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Shadreck Chirikure[1] and Sarah Paynter[2]

Summary

133.5kg of iron working debris was recovered, the vast majority of which was iron smelting waste. All of the slag from the site had been disposed of in ditches or pits or had been re-used. A large proportion of the waste was from mid to late Roman contexts, although approximately half was from contexts that also contained some later material or insecurely dated finds. Smelting probably took place at a location near to the site in the mid to late Roman period. The slag produced was phosphorus-rich and therefore smelting is likely to have produced some phosphoric iron. The phosphorus was derived from the ore, likely to be concretionary ironstone nodules and possibly some ferruginous sandstone, obtainable locally from the Lower Greensand. A small amount of smithing slag was also identified. A stone-lined hearth excavated at the site may have been used for ore roasting or alternatively may simply have been lined with ferruginous sandstone and used for a non-metallurgical application.

Keywords

Metalworking-Fe
Roman
Technology

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Introduction

In 1998 the Norfolk Archaeological Unit excavated a site on Station Road in Snettisham, Norfolk (site 28450SNT) in advance of housing development. A geophysical survey of the area was completed prior to excavation and twelve box trenches, covering a total area of just under 0.1ha, were sited over regions where strong readings were obtained. The lines stripped for new roadways were also excavated. The features identified were predominantly pits and ditches, many of which contained metalworking debris, as well as sections of two metalled Roman roads. Two early Romano-British kilns were also discovered (Flitcroft, 2001).

The archaeological evidence from this site compliments that from other investigations in the area, which indicates that there was extensive Romano-British settlement in the Ingol valley. Settlement was concentrated in valley-side or spring line locations along the west side of the chalk uplands, between the chalk and the coastal marshes or fens. Romano-British objects, including ceramics, coins and brooches, have been found across the area and iron-working slag has been recovered, principally from the regions near Snettisham and Ingoldisthorpe. McDonnell (1991) identified 35kg of iron-working slag from a previous excavation to the south west of Snettisham (site 1555) as being predominantly tap slag, produced by smelting activity probably close by.

The geology of the site consists of a mixture of Cretaceous deposits of Carstone, clays and sands. The term Lower Greensand has been loosely applied to these beds in Norfolk as in the South of England. However of the three divisions: the Carstone, the Snettisham clay and the Sandringham sands, only the Carstone is equivalent to the Lower Greensand of the South of England, the two lower divisions belong to an earlier stage (Chatwin, 1961). To the east of the site the land rises into a chalk landscape. To the west is an expanse of low-lying ground, that would have been subjected to tidal influence and flooding in the past. The western coastal plain rises gently towards the east (Flitcroft, 2001).

Identification of Iron-working Waste

Background

Iron working involves two types of process: extracting the metal from the ore (smelting) and then shaping the metal (smithing or forging). Iron smelting in the Romano-British period took place in bloomery furnaces, which were typically clay-built, rounded structures with an inside diameter of about 0.25m, a height of approximately 1m and with walls about 0.2m thick. Charcoal was used as the fuel for smelting and the furnaces were probably bellows-blown (Cleere and Crossley, 1985; Crew, 1991; Pleiner, 2000). Iron ore was fed into the furnace where some of it reacted to form a spongy mass of iron metal, known as a bloom. The gangue (non-iron minerals) in the ore also reacted with iron compounds from the ore to form a liquid waste product known as slag. The slag was tapped from the bottom of the furnace. The bloom produced by smelting was consolidated and formed into a bar or billet by smithing, before being traded or used.

Smithing is the process of hammering and shaping iron, generally at red heat since the metal is then more malleable. The iron metal was heated in a charcoal-fuelled, bellows-blown hearth, which was probably a shallow, walled structure, constructed from clay or stone, either on the floor or at waist height. The hot metal was hammered into shape on an anvil. During this process small flakes and spheres of iron oxide and slag, known as hammerscale, detached from the surface of the metal and collected on the floor. Since hammerscale is magnetic it can be detected in archaeological occupation surfaces with a magnet. Slag also accumulated in the hearth forming a characteristically shaped smithing hearth bottom (SHB) slag.

The metal working remains from Snettisham were examined and assigned to categories on the basis of their morphology. The different categories of iron-working material are listed below. A summary of the results is given in table 1 and a description of the debris from each context is given in full in the appendix.

Tap slag (smelting): Dense slag, with only a few larger bubbles, a rough lower surface and a smooth upper surface that looks like a lava flow.

Vitrified Lining (smelting and smithing): Clay that formed part of the furnace or hearth lining, with a surface that has reacted with the slag and the ash from the fuel at high temperatures and has developed a dark-coloured, slag-like or glassy surface. The furnace or hearth is hottest near the blowing hole for the bellows, and pieces of vitrified clay from a furnace or hearth wall with the outline of the blowing hole are sometimes found.

