor-element ratios for slags by site. Footnotes: 1 = T-tap slag; B-furnace bottom; 2 = no value for s is shown where only one measurement is available.

Site and slag type	**Ratio, mean (1σ)²**		
	Fe/Si	**TA/Al**	**TAE/Al**
Awre (Whitescourt), T	4.66 (1.56)	0.329 (0.083)	0.735 (0.279)
Awre (Whitescourt), B	3.27 (0.726)	0.216 (0.087)	0.290 (0.383)
Lydney Park Farm, T	3.30 (0.257)	0.364 (0.048)	0.528 (0.173)
Lydney Park Farm, B	8.26	0.176	0.518
Ley Pill (Woolaston), T	3.26 (1.18)	0.1406 (0.018)	0.930 (0.178)
Ley Pill (Woolaston), B	4.90 (0.755)	0.246 (0.134)	0.486 (0.330)
Horse Pill, T	7.51 (2.89)	0.521 (0.137)	1.18 (0.519)
Horse Pill, B	6.66 (2.68)	0.104 (0.046)	0.213 (0.05)
Pill House, T	3.34 (1.10)	0.427 (0.063)	0.959 (0.291)
Pill House, B	4.21 -	0.315 -	0.985 -
Rumney Great Wharf, B	3.56 (0.586)	0.92 (0.028)	0.133 (0.107)
Elmore (Windmill Hill), T	2.46 (0.259)	0.383 (0.040)	0.963 (0.205)
Elmore (Windmill Hill), B	5.92 (0.360)	0.310 (0.194)	0.795 (0.637)
Longney C, T	3.46 (0.130)	0.345 (0.045)	0.830 (0.266)
Longney C, B	3.90 -	0.700 -	0.400 -
Longney A, T	3.31 (1.33)	0.329 (0.067)	0.875 (0.665)
Longney A, B	4.17 (2.37)	0.282 (0.093)	0.779 (0.310)
Longney B, T	2.37 (0.178)	0.383 (0.083)	0.717 (0.123)
Arlingham, T	3.56 (0.767)	0.343 (0.009)	0.807 (0.159)
Whitminster (Packthorne Farm), T	4.61 (1.70)	0.259 (0.079)	0.927 (0.627)
Hills Flats with Severn House and Dayhouse Farms, T	3.82 (1.16)	0.229 (0.142)	0.830 (0.362)
Hills Flats with Severn House and Dayhouse Farms, B	6.46 (3.28)	0.167 (0.128)	0.249 (0.070)
Oldbury (Home Farm), T	3.99 (1.57)	0.360 (0.012)	0.734 (0.097)
Oldbury (Home Farm), B	6.94 (2.62)	0.094 (0.049)	0.238 (0.071)
Oldbury Flats, T	4.16 (1.92)	0.558 (0.144)	0.868 (0.147)
Oldbury Flats, B	5.84 (3.78)	0.378 (0.132)	1.42 (0.192)
Chesters villa, T	3.30 (0.569)	0.420 (0.056)	0.790 (0.280)

Wharf gives the other set, with a mean composition of Na_2O=0.37%, MgO=0.57%, Al_2O_3=9.37, SiO_2=19.28%, K_2O=0.47%, CaO=0.59% and Fe_2O_3=63.72%. Appendix A shows that both types of slag are dominated by iron oxide and subordinate silica, the tap slags proving to be slightly the more siliceous for each iron content (Figure 8). Alumina is present in moderate quantities (Rumney Great Wharf is exceptionally aluminous), followed by the alkaline-earth oxides and the alkali-metal oxides. Phosphorus, titanium and manganese are present in very minor amounts and are not hereafter considered.

Ratios

Figures 9 and 10 are plots of the TA/Al and TAE/Al ratios as a function of the Fe/Si ratio. Although the two types of slag span similar ranges in each case, with some tap slags like furnace bottoms, and some bottoms like tap slags, the alkali-metal ratio discriminates well between the

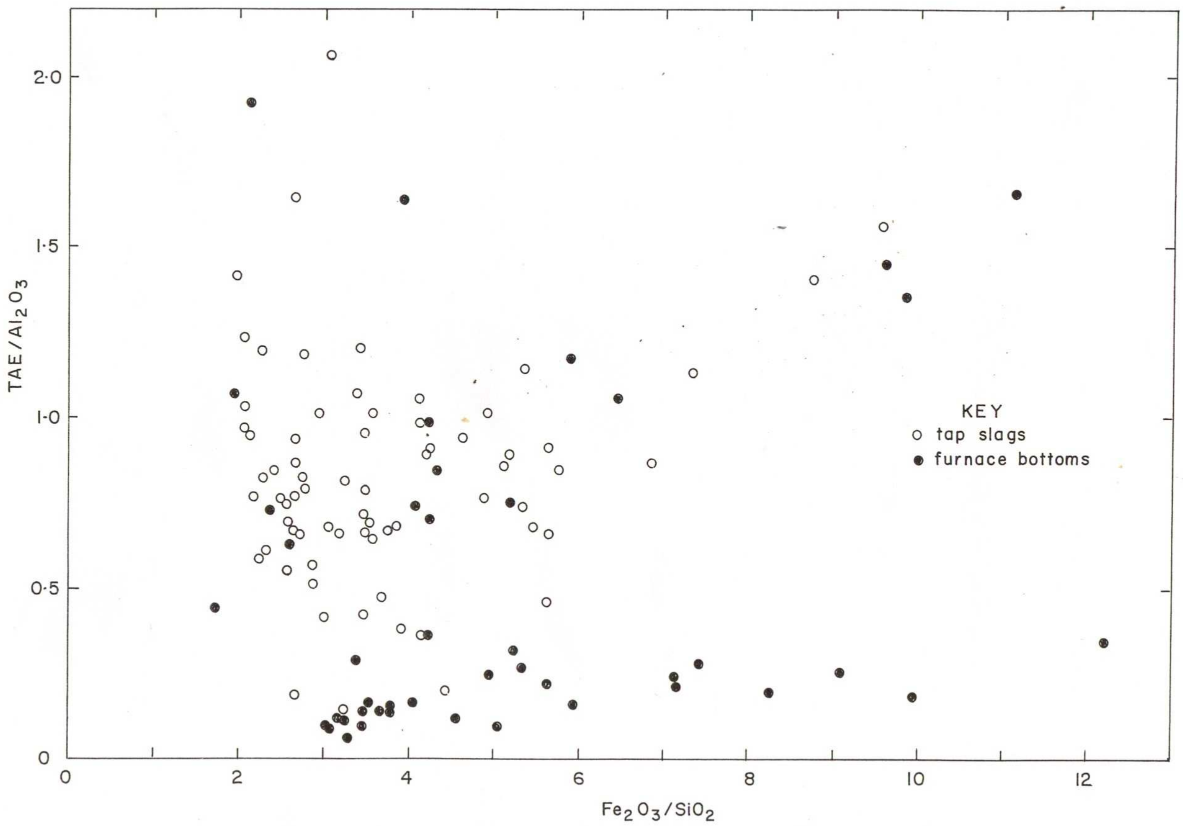

Figure 10. The ratio TA/Al_2O_3 as a function of the ratio Fe_2O_3/SiO_2 for tap slags and furnace bottoms from all sites.

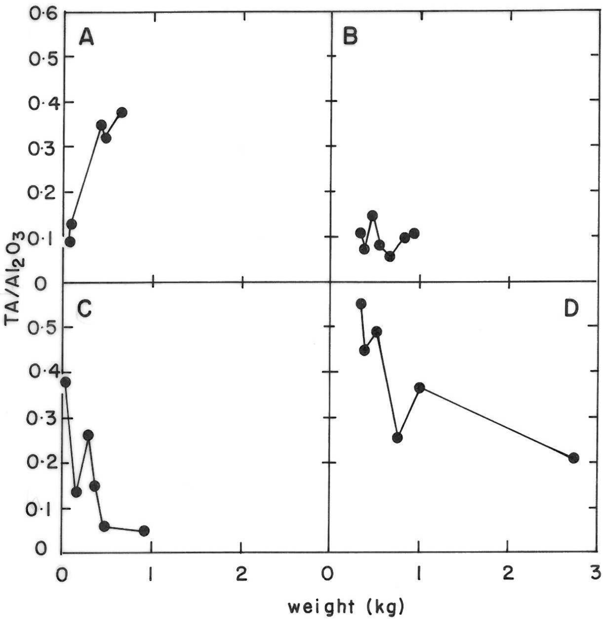

Figure 11. The ratio TA/Al_2O_3 as a function of weight for furnace bottoms from (A) Ley Pill, (B) Rumney Great Wharf, (C) Hills Flats (with Severn House and Dayhouse Farms), and (D) Oldbury Flats.

