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Analysis of bog iron ore from Littleton Manor, Reigate, Surrey

Dr Tim Young
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Dr T.P. Young

Abstract

Large deposits of bog iron ore were found at this site, forming lenticular bodies of moderate lateral extent. The ore represents the product of in-situ growth of iron and manganese minerals within a heterogeneous subsoil. In hand-specimen the ores show small nodules of dense, dark, oxides, typically up to about 2mm across, set in a network of soft brown oxides. Cavities between the iron oxides are often tubular and are filled with soft clay.

At high magnification the nodules can be seen to comprise zones of variable development of the iron and manganese minerals giving a mottled or pelletal texture. The densest oxide growths tend to be of iron oxides, with manganese more abundant in the more marginal parts of the concretions. The amount of sediment included within the concretions is variable, with a marked lack of coarse sand in some.

The chemical composition of the ores shows moderate enrichment in iron, manages and phosphorus. The trace elements vanadium, chromium, cobalt and nickel are also all moderately elevated. In contrast to many bog iron ores from organic environments, uranium is not enriched and the thorium:uranium ratio is similar to that for typical clays. The rare earth elements (REE) show an upper-crust normalised profile that shows only minor relative enrichment of the middle REE.

The ore is interpreted as having been formed from oxidation of iron-rich groundwaters produced through weathering of sediments of the Lower Greensand Group, which crop out on higher ground just to the north of the Littleton Manor Farm locality.

These textural and chemical criteria may aid the recognition of similar materials elsewhere, and also the recognition of slags resulting from the smelting of such ores.

The Reigate ore is placed in context through a review of occurrences of iron smelting which are interpreted to have employed similar resources. One group of smelting sites which probably smelted bog iron ores developed in valleys below rocks of the Tertiary Bracklesham Group is located in the N Hampshire-Berkshire-Surrey area. A second group of sites also occurs close to the base of the Tertiary succession at disparate locations, but may not be directly associated with the Bracklesham Group. The third group includes sites in Kent previously interpreted as smelting concretionary ironstones from Tertiary sands, despite some of the sites lying on outcrops of Wealden Group deposits. It is suggested that the ore sources for this group might be bog iron ores similar to the Reigate example, being derived from iron-rich groundwaters derived from the crop of the Lower Greensand Group, immediately to their east.

Contents

Methods

All supplied materials were initially examined visually with a low powered binocular microscope. A follow-up programme of analysis was designed to investigate the ores in more detail and two samples were selected for examination in polished section under the scanning electron microscope (SEM) and for chemical analysis. The two selected samples came from context (3) (sample <2>), which was designated samples SLT1 and from context 9 (sample <4>), designated sample SLT2.

Electron microscopy was undertaken on the LEO S360 analytical electron microscope in the School of Earth, Ocean and Planetary Sciences, Cardiff University. Microanalysis was undertaken using the system's Oxford Instruments INCA ENERGY energy-dispersive x-ray analysis system (EDX). All petrographic images presented in this report are backscattered electron photomicrographs. The polished blocks for investigation on the SEM were prepared in the Earth Science Department, The Open University. Chemical analysis was undertaken using two techniques. The major elements (Si, Al, Fe, Mn, Mg, Ca, Na, K, Ti, and P) were determined by X-Ray Fluorescence using fused beads, on the Open University Earth Science Department's Wavelength-Dispersive X-Ray Fluorescence (WD-XRF) system. Whole-specimen chemical analysis for minor and trace elements was undertaken using samples in solution on the ThermoElemental X-series Inductively-Coupled Plasma Mass Spectrometer (ICP-MS) in the School of Earth, Ocean and Planetary Sciences, Cardiff University.

Whole-specimen bulk chemical analyses are presented in Table 1 and EDS microanalyses in Table 2 (and their locations in Figure 3).

This project was undertaken for Pre-Construct Archaeology. The site has their code SLIT08.

Results

Petrography

The samples have a granular appearance on the external weathered surfaces, with the iron-rich granules appearing to be approximately 2mm in diameter. On a cut surface, dense hard iron-rich zones of about 5mm diameter are seen, with these being linked into a complex network by softer iron and manganese oxides surrounding elongate, rounded, voids filled with unconsolidated sediment, each of which may be up to 5mm width, but of complex tubular or tabular morphology with rounded outlines.

In section (Figures 1-3) the materials show this heterogeneity very clearly, with a well developed mottled texture.

There are zones of unconsolidated sediment, with quartz grains of up to 600µm (i.e. coarse sand grade) set in a clay matrix. The quartz grains show moderately high sphericity and high rounding, particularly amongst the larger grains.

