CAST COPPER-SLAG BUILDING BLOCKS ON THE SEVERN ESTUARY LEVELS: ST. THOMAS THE APOSTLE, REDWICK, GWENT

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A substantial part of the churchyard wall of St. Thomas the Apostle, Redwick, is capped by triangular coping blocks of cast slag, a by-product of the 18th to mid-19th century copper-smelting industry located in south-west Britain. The slags are silica-rich (unreacted flux), glassy to partly crystalline (fayalite), and contain spheroidal inclusions (prills) of copper-iron-sulphur compounds related to the smelting process (chiefly ?chalcocite, Cu_2S). A petrographic, mineralogical and chemical comparison of the blocks with slag blocks and waste slag from three other sites (two archaeological) in the Severn Estuary Levels suggests that this widely used, artificial building material is likely to prove very variable in character. More work is needed before it can be said whether the variability is indicative of provenance, technical advances in the industry, or the production of blocks at more than one stage in the elaborate copper-smelting process. The blocks, a high-mass but low-value product, appear to be have been traded chiefly by water.

INTRODUCTION

For several hundred years beginning in the 12th or 13th century AD fired brick was the only artificial building material used structurally in Britain (Brunskill 1990). By the 18th and 19th centuries, however, another pyrotechnology was giving rise in the west and south-west of the country to a second artificial material. As a by-product of the smelting of copper ores, chiefly from Cornwall but also from Anglesey and Ireland, cast building blocks of slag were being made in the north-west Midlands (Harris 1964; Hughes 2000), in the Forest of Dean (Redbrook) and Bristol area of the West of England (Hart 1971; Day 1973), at Neath and later Swansea in Wales (Hughes 2000), and at Copperhouse on the Hayle Estuary, Cornwall (Noall 1985). In the districts which contained these long-defunct industries, examples of the blocks can still be seen in many contemporaneous buildings and structures, in which they serve a variety of architectural functions.

An occurrence of these blocks, poised geographically between the sites of the Forest of Dean, Bristol and Welsh enterprises, is to be found at the church of St. Thomas the Apostle at Redwick on the Gwent Levels, one of the largest and outermost of the several outcrops of Holocene, chiefly estuarine alluvium which make up the Severn Estuary Levels (Allen 2000). The aim of this paper is to record this occurrence and to present new data - possibly critical for the issue of provenance - on the petrography, mineralogy and chemistry of these and similar slag blocks, chiefly in archaeological contexts, about which almost nothing is known. Petrographic analysis in thin-section (transmitted light) and polished section (reflected light) was supplemented by standard x-ray diffraction analysis (XRD). The chemistry of the blocks was explored by standard x-ray fluorescence analysis (XRF), and by the energy-dispersive analysis (EDAX) of polished sections using a scanning electron microscope (SEM). An introduction to these techniques is given by Tucker (1988).

ST. THOMAS THE APOSTLE'S CHURCHYARD WALL

Redwick is a village lying some 25 km to the east-north-east of Cardiff, 15 km to the south-west of Chepstow and roughly 1 km from the sea (Figure 1, overleaf). The present church of St.

