GeoArch

Report 2007/06

Evaluation of archaeometallurgical residues from the Pannal to Nether Kellet Pipeline (PNK06, principally plot 8-5)

Dr Tim Young
2nd March 2007

Evaluation of archaeometallurgical residues from the Pannal to Nether Kellet Pipeline (PNK06, principally plot 8-5)

Dr T.P. Young

Abstract

The main body of the submitted material comprised some 115kg of slag from plot 8-5 on the Pannal to Nether Kellet Pipeline. The residues are dominated by materials produced during iron smelting in a large slag-tapping bloomery furnace. At least 75% of the recovered slags were likely to have been tapped, and a further 17% of the assemblage is provided by the slags which cooled within furnace 11018 on its last smelt. Of the tapped slags approximately 77% are low density, highly vesicular forms with only 23% being dense "classic" tap slags.

The slag assemblage does not appear to have been collected evenly across the site. No residues were submitted from either the supposed smithing area, nor from the ore storage/preparation area, so no comment can be made on the interpretation of these areas. The slag dump, estimated as containing 15 tonne of material was represented by just 32kg of mainly rather small and abraded pieces.

A small amount of roasted claystone ironstone was recovered from other contexts and confirms the nature of the ore employed.

The survival of a large quantity of slag within the abandoned furnace [11018] provides an excellent opportunity to examine the chemical reactions taking place in such a furnace. This site has a high potential for producing important additional information on the smelting technology and materials being employed.

In addition to the main coverage of plot 8-5 this report also provides brief coverage of materials recovered from minor interventions within the same scheme.

Contents

Abstract 1

Methods 1

Results 1

Interpretation 2

Evaluation of potential..... 2

References 3

Catalogues

Table 1: Plot 8-5 slag catalogue 4

Table 2: Plot 8-5, slag types by context 7

Table 3: other sites 8

Methods

All material submitted for the evaluation has been inspected visually, weighed and recorded to a database. As an evaluation, the production of this report has not entailed any high powered microscopic investigation or chemical analysis, and the interpretations must therefore be seen as provisional.

Results

Plot 8-5

The slag assemblage from this site is of a remarkably low diversity. All slags identifiable to a reasonable degree of certainty were from iron smelting. No certain smithing residues were identified, although no slag assemblages were provided from the area of the site identified by the excavators as being involved with smithing.

The dominant materials from this site were highly vesicular, sometimes almost frothy, slags which often show flow-lobed or smooth upper surfaces. The slag is mid-grey in colour, though the high porosity has encouraged weathering and much of the material is pale yellowish-brown superficially. The upper flow surfaces commonly show a maroon or even purple tint.

The vesicles are dominantly small (<2mm), although some specimens suggest the slags are sometimes formed around large internal voids.

The most complete specimens show this material forms flows, of a morphology fairly similar to those commonly seen in classical dense tap-slags, but also forms large flat-topped to even smoothly convex-topped slag cakes. The example left within the tapping pit of furnace [11018] formed a slightly biconvex cake, about 300-350mm across and 80mm thick, with thin sheet like flowed extensions on some sides.

Some of this material has a morphology suggestive of contortion produced b y raking of the slags from the tapping area when the slags were still plastic.

The large specimens also suggested that the most highly vesicular textures may be present in the middle of flows, with the lower part of the flow forming a more dense basal crust, and with vesicularity also decreasing towards a slightly denser layer forming the upper surface.

These vesicular slags are accompanied by a smaller quantity of dense classic tap-slags with well developed flow lobes. This type of slag is present almost entirely as thin sheets, often only a single layer of flows in thickness.

Dense slags are also seen in the furnace, in the in-situ slag accumulations of (11078). These blocks are extremely dense, and include textures with vesicles and charcoal inclusions quite unlike those of the tap-slags. The external appearance of the blocks suggests that they may also include some brecciated textures. They suggest a similar facies of slag extended from the furnace bowl through the tap-arch, forming a layer approximately 170-180mm thick. The block within the furnace has a slightly dished top.

Several deposits show occurrences of rounded concretions, which are likely to be cored on pieces of iron.

A small quantity of ore was present within the submitted material. All the submitted material was claystone ironstone, presumably from the Namurian, but possibly from the more distant Carboniferous Coal Measures. All of these specimens had probably been roasted.

Furnace lining and lining-dominated slags were remarkably sparse in the assemblage.