Iron-rich stone / Ore (smelting): Any iron-rich stone in the assemblage was categorised as potential ore, although not all of the different types of stone were necessarily smelted. Ore was generally roasted prior to smelting, oxidising it so that it became a bright red to purplish black colour.

Smelting Slag (smelting): Large lumps of dense slag without the characteristic flow surface of tap slag, but which are nonetheless likely to be by-products of smelting. The lumps have fractured edges and varying porosity and commonly contain large quantities of incorporated fuel fragments. Much of this slag is likely to have formed in the base of a smelting furnace and fragments sometimes have flows or runs of slag emanating from the base.

Hammerscale (smithing): Small, magnetic flakes or spheres of slag and iron oxide expelled or detached from the bloom during consolidation.

Smithing Hearth Bottom or SHB (smithing): Spongy lumps of slag, with many small pores, characteristic convex bottom surfaces and concave upper surfaces, produced in the smith's hearth when the bloom is consolidated or when an object is being produced.

Iron: Lumps or fragments of partially consolidated, unshaped iron.

Undiagnostic Slag: A lot of iron-rich slag fragments do not possess enough diagnostic features to be categorised.

Fuel Ash Slag (smelting, smithing and other high temperature processes): Produced predominantly by reaction of ash from charcoal fuel with clay. It is usually vesicular (bubbly / spongy) and is lighter-coloured and less dense than iron-rich slags. Non-metallurgical processes can produce fuel ash slag, when a mixture of plant ashes and clay reach high temperatures, and so alone it is not diagnostic of a metalworking process.

Iron-working Waste from Snettisham

A total of 133.5kg of iron working debris was recovered from the site and an additional 8.8kg of iron-rich stone (from contexts which did not contain iron–working slag) was retained as part of the investigation of potential local ore sources. The assemblage included tap slag, other smelting slags, smithing hearth bottom slag, furnace / hearth lining, fired clay, fuel ash slag, iron fragments and some undiagnostic slag. Figure 1 shows the relative proportions of the different types of iron-working waste. This figure includes the debris from all of the contexts except those where only iron-rich stone was found. Tap slag constituted almost three-quarters of the waste by weight, with a large proportion of the rest being iron-rich stone / ore and smelting slag. As tap and smelting slag are by-products of iron smelting it can be concluded that smelting was the main activity at the site. Since smelting furnaces and smithing hearths were constructed largely using clay, and both the smelting and smithing processes utilise high temperatures and produce slag by-products, it can be difficult to distinguish vitrified clay lining material derived from a smithing hearth from that derived from a smelting furnace. However since the great majority of the waste from this site consists of smelting raw materials (ore) and by-products (tap and smelting slag) it is likely that the majority of the vitrified lining is from smelting furnaces.