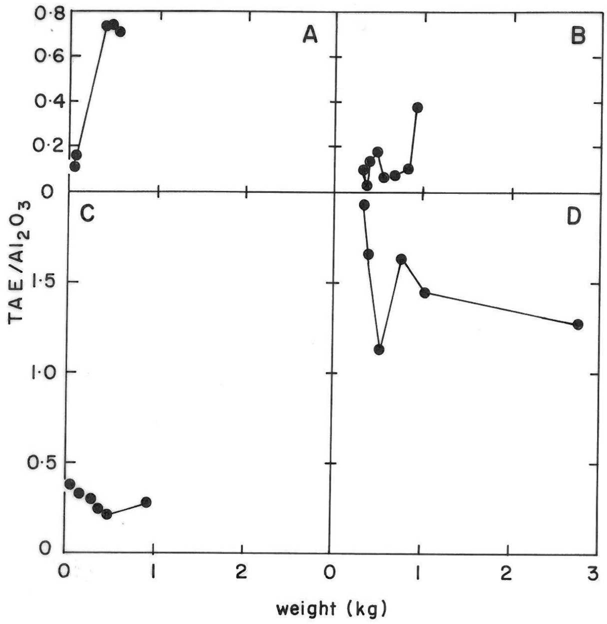

Figure 12. The ratio TAE/Al_2O_3 as a function of weight for furnace bottoms from (A) Ley Pill, (B) Rumney Great Wharf, (C) Hills Flats (with Severn House and Dayhouse Farms), and (D) Oldbury Flats.

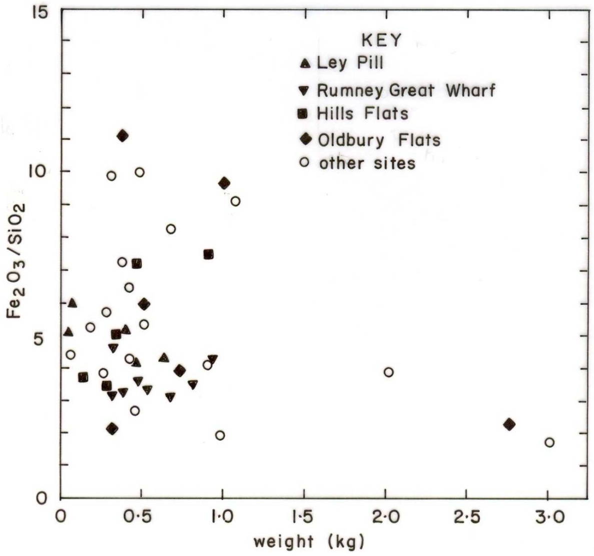

Figure 13. The ratio Fe_2O_3/SiO_2 as a function of weight for all furnace bottoms from (those from Ley Pill, Rumney Great Wharf, Hills Flats and Oldbury Flats are separately distinguished).

two types, and the alkaline-earth ratio is even more effective. Neither set of data reveals a trend, but the centre of gravity of the scatter for furnace bottoms in each case lies well below that for tap slags.

Much within-site and between-site variation is concealed by the scatter in Figures 9 and 10 (Table 12). The table also reveals that at most sites the tap slags yield the smaller average value of the Fe/Si ratio. Tap slags afford the larger average value of the TA/Al ratio at all sites where they can be compared, and the same is true in all but one case – Hills Flats with Severn House and Dayhouse Farms – for the TAE/Al ratio. The average TA/TAE ratio is not a consistent discriminator between slag types.

The TA/Al ratio has an overall average value of 0.38 for tap slags and 0.21 for furnace bottoms. For the TAE/Al ratio the corresponding values are 0.84 and 0.41. These may be compared to values for 'average' shale of 0.30 and 0.36 respectively (Clarke 1924; Klein and Hurlbut 1999).

Composition and weight of furnace bottoms

It was pointed out above that furnace bottoms recovered from Romano-British sites on the Severn Estuary Levels display a remarkable range of weights over two orders of magnitude, from a few tens of grams to a few kilograms. Regardless of weight, however, they share a common form, internal structure and the presence of tool marks on the underside.

There are strong hints that the chemical composition of these furnace bottoms is systematically linked in various ways to their weight. Four sites each afforded several analyses (Appendix A). The TA/Al ratio (Figure 11) increases with weight at Ley Pill, at the aluminous site of Rumney Great Wharf is independent of weight, and at Hills Flats and Oldbury Flats decreases with weight. It is interesting to note that a decrease in the ratio with weight is also observed over the three furnace bottoms analysed at each of Elmore (Windmill Hill) and Oldbury (Home Farm). The link is perhaps less strong in the case of the TAE/Al ratio. This quantity (Figure 12) increases with weight at Ley Pill (Woolaston) and Rumney Great Wharf, but declines at Hills Flats and Oldbury Flats. The latter trend, it may be noted, is also apparent at Elmore and Oldbury (Home Farm). Although it would seem that, overall, the Fe/Si ratio declines with weight (Figure 13), there is a clear trend (decline) only at Ley Pill among the sites yielding substantial data.

Interpretation

The emphasis in chemical work on bloomery slags has hitherto fallen mainly on two issues, the 'efficiency' of the process (eg Joosten *et al* 1997; Thomas and Young 1999a, 1999b; Schrüfer-Kolb 2004), and the involvement of ore-contaminants, fuel-ash, furnace lining or deliberately-added fluxing materials (eg Sperl 1980; Bachmann 1982; Fulford and Allen 1993; Serneels 1993,; Kronz 1998; Thomas and Young 1999a; Schrüfer-Kolb 2004). Most workers based their findings on major- and minor-element analyses, but Thomas and Young (1999a, 1999b) and Schrüfer-Kolb (2004) found that trace elements were useful. The bloomery process has long been recognized to be a chemically inefficient one, in which fluxing agents must be provided if not by the ore (lean ores only) then by fuel-ash, furnace linings, or dried clay or quartz sand added to the charge. Fulford and Allen (1993), and also Thomas and Young (1999a), showed using geochemical calculations that furnace lining (or added clay) made a major contribution to slags, particularly where rich ores that lacked silicate minerals had been used. Whatever the nature of the ore, at best no more than about one-half of the available iron goes into the bloom, the remainder, partitioned between the iron oxide wüstite and the iron silicate fayalite, or even as the free metal, entering the slag phase

Simple plots of iron oxide versus silica or alumina versus silica are often used to assess efficiency, but these can be no more than a rough guide because of the closed-system effect noted above. Applied to the slags described, where the oxide composition varies over a two-fold range (Figure 8, Appendix A), the process appears to have varied widely in efficiency from site to site and frequently from smelt to smelt at the same site. As the Fe/Si ratio increases above its minimum value of *c* 2, so the proportion of wüstite in the slag may be expected to grow, and at the highest values free metal is likely to be present (some of the slags are distinctly magnetic). Tappable furnaces emerge as no more efficient, however, than bowl furnaces, although the former offered advantages of other kinds. Tap slags from the shaft furnaces at Chesters villa are the most consistent in composition, suggesting that the semi-industrial operation here was well-controlled. There is less consistency at Rumney Great Wharf, where only simple bowl furnaces were used. The abundance of agglomeration-related vesicles in the furnace bottoms from here (Figure 6.4-6) perhaps suggest on the whole a lower-temperature process. Furnaces of this kind may have been more difficult to manage in a consistent way.

Figures 8-10 reveal unequivocally that the processes of smelting iron in tappable furnaces (tap slags) and simple bowl furnaces (furnace bottoms) differed in significant respects. Bowl furnaces yield slags with a slightly lower silica contents than tappable furnaces and with typically much lower values of the TA/Al and TAE/Al ratios. Was quartz sand deliberately added to tappable furnaces? It is certainly clear from the character of the furnace linings described above that these clayey materials, as they softened and melted on the inner walls of furnaces, contributed significantly to the composition of the slags that were produced. That pieces of dried clay were as well deliberately added to the charge may in fact be recorded by the discrete, tuberous lumps of furnace lining found at several sites (Table 5). Whatever the truth of this matter, however, the average TA/Al and TAE/Al ratios for furnace bottoms, and the average TA/Al value for tap slags, do not differ greatly from average shale (see above), a general proxy for furnace lining. The average TAE/Al ratio for tap slags (0.84), on the other hand, is more than twice that for shale (0.36). It is tempting to see this as evidence for the deliberate use of fluxing agents rich in alkaline-earth metals. These could also have been added to bowl furnaces at some sites, for example, Oldbury Flats, where furnace bottoms yield high values of the TAE/Al ratio. Suitable limestones and dolomites from the Lower Carboniferous sequence, as well as Liassic cementstones, all lay to hand in the form of natural exposures on or within reach of the Severn Estuary Levels. The addition of an unusually pure aluminous clay at Rumney Great Wharf, conceivably from the not too distant Coal Measures, could account for the exceptionally high alumina and low TAE/Al values observed there.

That different smelts in simple bowl furnaces lead to different outcomes is evident from Figures 11-13. As a number of factors are likely to interact to determine the outcome according to the strength of their individual influences – composition of fuel-ash, fuel to ore ratio, nature and proportion of added fluxing agents, furnace design, size and temperature – it is perhaps not surprising that a number of contrasting but apparently systematic patterns involving furnace-bottom composition and weight are evident. Carefully planned mass-balance experiments are needed to establish exactly how the possible controlling factors interact.

