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Summary

The Iron Age settlement site of North Cave, North Humberside, lies on the western escarpment of the Yorkshire Wolds. A large quantity of iron working slag was recovered from a small area of the site. The majority of the slag derived from the smelting process and contained about 1% manganese oxide (bulk analysis). The smelting slag derived from a furnace that was either raked out or in which the slag was allowed to cool. This technology has been identified on a number of other Iron Age sites.

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THE IRONWORKING SLAGS FROM NORTH CAVE,
NORTH HUMBERSIDE

1 INTRODUCTION

The excavation of an Iron Age/Romano-British settlement produced a large quantity (1087kg) of smelting slag and a small amount of smithing debris (33kg). Independent dating of the deposits has not been obtained, but slag morphology (below) indicates an Iron Age date. There was only the base of the furnace surviving, and it provided no information as to the exact dimensions or technological type. The majority of the slag, both smelting and smithing, was deposited within about 10 metres of the furnace (slag listing by Context Number are given in Appendix 1, and by Layer Number in Appendix 2). The presence of smithing slag and hearth bottoms from around the smelting furnace suggests the re-use of the furnace as a smithing hearth, perhaps for immediate primary smithing of the bloom (ie refining of the bloom by driving out excess slag).

2 SLAG MORPHOLOGY

2.1 Smelting Slag

There were two distinct morphological types of smelting slag. The first, resembled the characteristic 'tap slag', ie. it had a ropey flowed texture, indicating free-flowing of the slag. The total amount of this slag was about 30kg. The second type was the typical smelting slag, characterised by large charcoal inclusions, large vesicles, an irregular 'fingered' outer surface (ie frozen droplets on the surface, resembling short fingers of slag). Some of the slag was friable, due to high charcoal contents. The 'typical' smelting slag occurred in two forms, either randomly shaped pieces, ranging in weight from 100-1000's grammes. The second form were 'furnace bottoms', planoconvex lumps of slag. The range and mean dimensions (except weight) are given in Table 1.

TABLE 1 THE RANGE AND MEAN DIMENSIONS OF 6 'FURNACE BOTTOMS'

	Range	Mean
Major Diameter (mm)	400-680	540
Minor Diameter (mm)	300-450	370
Depth (mm)	200-300	250

2.2 Smithing Slags

The smithing slags occurred in two forms, randomly shaped pieces, termed smithing slag, and also characteristic hearth bottoms with the dimensions given in Table 2. These slags were distinguished by the absence of ropey flowed surfaces and large charcoal inclusions. Some of the hearth bottoms had a depression in the upper surface, caused by the air blast making the molten slag to flow to the sides. These slags had a higher 'apparent density' than the smelting slags, to which they had the closest resemblance. This was due to a lower vesicularity. The quantity of smithing slag recovered totalled 33.1kg. This represents working of the iron produced on the site, and also the general blacksmithing undertaken on the site throughout its occupation.

TABLE 2 MEAN DIMENSIONS OF HEARTH BOTTOMS

		Mean
Major Diameter	(mm)	110
Minor Diameter	(mm)	95
Depth	(mm)	45
Weight	(kg)	0.765

3 SLAG COMPOSITION

Samples of both types of smelting slag and an example of a hearth bottom were selected for analysis. There were three purposes to the investigation. Firstly, to determine the chemical and mineral composition of each slag type; secondly, to ascertain any compositional differences between the smelting slags and the smithing slags; thirdly, to determine whether the composition of the smelting slag, in association with its morphology, can indicate the type of smelting technology used on the site.

3.1 Sample NC/45/SE/1

Morphological Type: Smelting 'tap' slag.

Description: A single lump weighing 0.750kg. The lump is a fossilised liquid slag that flowed from the mouth (or 'break-out') of a furnace. It is 150mm long with a rounded ('right-angled') triangular profile, the thick end (height 50mm) was the furnace end. This is similar to the slag pieces termed 'sheep's skull' (farskallar) from Iron Age Sweden (Clarke 1979). The upper surface comprises run fingers of slag, and the lower surface has compressed or flattened fingers. In transverse cross-section the slag is blue/black in colour, few vesicles are present, but fine lines of vesicles or thin darker bands define fingers of slag throughout the cross-section. Mineral Texture: The slag comprised euhedral silicate laths (80%) and dendritic iron oxide (5%) in a glassy matrix (15%). There were fine crystallites present in some of the glass phase. No finger boundaries recorded in the cross-section could be discerned. The slag texture is of the form expected of a 'tap' slag, but the presence of euhedral silicate laths, rather than long thin dendritic ones, and a (relatively) low percentage of glass indicates a slow cooling tap slag.