Some zones of the samples show a low degree of cementation , often with rather diffuse margins and which have a high concentration of manganese (Figure 2). Other zones of iron enrichment are both more clearly defined and have a higher degree of enrichment. In some cases these well-defined zones may represent concretionary growth of iron oxides that has been slightly reworked. Whilst most of the areas of high iron enrichment are solid, the largest such zone in SLT1 (Figure 1 lower right, Figure 2 a-d, Figure 3a) shows a low density core, probably with organic matter, suggesting perhaps that this may be a tubular concretion around a root.

Several examples of the dense iron concretions show zones which are even more enriched in iron, but not manganese, with rounded outlines, and a grain size similar to that of the associated quartz grains (e.g. Figure 1 just below and left of centre, also just above centre; figure 3 above centre). These very high iron content particles may have been inherited from a precursor Greensand rock.

Chemical analysis

The whole sample bulk analyses (Table 1) show a high degree of enrichment in iron, manganese and phosphorus, low concentrations of sodium, potassium, calcium and magnesium and a high silica:alumina ratio.

The trace element analyses show that vanadium, chromium, cobalt and nickel are all moderately elevated. Barium and zinc show a possible enrichment with manganese. Other elements are in concentrations compatible with those in "normal" clay sediments. In particular, the low concentration of uranium is noteworthy, because this element is often present in raised concentrations on bog iron ores generated in organic-rich locations (such as bogs). The uranium:thorium ratio for the two samples is 0.30 and 0.33 – ratios that are typical for many clays.

The upper crust-normalised (Taylor & McLennan 1981; Figure 4a) rare earth element (REE) profile is fairly flat (as might be expected with material with a high input from siliciclastic sediments, but with a gently elevated ("humped") middle REE.

The EDS data (Table 2) are of semi-quantitative nature, because of the problems inherent in area analyses of highly porous materials, but give a good indication of the variability of the major elements within the different textural components of the materials.

Interpretation

The materials belong to a family of iron-enriched rocks known as bog iron ores (particularly where they are hosted by organic rich sediments such as peat) or iron pan (where they are hosted by mineral soils). The iron enrichment processes are probably similar in the two settings, and the currently terminology for the iron-enriched materials is both imprecise and non-genetic. The term bog iron ore will be used here for the Littleton Manor Farm materials because they closely resemble classic bog iron ores in texture, despite the low organic content of the host material.

The general chemical composition of the material, with elevation of iron, manganese and phosphorus is typical of the bog iron ores. It is noteworthy that the enrichment in these elements described above is not uniform, so any attempt to beneficiate the ore (for instance through crushing and washing), might result in a lowered manganese content. The segregation of iron and manganese during ore development means that slight variations in local conditions may lead to large variations in the ratio of the elements, even over quite small distances with the area of ore development

The REE profile (Figure 4a) somewhat resembles that from smelting slags from Hartshill Copse (Figure 4b), although they show a slight progressive depletion of the LREE. It is not known whether this overall slope to the Hartshill profiles is due to inheritance from the ore or whether the ore profile has been modified by the contribution to the slag of the furnace clay.

At Hartshill the uranium:thorium ratio in the smelting slags ranges from 0.33 to 0.71, similar to that for this ore. For upland bog ores at Crawcwellt (pers. obs.) observed ratios were also low, from 0.10 to 0.34. In contrast Irish bog ores, and the smelting slags derived from them, usually have ratios of >1. This enrichment of uranium appears to be a feature of the bog ores hosted in organic media, and so should not be taken as a necessary indicator of bog ores in general.

Discussion

The southern part of the London Basin, a synclinal geological structure were rocks of Tertiary age crop out, is becoming recognised as a significant area for early iron production. In particular, Iron Age iron smelting is now recognised from at least thirteen sites in the Berkshire-Surrey-N. Hampshire area (Table 3; Figure 5). During many early investigations of smelting remains from this area, the source of the iron being smelted was assumed to have been a horizon within the Tertiary bedrock, but even from the 1980s (e.g. Salter & Ehrenreich 1984, p.147) observed the concentration of iron "as hardpans or as bog ores" was a likely prerequisite for sources that were capable of being smelted.

Despite the long-recognised potential significance of bog iron ore in this part of southern Britain, particularly as a resource during the pre-Roman Iron Age, actual occurrences of sufficiently high-grade bog ores have proved elusive. Two occurrences of bog iron ore (or related facies of ore) are known, but neither is published (one currently being investigated by Cotswold Archaeology near Eversley and one, possibly bog ore, at a site investigated by the Surrey Heath Archaeology & Heritage Trust near Bagshot).

The early smelting sites for which exploitation of a bog iron ore or other superficial iron-enriched material is likely or suspected can be divided into three groups (Figure 4).