TRACE ELEMENTS

General values

The tap slags from the Chesters villa (Appendix B) give the most consistent results, affording a ‘reference set’ with mean values of Cu=14.0 ppm, Zn=22.8 ppm, Rb=42.3 ppm, Sr=59.3 ppm. Y=29.5 ppm and Zr=118 ppm. At the sites overall, the trace-element content is generally low. Copper and zinc are usually present to the extent of *c* 10-30 ppm, rubidium at *c* 20-40 ppm,

Table 13. Trace-element ratios for slags by site. Footnotes: 1, T = tap slag; B = Furnace bottom. 2, no value for σ is shown where only one measurement is available.

Site and slag-type[1]	Ratio, mean(1σ)[2]		
	Zn/Cu	Sr/Rb	Zr/Y
Awre (Whitescourt), T	1.09 (0.597)	3.40 (1.38)	5.38 (1.46)
Awre (Whitescourt), B	0.405 (0.290)	5.25 (4.83)	6.88 (2.36)
Lydney Park Farm, T	2.27 (1.69)	1.48 (0.064)	6.01 (3.20)
Lydney Park Farm, B	0.17 -	-	-
Ley Pill (Woolaston), T	1.98 (0.999)	1.80 (0.374)	5.83 (.201)
Ley Pill (Woolaston, B	0.721 (0.464)	2.97 (2.14)	8.39 (2.02)
Horse Pill, T	1.28 (0.454)	3.85 (2.48)	7.65 (1.20)
Horse Pill, B	0.425 (0.240)	3.40 (-)	7.89 (1.11)
Pill House, T	1.28 (0.717)	2.66 (1.42)	6.43 (1.92)
Pill House, B	0.516 (-)	5.43 (-)	8.75 (-)
Rumney Great Wharf, B	0.354 (0.184)	49.6 (42.9)	3.90 (1.30)
Elmore (Windmill Hill), T	2.09 (1.07)	2.49 (0.271)	6.72 (1.12)
Elmore (Windmill Hill), B	0.862 (1.06)	3.14 (2.76)	6.60 (3.59)
Longney C, T	1.39 (0.650)	2.00 (0.491)	6.49 (1.22)
Longney C, B	0.067 (-)	76.1 (-)	0.976 (-)
Longney A, T	1.37 (1.04)	2.77 (1.90)	7.99 (2.36)
Longney A, B	0.648 (0.569)	3.26 (1.44)	6.88 (0.813)
Longney B, T	0.881 (0.296)	2.22 (0.750)	9.77 (3.86)
Arlingham, T	1.82 (1.13)	2.28 (0.178)	7.87 (2.69)
Whitminster (Packthorne Farm), T	0.928 (0.145)	8.59 (5.73)	3.78 (0.731)
Hills Flats with Severn House and Dayhouse Farms, T	0.693 (1.16)	8.57 (5.47)	4.65 (1.32)
Hills Flats with Severn House and Dayhouse Farms, T	0.275 (0.062)	13.2 (5.27)	6.68 (1.22)
Oldbury (Home Farm), T	1.50 (1.21)	1.52 (0.261)	5.95 (0.218)
Oldbury (Home Farm), B	0.162 (0.095)	35.2 (13.2)	3.75 (0.658)
Oldbury Flats, T	2.31 (1.08)	2.92 (1.61)	6.51 (1.78)
Oldbury Flats, B	2.22 (1.05)	4.16 (1.92)	4.20 (1.2)
Chesters villa, T	1.18 (1.02)	1.40 (0.324)	4.53 (1.50)

strontium at *c* 50-80 ppm, yttrium at *c* 10-25 ppm and zirconium at *c* 80-100 ppm.

On the west bank, significant departures from these patterns are shown by one site and many individual samples (Appendix B). All of the furnace bottoms from Rumney Great Wharf yield greatly elevated values of strontium (max.=2839 ppm), and values for copper that are roughly twice the general level (but much less than in copper-smelting slags). The values measured for MgO and CaO (Appendix A), however, are correspondingly low. At Awre (Whitescourt) one furnace bottom gave a combination of raised copper and high strontium, and four bottoms and one tap slag had raised copper values, but without heightened strontium. Elevated copper values, coupled in one case with slightly raised strontium, are found among furnace bottoms from Horse Pill.

A similar behaviour is common on the east bank (Appendix B). At Elmore (Windmill Hill) and Longney C one furnace bottom combines high

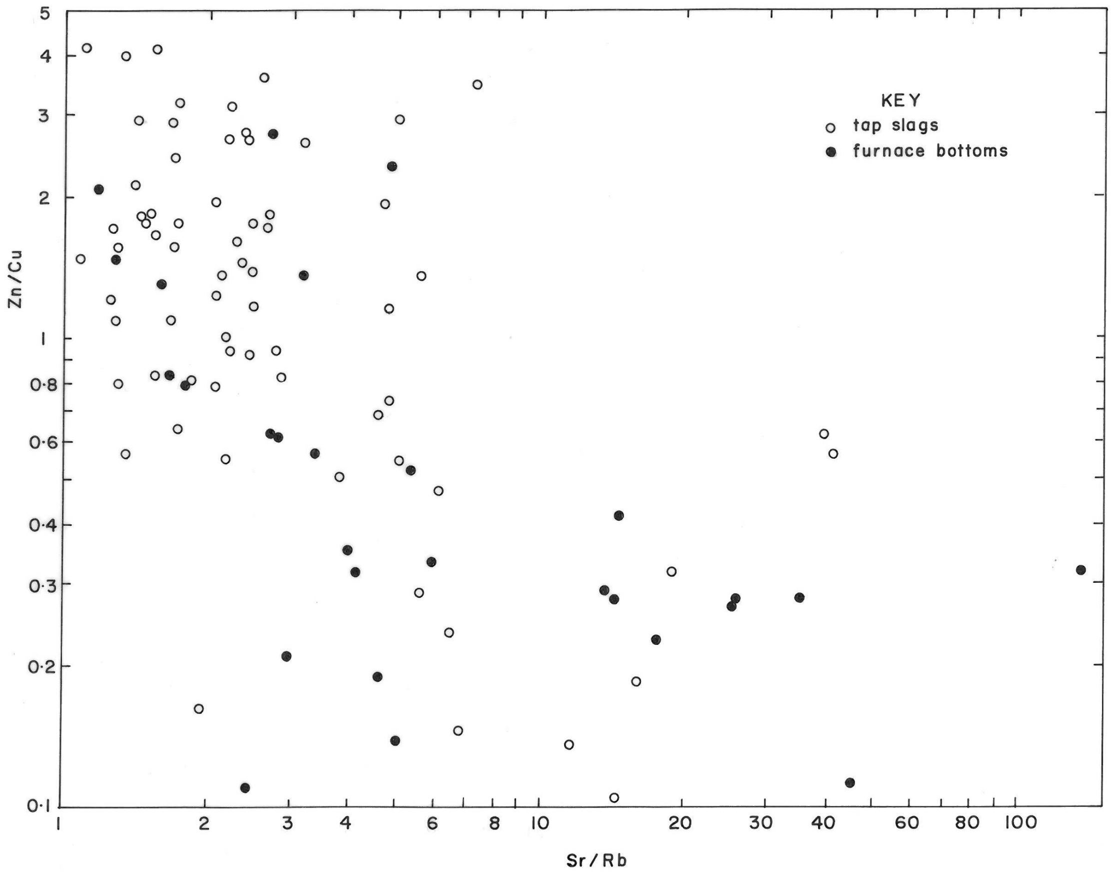

Figure 14. The ratio Zn/Cu as a function of the ratio Sr/Rb for tap slags and furnace bottoms