Other sites

Material recovered from the other sites includes coal, partially burnt coal (coke), burnt coal shale, clinker (melted coal residue) and other partially vitrified stones (possibly in some cases residues from lime burning). In only two cases were the residues certainly of metallurgical origin (15104 and 15026). Except where burnt, coal should not be taken as an indicator of human activity in this area.

The finds of clinker (in which the inorganic component of the impure coal has become at least partially molten) may be indicators of more intense burning. Clinker can be generated rarely in a domestic type of fire, but will be more common in the residues of industrial coal-burning processes (including lime burning and also the fire boxes of steam engines, including traction engines). The denser clinker, such as that from (4034) might just be indicative of a metallurgical origin; dense clinkers are produced in coal or coke fired blacksmiths hearths for instance, particularly after the advent of cast iron tuyères in the 19th century reduced the silicate input to the hearth.

The vitrified, glazed and slagged stone pieces in the collection might also result from many different processes, for instance impure limestones being burnt in limestone kilns and the accidental inclusion of sandstone or siltstone fragments within coal fires.

Interpretation

Plot 8-5

The assemblage from this site provides good evidence for bloomery iron smelting. The large size of the slag flows (the apparently in-situ material associated with furnace [11018] suggests the tapped low-density slag amounts to 20kg, with over 19kg of untapped material still within the furnace) is consistent with a relatively late date for this furnace, probably 14th-17th century.

The highly vesicular tap slag flows are a common feature of later medieval bloomery sites, but their significance (beyond a probable association with the smelting of claystone ironstone ores) is not fully understood, nor is their relationship to the dense tap-slags with which they occur. The large highly vesicular slag cake retrieved from the tapping pit of the furnace [11018] appears to show a single tapping event with a very fluid slag.

Other sites

There is little evidence for significant metallurgical activity close to these other sites.

Evaluation of potential

Plot 8-5

The assemblage has significant potential to enhance understanding of the nature of the technology being employed and to enhance understanding of the local economy.

The in-situ slags within furnace [11018] provide a good opportunity to understand the different slag types generated within a furnace of this type, which may enhance understanding of the occurrence of these slag types when found in other circumstances. This exercise should be undertaken bearing in mind that the massive accumulation of slag in the base of the furnace may not have been a normal occurrence, and it is possible that the problem of extracting this amount of slag without causing major damage to the furnace might have been the reason for its abandonment. It is certainly surprising that if this were to have been the normal slag production in a smelt, that there was no significant quantity of slag resembling the internal accumulation recovered from other contexts within the site.

A key question that this assemblage may help to address is that of the relationship between the highly vesicular and the dense tap-slags. Some fragments appear to show both textures within a single piece, and any such observation would be worthy of further

investigation. It is conceivable that the two textures were produced at different stages within a smelt for instance.

There are several questions still to be asked of the material which may have been collected by the excavators but not submitted for evaluation:

1. What is the evidence for the northern features being used for smithing?
2. What is the evidence for the ore handling area to the NW?
3. What is the geological evidence for the origin of the iron ore found in that area?
4. What is the significance of the ceramic materials found on the slag dump? Are they metallurgical ceramics, or unrelated materials?
5. What is the evidence for the nature of furnace superstructure or lining? Are there significant fired clay assemblages associated with the metallurgical features?

The presence on the site of ore materials, can be taken with the apparently complete suite of smelting slags (and the probable existence of suitable ore and clay samples), to work towards a mass-balance description of the furnace operation (Thomas & Young 1999a and 1999b). This would enable modelling of the size of bloom being produced and the efficiency (in terms of iron yield) of the furnace.

A further aspect of interest of this site is its location on Namurian strata. These beds are known to have been exploited for iron ore in early times in the North Pennines, but the nature of that exploitation is not so well documented as that from the geologically overlying Westphalian Coal Measures.

Further investigation of the residues should be co-ordinated with a detailed review of the associated features to ensure the maximum amount of information is retrieved.

No detailed work proposal for the analysis phase is included here because of the uncertainty over possibility of additional information or samples from the smithing and ore preparation areas, and of the existence of any furnace material samples (fired clay).

References

THOMAS G.R. & YOUNG, T.P. 1999a. Bloomery furnace mass balance and efficiency. *In:* POLLARD, A.M. (ed) *Geoarchaeology: exploration, environments, resources*, Geological Society of London, Special Publication, 165, 155-164.