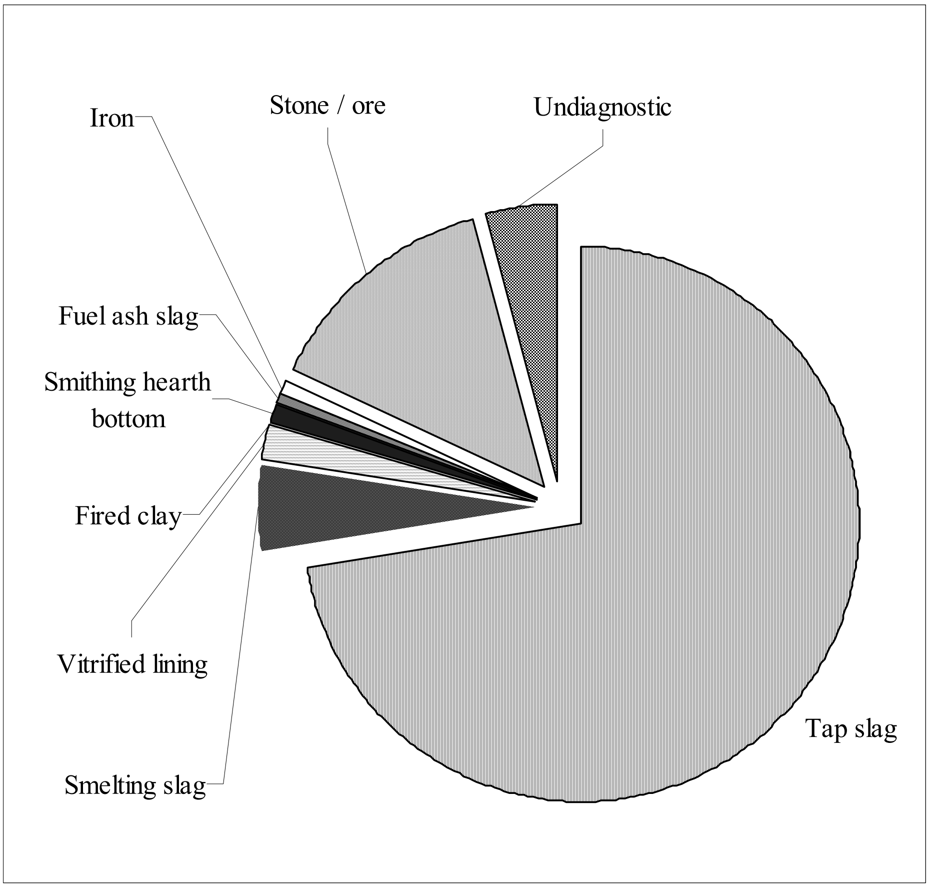

Figure 1:Proportions by weight of different types of iron-working waste from Snettisham

In table 1, the contexts containing more than 2kg of metal-working waste are listed. The waste from these contexts comprises over 75wt% of the debris recovered from the site. Of this metalworking waste, about half is from mid to late Roman contexts. The other half of the waste is from contexts that include later material, in addition to Roman material, as well as unstratified and topsoil finds of uncertain date. Therefore smelting activity probably took place in the mid to late Roman period but there is insufficient evidence to determine whether smelting continued in later periods.

Table 1: Contexts containing more than 2kg of iron-working waste

Context	Total Waste (g)	Trench	Type	Date
574	17329	T4	Fill of pit / furnace pit	Mid-Roman +
577	12827	T9	Deposit around pit	Mid-Roman
366	8100	T10	topsoil	Post-Roman
300	6532	T1	U/S	Post-Roman +
527	5946	R4	Pit fill	Late-Roman +
616	5119	T4	Pit fill	Late-Roman
531	4868	T10	Fill of pit	Late-Roman
589	4486	T7	Fill of roadside ditch	Mid-Roman +
310	3878	R1.13	Curving strip	Medieval +
303	3342	T4	U/S topsoil	U/S
U/S	3332			U/S
318	3048	T5	U/S	Late-Roman +
516	2801	T11	Pit fill	Late-Roman
302	2738	T3	U/S topsoil	U/S
610	2703	T7	Fill of roadside ditch	Mid-late Roman
458	2561	T12	Pit fill	Late-Roman
388	2489	T11	U/S topsoil	U/S
381	2206	T6	Roman road	Early-mid Roman
319	2046	T6	Topsoil	Late-Roman
392	2026	T6	Fill of roadside ditch	Prehistoric to late-Roman

A small quantity (1.3kg) of smithing slag was identified from six contexts, details of which are given in table 2. Some tap slag was also found in each of these contexts. The smithing slag was scattered about the site but was most commonly recovered from the topsoil with some found in mid to late Roman features. The iron produced by bloomery smelting was spongy and had to be consolidated by smithing to form a bar or billet for trading or for producing an object. Therefore some smithing debris would be anticipated from this site. However the great majority of the smithing slag recovered at Snettisham is from late, or insecurely dated, contexts and so in itself is poor evidence that smithing took place on the site in the Roman period.

Table 2: Contexts containing smithing hearth bottom slag

Context	Smithing hearth slag (g)	Trench	Description	Allocated Date
320	641	T7	Topsoil	Late Roman +
366	304	T10	Topsoil	Late Roman +
319	168	T6	Topsoil	Late Roman +
352	93	T6	Upper tip fill of pit	Late Roman
323	55	T2	Fill of pit	Mid-late Roman
344	25	R1.39	Subsoil	Mid Roman +

Soil Samples

Soil samples were also collected from across the site. Although some of these contained small quantities of hammerscale, a by-product of smithing, as well as some slag and small fragments of oxidised-fired, iron-rich stone (possibly ore fines, indicative of smelting), the majority contained only particles of highly fired clay, which was noticeably magnetic. The quantity of these particles was unusually large relative to the quantities observed in samples from other smelting sites (Paynter, 2002) and so may be related to the pottery industry activity in the area. The largest quantities of hammerscale and oxidised stone fragments were found in samples from contexts 579 and 596.