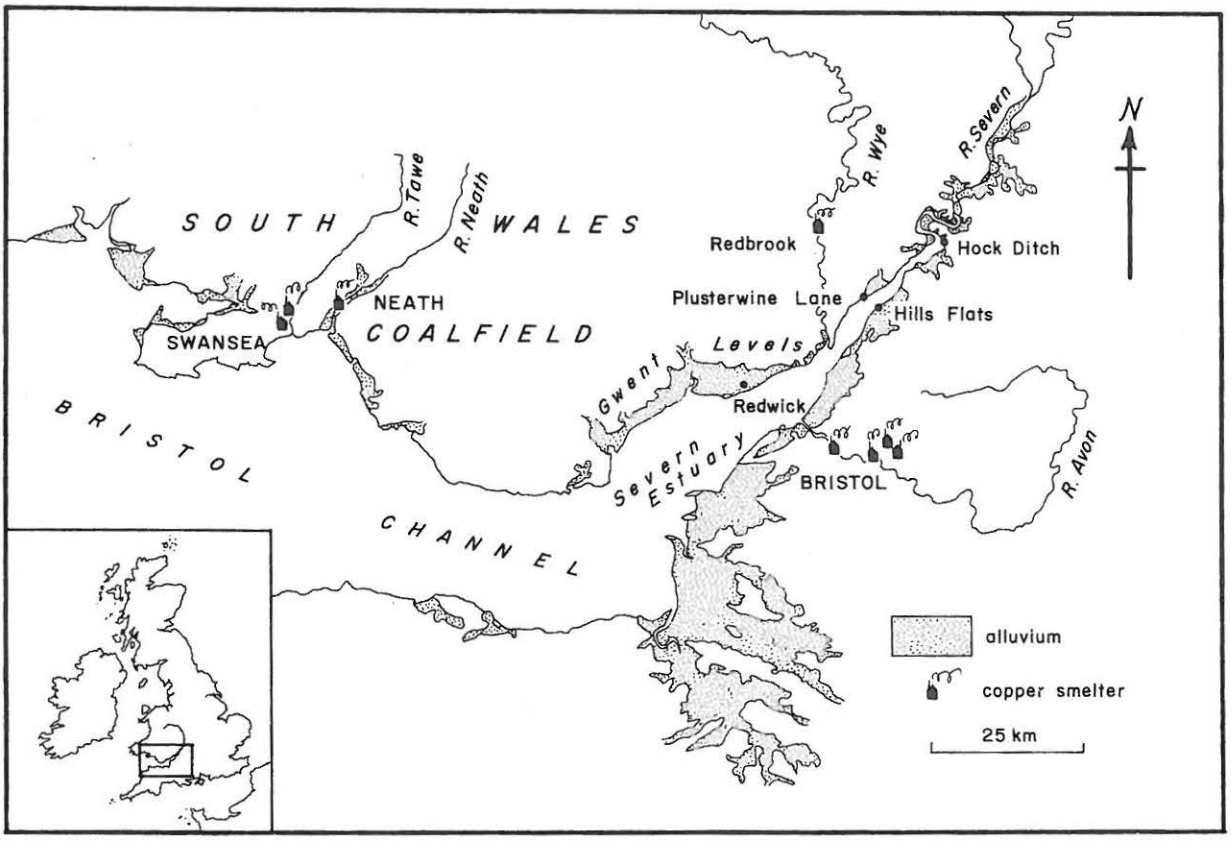

Figure 1: The inner Bristol Channel and Severn Estuary Levels, showing the main sites of the copper-smelting industry and the localities from which copper-smelting slag blocks are described.

Thomas (Nat. Grid. Ref. ST 412841) is a comparatively large building constructed chiefly from building stones available in the general district. It appears to date from not earlier than the mid-14th century, but may replace a more modest 12th-century structure.

The churchyard is almost oval in form, the stone wall along its southern and western sides being topped by a long row of cast-slag coping blocks. These are of a triangular form, measuring approximately 0.42 m long and 0.19 m wide at the base, and 0.35 m in height, with a rounded top, the dimensions of individual blocks varying by up to 0.02 m from these values (Figure 2). Externally, they are black in colour, with a generally dull surface, and invariably carry large wrinkle-like flow markings (Figures 2 and 3). The markings, as seen on the exposed sides, lie roughly parallel with the base of each block, but can include a variety of more local patterns, including oval or node-like ones. Recalling the way golden syrup or decorator's oil paint repeatedly folds and unevenly spreads when

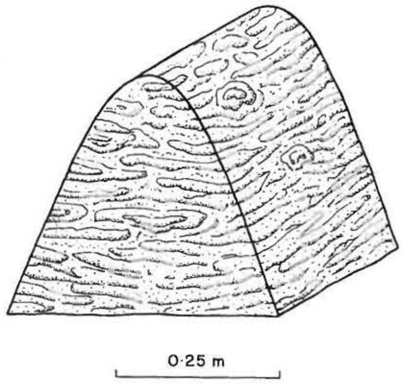

Figure 2: St. Thomas the Apostle, Redwick. Partly schematic form and size of coping blocks on churchyard wall.