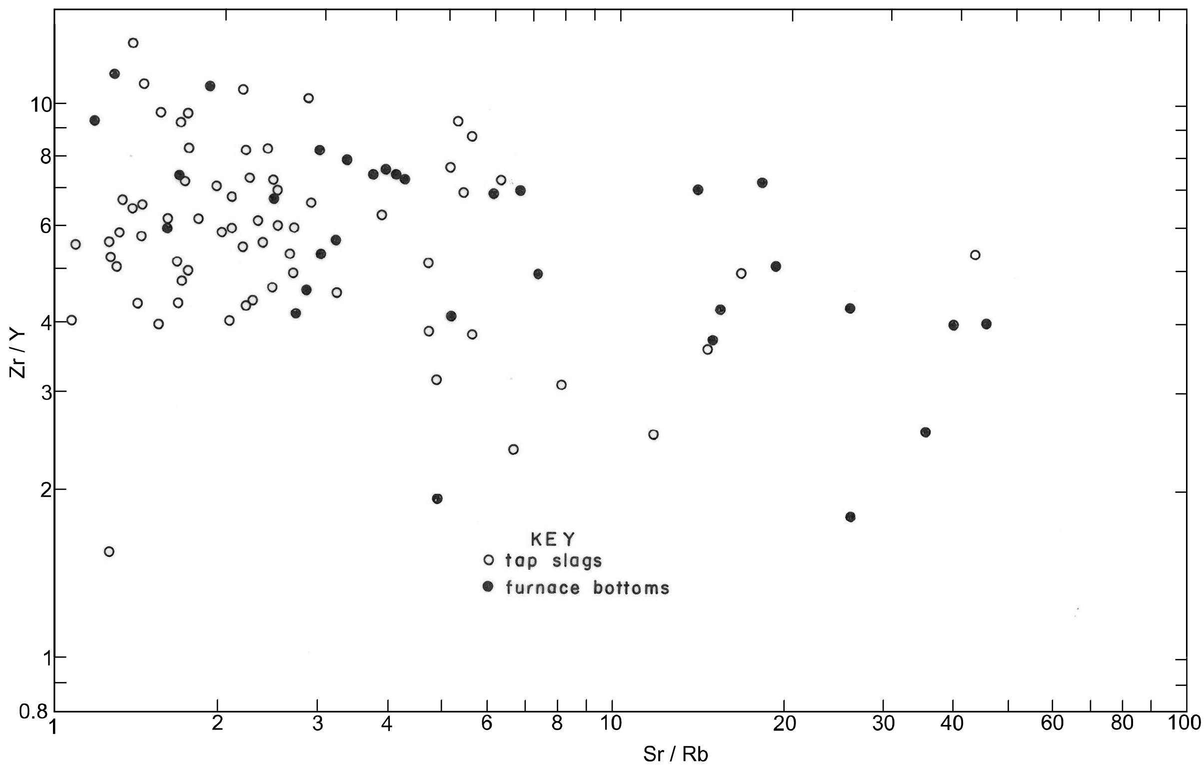

Figure 15. The ratio Zr/Y as a function of the ratio Sr/Rb for tap slags and furnace bottoms from all sites.

copper with high strontium, unusually high values for MgO and CaO being observed at Longney. A combination of high copper and high strontium typifies two of the three tap slags from Whitminster (Packthorne Farm), one of these samples also yielding an exceptionally high value for lead (1744 ppm). Ten samples from Hills Flats (with Severn House and Day House Farms) yield high copper values; these were coupled in the case of four tap slags and three bottoms with elevated levels of strontium. At Oldbury (Home Farm) three bottoms combine high copper with high strontium values. High strontium is observed in two bottoms here. There is no consistent relationship at these east-bank sites between raised copper and strontium values and elevated proportions of MgO and CaO.

Ratios

Plots of the trace-element ratios Zn/Cu versus Sr/Rb and Zr/Y versus Sr/Rb for tap slags and furnace bottoms appear in Figures 14 and 15. A strong but scattered inverse relationship is apparent between the first pair which, on an overall basis, discriminates to only a modest extent between tap slags and furnace bottoms. While the centre of gravity of the scatter for tap slags lies in the upper right of the graph, that for furnace bottoms lies in the lower centre, at lower values for Zn/Cu and higher values for Sr/Rb. A weak inverse trend marks the plot of Zr/Y against Sr/Rb, but there is overall no significant discrimination between slag types, other than that tap slags in general yield the lower values of Sr/Rb.

As with the major and minor elements, the scatter evident in Figures 14 and 15 conceals important within-site and between-site variations (Table 13). On a site-by-site basis, the Zn/Cu ratio is invariably and substantially greater for tap slags than for furnace bottoms. At all but one site with both types of slag, the Sr/Rb ratio is substantially least for the tap slags. The only pattern that seems to be suggested by the Zr/Y ratio is that the largest values for tap slags are restricted to east-bank sites. One site stands apart from the rest. The furnace bottoms at Rumney Great Wharf have greatly elevated values for Sr (Appendix B) and present Sr/Rb ratios generally an order of magnitude greater than both furnace bottoms and tap slags elsewhere (Table 13). The site at Whitminster (Packthorne Farm), and the clusters at Hills Flats (with Severn House and Dayhouse Farms), Oldbury (Home Farm) and Oldbury Flats, also stand rather apart from the rest in terms of the Sr/Rb ratio and the levels of Cu and Sr.

Interpretation

Elevated levels of Cu and Sr – there is no consistent relationship between the two - could have entered the slags from either the ore or the clays used to make furnaces, or from accidental or deliberate additions to the charges of materials containing these elements.

The copper is most likely to have come from some of the sources of ore. There is evidence for a low level of copper mineralization in the Forest of Dean (Applied Geochemistry Research Group 1978), and it is said that copper was smelted at Redbrook on the western flanks of the Forest in early modern times, using local ore (Hart 1971; Bick 1980). It is certainly true that traces of copper mineralization (malachite films/disseminations) can occasionally be found in some of the Carboniferous sandstones of the area. The levels of copper found in the slags, however, are such as to rule out any possibility that they are related to copper-smelting.

Enrichment in strontium can be explained in two ways, as the element readily substitutes in small amounts for calcium in the atomic lattices of common minerals. Either substituted for calcium in gypsum ($CaSO_4.2H_2O$), or as the free mineral celestite ($SrS0_4$), strontium is very significantly enriched in the gypsiferous Triassic mudrocks outcropping on both sides of the Severn Estuary (Applied Geochemistry Research Group 1978). At Yate, north of Bristol, celestite is abundant enough to be worked commercially (Welch and Trotter 1961). Hence the slags could have gained strontium as the result of the construction of some furnaces from weathered Triassic mudrocks or from Trias-derived head deposits. The chemistry (Appendix B, Table 13) allows this to have been the case for some or all slags at Rumney Great Wharf, Whitminster (Packthorne Farm), and Hills Flats (with Severn House and Dayhouse Farms), Oldbury (Home Farm) and Oldbury Flats. Slags without strontium enrichment could have come from furnaces built of non-Triassic clays, such as

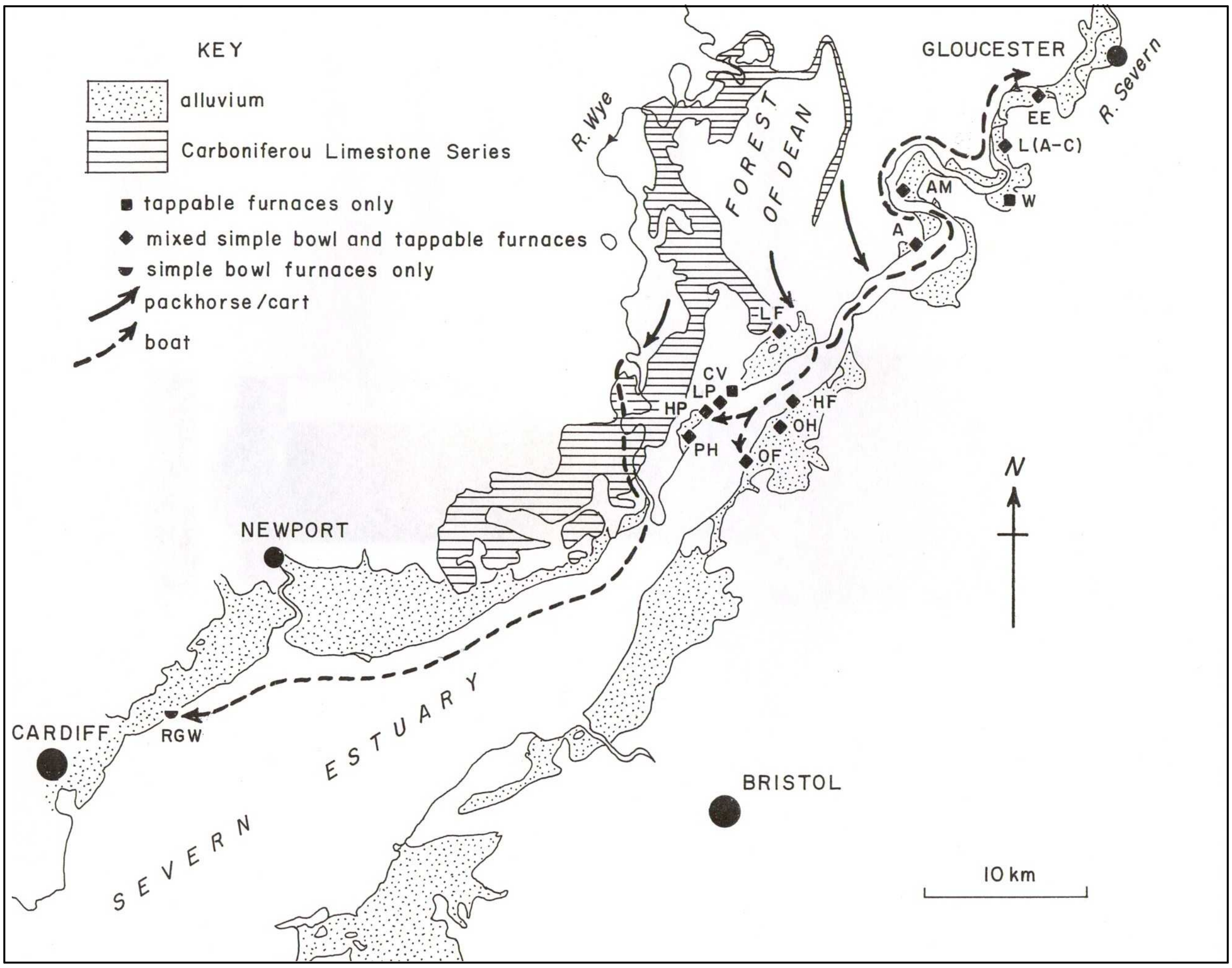

Figure 16. *The distribution of furnace types at Romano-British sites on the Severn Estuary Levels, and conjectural ore transport routes. Key to west-bank sites: A – Awre (Whitescourt); LF – Lydney Park Farm; CV – Chesters villa; LP – Ley Pill (Woolaston); HP – Horse Pill; PH – Pill House; RGW – Rumney Great Wharf. Key to east-bank sites: EE – Elmore (Windmill Hill); L – Longney (sites A, B, C); AM – Arlingham; W – Whitminster (Packthorne Farm); HF – Hills Flats; OH – Oldbury (Home Farm); OF – Oldbury Flats.*