THOMAS, G.R. & YOUNG, T.P. 1999b. A graphical method to determine furnace efficiency and lining contribution to Romano-British bloomery iron-making slags (Bristol Channel Orefield, UK). *In:* YOUNG, S.M.M., BUDD, P.D., IXER, R.A. and POLLARD, A.M. (eds). *Metals in Antiquity*, British Archaeological Reports International Series, **792**, 223-226. Archaeopress, Oxford.

context	notes	weight	number	description
11003		17459		extremely vesicular slags, mainly with evidence for flow
		9605		dense conventional tapped slags
		352		natural stones
		388		corroded iron pieces
		190	1	dense basal crusts from slag cakes
		8	1	coke
		18	1	burnt coal shale
		4570	1	undifferentiated small iron slag pieces
11004		57.25		dense slag fragments
		15.86		low density flow carrying small ore particles on highly vesicular slag lobes
11008		28	4	dense slag fragments and lobes
		216	9	pieces of dense tap slag
		54	1	dense slag piece with glassy patch - edge of a cake or flow - possibly na shc margin?
		116	8	highly vesicular slag pieces
		84	3	stones
11012	<359>	1900	1	large block of highly vesicular flow c250 across,
		3125	20	other highly vesicular flows, one of them has brecciated lower dense unit
		360	1	flat topped dense flow,
		128	1	irregular mass of mainly highly vesicular, probably raked flow,
		464	1	lock of highly vesicular flow with probable inverted section
		1090	1	large thin flow of v irregular nature, all sorts of blebs etc stuck to top, base almost nodular,
		1225	1	large irregular mass of brecciated highly vesicular flow pieces
		42	2	pieces of roasted claystone ironstone
11013		982	18	highly vesicular flow
11015		1160		low density flows,
		1585		dense tap slag
		776		slag in concretionary material
		234		rusty rounded accretionary material - iron
		86		stones

context	*notes*	*weight*	*number*	*description*
11016		1156	40	dense tapslag
		3935	188	highly vesicular slags
		22	1	stone
		8	1	vitrified lining?
		72	2	rusty charcoal-rich slag
		104	2	fairly dense slag with distinct glassy texture - lining slags?
11017		446	30	pieces of dense but vesicular slag with charcoal inclusions - possibly a single piece on excavation - could be SHC or furnace slag fragment
		10	1	dense flow lobe
		4	3	small stones with adhering slag
		22	2	pieces of lining slag
		24	1	fired clay
11021		310		highly vesicular crusts - possibly from flows,
		3940		highly vesicular slag, all or mainly flows,
		290		dense tap-slag,
		716	7	rounded accretionary masses - probably cored on iron
		160		accretionary mass with large charcoal fragment
		36		stone
11030		10782	210	highly vesicular slag flows
		5603	70	dense tap slag flows
		138	5	rusty rounded concretions probably cored on iron
		60	5	stones
		1201	1	dense crust piece with charcoal moulds on upper surface
		502	4	moderately dense irregular slag concretions
		34	2	vitrified lining
		14	3	pieces of roasted claystone ironstone
11032		320	8	pieces of highly vesicular slag, probably flows
		412	5	pieces of dense flow
		234	1	extremely acute angle edge to highly vesicular cake. Has distinct but thin lower crust to about 5mm. Top is broken but has included glass and stone bits. Extreme margin shows flat-topped flow
		392	1	edge of dense cake - probably a flow but hard to exclude this as an SHC margin
11038		1321	29	highly vesicular flow

context	*notes*	*weight*	*number*	*description*
11039		40	5	charcoal rich rusty slag nubs
		102	1	flat topped smooth slag sheet from top of highly vesicular cake
		164	1	fragment of slag of variable density - core is dense, rather SHC like slag with vesicular material below and charcoal-rich above. Could be either smelting or smithing, possibly contorted
11065		7995	1	large highly vesicular textured cake, surviving piece 300 diameter x 80 thick
		7030	4	pieces forming edges broken from 7995 block above
		4490	8	other blocks including possible burr area or channel, but all low density,
		176	7	small fragments, material shows basal crust, very low density material above then convex smooth but flat, gently wrinkled top in a slightly denser crust
11078	<1385>	9425	1	main block300x190x170, steep sides, one probable contact, the other more broken, one rounded end, one broken end, rather rubbly appearing slag, vesicular, dense, with included charcoal. Base has some fired clay, V profile base has dense slag, upper part more vesicular, top has some rusty areas
		270		bits probably fractured from above
	<1385>	9105	1	250x240x180 massive block of dense vesicular slag. Slightly dished smooth top, steep but damaged sides, one side appears to be wall contact, other rough