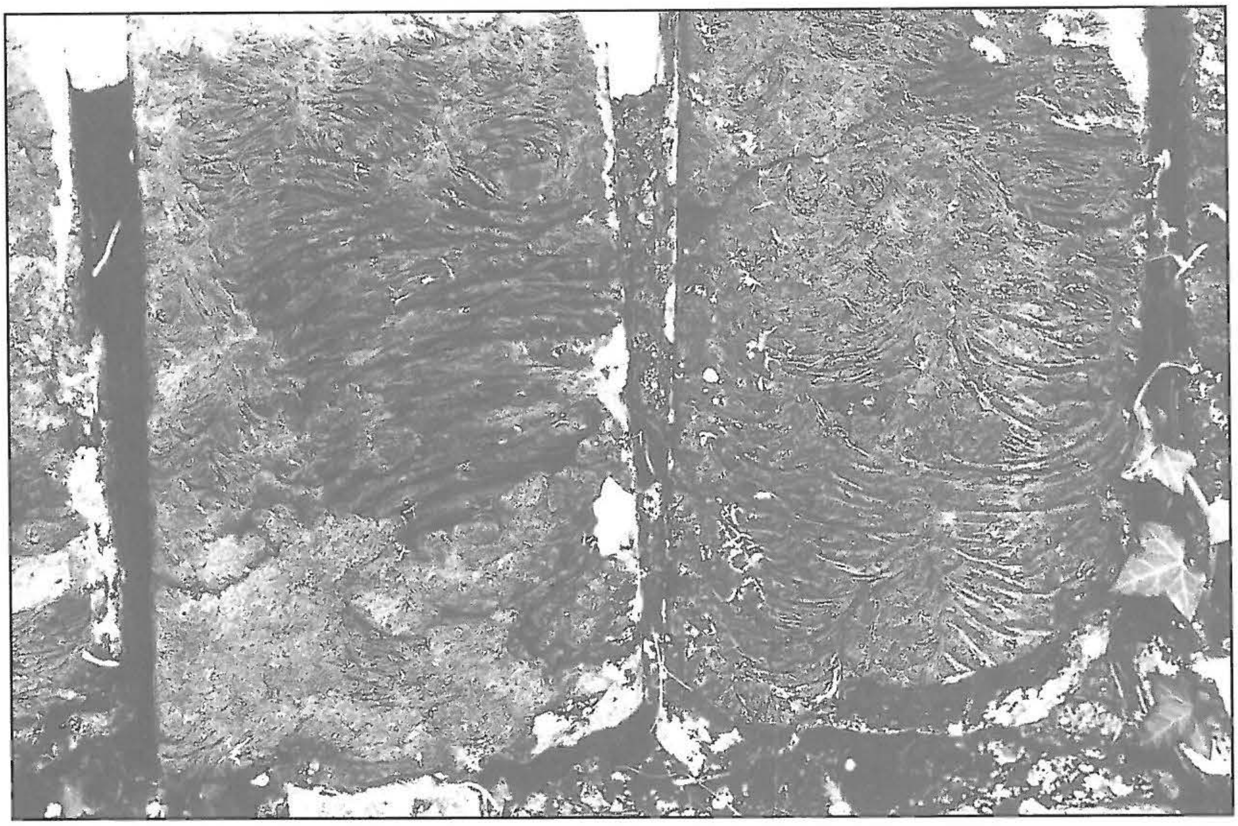

Figure 3: St. Thomas the Apostle, Redwick. Flow markings on the sides of two slag coping blocks (about 0.19 m wide).

poured in a thick stream into a container, they are a sure proof of the origin of the blocks as the result of the casting of an incandescent, viscous slag into a cold mould, in which it congealed, beginning at the walls. The form of the undersides, as seen on broken examples, shows that the blocks were apex-down when cast, the opposite of their orientation on the wall. Normally, a slight vesicularity is evident in hand-specimens.

Samples were taken from four blocks which had tumbled from the wall and smashed. Thin-sections examined in transmitted light show a low to moderate amount of crystalline components set in a generally opaque, dark grey to greenish grey, very finely textured to locally glassy groundmass. A low amount (5-10%) of monocrystalline to polycrystalline quartz is present in all samples. The particles, up to 6 mm in length, have smoothly curving, commonly deeply embayed margins. They are minutely and intricately fractured and veined with clear to slightly opaque material (?cristobalite). Recalling quartz phenocrysts in some felsic lavas, these features suggest that the particles had been involved in a vigorous chemical reaction before the slag chilled. The other and much more abundant, optically determinable crystalline component is fayalite ($\leq$40%), typically as interwoven sheaves of needle-like crystals and crystallites large enough to be also visible in the hand-specimen. XRD-analysis confirmed the presence of these minerals and showed the occurrence of others (Table 1, overleaf), including maghemite, and the pyroxene-group minerals ?diopside and clinoferrosilite.

The preparation of polished sections, and their subsequent examination in reflected light and by EDAX, showed that all of the slag specimens contained spherical to sub-spherical, drop-like particles, or prills, of copper-iron-sulphur compounds. Although comparatively evenly dispersed, the amounts present are very small, and in no case do the spheroids exceed about 1 mm in diameter. In reflected light the majority appear metallic and lead grey, commonly with a bluish or violet tinge, but some also exhibit yellow-brown patches. As a rough

Sample	fayalite	crisobalite	quartz	maghemite	?diopside	clinoferrosilite
Redwick 1	xx	x	x	-	-	x
Redwick 2	x	x	x	-	-	x
Redwick 3	xx	x	x	x	-	-
Redwick 4	xx	x	x	-	-	x
Hills Flats	x	x	x	x	-	-
Plusterwine Lane	-	x	xx	-	x	-
Hock Ditch	x	-	-	-	-	-

Table 1: Mineralogy by XRD-analysis of copper-smelting slags from the Severn Estuary Levels (key: x - mineral present; xx - dominant crystalline component). Note: The mineral recorded as ?diopside may be augite, and the clinoferrosilite may include ferrosilite.

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	total
Redwick 1	0.89	0.44	5.40	45.92	0.06	0.09	4.84	0.16	0.21	39.34	97.36
Redwick 2	0.83	0.50	5.08	47.92	0.06	0.08	5.34	0.17	0.23	36.11	96.31
Redwick 3	0.84	0.38	5.97	48.18	0.06	0.09	4.92	0.16	0.22	39.06	99.88
Redwick 4	0.80	0.43	4.93	50.99	0.06	0.09	4.44	0.15	0.20	36.57	98.65
Hills Flats	0.35	0.54	3.99	55.16	0.04	0.38	3.06	0.21	0.11	38.49	102.34
Plusterwine Lane	0.26	1.29	4.42	59.21	0.07	0.27	8.50	0.22	0.14	17.66	92.03
Hock Ditch	0.03	1.27	6.52	37.79	0.21	0.51	1.13	0.33	0.04	52.28	106.11

Table 2: Bulk chemical composition (wt. %) by XRF-analysis of copper-smelting slags from the Severn Estuary Levels.

Sample	Pb	Cu	Zn
Redwick 1	1828	4229	27760
Redwick 2	1646	2942	26940
Redwick 3	1891	4517	27760
Redwick 4	1756	3470	26010
Redwick (average)	1780	3790	27120
Hills Flats	1095	5836	11300
Plusterwine Lane	883	6793	9725
Hock Ditch	1569	1945	4281

Table 3: Trace element composition (ppm) of copper-smelting slags from the Severn Estuary Levels.