Group 1 includes sites in the N Hampshire/Berkshire/ Surrey area. Many of these are suspected of being rather early in the Iron Age. They occur in an area where the Bracklesham Group caps many of the areas of higher ground. The sites in the Bagshot area lie within the area of outcrop of this group and the ores are of uncertain nature, but have a very restricted outcrop within the floor of the Windle Brook. The more western sites tend to lie on the Thames Group, on valley sides or floors below the Bracklesham Group outcrop. The eastern group of these sites again all lie on low ground in the Wey and Thames valleys. The Eversley site may, it is to be hoped, provide evidence for the link between smelting and bog ores within this group.

Group 2 is geographically disparate, but includes sites which lie close to the outcrop of the boundary of the Chalk Group with the overlying Tertiary sediments (Thanet Sands Formation and Lambeth Group), and includes samples from both the London and Hampshire basins. These sites lack geomorphological or geological settings which would make it likely that they include bog ores derived by weathering of the Bracklesham Group (although this is possible, perhaps, at Romsey).

Group 3 comprises sites in Kent, identified by Paynter (2006) as having smelted iron from 'Tertiary sands' and includes both Iron Age and Roman sites. The provenancing of resource rests on samples of 'concretionary ironstone' from Westhawk Farm, near Ashford in Kent (Paynter 2002).

Littleton Manor lies between the clusters of known smelting sites of Groups 1 and 3 (Figure 5). Although it lies geographically close to sites in Groups 1 and 2, it differs markedly in geological setting. The site lies on beds of the Lower Greensand Group to the south of the North Downs, in contrast to the western group of sites which lie on Tertiary strata of the Thames and Bracklesham groups north of the North Downs. It may be significant however, that three of the four sites attributed by Paynter to her 'Kent Tertiary Sands' group (Leda Cottages, Brisley and Westhawk Farm) actually lie in the valleys of the Great Stour and East Stour Rivers close to the base of the Lower Greensand Group – a broadly similar stratigraphic and geomorphological setting to Littleton Manor Farm.

Paynter (2006) described the chemical distinguishing features of members of her group of samples from Kent, equivalent to Group 3 here, contained "low levels of magnesia, potash and lime, between 1 and 2 wt% phosphorus pentoxide and 5-6 wt% alumina". It would be anticipated, depending on the composition of the furnace clays, that smelting an ore of the composition of the Little Manor samples would generate slags with both phosphorus and manganese contents much higher than those observed by Paynter, but with broadly similar low levels of magnesium, potassium and sodium. This apparent disparity may, however, possibly be explained by the local variability of manganese and phosphorus within bog iron deposits. Since these elements appear concentrated in the softer parts of the ore, any attempt to wash the ore to reduce the amount of siliciclastic material within it, would also very likely lower the manganese and phosphorus contents markedly.

The Littleton Manor bog iron ore is therefore significant, for it provides direct evidence of style of deposit, a bog iron ore formed on or close to the Lower Greensand Group, which has been suggested to be a potential ore resource in southern England. Although the Littleton Manor ore was not of extremely high grade, its composition may provide some evidence for the means of identifying the utilisation of such ores elsewhere. In particular, the similarity of its geological setting with those of the iron smelting sites of the Ashford area (Paynter 2006) may suggest that similar ores should be considered as potential sources in that area, instead of (or perhaps as well as) sources in the Tertiary sands overlying the chalk, as she suggested.

The recognition of bog iron ores as potential sources for iron smelting in SE England should influence the assessment of the archaeological potential of sites in appropriate geomorphological locations and presents new targets for proactive fieldwork to locate additional iron smelting sites.

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Table 1: Bulk chemical analyses of samples SLT1a and SLT2.
(a) major elements, expressed as weight% oxides, determined by XRF.
(b) major elements, expressed as weight% oxides, determined by ICP-MS.
(c)-(e) trace elements, expressed in ppm, determined by ICP-MS.

(a)	SiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	LOI	total
	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%
SLT1	26.22	3.05	48.84	2.095	0.10	0.40	0.18	0.35	0.216	1.421	11.67	94.55
SLT2	48.69	3.83	32.83	1.282	0.11	0.32	0.24	0.49	0.304	0.677	8.86	97.64

(b)	MnO	Fe2O3	TiO2	P2O5
	wt%	wt%	wt%	wt%
SLT1	2.16	45.40	0.19	1.46
SLT2	1.31	30.84	0.28	0.73

(c)	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
SLT1	3.5	51.0	64.7	95.1	58.5	26.4	112.8	4.4	21.8	32.8	20.2	124.1
SLT2	4.6	56.9	61.1	94.1	32.4	27.7	72.0	4.6	28.7	27.3	20.2	176.1

(d)	Nb	Mo	Sn	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
SLT1	4.80	1.27	0.62	1.63	1193.2	21.44	53.78	6.10	22.57	4.81	0.99	4.27
SLT2	5.96	0.70	0.54	1.86	469.1	21.36	61.13	6.28	23.51	5.12	1.02	4.45