Chemical and Mineral Composition: The bulk and phase compositions are given in Table 3. The bulk analyses display a typical fayalitic composition. The identification of the slag as a smelting slag is confirmed by the manganese oxide contents, levels greater than 1% are only found in smelting slags and not in smithing slags. The levels of glass forming oxides (Al,K,Ca) are low. The silicate phase analyses confirms the identification as fayalite, although the level of manganese oxide is not as high as expected. The glass phase reflects the overall low levels of glass forming oxides, with a significant silica plus iron oxide content. The iron oxide analysis is very unusual, the very high alumina and titania levels have not been recorded previously and indicates that the oxide is a spinel, ie magnetite rather than wustite. The oxide is also high in vanadium and cobalt.

Sample NC/45/SE/1 Summary:

The slag lump had morphology, mineral texture and chemical and mineral composition expected of a slag deriving from a smelting process.

TABLE 3 SAMPLE NC/45/SE/1 BULK AND PHASE ANALYSES

	B1	B2	B3	B4	B5	SIL	GLASS	FEOX
NaO	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
MgO	0.3	N.D	N.D	0.1	0.1	0.3	N.D	N.D
Al2O3	4.4	4.7	4.1	4.7	4.9	0.6	10.0	10.4
SiO2	30.4	31.8	30.6	30.7	31.4	29.4	36.7	1.3
P2O5	0.7	1.1	1.0	0.7	1.2	N.D	3.6	N.D
S	0.2	0.1	0.1	N.D	N.D	0.1	0.3	N.D
K2O	1.1	1.0	0.8	1.2	1.0	0.1	4.1	0.1
CaO	3.1	3.0	2.2	2.8	2.6	0.5	9.3	0.1
TiO2	0.1	0.3	0.3	0.2	0.3	N.D	0.3	2.9
V2O5	N.D	N.D	N.D	N.D	N.D	0.1	0.1	0.9
Cr2O6	0.1	0.1	N.D	N.D	0.1	N.D	N.D	0.2
MnO	1.1	1.1	0.8	1.0	0.9	1.6	0.4	0.4
FeO	56.1	56.5	56.4	58.3	56.4	67.6	34.3	77.5
CoO	0.2	0.4	0.4	N.D	0.3	0.4	N.D	0.5
NiO	0.1	0.2	0.1	N.D	N.D	0.2	N.D	N.D
CuO	0.1	0.1	0.1	N.D	0.1	N.D	N.D	0.3
Total	98.1	100.7	97.2	99.7	99.6	100.9	99.5	84.6

3.2 Sample NC/45/SE/2

Morphological Type: Smelting 'Furnace' Slag

Description: A large fist-sized lump of slag weighing 0.550kg, 140mm long, and with diameters 80 and 65mm. The slag had run surfaces and large charcoal impressions on the surface (up to 25mm long and 15mm across). In section the slag was heavily vesicular due to charcoal impressions and gas bubbles.

Mineral Texture: The slag comprised massive silicate (80-90%) and fine iron oxide dendrites (5%) in a glassy matrix (5-10%). Small metallic inclusions were present in some areas.

Bulk and Phase Chemical Composition: The bulk analyses (Table 4) differ from those obtained for Sample NC/45/SE/1 in having lower levels of alumina, potash, lime, and manganese oxide. Two results, B2 and B5, total less than 100%, probably due to high vesicularity. The silicate phase is fayalitic and low in manganese oxide, and the glass phase has high potash but low lime contents. The iron oxide analysis indicates that it is wustite, but with a small silica content.

Sample NC/45/SE/2 Summary: The slag has the typical morphology of a furnace slag, but it is unusually low in some oxides, in particular manganese oxide.