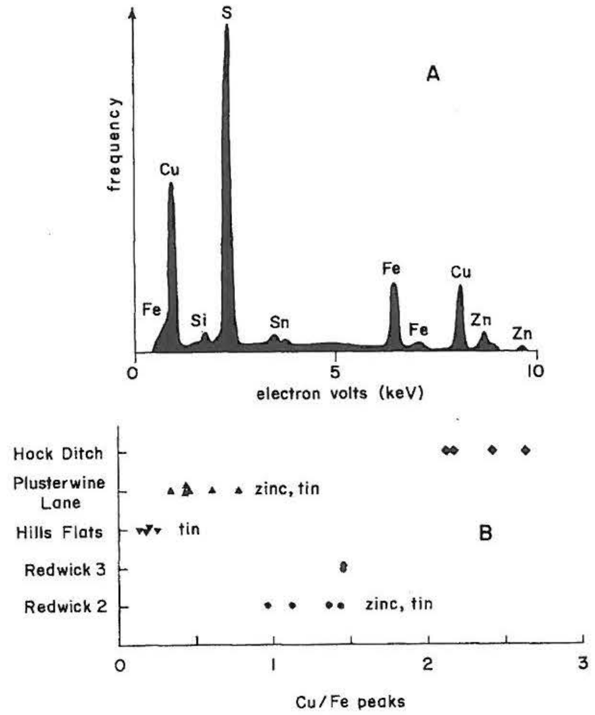

Figure 4: EDAX-analyses of prills of copper-iron sulphides in slags from Redwick, Hills Flats, Plusterwine Lane and Hock Ditch. A - Representative EDAX trace showing the elements detected and their peaks (Redwick 2). B - Ratios of the principal Cu and Fe peaks from representative prills, together with elements (Sn, Zn) present in trace amounts.

guide to composition, the heights of the diffraction peaks (Figure 4A) for copper (8.04 keV) and iron (6.40 keV) were compared on two of the larger particles present in sample Redwick 2 and on one large particle in Redwick 3 (Figure 4B). Redwick 2 revealed traces of zinc and tin.

Chemically, as determined by XRF-analysis, the four samples differ little in terms of the major and minor elements present, calculated as oxides (Table 2). The proportion of SiO_2 exceeds Fe_2O_3, as might be expected from the presence of free silica, the alkali metals have a very low to low abundance, the alkaline earths occur in low to moderate amounts, and alumina is moderately abundant. Figure 5 shows values for the ratios of selected oxides, on the basis of the average of the analyses of the four samples (Table 2). Of the heavy metals of interest, lead and copper are present in substantial but trace amounts, whereas zinc approaches in status a minor element (Table 3). Except for copper, there is little difference between the four samples. Figure 6 shows the average proportions of lead and copper as a function of the average proportion of zinc.

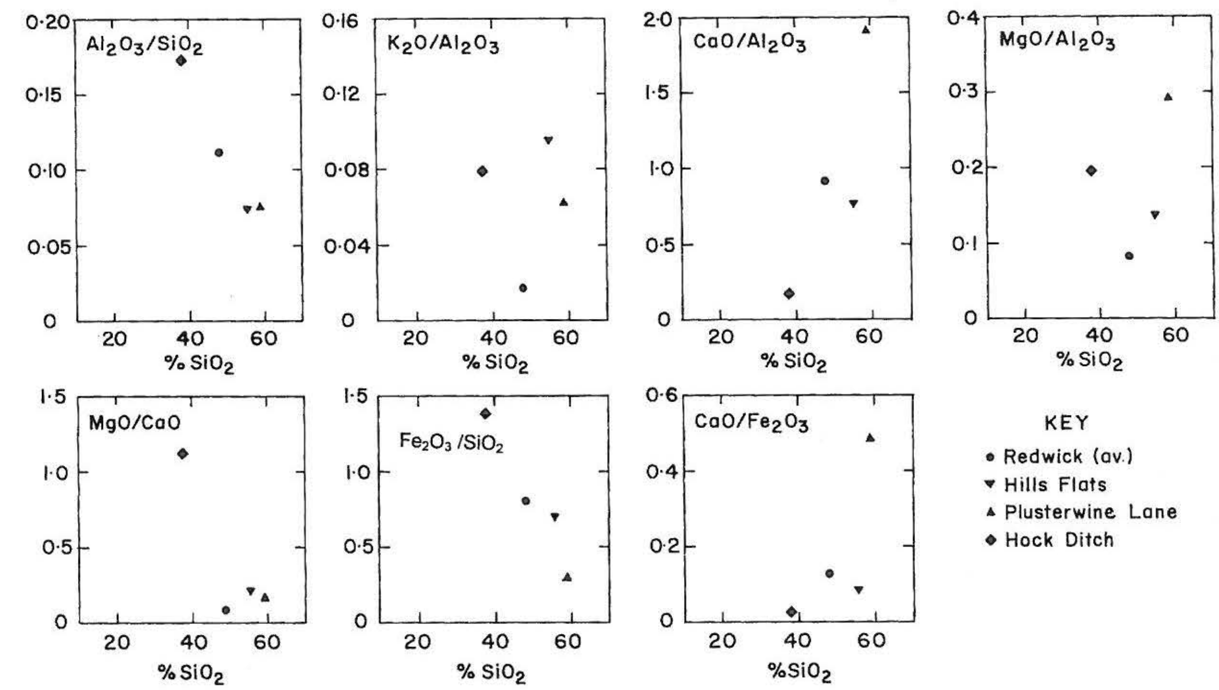

Figure 5: Bulk chemistry of slags from Redwick, Hills Flats, Plusterwine Lane and Hock Ditch, as illustrated by oxide ratios (see also Table 2).