Iron-rich Stone

Iron-rich stone was also collected from the site during the excavation, in order to evaluate potential local sources iron ore. The stone samples included ferruginous sandstone, consisting of a matrix of hydrous iron oxide surrounding angular quartz grains, and nodules of hydrous iron oxide (goethite), also containing varying proportions of angular quartz grains. Several contexts produced stone that had been heated in an oxidising atmosphere and was deep red or purplish-black in colour. This included ferruginous sandstone from contexts 459, 461 and 352 and a goethite nodule from context 465. Contexts 461 and 459 are fills from hearth 462 in trench T9, context 352 is a pit in trench T6 and context 465 is a road-side ditch fill in T9. The former two contexts did not contain any additional iron-working waste whereas the latter two contexts also contained slag and other debris. A goethite nodule, unroasted, was also found in context 577 with large amounts of metalworking waste.

Discussion

Metalworking waste was found across the site in pits, ditches, sections of Roman road and the topsoil. The largest quantities of debris from individual contexts were found in and around pits in trenches T4 and T9. The only feature with evidence of having been heated was pit 462 in trench T9, which was consequently interpreted as a hearth. The feature was oval with dimensions of approximately 1m by 1.75m and was described as having a vitrified, dark brown to red clay surface in situ, beneath which were thin, long slabs of chalk. Although there was no slag in the hearth fill, large quantities of smelting debris were recovered from context 577, which was a deposit around the feature. A small quantity of slag was also recovered from context 579, which was a layer of burnt clay thought to relate to the hearth. A soil sample was taken from context 579, which was red in colour and contained many highly fired, iron-rich stone fragments but only a small amount of hammerscale. The absence of significant quantities of hammerscale and smithing slag from this area indicates that this hearth was not used for smithing. Neither was the feature part of a smelting furnace as the base was oxidised-fired and the surface was not blackened as would be expected if it had been in contact with slag. However large quantities of oxidised-fired ferruginous sandstone were found in the fill of this feature and therefore it is possible that this hearth was used for roasting ore in preparation for smelting. However it is equally possible that the hearth was simply lined with sandstone, this being a temperature resistant material, and that the iron-rich stone was oxidised-fired and vitrified as a result of normal hearth use.

None of the slag appears to have been found in-situ, none of the contexts was particularly charcoal-rich and there is no evidence of heating in the features except for pit 462 described previously. Therefore none of these features, with the possible exception of pit 462, can be interpreted as the remains of structures associated with iron-working. It is most likely that the metalworking waste recovered was disposed of in the pits and ditches where it was subsequently discovered or that it had been re-used for road metalling or post-hole packing. Since iron smelting generates such large quantities of waste, it is most often found dumped in pits and ditches, or in contexts where it was re-used, rather than in-situ. Slag can also be found some distance from where the iron-working actually took place, although the largest concentrations of waste are generally in the vicinity of the iron-working furnaces and hearths themselves. Therefore it is not possible to determine where the smelting furnaces were located from the evidence available from Snettisham, since no smelting furnaces or smithing hearths were identified. However analysis shows that the slag is of a composition typical of the local area (by comparison with sites such as Ashwicken and West Runton – see a later section of this report) and it is probable that it was produced nearby. This is particularly true if pit 462 is interpreted as an ore-roasting hearth.

Analysis of Smelting Raw Materials and By-Products

Samples of iron-working raw materials and waste were examined using scanning electron microscopy and analysed using energy dispersive X-ray spectrometry (EDS) (25keV and 1.5nA), X-ray fluorescence spectrometry (XRF) and X-ray diffraction (XRD). The full analytical results are given in the appendices.

Furnace lining

Fragments of heavily-fired clay with a distinctive quartz-rich fabric and slag-lined surface were found amongst the assemblage. These are pieces of furnace lining, discarded during the destruction, repair or rebuilding of a smelting furnace. Analysis of the fragments detected in excess of 80wt% silica as a result of the large number of sub-angular to round quartz grains in the material. The majority of the quartz grains were less than 0.1mm in diameter. The practice of using very quartz-rich clay for furnace construction or lining, due to its temperature resistant properties, has been identified at other Roman sites, including Woolaston in Gloucestershire, Westhawk Farm in Kent and Laxton in Northamptonshire (Fulford and Allen, 1992; Paynter, 2002; Crew, 1998).

Ore

Some examples of potential ore were identified in contexts containing metalworking debris, such as the large goethite nodule from context 577. Others were collected from across the site during excavation to give an overview of the types of iron-rich stone available in the vicinity. The stone samples consisted predominantly of fine-grained, orange-coloured nodules and tabular sheets as well as pieces of coarser ferruginous sandstone and both types of stone were made up predominantly of hydrous iron oxides (goethite and lepidocrocite) with some iron oxide (hematite) and varying quantities of quartz grains. Some of the material had been strongly heated in oxidising conditions and was deep red / purple in colour as a result. In some instances this may be indicative of ore roasting, since archaeological evidence suggests that ore was often roasted prior to smelting in order to break up the ore and also convert the other iron compounds present to oxides of iron (Pleiner, 2000).