TABLE 4 SAMPLE NC/45/SE/2 BULK AND PHASE COMPOSITION (Weight %)

	B1	B2	B3	B4	B5	SIL	GLASS	FEOX
Na2O	0.3	0.3	0.2	0.1	N.D	N.D	0.2	N.D
MgO	0.3	N.D	0.2	0.1	0.1	0.2	0.3	N.D
Al2O3	1.9	0.9	2.2	1.6	1.6	0.4	18.9	0.5
SiO2	22.9	20.9	21.9	23.8	22.2	28.3	44.0	1.0
P2O5	0.9	1.3	0.6	0.7	0.8	0.1	1.7	N.D
S	0.1	0.1	0.1	0.1	0.1	N.D	0.1	N.D
K2O	0.1	0.2	0.2	0.2	0.2	N.D	13.5	N.D
CaO	1.0	1.1	0.7	0.7	0.7	0.4	1.5	N.D
TiO2	0.1	0.2	N.D	0.1	N.D	N.D	0.4	0.3
V2O5	N.D	0.1	0.1	0.2	N.D	N.D	N.D	N.D
Cr2O6	N.D	N.D	0.1	0.1	N.D	0.1	N.D	N.D
MnO	0.3	0.5	0.2	0.2	0.6	0.4	0.1	0.1
FeO	72.1	70.4	74.2	72.1	66.7	69.2	3.3	95.8
CoO	0.1	0.3	0.1	0.1	0.1	0.1	N.D	0.5
NiO	0.2	0.3	N.D	0.2	0.1	0.3	N.D	0.7
CuO	0.1	N.D	0.1	0.2	0.1	0.1	N.D	0.2
Total	101.4	96.6	100.9	100.5	93.3	99.6	84.0	99.2

3.3 Sample NC/85/LY

Morphological Identification: Smelting Slag

Description: Small (100gms) lumps of smelting slag, highly vesicular, flowed surfaces, and large charcoal impressions.

Mineral Texture: Massive silicate (90%) and iron oxide blebs (5%) in a glassy matrix (5%).

Bulk and Phase Chemical Composition: Overall the results (Table 5) are low, ie totalling less than 100% (but within experimental error). The bulk analyses are low in the glass forming oxides (reflecting the low percentage of glass observed in the optical study). The manganese oxide is slightly elevated, and is high in the silicate phase analysis, which confirmed the phase as fayalite. The glass phase is predominantly silica, and the iron oxide contains no significant levels of other oxides.

Sample NC/85/LY Summary: This slag had a typical smelting slag morphology and contained slightly elevated manganese oxide contents.

TABLE 5 SAMPLE NC/85/LY BULK AND PHASE ANALYSES (Weight %)

	B1	B2	B3	B4	B5	SIL	GLASS	FEOX
Na2O	0.3	0.2	0.1	0.3	0.3	0.4	1.0	N.D
MgO	N.D	N.D	0.1	0.2	0.2	0.3	N.D	N.D
Al2O3	0.6	1.7	1.6	5.1	1.8	N.D	4.0	0.6
SiO2	19.9	22.8	24.9	23.5	25.5	28.4	49.2	0.8
P2O5	0.8	0.6	0.3	1.4	0.8	0.4	3.1	N.D
S	0.1	0.1	0.1	N.D	0.1	0.1	0.8	N.D
K2O	N.D	0.1	0.1	0.3	0.1	N.D	0.4	N.D
CaO	0.2	0.3	0.4	1.1	0.4	0.2	0.6	0.1
TiO2	0.1	0.1	N.D	0.1	N.D	N.D	1.0	0.1
V2O5	N.D	0.1	N.D	N.D	0.2	N.D	N.D	N.D
Cr2O6	0.1	N.D	N.D	0.1	N.D	0.1	N.D	N.D
MnO	0.7	0.7	0.6	0.8	0.7	1.1	N.D	0.5
FeO	69.8	65.7	66.1	62.9	61.5	66.5	12.1	92.4
CoO	0.2	0.4	0.2	0.4	0.3	0.5	N.D	0.2
NiO	0.3	0.2	0.2	0.4	0.2	0.2	N.D	0.4
CuO	0.2	0.2	0.3	0.2	N.D	0.1	0.1	0.1
Total	93.3	93.2	95.0	96.6	92.1	98.3	72.5	95.2

3.4 Sample NC/45/SE/3

Morphological Identification: Smithing Slag Description: A hearth bottom with dimensions:

Major Diameter	110mm
Minor Diameter	100mm
Depth	35mm
Weight	450gms

It had a typical agglomerated texture and a depression in the upper surface. There was a 'tail' which could be interpreted as a tap slag 'feeder', but probably derived from further development of the hearth bottom. In cross-section the slag was vesicular with some small charcoal inclusions present.

Mineral Texture: Large iron oxide dendrites (55%) and massive silicate (40%) in a small amount of glassy matrix (5%).