OTHER SLAG BLOCKS AND SLAGS

Copper slags have been examined from three other localities in the Severn Estuary Levels, at Hills Flats, Plusterwine Lane, and Hock Ditch (Fig. 1). They occur as cast building blocks at Hills Flats and, in an archaeological context, at Plusterwine Lane. The slag at Hock Ditch, also in an archaeological context, occurs as waste.

The block sampled from Hills Flats (ST 631977) was found as part of an obscure, linear dispersion of lumps of rock lying across the tidal foreshore, perhaps originally a groyne intended to protect the nearby salt-marsh coast. Rectangular in form, glistening black in colour, and with flat, flow-marked sides, it measured approximately 0.45 m in length and 0.20 m by 0.25 m in cross-section. In thin-section, abundant (20%), rounded to embayed, minutely fractured and veined quartz ($\leq$11 mm) is set in a slightly vesicular, yellowish green glass in which contorted bands of spherulites (?fayalite) emphasize a strong flow-banding. XRD-analysis showed the additional presence of cristobalite and maghemite (Table 1). Spherical to sub-spherical prills of copper-iron-sulphur compounds are more common than at Redwick, reaching up to 3 mm in length. Their character in reflected light is very variable. Some appear lead-grey, others yellow-brown, but many have a granulated grey-yellow/brown appearance. The ratio of the copper to iron peaks is considerably lower than at Redwick, varying between 0.15 and 0.26 (Fig. 4B). Traces of tin were detected in one of the two particles examined by EDAX. The bulk chemical analysis revealed both more SiO_2 and a little more Fe_2O_3 than at Redwick (Table 2), and there are also some differences in the oxide ratios (Fig. 5), notably in the value for MgO/CaO (Fig. 5). The proportions of lead, copper and zinc are of the same high order as at Redwick, but whereas the figure for copper is higher, the values for lead and zinc are lower (Table 3, Fig. 6).

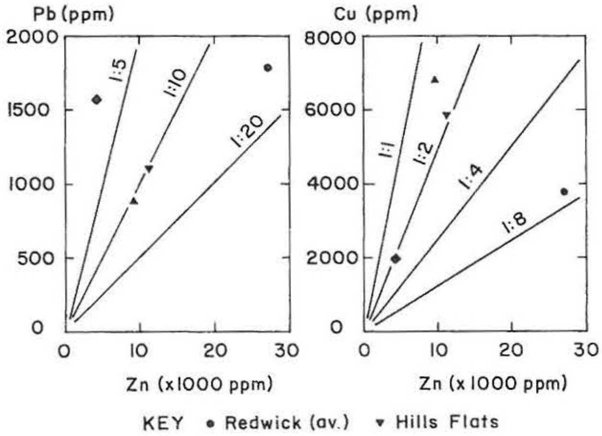

Figure 6: Amounts of lead, copper and zinc in copper-smelting slags from Redwick, Hills Flats, Plusterwine Lane and Hock Ditch (see also Table 3).

Plusterwine Lane (Fig. 1) is a metalled road and then a hardened track which is the sole means of communication between the main Gloucester-Chepstow road south-eastward down to Cone Pill in the Lydney Level on the western bank of the Severn Estuary (Allen 2001a). At the coast, the track (ST 604990) is seen buried as deep as 2 m among pale brown, estuarine silts of the Upper Rumney Formation, the inception of which probably dates from the late 17th century. In response to the apparently rapid upward and outward accretion of these silts, the track was frequently reset and repaired using a variety of materials: bundles of willow overlain by quarried stone succeeded by lime-cemented brushwood and straw, bundles of furze and sticks, haphazardly arranged roundwood and stone, or close-packed broken brick, tiles, stone and roundwood. Among these hardenings there occurred a variety of artefacts, including pottery and a clay tobacco pipe, dating from the mid or late 17th century to the mid 18th century. Also present were a few damaged copper-slag building blocks, one of which was sampled, similar in size, shape and appearance to that at Hills Flats (Figure 7). The maintenance of the track is explained by the fact that Cone Pill was used for ship-building in the 17th and 18th centuries (Scott-Garrett 1938; Farr 1954), and was an important landing and loading place during the first half of the latter period (Hart 1967; Smith 1972). Judging by the profusion of cattle and human tracks preserved in the silts near Plusterwine Lane, the route was also used for the droving of animals (Allen 1997), probably eastward to markets in England beyond the Severn. By the end of the 18th century, however, trade apparently had dwindled away.