(e)	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
SLT1	0.62	3.37	0.60	1.74	0.28	1.72	0.27	2.92	0.23	9.41	4.18	1.39
SLT2	0.67	3.67	0.65	1.89	0.30	1.91	0.29	4.28	0.38	10.49	4.77	1.45

Table 2: EDS analyses

Sample	Site		Spectrum	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe
SLT1	7	Area 1	Dense Fe-oxide small nodule	55.04	<	<	2.79	5.42	2.18	<	<	<	0.32	<	0.11	34.13
SLT1	7	Area 2	Outermost layer of large nodule	54.13	<	<	3.20	3.62	2.03	<	<	<	0.33	<	0.25	36.45
SLT1	7	Area 3	Mid layer of large nodule	52.95	<	<	2.02	2.71	1.36	0.13	0.11	<	0.29	<	1.95	38.26
SLT1	7	Area 4	Core of large nodule	51.91	<	<	2.32	1.66	1.19	<	0.78	<	0.44	<	2.79	38.91
SLT1	7	Area 5	Clay-rich matrix	63.45	0.56	0.46	6.46	23.92	0.15	0.12	0.34	0.81	0.35	0.32	<	3.08
SLT1	7	Total	Sum Spectrum	58.54	0.21	0.20	3.33	14.32	0.87	0.11	0.27	0.24	0.35	0.07	1.19	20.23
SLT1	8	Total	Sum Spectrum	59.94	0.44	0.23	3.69	17.89	0.58	<	0.36	0.34	0.40	0.13	2.18	13.83
SLT 2	2	Spot 1	Dense cracked Fe oxide grain	52.70	<	<	4.51	0.80	1.56	<	<	<	0.17	<	<	40.26
SLT 2	2	Spot 2	Dense Fe oxide	53.56	<	<	4.66	3.66	0.83	<	<	0.21	<	<	0.30	36.78
SLT 2	2	Spot 3	Quartz grain	66.21	<	<	2.73	31.05	<	<	<	<	<	<	<	<
SLT 2	2	Spot 4	Alumina	56.21	<	<	36.49	<	<	0.35	6.51	<	<	<	<	0.43
SLT 2	2	Spot 5	Alumina	57.91	<	<	36.80	0.65	<	0.33	3.88	<	0.21	<	<	0.22
SLT 2	2	Area 6	Poorly cemented fine	61.74	0.56	<	4.00	21.55	0.28	<	<	0.42	0.37	<	0.24	10.84
SLT 2	2	Area 7	Well cemented coarse	61.52	0.42	<	2.59	21.71	0.23	<	<	0.22	<	<	<	13.31
SLT 2	2	Area 8	Uncemented fine	64.71	0.48	0.20	4.57	27.19	<	0.16	0.15	0.43	0.15	0.25		1.70
SLT 2	2	Area 9	Slightly cemented coarse	64.47	<	<	5.50	26.68	<	0.10	0.61	0.13	0.14	<	0.64	1.73
SLT 2	3	Total	Sum Spectrum	61.91	<	0.20	5.49	15.64	0.41	0.11	0.29	0.24	0.24	0.10	1.11	14.19

Table 3. Localities of iron smelting sites sources in SE England which certainly, or probably, smelted bog iron ore or ore from other non- bedrock sources.

Group 1

Hartshill Copse	4-6th (and ?10th) century BC .	Collard et al. 2006
Dunston's Park	7th century BC	Fitzpatrick 1995
Heckfield	4th century BC	Dungworth 2007
Baird Road, Arborfield	3rd - 4th century BC	Hammond, forthcoming
Whitehall brickworks	late Iron Age to Roman	Pine 2003
Fleet Hill Farm, Eversley	Iron Age?	Pers. obs
West End, Bagshot Village	Iron Age?	http://heathhist.pbworks.com/ArchaeologyIronAge
Lutine Farm, Bagshot	Iron Age?	http://heathhist.pbworks.com/ArchaeologyIronAge
Queen's Farm, Bagshot	Iron Age?	http://heathhist.pbworks.com/ArchaeologyIronAge
Ashleigh Farm, Windlesham	Iron Age?	http://www.chobham.info/ashleigh_farm.htm
Windlesham Arboretum	Iron Age?	http://heathhist.pbworks.com/ArchaeologyIronAge
Lightwater	Iron Age?	http://heathhist.pbworks.com/ArchaeologyIronAge
Brooklands	Iron Age	Hanworth & Tomalin 1977
Thorpe Lea	Iron Age to Roman	Starley 1998
Wraysbury	Saxon	Astill & Lobb 1989