Samples of iron-rich stone, from contexts 577 and 465, were examined using a scanning electron microscope and analysed using EDS (table 3) and samples from contexts 388 and 461, as well as the previous two samples, were analysed using XRF (table 4). The sample from context 577 contained angular quartz grains up to 0.5mm in diameter in an iron-rich matrix. The sample from context 465 was similar but contained smaller quartz grains less than 0.2mm in diameter. The analytical results are presented in the form of oxides with iron quantified as FeO, although elements may actually be present in the form of different compounds, for example carbonates, hydrous oxides etc, or with different oxidation states, for example Fe_2O_3 and Fe_3O_4. The ore was heterogeneous and therefore a number of analyses were completed for each sample to obtain more representative data. The XRF analyses are each of an area of about 0.4mm diameter. The SEM analyses are each of an area 1-5mm in width. The slight differences between the results of the EDS and XRF analyses are due to the heterogeneity of the ore.

Table 3: Composition of iron-rich stone (wt%), average of two EDS analyses, normalised

Context	Type	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
577	Goethite nodule	0.11	0.22	2.08	27.71	0.42	0.16	0.27	0.48	0.10	0.21	68.25
465	Roasted nodule	0.00	0.33	4.29	24.95	0.61	0.21	0.51	0.24	0.16	0.20	68.51

Table 4: Composition of iron-rich stone (wt%), average of at least three XRF analyses, normalised

Context	Type	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
577	Goethite nodule	7.0	24.0	0.4	0.1	0.3	0.2	0.8	0.3	66.9
388	Angular black goethite nodule	0.7	1.9	2.2	0.3	0.0	0.9	0.2	0.3	93.4
465	Roasted nodule	3.0	21.5	0.5	0.2	0.3	0.3	0.4	0.3	73.4
461	Roasted ferruginous sandstone	3.0	46.2	1.3	0.2	0.1	0.5	0.2	0.1	48.3

Although all of the stone specimens analysed contained some impurities known collectively as gangue (predominantly silica) they nonetheless contained between 50wt% and 93wt% of iron oxide. The fine-grained goethite nodules had higher iron contents than the coarse-grained ferruginous sandstone. The bloomery smelting process was inefficient since the slag waste produced contained in excess of 60wt% iron oxide and so relatively rich sources of ore were required in order to extract iron metal successfully by this process. Therefore the iron-rich goethite nodules are likely to have made up a large proportion of the ore used. Some ferruginous sandstone may also have been smelted although sandstone with very low iron contents would have been discarded.

The stone samples also contained variable amounts of phosphorus oxide, reaching high levels of up to 2.2wt%. High levels of phosphorus are consequently detected in the slag by-products of smelting (see table 6) and would be anticipated to also be present in some of the iron produced. The composition of the ore is similar to that described in the literature for other bloomery smelting sites in Norfolk (table 5) although the manganese contents of the latter are rather higher.

Table 5: Composition of roasted ore from Ashwicken and West Runton, Norfolk, from Tylecote (1962a and b respectively)

Site	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
Ashwicken	1.10	4.20	19.96	0.31	0.00	0.00	1.28	0.00	0.86	72.30
West Runton	0.13	4.83	14.76	1.77	0.27	0.00	0.67	0.27	0.94	76.36

Tap Slag

Fragments of tap slag were selected for analysis from the contexts where the largest amounts of iron-working debris were recovered, one sample from context 579 in region T9 and one sample from context 574 in region T4. The average compositions of the samples are given in table 6. The sample from context 579 consisted largely of fayalite (iron silicate) laths and wustite (iron oxide) dendrites in a glass matrix. The sample from context 574 consisted predominantly of fayalite with small areas containing fine magnetite (iron oxide) dendrites. This sample had cooled slowly as the crystals within the tap slag had grown large enough to be visible with the naked eye. Many fragments of this coarsely-crystalline slag were noted within the assemblage.

Table 6: Composition of tap slag measured by EDS, average of four analyses, normalised

Context	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
574	0.04	0.21	1.92	30.79	1.12	0.17	0.47	1.87	0.08	0.86	62.46
579	0.12	0.23	2.04	17.36	1.63	0.27	0.16	0.81	0.08	0.08	77.22

This compositional data compares well with that for tap slag from Ashwicken, near Kings Lynn (2nd century AD) and from West Runton (early medieval to medieval in date) (table 7). Bloomery tap slag from Norfolk (West Runton, Ashwicken and Snettisham) can be differentiated compositionally from slag from many other bloomery smelting sites because of its high phosphorus content. The manganese content of the Norfolk tap slags is variable, even within the same site, as illustrated by the Snettisham samples. Both the manganese and the phosphorus in the slag derive predominantly from the ore used.