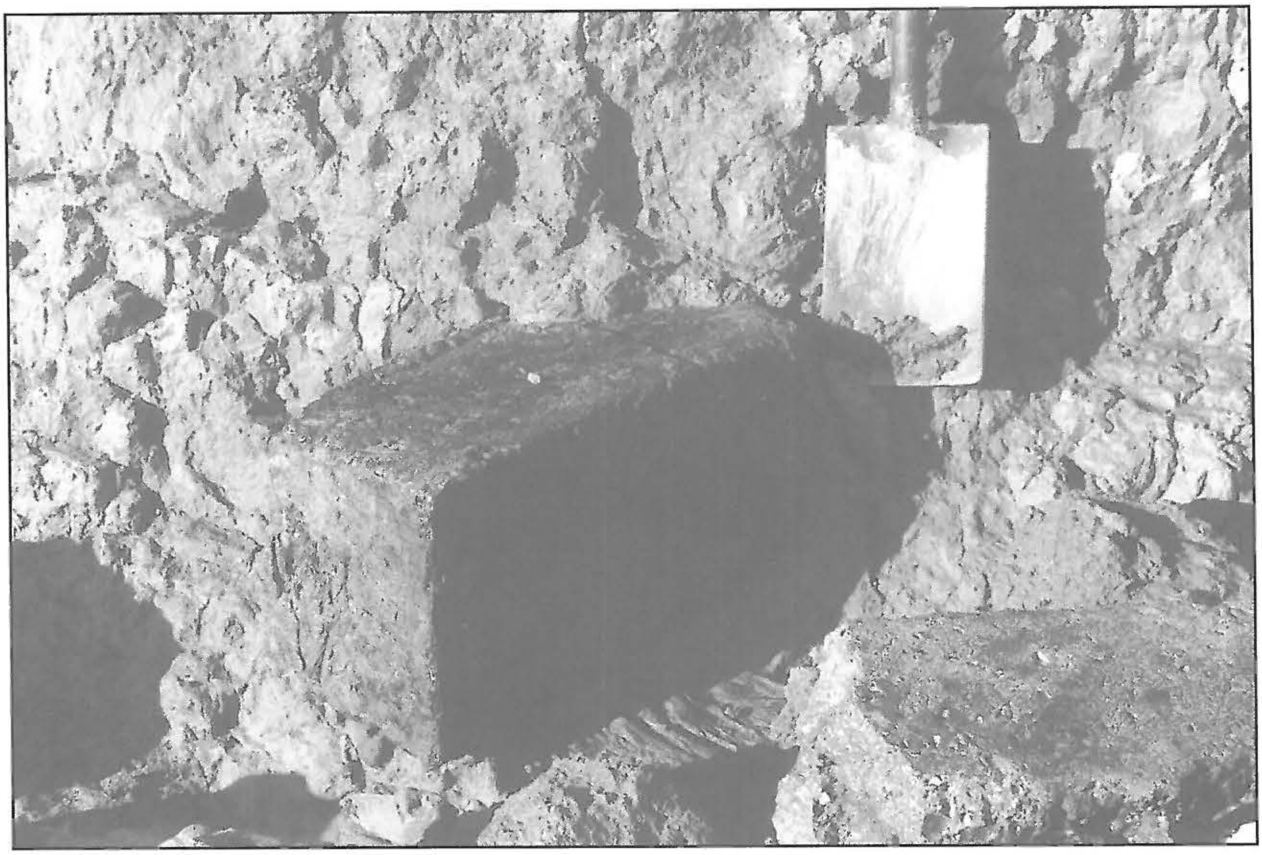

Figure 7: Plusterwine Lane. Detail of coastal exposure showing two slag building blocks among other debris embedded in pale brown silts. Spade for scale.

In hand-specimen the slag from Plusterwine Lane varies from dull and dark grey to black and glassy, carrying abundant (25%) and generally large (≤8 mm) white to glassy inclusions. The latter in thin-section prove to be a mixture of commonly polycrystalline quartz, partly idiomorphic crystals of orthoclase, and some partly intergrown quartz and subordinate orthoclase (?granite). All of these particles exhibit a degree of fracturing and veining by cristobalite, but not to the degree seen at Redwick. Rounded and embayed margins are also less evident than at Redwick. The inclusions are set in a partly glassy groundmass with complex flow-banding, varying in colour from olive green through reddish brown to black and opaque, some of the flow bands consisting of rows of small spherulites. XRD-analysis revealed the presence of fayalite (Table 1). Also present are scattered, spherical to sub-spherical prills (≤3 mm) of copper-iron-sulphur compounds with a lead grey to yellow-brown reflectance. The ratio of the copper to iron peaks by EDAX, varying between 0.35 and 0.78, is intermediate between that at Redwick and Hills Flats (Fig. 4B). Traces of both zinc and tin were detected in some of the spheroids. The slag from Plusterwine resembles chemically the samples from Redwick and Hills Flats but contains more SiO_2, considerably more CaO, and substantially less Fe_2O_3 (Table 2, Fig. 5). Lead, copper and zinc are similar in abundance to Hills Flats, but the ratio of Cu to Zn is much greater than at Redwick (Table 3, Fig. 6).

Copper-smelting slag was also recovered from Hock Ditch (SO 735086), a small tidal inlet below the Arlingham peninsula high on the east bank of the Severn Estuary (Fig. 1). Vigorous erosion around the mouth of this pill has exposed a thick silt unit at the base of which lies a jumble of rounded lumps and blocks of silt, a range of quarried stone (including dressed oolite), lumps of slag and a variety of artefacts (Allen 2001b). The latter include a Buckley pancheon of the late 17th to early 18th century, Staffordshire stoneware of the early 18th century, and an 18th century glass flagon, dating the inception of the unit to not earlier than the early 18th century. Geochemically (Allen and Rae 1987; French 1996), the inception of the unit dates to before 1840-50. The slag appears to have come from a waste dump. It occurs as fragments from sheets of vesicular tap slag and as large lumps broken from masses of slag that may have chilled in the crucible-wagons used to carry it from furnace to spoil heap. The slag and stone may register an attempt to halt an earlier phase of salt-marsh erosion at the pill mouth. On the alluvium further up the estuary, however, copper-smelting tap slag had also been used as an experimental field dressing (Allen and Fulford 1990).