Group 2

Romsey	Saxon	Russel 1987, Scott 1996, McDonnell 1988
Basingstoke: Rucstalls Hill	Iron Age	Oliver & Applin 1978
Basingstoke: Riverdene	Saxon	Hall-Torrance, M & Weaver, S, 2003
Shooters Hill	Iron Age	Wessex Archaeology 2008
Mucking	Saxon	McDonnell 1993

Group 3

Leda Cottages	late Iron Age to Roman	Paynter 2006
Hawkinge	Iron Age	Paynter 2002a
Brisley	Iron Age to Roman	Paynter 2006
Westhawk Farm	Roman	Paynter 2002b

Figure 1. Mosaic of BSEM images of sample SLT1. Scale bar 2mm. Bright areas are those rich in iron and manganese oxides, even mid-grey tones are quartz grains. Black is the mounting medium.

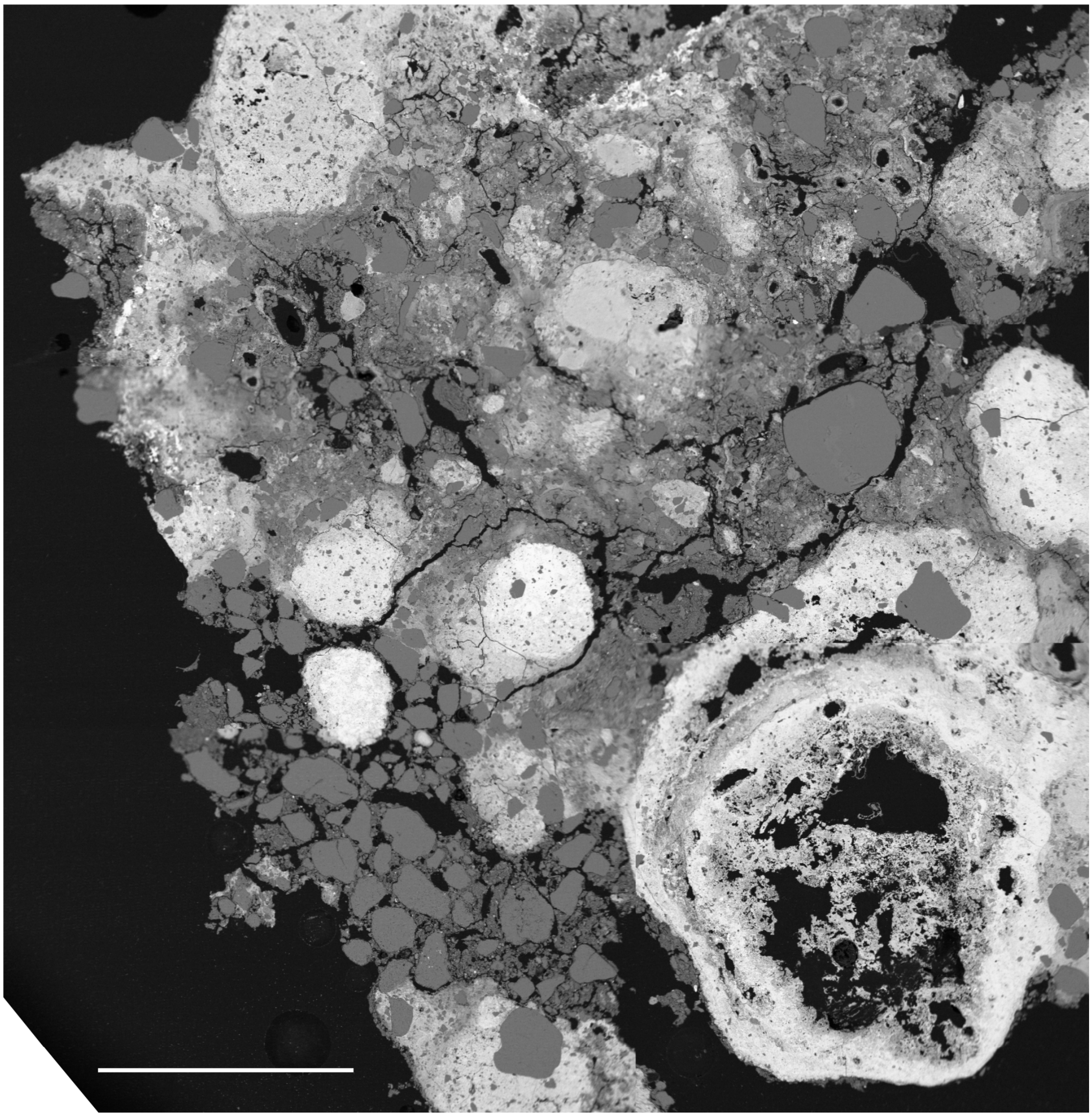


Figure 2.
(a) – (d): Sample SLT1 area 7, (a) BSEM image, scale bar 2mm; (b) EDS element map for silicon; (c) EDS element map for iron; (d) EDS element map for manganese.
(e) – (h): Sample SLT1 area 8, (e) BSEM image, scale bar 2mm; (f) EDS element map for silicon; (g) EDS element map for iron; (h) EDS element map for manganese.
The brightness on the element maps indicates relative elemental abundance