Table 7: Composition of tap slag from Ashwicken and West Runton, Norfolk, from Tylecote (1962a and b respectively)

Site	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	MnO	FeO
Ashwicken	1.4	3.3	21.8	1.8	nm	0.0	0.4	0.5	70.8
West Runton	0.2	9.1	25.6	2.0	0.1	0.0	1.5	3.1	58.4
West Runton	0.8	10.1	26.9	1.6	0.1	0.0	1.4	3.0	56.2

nm = not measured

Three smelting sites were identified outside Norfolk where phosphorus-rich bloomery slag was also produced and additional sites are likely to be found in the future as more material is analysed, particularly in these areas. Of the three sites two are in North Yorkshire (Baysdale and Ouse Gill) (McDonnell, 1986) and one is in Kent. Of these, only Westhawk Farm near Ashford in Kent (Paynter, 2002) is known to be Roman. The phosphorus-rich compositions of tap slag from these sites are given in table 8, where they are compared to compositions of tap slag from some other Roman sites.

Table 8: Composition of phosphorus-rich tap slag from Westhawk Farm, Kent and Baysdale and Ouse Gill, Yorkshire, compared to the composition of low-phosphorus Roman tap slag from other sites (A: Paynter, 2002, B: McDonnell, 1986, C: Tylecote, 1990 and D: Morton and Wingrove, 1969)

Site	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO	Ref
Westhawk Farm	0.3	0.4	6.6	24.3	1.9	0.1	0.7	2.2	0.3	0.5	62.9	A
Baysdale	0.3	4.1	9.7	27.4	2.5	0.5	2.2	10.4	0.6	1.3	41.1	
Ouse Gill	0.4	4.2	9.6	30.9	1.8	0.5	2.4	11.3	0.6	1.2	36.2	
Camerton	nm	0.3	6.9	13.0	0.6	0.4	nm	2.3	0.4	nm	76.2	C
Wilderspool	nm	0.0	2.1	29.6	0.3	nm	nm	1.7	nm	nm	66.2	
Sharpley Pool	nm	1.1	6.0	32.8	0.0	0.0	nm	1.9	nm	trace	58.2	D
Worcester	nm	1.3	6.0	16.5	0.0	0.0	nm	3.1	nm	0.2	72.8	

nm = not measured

At Westhawk Farm concretionary ironstone was smelted, which was composed predominantly of goethite with varying quartz grain contents ranging from very iron-rich, fine-grained goethite nodules to more silica-rich, coarse-grained, ferruginous sandstone nodules. The site is situated on the edge of the Lower Greensand although the iron ore, which had a variable but significant phosphorus content, was probably obtained from sandy deposits in the Clay-with-Flints on top of the nearby downs (Gallois, 1965). Snettisham is situated on the Lower Greensand and ferruginous sandstone, known as the Carstone, is found in this area. Ferruginous and phosphatic nodules are found in beds within the Lower Greensand (Chatwin, 1961) and the ore derived from the Greensand appears to have also been phosphorus-rich.

Ferruginous sandstone nodules derived from the Lower Greensand Carstone were probably also smelted at Ashwicken, situated on the Lower Greensand (Chatwin, 1961; Tylecote, 1962a) where Tylecote identified two large pits with 12m and 24m diameters as the places from which the ore was obtained. Tylecote (1962b) described a sandy ferruginous conglomerate in the area of West Runton, on the coast near Cromer, as being a potential ore source. This stone sometimes contained flint or shells as well as nodules of hydrated iron oxides and maybe derived from Pliocene and Pleistocene Crag deposits, which extend over the eastern part of Norfolk. Therefore similar types of ore derived from sandy deposits (nodules consisting of hydrous iron oxides with varying concentrations of quartz grains and significant phosphorus contents) were probably smelted at the Norfolk sites as at Westhawk. However ironworkers at the North Yorkshire sites utilised a different type of ore, for example Jurassic ironstone or ironstone from the Coal Measures. Phosphorus-rich smelting slag was also produced when bog iron ore was smelted, such as at the Iron Age settlement of Snorup in Denmark (Høst-Madsen and Buchwald, 1999).