The large lumps have a metallic, lead grey colour but when freshly broken appear black and medium crystalline. A representative thin-section showed interwoven sheaves of dendrites and crystals of fayalite (50%), confirmed by XRD-analysis (Table 1), set in a very slightly vesicular, opaque, black groundmass. The only other mineral seen is a little ?diopside, occurring as small, single or clustered, idiomorphic crystals showing signs of resorbtion. In contrast to the other slags, no free quartz was detected. The polished section showed that the slag contained a scattering of prills ($\leq$0.5 mm) of copper-iron-sulphur compounds with an exclusively lead-grey, occasionally blue-violet reflectance. Two of these were examined by EDAX. The ratio of the copper to iron peaks ranges between 2.13 and 2.64, and is up to an order of magnitude larger than for the other slags (Fig. 4B). In bulk chemistry (Table 2, Fig. 5) the slag is low in SiO_2 and CaO but comparatively high in Al_2O_3 and Fe_2O_3. The ratio of MgO to CaO is very high compared to the other slags. Of the trace heavy metals, lead occurs in about the same proportion as in the other slags, but the amounts of copper and zinc are substantially lower, although still relatively large (Table 3). The ratio of lead to copper is higher than in the other slags (Fig.6).

DISCUSSION AND CONCLUSIONS

No documentary evidence has been traced which establishes when the churchyard wall at St. Thomas's, Redwick, was coped with slag blocks, but a date in the 18th to mid 19th century, and a provenance in the British copper-smelting industry, may be confidently proposed.

The slags (Tables 1-3) are petrographically, mineralogically and chemically similar to other recent copper-smelting slags (eg Tylecote 1976, table 71; 1987, table 8.6), different in bulk chemistry from blast-furnace iron slags (Tylecote 1976, tables 44, 59), and distinct by orders of magnitude in the levels of lead, copper and zinc from medieval and older iron bloomery slags (Allen and Fulford 1990, table 7; Fulford and Allen 1992, table 9). In *bulk* composition, however, the Redwick slags do resemble iron bloomery slags (eg Tylecote 1986, tables 76, 79; Tylecote 1987, table 8.10; Allen and Fulford 1987, table 7; 1990, table 5; Fulford and Allen 1992, table 9), for both are basically fayalitic, with an iron content as high as or higher than the ores from which they were derived. The slag blocks at Redwick - and on the same

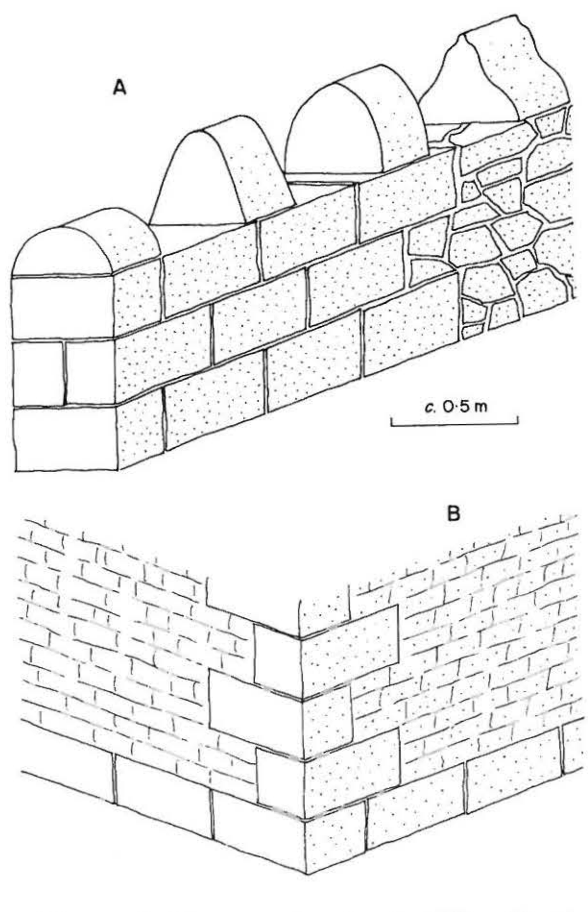

Figure 8: Cast copper-slag building blocks. A - Range of forms, partly adapted from Day (1973). B - Use of rectangular blocks in footings and quoins.

compositional grounds the slags from Hills Flats, Plusterwine Lane and Hock Ditch - are not the by-product of the iron industry in Wales or the Forest of Dean.