the local Holocene silts or, in the case of the stores of red clay at the Chesters villa, Lower Old Red Sandstone mudrocks/derived head. There is no archaeological evidence for the other possible but less likely route, the deliberate addition of strontium-rich shell or limestone debris as a flux to the furnaces.

DISCUSSION

An account is given above of the occurrence, character and geochemistry of iron-making materials and residues at total of 18 Romano-British sites on or closely associated with the Severn Estuary Levels, the great, largely embanked outcrop of Holocene marine to freshwater sediments encountered on the margins of the Severn Estuary. The findings allow some progress to be made toward identifying the character and importance of this portion of the Dean-dependent industry, that is, toward defining the 'metallurgical landscape' these sites represent.

The concept of a metallurgical landscape – the term is Taylor's (2007) – can be traced in varying degrees of completeness in many archaeometallurgical works (eg Day 1973; Cleere and Crossley 1985; Pigott 1998; Walters 1999; Bowden 2000; Hughes 2000; Schrüfer-Kolb 2004). At its most complete, the concept embraces: (1) the geological context and location of sources of ore; (2) the transport of ore to smelting sites where these were not at mines; (3) the character and siting of smelters and the nature and sources of materials used to construct them; (4) the preparation of ores for smelting; (5) the character, provenance and transport of fuels used for smelting; (6) the smelting process and any necessary provision of power to operate furnaces; (7) metal purification; (8) the marketing and transport of purified metal to sites of artefact production; and (9) the consumption and marketing of finished metal products. The further back in time a particular industry lies, however, the more difficult is it to explore all of these aspects of its metallurgical landscape.

Despite claims to the contrary, only two iron-ore mines in the Forest of Dean, at Lydney Park (Scott-Garrett 1959) and less certainly Wigpool (Wildgoose 1988), bear scrutiny as Roman (Fulford and Allen 1992; Walters 1992). There can be little doubt that there were others, but the evidence for them has been lost as the result of further working in medieval and modern times. There are, however, very many attested sites of smelting within Dean and the wider region, at some of which shaft furnaces or bowl furnaces have been excavated (Walters 1992). As Fulford and Allen (1992) emphasized, these are generally far-removed from the ore-bearing outcrops where mines could have been sited.

How did ore reach the smelting sites described above? The Forest of Dean is an area of some altitude (*c* 150-200 m) and bold relief, typified by steep marginal slopes and many deep, commonly winding stream valleys. The only certain or possible Roman roads known in the area all skirt this massif. Ore-bearing packhorse trains are likely to have been better able to negotiate this difficult terrain than carts on tracks that were inevitably narrow, steep and rough. This mode of supply could have applied to the west-bank sites that border the Forest (Figure 16). A mixed mode of transport is demanded for sites across the Severn Estuary on the east bank, with an intermediate step by water. Many small streams ending in tidal creeks flow easterly or southeasterly from the Forest into the Estuary, the largest being the Lydney and Forge Brooks rising in the heart of the area. Of these the Lydney Brook, as suggested by Walters (1992), is best placed to have been a Roman port for the export of ore. On the opposite bank from Lydney lies the substantial Berkeley Pill and, several kilometers futher downstream, Oldbury Pill and the dispersed Roman-British settlement of Oldbury Flats, associated with a major palaeochannel system open in late Iron Age and Roman times (Allen and Rippon 1997). The geochemical similarities noted above between the sites at Hills Flats, Oldbury (Home Farm) and Oldbury Flats, as well as other evidence (Tables 2, 7), suggest that substantial amounts of ore may have entered this part of the area through this system before further dispersal. Boat journeys along the inner estuary could have brought ore to the northeasterly site of Elmore (Windmill Hill) and, by way of the tidal Frome, to Whitminster (Packthorne Farm). If as appears to be the case that ore came from the Forest of Dean, it seems most likely that it was also shipped down-estuary, perhaps from western mines near the Wye, to the outlying site at Rumney Great Wharf.

The location of blast-furnace smelters in the Early Modern Weald (Cleere and Crossley 1985), and late Early Modern to Modern Furness (Bowden 2000), was strictly determined by the need for plentiful water power to provide the blast. These smelters were therefore located on streams, often far distant from mines and settlements, with a good year-round flow. No such requirement was placed on the Roman industry of Dean, which used a range of much smaller, batch-process furnaces that could be blown by a combination of natural draught and hand-operated bellows. The Roman smelters seem to be located in or near particular settlements (Figure 16), such as Blakeney, Rumney Great Wharf, Hills Flats and Oldbury Flats, the siting of which is likely to have been determined by a number of factors, only one of which need have been ease of access to supplies of ore. Not all settlements in the area had smelters, probably because their economies were strongly rooted in other trades. There is little or no evidence of iron-making at the apparently substantial coastal settlement at Magor Pill (Allen 1998), for example, to which ore could easily have been shipped, or at the less accessible inland villa at Frocester (Price 2000a, 2000b), although ore and tap slag are recorded from Gatcombe (Branigan 1977).

Substantial quantities of clay, commonly tempered with sand or pebbly sand, were used in furnace construction at the sites (Tables 5, 6). The geochemistry of the slags (Appendices A, B) suggests that a wide variety of probably local sources were exploited, including weathered Triassic mudrocks/derived head. The only direct archaeological evidence of stores of clay for furnaces, however, comes from the Chesters villa (Fulford and Allen 1992), where a Lower Old Red Sandstone source apparently was used.

As Bowden's (2000) work emphasizes, an essential infrastructural requirement of both the bloomery and the early blast-furnace processes was the ready supply of large amounts of charcoal fuel, best achieved from dedicated, managed woodlands. Where these woodlands and their charcoal-burning platforms lay in Roman Dean and the Severn Estuary Levels is perhaps no longer discoverable, but the comparative list of species from four sites yielding charcoal (Table 4) implies that they were probably more local than the sources of ore. The evidence further shows that throughout the Levels the charcoal required was made almost exclusively from small roundwood. While this could have been gathered opportunistically, the magnitude of the demand points to organized charcoal-burning in managed woodlands and to orderly, well-developed arrangements for conveying the product to smelting sites. Walters (1992) estimates that, over the wider Forest of Dean area, of the order of at least 750,000 tonnes of ore was smelted between the first and fourth centuries AD. As about twice as much charcoal as ore is required on average, this quantity suggests that the rate of charcoal production over wider Dean could have been as great as 3,800 tonnes annually if not more. This would have called for the procurement of about 19,000 tonnes of wood, that is, the produce from about 3,800 ha of coppiced woodland. Since the area of greater Dean is of the order of 100,000 ha, about 4% of the landscape could have been given over to charcoal production just in support of the iron industry of the region.

The Roman iron industry in the greater Forest of Dean area originated in the late Iron Age and ranged into the fourth century AD. On the basis of estimates given by Walter (1992), production amounted to not less than the order of 260,000 and 360,000 tonnes in the first and second centuries respectively, with a focus on the Roman iron-making town of *Ariconium* (Weston-under-Penyard), falling to a minimum order of 100,000 tonnes spread over the following two centuries, chiefly at Monmouth. Arguably one of the main purposes of the early industry, perhaps under military oversight from the legionary based at Caerleon, was the support of military campaigns in the west and north. From the dating evidence given above, it is clear that sites on the Severn Estuary Levels participated chiefly in the later phases of the industry, which probably had a more civil-domestic thrust. The only certain exception is Whitminster (Packthorne Farm), where activity, apparently minor, seems to be restricted to the early Roman period.