In summary, concretionary ironstone varying from iron-rich to quartz-rich ferruginous sandstone is likely to have been used as the ore for smelting at Snettisham, resulting in a tap slag by-product with characteristically high phosphorus contents. The iron produced is likely to have had a variable phosphorus content as a result of the phosphorus-rich nature of the ore used with some high phosphorus alloys (phosphoric iron) being produced. Phosphoric iron is harder than pure iron, although also more brittle, and was well suited for certain applications as a result. For example phosphoric iron was widely used, along with carburised iron (iron with an increased carbon content), in Romano-British tools (Tylecote, 1990).

Conclusions

The metalworking debris from Snettisham consists predominantly of waste from iron smelting, largely from the mid to late Roman period, although approximately half of the contexts contain later material or are insecurely dated. Bloomery furnaces were used from which the slag waste product was tapped whilst molten. The furnaces were constructed from very quartz-rich clay, which had good temperature resistance. The slag produced was phosphorus-rich. More research is required to understand the factors effecting the partitioning of phosphorus between the iron metal product and slag waste during the bloomery smelting process. However it is likely that some phosphorus was reduced and dissolved in the metal to produce phosphoric, as well as pure, iron (Høst-Madsen and Bouchwald, 1999). Phosphoric iron is harder than plain iron and therefore well suited for use in tools, for example.

The phosphorus was derived from the ore, likely to be concretionary ironstone nodules and possibly some ferruginous sandstone, obtained locally from the Lower Greensand. Samples of these types of stone obtained from the site had varying quartz contents but generally contained in excess of 50wt% iron oxide. The concretionary nodules were the most iron-rich. The ore may have been obtained by digging pits although outcrops may have first been observed where these were exposed along river courses (Tyelcote, 1962b; Cleere and Crossley, 1985). The large pits at Snettisham, which date to the mid to late Roman period, as does much of the iron-working waste, have been identified as Carstone quarry pits. It is possible that iron-rich stone extracted during quarrying was used for smelting and sand, or sand-rich clay, would also have been required for furnace construction. However sandstone may also have been quarried for non-metallurgical applications and therefore it is not possible to conclusively establish a link between the quarry pits and metallurgical activity.

A small amount of smithing waste was found on the site, and it is likely that some smithing took place, if only to consolidate the metal produced by smelting. However the majority of the smithing slag identified was from late or insecurely dated contexts.

All of the slag from the site had been disposed of in ditches or pits or had been re-used as packing for post-holes or for road metalling. Feature 462 had been fired in an oxidising atmosphere to quite high temperatures and contained large quantities of iron-rich stone. It is not possible to establish whether this feature was used as an ore roasting hearth, to prepare ore for smelting, or was simply a hearth for non-metallurgical use that had been lined with ferruginous sandstone.

The exact location of the iron-working activity cannot be determined from the evidence available but it is unlikely to have been within the area covered by the geophysical survey since furnaces, hearths and large deposits of iron-working waste would have given rise to strong readings. In addition very large quantities of slag (tonnes) are generally recovered from the vicinity of Roman smelting areas whereas only 130kg was recovered from this site (Cleere and Crossley, 1985; Paynter, 2002). These observations suggest that although the iron-working slag recovered from Snettisham was produced fairly locally, the activity was focused outside the perimeter of the area investigated.

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Appendix

Table A1: Composition of tap slag from context 579, wt% normalised, measured by EDS

Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
0.00	0.15	1.97	16.89	1.57	0.24	0.16	0.74	0.07	0.08	78.13
0.28	0.34	2.25	17.14	1.82	0.28	0.14	0.95	0.08	0.09	76.63
0.09	0.21	2.07	17.34	1.49	0.17	0.20	0.75	0.10	0.09	77.49
0.10	0.24	1.88	18.08	1.63	0.38	0.14	0.78	0.07	0.04	76.65

Table A2: Composition of tap slag from context 574, wt% normalised, measured by EDS

Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
0.17	0.18	2.02	30.98	1.21	0.11	0.50	2.07	0.11	0.84	61.80
0.00	0.15	1.92	30.48	1.07	0.13	0.40	1.72	0.08	0.88	63.16
0.00	0.26	1.79	30.89	1.08	0.22	0.43	1.75	0.05	0.88	62.65
0.00	0.25	1.96	30.82	1.11	0.22	0.55	1.92	0.08	0.84	62.24

Ore

Table A3: Composition of iron-rich stone from context 577, wt% normalised, measured by EDS

Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
0.00	0.21	2.09	26.28	0.36	0.18	0.23	0.51	0.08	0.21	69.85
0.22	0.23	2.07	29.13	0.47	0.14	0.31	0.45	0.12	0.20	66.65

Table A4: Composition of iron-rich stone from context 465, wt% normalised, measured by EDS

Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
0.00	0.32	4.44	23.19	0.67	0.26	0.55	0.28	0.19	0.20	69.91
0.00	0.34	4.14	26.72	0.55	0.16	0.46	0.20	0.13	0.20	67.11