The coping blocks at Redwick, and the rectangular blocks described from Hills Flats and Plusterwine, are just two of a range of forms of cast-slag building blocks produced by the copper-smelting industry in the west and south-west of Britain (Figure 8A, opposite). These are widely evident in contemporaneous buildings and structures (18th to mid-19th century) in the West of England, South Wales and Cornwall. Triangular and half-round coping blocks are reported from the West of England (Day 1973), and rectangular blocks, used chiefly for footings and quoins (Figure 8B), can as Day has noted be seen in many of the towns and villages along the Severn and Wye, for example, Redbrook, Whitebrook, Newnham (commonly misidentified as furnace lining), and Berkeley (village and later buildings at the castle). Perhaps the most famous and conspicuous survival in the Bristol-Bath area is the mid-18th century 'Black Castle' (Arno's Vale, Bristol), where entire walls, except for window and door fittings, are of these blocks. Rectangular blocks and half-round copings are widely seen in central and eastern parts of South Wales, particularly in the Port Talbot-Swansea-Bury Port area, where the industry was based, and broken lumps of slag (Fig. 8A) feature frequently in boundary walls (Hughes 2000, fig. 230). Mitre-shaped coping blocks and those of double ogee-section (Fig. 8A), have been recorded here and there (Hughes 2000, 54, fig. 138). Beginning in the mid-18th century, copper-smelting slags were also cast into rectangular blocks at Copperhouse on the Hayle Estuary in Cornwall (Noall 1985), where they survive in many buildings in and around Hayle and Copperhouse and, perhaps most impressively, as the facing of the long causeway that bridges the estuary at the latter place.

The business, architectural and infrastructural aspects of 18th and 19th century copper-smelting in the west and south-west of Britain have been given much more prominence than the techniques used in the industry and the nature of its intermediate products and by-products (Hart 1971; Day 1973; Noall 1985; Hughes 2000). Broadly, high-grade ores of mixed chalcocite (Cu_2S) and chalcopyrite ($CuFeS_2$) from Cornwall (Dines 1956) and to some extent Anglesey (Greenly 1919) and Ireland were smelted, as summarized by Tylecote (1976, 128-131) and Craddock (1995, 149-153), in an elaborate, fuel-hungry process which terminated in the double decomposition of Cu_2O and Cu_2S to yield metallic copper and gaseous sulphur dioxide. The numerous intermediate stages were intended to remove the iron and convert the copper into the appropriate species and proportions of sulphide and oxide. The iron is said to have been slagged 'with the aid of silica from the hearth' or 'sand from the furnace bottom' (Tylecote 1976). The petrographic features described, however, suggest that quartz sand/gravel (Redwick, Hills Flats), and even crushed/weathered granite (Plusterwine Lane), perhaps imported from Cornwall with the ore, may have been deliberately mixed as a flux into the charges introduced into the furnaces. Given the large amounts of silica present, the proportions of MgO and CaO in the slags suggest that either limestone (Redwick, Hills Flats, Plusterwine Lane) or dolomite (Hock Ditch) also figured in the flux (Table 2, Fig. 5).

What is clear from the limited number of samples so far examined is the considerable petrographic and mineralogical diversity shown by the copper-smelting slags described above (Table 1). Within the bounds of a general fayalitic composition, the slags are also diverse chemically (Tables 2, 3; Figs. 5, 6). Those from Redwick and Hock Ditch are substantially crystalline, whereas the slags from Hills Flats and Plusterwine Lane are essentially glassy, a contrast which perhaps suggests that the latter had not been raised to so high a temperature. The only possibly distinguishing chemical factor, however, is the comparatively high ratio (mostly >1) of the copper to iron peaks in the copper-iron-sulphur prills present at Hock Ditch and Redwick (Fig. 4B). These distinctive inclusions may be identified with the immiscible, liquid 'mattes' produced at different stages in the smelting process. Within and between these spheroids there is little consistency in the distribution of traces of tin and zinc. Neither element was recorded in the two prills examined from Hock Ditch, and in one of the prills at Hills Flats. The other spheroid from Hills Flats included tin at one sampled point but neither zinc nor tin at a second. By contrast, both prills examined from Plusterwine Lane showed zinc and tin, except at one sampled point which revealed neither. One of the Redwick spheroids showed both tin and zinc, another had zinc only, and a third lacked both metals. The presence of tin is consistent with the use of Cornish ores.

Of the possible explanations for the diversity encountered, it is not clear without much more work on which grounds any particular one should be preferred. The diversity may reflect differences in materials and practices between different companies operating in the copper-smelting industry, and thus be indicative of provenance, but a chronological explanation is also possible, as important technical developments occurred in the early 19th century (Tylecote 1976, 129). It is equally plausible that the diversity records slag-block production at more than one stage in the smelting process. Perhaps tellingly, the range by an order of magnitude in the copper to iron ratio for the included prills (Fig. 4B) finds a parallel in contemporary analyses of three kinds of matte from the mid-19th century Welsh industry (Tylecote 1976, table 70). In harmony, the lead-grey reflectance typical of the inclusions in the high-ratio slags from Hock Ditch and Redwick suggests that chalcocite (Cu_2S) is the dominant mineral phase present, as in the advanced matte known as 'white metal'. It is possible, therefore, that the slags from Hills Flats and Plusterwine Lane register a different and probably earlier stage in the smelting sequence than those from Redwick and Hock Ditch.

Just as the Cornish, Anglesey and Irish ores were brought to the smelters by sea (Harris 1964; Day 1973; Hughes 2000), so the trade in copper-slag building blocks appears from their general distribution, on and near the shores of the Bristol Channel and along the Severn and Wye, to have been conducted primarily by water. The blocks at Plusterwine Lane occur, as already explained, at a documented landing place, and the placing of the finds at Hills Flats and Hock Ditch - both perhaps related to attempts at coastal protection - suggests that they too arrived by water.

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