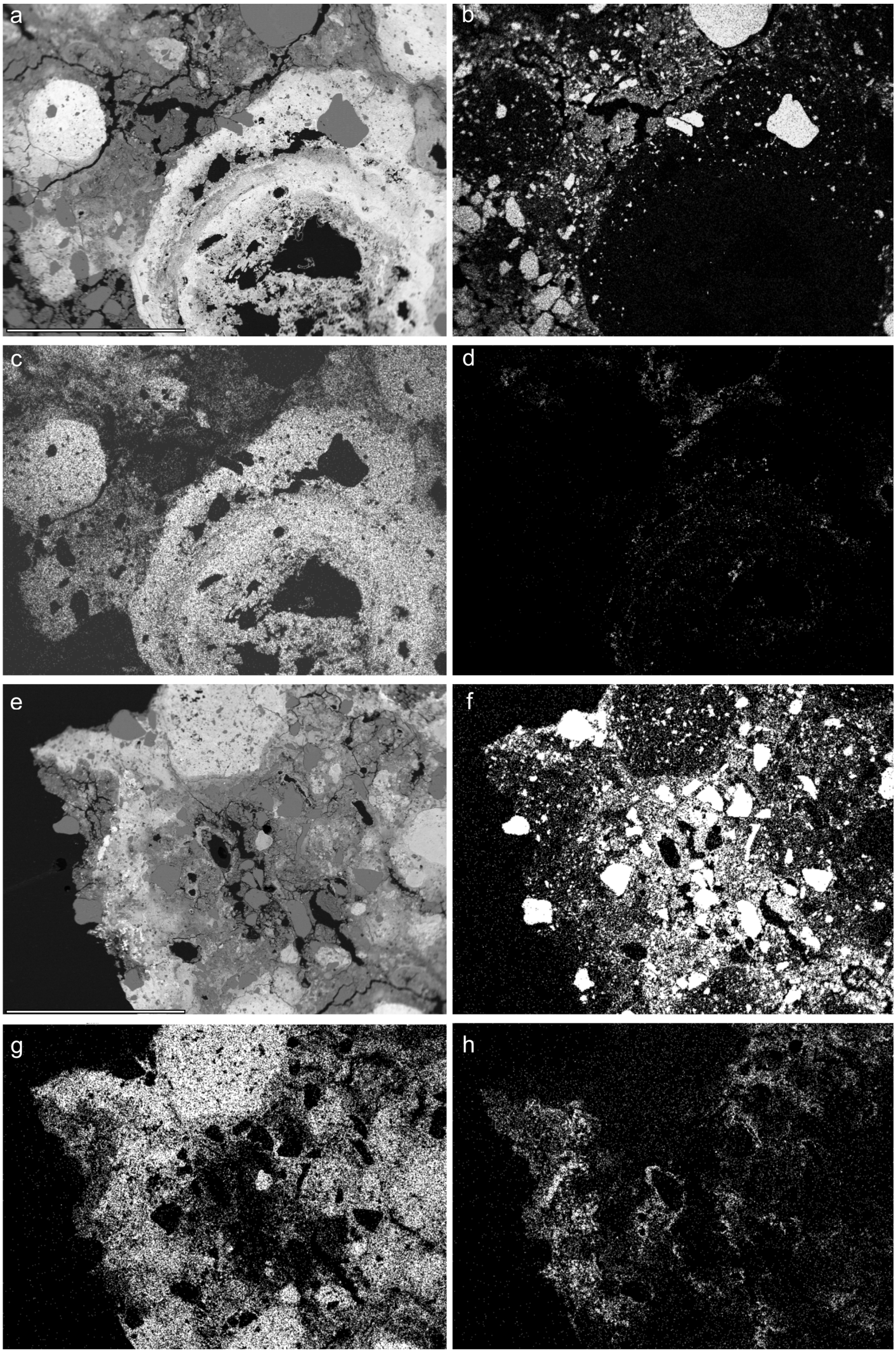
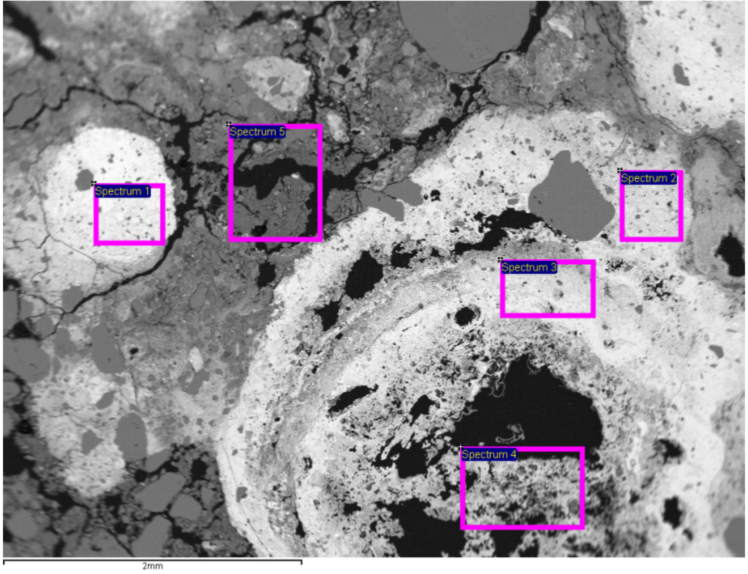