Table A5: Composition of iron-rich stone from contexts 577, 388, 465 and 461, wt% normalised, measured by XRF

Context	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
577	4.8	16.5	0.5	0.1	0.3	0.2	0.4	0.3	76.8
	9.6	37.2	0.3	0.1	0.5	0.2	2.0	0.2	49.9
	6.2	17.3	0.4	0.2	0.3	0.3	0.3	0.4	74.5
	1.8	3.1	0.4	0.1	0.1	0.3	0.2	0.6	93.4
	9.5	36.0	0.6	0.2	0.5	0.3	0.3	0.3	52.5
388	0.6	1.9	2.7	0.2	0.0	0.9	0.2	0.3	93.2
	0.8	2.2	2.8	0.3	0.0	1.1	0.2	0.3	92.4
	0.4	1.4	1.5	0.3	0.0	0.6	0.2	0.3	95.3
	0.6	1.4	0.9	0.3	0.0	0.5	0.2	0.3	95.8
465	1.3	22.1	0.3	0.2	0.1	0.2	0.2	0.3	75.4
	1.1	17.3	0.3	0.2	0.1	0.2	0.3	0.4	80.2
	3.6	12.9	0.6	0.2	0.4	0.3	0.5	0.3	81.3
	2.5	15.4	0.7	0.2	0.2	0.3	0.4	0.3	79.9
	5.2	30.3	0.8	0.2	0.8	0.4	0.5	0.2	61.5
461	1.6	66.4	0.7	0.1	0.0	0.2	0.1	0.1	30.8
	4.4	18.6	1.6	0.3	0.2	0.7	0.5	0.2	73.6
	3.4	53.2	1.3	0.3	0.1	0.6	0.2	0.1	40.8
	1.7	35.9	1.1	0.3	0.0	0.4	0.2	0.2	60.4

Table A6: Quantification of different categories of iron-working waste by context, with weights in grams, including the iron-rich stone collected from various contexts (the table is continued over three pages)

Context	Tap slag	Smelting Slag	Vitrified lining	Fired clay	Smithing Hearth Bottom	Fuel ash slag	Iron	Stone/ Ore	Undiagnostic
251									3
256	88								
260	1012								
264	89							100	
294		415				175			
300	4816	418	8			16		306	968
301	299							62	5
302	811		50					292	1585
303	2073			7				1262	
306	1173								
310	28							3850	
311	16								
318	2111							832	105
319	1878				168				
320	941				641				
321	159	6							
323	291				55	189			
324						129		94	
327	122								
336	234								
339								26	
340	150								
341	14								
342	10								
343	468							28	
344	49				25				
345	147							28	
346	94								
352	497				93			489	105
360	309							150	
365	201								
366	5820				304			1976	
374	864							32	
375									285
381	2099	107							
382	183								
388	1639							634	216
391	843						44		
392	1958							68	
396								105	
397	729								207
399	192								
399	116								90
405	53								
406	11								
407	334								
408	3					11			
409	232								

Table A6: continued

Context	Tap slag	Smelting Slag	Vitrified lining	Fired clay	Smithing Hearth Bottom	Fuel ash slag	Iron	Stone/ Ore	Undiagnostic
410	72								
411	1266								
412	521							50	
413	38								
414	133								
415	150								
417	169								
423	85								
426								94	
426								243	
429								949	
433								18	
435	106							289	
436	508								
441							127		
458	681	447	192			270		792	179
459								1959	
461								2667	
465		353	50					94	437
468								51	
505	90								
507	655	881							
507	300								
514	526		107				11	430	
516	1183							1618	
519	570							24	
522	773							711	
523								62	
526	50								
527	5606	62	139	139					
530	35								
531	3942							926	
534									7
538	37		171						35
550		503							
556	96								
571	13		760					829	
572	1180							186	
574	17294								35
577	11891							541	395
579								20	187
586									17
588	658		100			29	134		454
589	2474	1700	133						179
596	1034							10	
596	475								
610	2341	194					168		

Table A6: continued

Context	Tap slag	Smelting Slag	Vitrified lining	Fired clay	Smithing Hearth Bottom	Fuel ash slag	Iron	Stone/ Ore	Undiagnostic
616	5119								
617	138								
618	540								
620	61								
621		48	276						
637									14
718								2158	
754	87		562						
792								718	
792		1236							
830	47								
832	990								
862				5					44
887		5							
U/S	1151						533	1482	166
U/S	763							141	
Total	**97004**	**6375**	**2548**	**151**	**1286**	**819**	**1017**	**27396**	**5718**