Over the entire duration of the industry, the traditional simple bowl furnace of the Iron Age continued to be used alongside the newer tappable furnaces, including the Roman-promoted shaft furnace. Although furnace lining is a frequent find, direct archaeological evidence for furnaces is comparatively rare even where there has been excavation. Walters (1992) cites the discovery of the remains of shaft furnaces at just six out of roughly 100 sites (excluding Chesters villa) in the greater Forest area and the remains also of bowl furnaces at one of these (*Ariconium*). Most smelting sites on or associated with the Severn Estuary Levels (Table 7) afford evidence for the use of both simple bowl and tappable furnaces (Figure 16). These include the supplementary site of Thornwell Farm (Chepstow). It is only at Rumney Great Wharf and the Chesters villa that bowl furnaces and shaft furnaces respectively were exclusively in use, conclusions that can be regarded as firm, given the extent of the evidence. Only tap slag is recorded from Longney B and Whitminster (Table 7), but the samples are too small for it to be argued that simple bowl furnaces were not also employed. The supplementary site at Blakeney (Millend Lane) may have employed only tappabe furnaces. Both kinds of furnace are limited to batch production. The geochemical and other evidence presented above (Figures 9-13) suggests that the bowl furnace was more difficult to operate in a consistent manner. They were dug using simple implements, such as entrenching tools and mattocks, as shown by the marks preserved on the undersides of furnace bottoms (Figure 7, Table 8). The bowl furnaces yielded bottoms differing in general weight from site to site (Figure 4), further suggesting differences in furnace efficiency or perhaps size. Tappable furnaces have the additional advantage over bowl furnaces that they can be re-lined for further use, a practice attested by some finds of lining. The geochemical evidence further points to significant differences between the two kinds of furnace in some aspects of the smelting process, and hints that the operators of tappable furnaces may have used a range of fluxing agents, as well as relying on the incorporation of fuel-ash and furnace lining into the slags. Systematic experiments are needed in order to explore these findings more deeply.

The bloomery process is a two-stage one which calls, in the second stage, for the forging of contaminated slag out of the bloom in order to obtain marketable metal (Sim 1998). There is not much evidence of this stage of the iron-making process from the Severn Estuary Levels. Lydney Park Farm has yielded what appears to be a small bloom, and hammerscale was found at a few sites, notably at Ley Pill (Woolaston). What happened to marketable metal produced on the Severn Estuary Levels can only be conjectured. It is probably only at Awre, Chesters villa, Rumney Great Wharf, Hills Flats and Oldbury Flats that production seems to have been of a sufficient extent to have fed an export market.

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APPPENDIX A – MAJOR AND MINOR ELEMENTS (wt. %)

Sample[1]	**Na_2O**	**MgO**	**Al_20_3**	**SiO_2**	**P_20_5**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**Fe_2O_3**	**LOI**	**Total**
Awre (Whitescourt)												
A111T	0.23	0.38	4.11	26.86	0.25	0.58	0.36	0.22	0.05	71.58	-4.01	100.53
A206T	0.31	1.16	2.79	19.42	0.37	0.87	1.37	0.21	0.13	78.76	-6.70	98.70
A301T	0.24	0.89	2.35	15.46	0.35	0.59	1.25	0.17	1.30	87.23	-6.80	101.86
A425T	0.35	1.51	4.10	22.45	0.33	1.22	1.81	0.24	0.24	72.92	-4.80	100.36
A908T	0.15	0.31	3.81	19.71	0.23	0.53	0.30	0.21	0.05	79.96	-4.20	101.06
A983T	0.26	2.08	4.32	31.70	0.24	1.41	2.54	0.27	0.20	62.04	-5.10	99.97
A238B	0.13	1.04	3.01	16.01	0.41	0.95	1.19	0.18	0.17	84.95	-6.77	101.27
A607B	0.17	0.88	2.09	13.04	0.53	0.38	0.92	0.13	0.13	89.01	-5.65	101.62
B1B	0.37	0.33	4.86	21.79	0.21	0.63	0.30	0.24	0.06	75.33	-3.37	100.74
B2B	0.09	0.30	4.25	20.54	0.22	0.82	0.25	0.21	0.05	77.77	-3.62	100.86
B3B	0.49	0.31	4.99	22.81	0.44	0.35	0.26	0.22	0.06	71.71	-0.47	101.16
U1B	0.23	0.36	6.65	20.90	0.28	0.76	0.34	0.28	0.04	67.12	0.31	97.26
Lydney Park Farm												
LP75T	0.35	0.83	4.18	24.93	0.21	1.34	0.90	0.24	0.12	74.73	-6.40	101.44
LP81T	0.10	0.75	4.27	22.34	0.31	1.23	1.05	0.25	0.20	77.14	-6.50	101.15
LP271T	0.30	1.18	3.43	22.56	0.24	0.99	1.28	0.20	0.27	77.59	-6.60	101.44
LP699B	0.05	0.04	0.51	11.52	0.44	0.04	0.06	0.21	0.68	95.19	-5.90	102.84
Ley Pill (Woolaston)												
W92T	0.24	2.20	5.59	29.35	0.27	1.96	3.08	0.33	0.28	61.94	-5.30	99.96
W124T	0.10	2.17	5.10	23.58	0.48	2.30	3.04	0.29	0.18	69.18	-5.90	100.51
W205T	0.17	1.53	3.05	16.88	0.19	1.07	1.76	0.18	0.18	82.87	-6.93	100.96
W283T	0.22	1.32	3.83	24.26	0.26	1.28	1.37	0.23	0.21	73.94	-5.70	101.22
W59B	0.28	0.40	5.93	15.78	0.22	0.23	0.17	0.29	0.05	79.48	-1.50	101.33
W76B	0.18	0.33	3.46	14.49	0.19	0.24	0.21	0.19	0.06	86.07	-3.70	101.70
W405B	0.19	1.30	3.18	15.91	0.18	0.91	1.08	0.20	0.15	82.63	-3.70	102.04
W470B	0.29	1.46	3.74	18.96	0.29	0.90	1.28	0.23	0.16	77.34	-4.78	99.87
W648B	0.39	1.46	3.92	18.76	0.20	1.07	1.27	0.24	0.15	79.70	-5.30	101.87
Horse Pill, beach and cliff												
HP30T	0.07	1.02	1.05	10.12	0.25	0.40	0.62	0.09	0.13	96.8	-7.90	102.65
HP45T	0.29	1.36	3.51	18.94	0.46	1.24	1.77	0.23	0.18	79.64	-6.70	100.92
HP120T	0.42	0.79	1.06	10.84	0.24	0.30	0.69	0.10	0.13	94.81	-7.68	101.70
HP257B	0.09	0.39	3.93	20.88	0.18	0.50	0.19	0.25	0.04	78.87	-4.30	101.01
HP426B	0.04	0.27	3.11	12.34	0.21	0.14	0.48	0.18	0.05	87.90	-2.80	101.92
HP1086B	0.22	0.49	3.24	9.76	0.29	0.12	0.87	0.17	0.08	88.61	-1.60	102.26
Pill House												
PR37T	0.41	3.50	5.62	28.81	0.55	2.46	4.50	0.33	0.32	57.29	-4.32	99.48
PR39T	0.30	2.34	4.76	20.62	0.33	1.90	2.45	0.27	0.21	73.68	-6.12	100.75
PR42T	0.27	2.20	4.82	25.83	0.33	1.45	2.31	0.30	0.24	67.86	-5.80	99.80
PR252T	0.28	0.88	2.32	17.40	0.38	0.71	0.88	0.15	0.09	84.72	-5.50	102.32
PR344T	0.21	0.98	3.46	26.88	0.35	1.09	1.34	0.21	0.13	71.03	-5.40	100.28