Figure 3. BSEM images showing locations of EDS analyse (a) in SLT1 area 7 and (b) in SLT2 area 2. See Table 2 for analyses. Scale bars 2mm

(a)



(b)

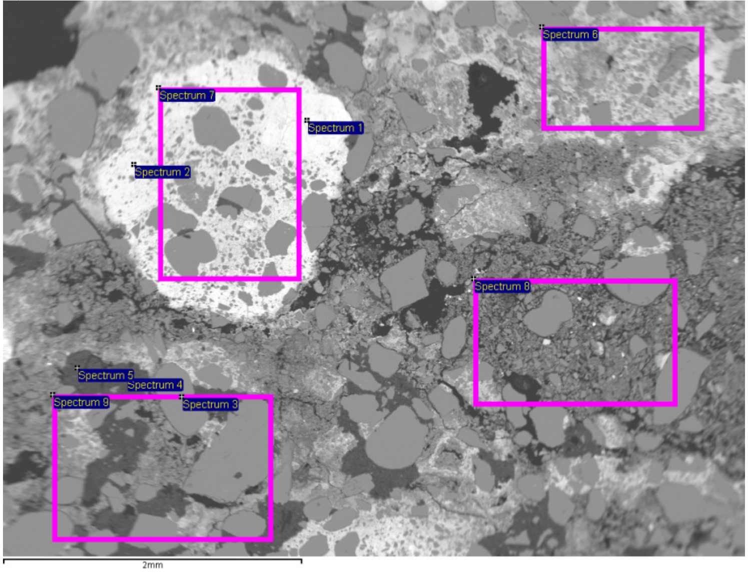
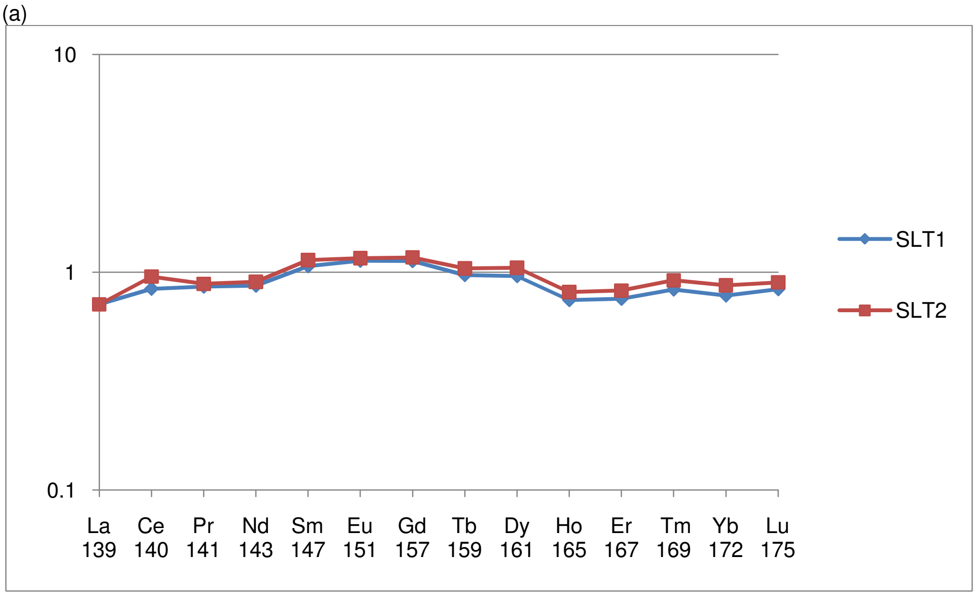


Figure 4. Upper crust-normalised rare earth element profiles (normalisation after Taylor & McLennan 1981)
(a) samples SLT1 and SLT2 from Littleton Manor Farm, Reigate
(b) four samples of smelting slags from Hartshill Copse, after Young (2006)