Bulk and Phase Chemical Composition: Only three bulk analyses were obtained (Table 6), and reflect the high free iron oxide content observed in the optical study. They show a typical smithing slag composition, low in glass forming oxides (also reflecting the low glass content recorded in the optical study). The manganese oxide content is similar to that obtained for the smelting slag NC/45/SE/2. The manganese oxide content of the silicate phase is very low, and confirms the phase as fayalite, with minor levels of other oxides. The iron oxide phase shows a typical composition and is probably wustite rather than magnetite. No glass phase was analysed.

Sample NC/45/SE/3 Summary. This sample has a typical hearth bottom morphology, except for the 'tail'. It shows a typical smithing slag composition, reflecting the high iron oxide content of the slag. The manganese oxide content was low.

TABLE 6 SAMPLE NC/45/SE/3 BULK AND PHASE ANALYSES (Weight %).

	B1	B2	B3	SIL	FEOX
Na2O	0.3	0.3	0.1	N.D	N.D
MgO	0.6	0.5	0.3	0.6	0.1
Al2O3	0.7	0.4	0.6	0.4	0.4
SiO2	17.1	25.1	20.9	30.3	0.9
P2O5	0.5	N.D	N.D	N.D	N.D
S	N.D	0.1	N.D	N.D	N.D
K2O	N.D	0.1	N.D	N.D	N.D
CaO	0.8	0.4	0.4	0.3	N.D
TiO2	0.2	N.D	0.1	N.D	N.D
V2O5	N.D	N.D	0.1	N.D	0.1
Cr2O6	N.D	N.D	0.1	0.1	N.D
MnO	0.3	0.5	0.2	0.2	0.2
FeO	78.6	71.4	75.5	68.0	96.6
CoO	0.4	0.3	0.5	0.3	0.3
NiO	0.1	0.4	0.1	0.4	0.3
CuO	0.1	N.D	N.D	0.1	0.3
Total	99.7	99.5	98.9	100.7	99.2

3.5 Summary of Analyses

The morphological identification enabled smithing slags and smelting slags to be distinguished. The tapped slag sample (NC/45/SE/1) was typical of a free flowing slag, although the finger-like form of the slag indicated that it was more viscous than the typical Roman or medieval tap slags. The other smelting slags had the classic texture with flowed surfaces and 'dribbles', large charcoal inclusions and *were* heavily vesicular. The smithing slag sample was a typical hearth bottom except for a 'tail' that could have been interpreted as a feeder of a slag cake.

The mineral texture of the slags reflected their cooling regimes. The tapped slag had silicate laths, indicative of (relative) fast cooling, and the furnace slags had massive silicate due to a slow furnace cool. The mass of slag present in the furnace bottoms (NC/45/SE/2), would only cool slowly, whether it was inside or outside a furnace. The smithing slag had a very different mineral structure due to the high free iron oxide content.

The analyses show that the tap slag (NC/45/SE/1) and the smelting slag (NC/85/LY) had similar manganese oxide contents, both in the bulk and the silicate phase analyses. The furnace slag NC/45/SE/2 was low in manganese oxide and in glass forming oxides (Al, K, Ca). This was similar to the smithing slag composition (NC/45/SE/3), but this composition is distorted due to the high free iron oxide content, ie resulting in a low fayalite percentage in which the manganese is concentrated. The analysis of the silicate phase does confirm a low manganese oxide content. It is therefore possible that Sample NC/45/SE/2 derived from the smithing rather than the smelting process. This may have resulted from re-use of the furnace as a primary smithing hearth, ie refining the bloom which utilised the larger charcoal size.

4 CONSIDERATION OF THE FURNACE TECHNOLOGY

4.1 The Evidence for Iron Smelting in the Iron Age

There is very little evidence for Iron Age iron smelting in the British Isles. This has been summarised by Tylecote (1986), although other sites could now be included, eg Farthingstone, Northamptonshire (D.Knight Forthcoming). There is no good evidence for tapping furnaces prior to the Late Iron Age (ie the century before the Roman Conquest). The conclusion is that furnaces were either raked clean and/or the slag was allowed to cool in the furnace. Although there have been few Iron Age smelting sites excavated in the major centres of later iron production, (the Weald etc), and therefore the evidence relies on small 'one-off' sites.