Sample[1]	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	LOI	Total
PR445B	0.25	1.03	2.73	18.82	0.32	0.61	1.66	0.17	0.22	79.23	-4.30	100.74
Rumney Great Wharf												
RGW322B	0.50	0.44	10.21	19.84	0.35	0.55	0.28	0.36	0.05	60.89	6.40	99.86
RGW331B	0.26	0.39	6.72	16.39	0.63	0.53	0.22	0.24	0.05	76.49	-1.80	99.93
RGW395B	0.23	0.84	8.96	20.60	0.38	0.33	0.39	0.38	0.06	66.25	1.18	99.61
RGW490B	0.55	0.64	7.36	20.41	0.45	0.52	0.55	0.30	0.06	72.14	-3.00	99.98
RGW537B	0.56	0.54	15.78	19.80	0.71	0.70	0.47	0.39	0.04	65.11	-5.20	98.90
RGW678B	0.13	0.54	10.38	21.96	0.29	0.45	0.27	0.49	0.04	66.32	-0.90	99.97
RGW810B	0.35	0.50	7.92	20.84	0.49	0.44	0.23	0.36	0.04	71.84	-2.40	100.60
RGW945B	0.34	0.66	7.59	14.39	0.57	0.43	2.30	0.20	0.16	60.72	13.20	100.56
Elmore (Windmill Hill)												
E51T	0.21	1.41	3.44	29.76	0.24	1.36	2.68	0.22	0.26	67.11	-6.10	100.58
E78T	0.17	0.99	3.19	31.27	0.18	0.96	1.46	0.20	0.16	68.22	-6.08	100.71
E95T	0.30	0.96	2.86	23.09	0.23	0.81	1.43	0.17	0.11	61.63	-5.80	85.78
EE138T	0.24	1.08	3.07	25.86	0.26	0.89	2.54	0.20	0.18	71.85	-5.83	100.35
EE172T	0.23	0.92	3.08	28.65	0.20	0.87	1.67	0.18	0.18	69.07	-4.71	100.83
E314B	0.26	0.38	0.89	9.33	0.22	0.21	0.90	0.07	0.11	91.89	-1.60	102.66
E461B	0.09	0.80	2.77	25.44	0.17	0.59	0.88	0.16	0.15	66.22	3.00	100.27
E513B	0.04	0.54	4.77	14.91	0.17	0.71	0.71	0.20	0.10	79.38	-0.94	100.59
Longney C												
LC76T	0.11	1.02	2.08	16.20	0.16	0.67	1.35	0.14	0.14	86.59	-7.2	101.26
LC106T	0.16	1.02	3.90	20.09	0.23	1.04	1.65	0.19	0.22	76.95	-5.0	100.44
LC136T	0.21	1.46	3.30	30.87	0.17	1.12	1.93	0.20	0.20	67.27	-6.10	100.62
LC272T	0.29	0.66	2.80	21.77	0.16	0.54	0.67	0.15	0.11	79.93	-5.90	101.17
LC1172T	0.16	0.99	3.36	29.85	0.16	0.99	1.77	0.19	0.18	68.04	-5.41	100.27
LC2083B	0.18	0.74	8.48	12.19	0.50	0.42	2.65	0.32	0.14	47.59	26.1	99.30
Longney A												
LA152T	0.20	0.85	2.88	15.25	0.25	0.70	1.03	0.16	0.18	85.85	-5.76	101.50
LA188T	0.23	0.79	3.49	25.82	0.18	0.87	0.97	0.21	0.17	74.59	-6.62	100.70
LA241T	0.31	2.01	2.50	23.78	0.33	0.75	3.15	0.16	0.15	72.80	-5.06	100.87
LA248T	0.00	0.76	3.09	27.43	0.21	0.74	0.94	0.19	0.14	73.11	-5.90	100.70
LA620T	0.24	0.94	3.81	29.51	0.26	1.11	1.37	0.22	0.21	68.20	-5.62	100.26
LA57B	0.29	0.71	2.87	17.72	0.40	0.50	1.72	0.17	0.15	76.70	0.60	101.83
LA425B	0.12	0.63	1.87	13.15	0.22	0.24	1.33	0.13	0.12	0.85	-0.90	101.91
LA3067B	0.17	0.85	4.04	36.11	0.13	1.26	0.93	0.21	0.17	61.98	-5.70	100.14
Longney B												
LB71T	0.19	0.87	3.59	30.59	0.21	1.13	1.22	0.23	0.22	68.35	-6.17	100.43
LB297T	0.13	0.91	3.14	29.72	0.17	0.97	1.67	0.18	0.16	68.57	-5.60	100.02
LB1103T	0.31	0.93	3.18	27.56	0.24	1.06	1.45	0.18	0.19	70.96	-5.86	100.19
Arlingham												
AM123T	0.14	1.36	2.64	19.70	0.27	0.75	1.23	0.18	0.23	81.11	-6.70	100.93
AM168T	0.32	1.36	3.50	26.67	0.55	0.92	1.33	0.23	0.36	70.44	-5.30	100.39

Sample[1]	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	LOI	Total
AM411T	0.23	0.83	2.33	21.56	0.33	0.56	0.73	0.17	0.28	80.47	-6.10	101.38
Whitminster (Packthorne Farm)												
PF14T	0.09	1.40	4.68	14.13	0.20	1.01	1.77	0.21	0.18	77.2	-0.30	100.59
PF20T	0.19	0.43	4.30	14.62	0.31	0.65	1.56	0.23	0.04	83.52	-7.00	98.84
PF154T	0.21	1.46	3.65	25.80	0.67	1.06	4.54	0.23	0.16	68.49	-5.50	100.78
Hills Flats with Severn House and Dayhouse Farms												
HF24T	0.38	1.97	4.25	30.61	0.35	1.60	2.16	0.28	0.15	63.30	-5.33	99.73
DF83T	0.47	2.70	6.31	20.20	0.33	0.94	4.03	0.30	0.18	68.53	-4.30	99.68
DF91T	0.06	0.68	6.45	17.44	0.17	0.51	0.61	0.25	0.06	77.23	-3.00	100.47
DF123T	0.33	2.81	6.42	17.67	0.26	0.81	3.92	0.26	0.11	72.70	-4.80	100.48
DF262T	0.28	1.61	5.67	15.24	0.59	0.79	3.25	0.28	0.29	78.02	-5.50	100.52
HF38B	0.25	0.54	2.30	7.10	0.52	0.61	0.25	0.16	0.07	86.66	2.94	101.39
DF147B	0.12	0.56	7.38	19.72	0.37	0.86	0.46	0.31	0.06	72.39	-2.20	100.04
DF297B	0.79	0.82	6.11	21.55	0.21	0.79	0.92	0.31	0.04	72.96	-3.50	101.00
SHF350B	0.36	0.63	5.01	16.27	0.31	0.35	0.57	0.26	0.06	80.45	-3.22	101.04
DF470B	0.00	0.42	4.53	12.24	0.22	0.23	0.54	0.22	0.05	87.31	-4.20	101.56
DF911B	0.00	0.45	3.57	11.71	0.20	0.15	0.53	0.18	0.10	86.89	-1.70	102.08
Oldbury (Home Farm)												
HM29T	0.18	1.13	3.68	21.96	0.20	1.16	1.41	0.23	0.22	77.34	-6.60	100.9
HM83T	0.19	1.06	4.41	26.10	0.23	1.44	1.88	0.27	0.21	70.46	-6.30	99.93
HM149T	0.24	1.12	2.86	15.05	0.28	0.75	1.30	0.20	0.17	86.45	-6.60	101.83
HM193B	0.44	0.54	5.65	15.29	0.18	0.39	1.25	0.30	0.05	80.06	-3.60	100.54
HM283B	0.09	0.51	5.69	14.39	0.38	0.33	0.73	0.26	0.06	80.91	-2.50	100.86
HM492B	0.07	0.32	3.99	9.01	0.14	0.16	0.40	0.19	0.03	89.67	-1.40	102.58
Oldbury Flats												
OF146T	0.28	1.18	2.00	12.44	0.27	0.67	1.04	0.13	0.20	91.15	-7.10	102.25
OF299T	0.38	1.74	4.21	26.54	0.27	1.42	1.10	0.28	0.24	68.55	-4.60	100.23
OF423T	0.19	1.23	3.08	17.41	0.29	0.62	1.66	0.20	0.16	80.42	-4.00	101.28
OF441T	0.16	1.23	2.61	25.77	0.27	0.78	0.83	0.17	0.15	71.48	-2.80	100.66
OF578T	0.13	1.20	2.67	15.28	0.27	0.57	1.19	0.17	0.17	82.15	-5.44	98.39
OF598T	0.74	2.02	4.20	27.47	0.32	0.98	1.24	0.26	0.30	68.54	-4.01	102.04
OF323B	0.39	3.07	3.94	26.72	0.33	1.75	4.48	0.26	0.25	56.54	3.60	101.33
OF367B	0.17	1.39	1.16	8.20	0.23	0.32	0.52	0.08	0.13	91.77	-1.10	102.25
OF508B	0.40	1.83	2.56	13.80	0.61	0.84	1.15	0.16	0.13	81.38	-1.50	101.35
OF746B	0.24	2.13	2.40	28.94	0.27	0.36	1.78	0.15	0.21	74.29	0.43	101.19
OF1005B	0.33	2.10	1.82	9.39	0.26	0.33	0.52	0.14	0.17	90.10	-3.40	101.76
OF2757B	0.73	3.19	9.56	24.15	0.32	1.22	3.75	0.39	0.13	57.13	-1.40	99.17
Chesters villa												
WN25T	0.18	1.63	4.64	21.71	0.21	1.50	2.04	0.24	0.27	75.6	-6.33	101.78
WN27T	0.40	2.70	5.77	28.74	0.28	2.25	4.39	0.34	0.29	59.91	-5.11	99.96
WN29T	0.34	1.65	4.71	22.70	0.17	1.53	1.57	0.26	0.18	72.36	-5.52	99.91
WN31T	0.39	1.39	4.23	21.87	0.15	1.62	1.44	0.25	0.18	75.76	-6.51	100.77