(a)



(b)

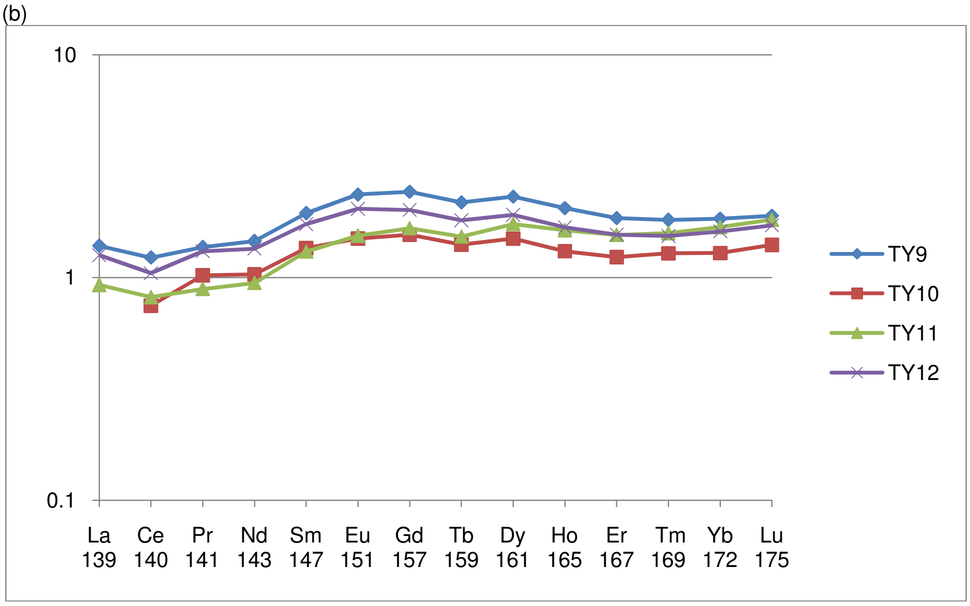
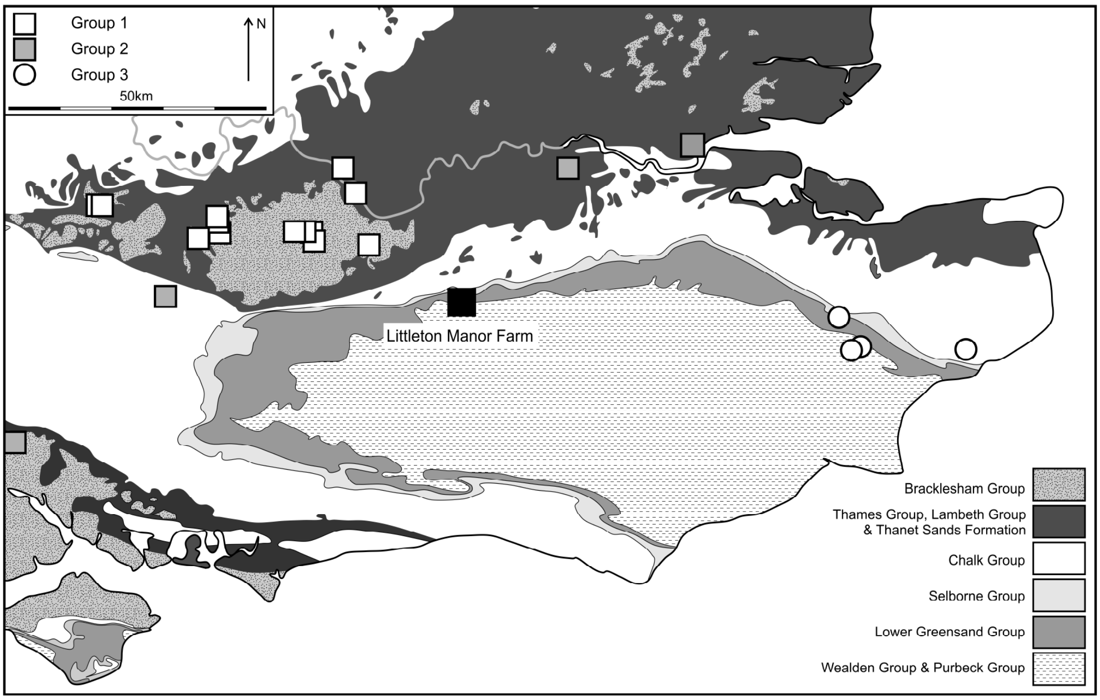


Figure 5. Simplified geological map of SE England showing the study site and the location of early iron-smelting sites interpreted as having smelted bog iron ores and other non-bedrock sources.



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