4.2 The North Cave Technology

The presence of two smelting slag types on the site does not indicate two smelting technologies. The flowed 'tap' slag probably derived from either deliberate tapping of the furnace or accidental break-outs of the slag. The 'furnace slag' or 'smelting slag' probably results from slag cooling within the furnace or being raked out and allowed to cool outside the furnace. Therefore, the North Cave furnace technology is typical of the type current in the Iron Age, as is the nearby site of Welhambridge where Durham University (M.Millet) have recovered a large quantity of slag. The technology did not utilise high temperatures sufficient to cause the slag to flow freely.

5 CONSIDERATION OF ORE SOURCES

Small 'one-off' iron smelting furnaces did not require regular supplies of large amounts of iron ore. Therefore, very localised deposits of 'iron ores' could have been used. A number of possible deposits are near to the site.

5.1 The Lower Lias that include the Frodingham Ironstone Beds on the south side of the Humber are present on the north side, on the west facing slope of the Wolds. The geological reports (Rayner and Hemingway 1971) conclude that the upper beds (which includes the Frodingham ironstone) of the Lower Lias are absent in this area, as is the Dogger Iron Seam which is present between the Upper Lias and the Ravenscar Formation in the Cleveland Hills to the North. It is possible that very small deposits of these ores were present, but were not considered worth recording.

5.2 The Oxford Clays outcrop along the west face of the Wolds. These were probably exploited for their clay (for pottery, daub etc), and ironstone nodules could have been present.

5.3 The low lying areas to the west of the site could have contained deposits of 'bog ore'.

6 CONCLUSIONS

Study of the slags from North Cave show that iron ore was smelted on the site, as well as the expected smithing activity. The smelting slag contained a significant percentage of manganese oxide (1% in the bulk analyses) which confirmed the identification (but which can be considered as relatively low with respect to many other manganese bearing smelting slags). The smelting technology used was similar to that observed on other Iron Age sites, ie non-free flowing tapping furnaces, the slag was either allowed to cool within the furnace or was raked out. The smelting operation probably comprised several separate smelts to supply limited local (immediate) needs.

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APPENDIX 1

NORTH CAVE, NORTH HUMBERSIDE SLAG LISTING BY CONTEXT NUMBER
(Weight in Grammes)

CONTEXT	LAYER	SMELT	SMITH	HB
4	SB	15000	0	0
7	GV	6000	0	0
45	SD	25000	0	500
46	EJ	25000	3500	0
47	DJ	0	2000	0
50	DE	4500	0	0
51	CZ	0	0	800
52	DL	0	13200	0
53	NY	22000	0	0
54	EL	0	6000	3500
56	RZ	230000	0	800
57		601500	0	0
62	KG	1100	0	0
63	LD	3350	0	0
69	IV	30000	0	0
71	KZ	1250	0	0
82	LF	7000	0	0
83	OH	1600	0	0
85	LY	8600	0	0
86	KO	30000	0	0
89	MG	2500	0	0
101	SN	3000	0	0
105	SC	30000	0	0
110	SA	5000	0	0
118	SO	3250	0	0
119	SP	9000	0	0
126	QC	2300	0	0
128	SQ	0	2800	0
141	SF	20000	0	0
** Total **				
		1086950	27500	5600

APPENDIX 2

NORTH CAVE, NORTH HUMBERSIDE SLAG LISTING BY LAYER NUMBER (Weight in Grammes)

CONTEXT	LAYER	SMELT	SMITH	HB
57		600000	0	0
46	CD	0	3500	0
51	CZ	0	0	800
50	DE	4500	0	0
47	DJ	0	2000	0
52	DL	0	5500	0
52	DP	0	7700	0
46	EH	10000	0	0
46	EI	10000	0	0
46	EJ	5000	0	0
53	EK	19000	0	0
54	EL	0	6000	3500
7	GV	6000	0	0
69	IV	30000	0	0
82	KB	5000	0	0
62	KG	1100	0	0
56	KN	0	0	800
86	KO	30000	0	0
63	KY	600	0	0
71	KZ	1250	0	0
57	LB	1500	0	0
63	LD	2750	0	0
82	LF	2000	0	0
85	LY	6000	0	0
85	LZ	2600	0	0
89	MG	2500	0	0
53	NY	3000	0	0
83	OH	1600	0	0
126	QC	2300	0	0
56	RZ	230000	0	0
110	SA	5000	0	0
4	SB	15000	0	0
105	SC	30000	0	0
45	SD	15000	0	0
45	SE	10000	0	500
141	SF	20000	0	0
101	SN	3000	0	0
118	SO	3250	0	0
119	SP	9000	0	0
128	SQ	0	2800	0
** Total **				
		1086950	27500	5600