Sample[1]	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	LOI	Total
WN33T	0.17	1.25	4.16	25.11	0.28	1.55	1.08	0.23	0.38	71.89	-6.02	100.18
WN34T	0.31	0.95	3.38	19.46	0.12	0.79	0.33	0.19	0.24	80.81	-6.19	100.37
WN35T	0.21	1.45	4.46	21.39	0.17	1.59	1.44	0.25	0.23	76.14	-6.77	100.58
WN37T	0.22	1.98	4.41	21.53	0.29	1.92	2.21	0.26	0.12	74.90	-6.99	101.15
WN43T	0.14	2.38	4.02	21.83	0.37	1.74	2.46	0.24	0.23	74.45	-6.29	101.57

APPENDIX B – TRACE ELEMENTS (ppm)

[1]- sample codes ending in T=tap slags; those ending in B=furnace bottoms

Sample[1]	V	Cr	Co	Ni	Cu	Zn	Pb	Rb	Sr	Y	Zr
Awre (Whitescourt)											
A111T	46	45	6	-	77	39	8	25	95	14	88
A206T	55	50	-	-	42	23	10	22	95	16	69
A238T	46	46	-	-	14	22	8	27	46	15	72
A301T	47	36	-	-	15	20	-	-	32	11	86
A425T	76	52	-	-	12	23	33	16	17	30	116
A607T	52	37	24	-	28	19	-	10	46	12	62
A908B	42	42	23	73	112	21	17	15	70	11	81
A983B	72	67	-	-	23	18	-	40	72	18	193
B1B	57	50	97	39	157	17	15	29	71	16	107
B2B	47	49	15	11	110	23	28	23	68	16	85
B3B	60	51	13	-	44	32	36	18	87	14	105
U1B	98	57	17	17	86	36	23	27	399	14	52
Lydney Park Farm											
LP81T	83	46	-	-	23	19	11	40	62	16	155
LP271T	44	46	-	-	8	33	-	31	45	26	103
LP75T	63	46	7	-	19	35	10	37	53	19	83
LP699B	224	130	6	-	88	15	-	8	-	-	36
Ley Pill (Woolaston)											
W43T	59	42	26	-	14	17	29	33	69	24	118
W92T	127	63	-	-	8	23	30	61	103	27	252
W124T	91	60	-	-	6	19	9	48	83	25	125
W205T	44	50	-	-	15	14	23	19	42	22	95
W283T	59	49	-	-	17	29	38	34	43	19	106
W59B	62	46	12	-	63	21	37	10	60	16	109
W76B	35	27	-	-	50	18	66	-	50	-	88
W405B	50	44	-	-	17	14	33	21	35	13	95
W470B	44	48	-	-	21	13	8	28	82	15	122
W648B	51	44	-	-	17	25	10	35	45	7	79
Horse Pill, beach and cliff											
HP30T	28	24	-	-	19	26	-	5	28	-	56
HP45T	40	41	-	-	14	11	-	34	71	15	102
HP120T	34	24	-	-	19	32	47	-	23	6	51

Sample[1]	V	Cr	Co	Ni	Cu	Zn	Pb	Rb	Sr	Y	Zr
HP257B	47	45	6	10	62	35	-	15	51	16	126
HP426B	33	34	-	-	5	32	-	-	61	11	99
HP1086B	50	40	-	20	116	16	49	-	78	9	61
Pill House											
PR37T	90	74	23	-	16	23	32	43	101	28	157
PR39T	54	52	32	-	23	25	25	44	74	20	104
PR42T	79	55	-	-	23	21	-	34	84	25	116
PR252T	33	27	-	-	33	18	33	9	46	9	84
PR344T	70	41	-	-	14	34	9	30	51	18	133
PR445B	39	33	-	-	31	16	87	14	76	8	70
Rumney Great Wharf											
RGW322B	97	73	9	-	54	17	-	24	456	21	107
RGW331B	51	31	-	-	45	22	-	-	869	12	53
RGW395B	116	83	19	-	41	23	34	10	429	19	102
RGW490B	57	49	10	-	46	29	7	19	744	19	76
RGW537B	127	112	10	11	54	17	-	21	2839	23	-
RGW678B	118	108	10	-	77	13	58	-	256	35	143
RGW810B	60	35	-	-	45	8	-	19	668	33	84
RGW945B	73	60	21	22	73	13	6	30	519	28	50
Elmore (Windmill Hill)											
E51T	69	53	-	-	8	14	21	35	86	18	132
EE78T	54	54	8	-	9	24	49	26	57	19	156
E95T	47	45	-	-	10	36	-	23	60	20	106
EE138T	58	46	-	-	17	27	-	30	69	19	116
EE172T	65	48	13	-	23	19	49	24	69	18	120
E314B	20	27	-	-	38	14	33	-	44	-	29
E461B	64	48	-	-	12	25	19	28	33	14	128
E513B	67	49	21	70	58	8	-	33	168	16	6
Longney C											
LC106T	55	55	-	-	25	16	-	39	68	14	116
LC136T	56	52	-	-	-	21	35	35	70	19	106
LC272T	36	31	8	-	32	54	8	16	25	13	80
LC1172T	55	41	7	-	12	22	14	28	75	19	113
LC2083B	158	141	92	197	372	25	-	17	1294	41	40
Longney A											
LA152T	49	53	14	-	11	19	4	34	58	16	154
LA188T	45	40	-	-	31	5	-	19	37	13	9
LA241T	43	36	-	-	32	15	38	13	79	14	10
LA248T	68	43	-	-	10	27	-	20	53	22	109
LA620T	85	57	-	-	16	29	-	33	48	14	154
LA57B	46	43	-	17	33	13	47	16	67	14	102
LA425B	72	58	23	26	56	14	11	8	32	10	74

Sample[1]	V	Cr	Co	Ni	Cu	Zn	Pb	Rb	Sr	Y	Zr
LA3067B	70	47	-	-	23	30	-	45	72	18	107
Longney B											
LB71T	56	53	22	-	16	9	6	41	56	10	137
LB297T	74	46	-	-	14	13	-	28	78	11	112
LB1103T	55	45	17	-	13	15	-	36	90	17	102
Arlingham											
AM123T	47	44	-	-	6	6	30	17	37	23	127
AM168T	53	50	-	-	9	28	16	23	51	17	124
AM411T	43	41	-	-	17	23	23	14	30	9	97
Whitminster (Packthorne Farm)											
PF14T	69	53	-	7	311	25	-	40	320	19	59
PF20T	48	38	28	82	251	26	1744	14	204	30	110
PF154T	49	48	-	-	10	26	11	33	105	27	123
Hills Flats with Severn House and Dayhouse Farm											
HF24T	67	56	57	-	13	36	-	34	81	25	165
DF83T	57	50	13	-	108	20	58	24	391	21	104
DF91T	61	54	17	-	82	12	46	17	118	14	74
DF123T	64	57	18	21	81	19	43	31	172	22	84
DF262T	87	64	159	195	178	24	45	23	269	27	70
HF38B	56	173	74	348	182	68	44	-	60	7	67
DF147B	61	41	6	-	67	19	13	49	278	12	83
DF297B	83	51	6	-	76	21	9	14	216	27	114
SHF350B	70	43	6	-	76	22	31	7	97	13	91
DF470B	41	33	9	-	55	13	13	8	149	11	78
DF911	38	26	11	-	91	18	-	-	39	10	72
Oldbury (Home Farm)											
HM29T	50	54	6	-	24	19	45	35	46	17	100
HM83T	64	57	-	-	10	29	-	47	67	22	127
HM149T	59	42	-	-	20	16	11	26	47	16	99
HM193B	66	53	69	186	135	15	17	4	178	24	96
HM283B	66	36	8	-	85	23	-	9	232	17	72
HM49B	46	30	22	147	174	18	6	-	98	16	4
Oldbury Flats											
OF1456T	42	37	-	-	21	24	-	10	48	18	57
OF299T	65	56	-	-	10	40	-	33	44	24	160
OF423T	46	42	-	-	11	32	45	15	75	13	100
OF441T	53	42	-	-	21	56	-	17	41	12	99
OF578T	39	35	-	-	18	25	-	21	52	10	69
OF598T	73	54	-	-	21	37	-	31	46	23	149
OF323B	74	55	26	61	25	34	19	48	153	27	153
OF367B	27	19	-	-	19	44	37	9	44	11	21
OF508B	44	42	-	-	19	66	-	14	101	13	64

Sample[1]	**V**	**Cr**	**Co**	**Ni**	**Cu**	**Zn**	**Pb**	**Rb**	**Sr**	**Y**	**Zr**
OF746B	81	43	-	-	26	74	61	-	67	29	115
OF1005B	31	25	-	-	10	27	45	-	39	13	54
OF2757B	95	86	23	14	56	34	16	45	515	25	115
Chesters Villa											
WN25T	77	52			14	27	49	40	82	28	113
WN27T	92	76			16	16		51	86	37	162
WN29T	54	60			8	33	27	41	42	24	133
WN31T	50	45			20	24	24	46	58	21	111
WN33T	77	53			10	21	25	45	63	21	136
WN34	74	53			13	14		24	31	60	87
WN35	57	54			16	25		46	60	21	106
WN37T	58	45			15	22	26	45	49	24	97