Table 1. Summary catalogue of archaeometallurgical residues from PNK06, plot 8-5.

context	*description*	*vesicular flows*	*dense flows*	*other dense*	*undiff*	*iron nodules*	*coke/coal shale*	*ore*	*lining*	*total*
11003	slag mound	17459	9605	190	4570	388	26			*32238*
11004	surface	16	57							*73*
11008	?	116	244	54						*414*
11012	pit fill (11014)	6842	360					42		*7244*
11013	pit fill (11014)	982								*982*
11015	layer	1160	1585		776	234				*3755*
11016	VOID	3935	1156		72				112	*5275*
11017	fill of furnace 11024		10	446					46	*502*
11021	layer	4250	290		160	716				*5416*
11030	fill of gully 11022	10782	5603	1201	502	138		14	34	*18274*
11032	fill of tree bowl	554	412	392						*1358*
11038	pit fill (11014)	1321								*1321*
11039	dump	102		164	40					*306*
11065	fill of furnace 11023	19691								*19691*
11078	fill of furnace 11024			18800						*18800*
		67210	*19322*	*21247*	*6120*	*1476*	*26*	*56*	*192*	***115649***

Table 2. Summary of distribution of residue type by context for PNK06, plot 8-5

context	*site*	*weight*	*description*
Coal samples			
15559	tp3	2.16	coal
15016	wb u/s	1.69	coal shale (burnt?)
7000		7.76	coal
7044		25.37	coal 4 pieces
		5.48	2 pieces part burnt coal
12010		31.9	9 pieces coal
		0.8	1 piece burnt coal
8022		2.87	3 pieces of coal
15023	tr12	4.62	coal
15031	tr22	5.01	burnt coal shale
15046	tr23	60	impure shaley coal, partly burnt?
15047	tr23	51	7 pieces of coal
15050	tr24	2.76	3 pieces of coal
15055	tr26	20.64	partly burnt coal
15062	tr30	44.63	3 pieces of part burnt coal
15111	tr 113	3.38	fragmented burnt? Shale
5026	w.b.	6.08	3 pieces part burnt coal
5032	w.bx	6.24	coal
5238	w.b.	0.89	charcoal
5364	w.b.	172	many coal pieces
10059	21/18	8.26	coal
10059	21/18	0.67	coal
10132	21/18	0.05	coal
10303	21/18	2.04	coal
10318	21/18	10.33	coal
10400	21/18	1.33	coal
10414	21/18	0.42	coal - 3 pieces

context	*site*	*weight*	*description*
13001	.7/18	3.01	coal
13001	.7/18	42.65	5 pieces of coal
13001	.7/18	32.18	coal
13002	.7/18	15.15	6 pieces of coal
13002	.7/18	75.09	12 pieces of coal
13007	.7/18	11.38	coal 5 pieces
13007	.7/18	1.49	coal
13010	.7/18	3.18	coal
13011	.7/18	0.96	coal
13033	.7/18	4.31	2 pieces of coal
13043	.7/18	8.12	charcoal
13096	.7/18	34.16	3 pieces of coal
13097	.7/18	1.03	coal
13111	.7/18	4.56	coal

Residue Samples

residues from test pits

15504	tp4	1.77	coke
15511	tp5	4.47	shale fragment coated in red slag like that from 15584
15513	tp5	0.66	coal
15520	tp16	1.13	coke
15533	tp43	10.45	clinker
15548	tp1	8.57	quartz-rich dense clinker
15554	tp2	0.5	coke
15556	tp3	7.22	clinker
15559	tp3	3.07	2 pieces of coke
15563	tp3	0.69	coal
15563	tp3	3.15	quartz rich clinker (or lining slag?)
15569	tp4	4.86	4 pieces of coal
15584	tp6	5.2	partially melted and reddened ceramic bearing large quartz grains - nature of original material not clear
15586	tp7	0.81	coke
15602	tp23	23.71	coke

context	*site*	*weight*	*description*
loose bags			
15104	w.b. u/s	248	irregular slag piece with microdimpled base and slightly lobate top, covered partially by accretion including large iron lump on one side
7000	.3/5	1.46	partially burnt coal
5239	.19/1	0.58	tiny piece of charcoal plus two clinker fragments
9012	.28/1	2.07	vitrified stone fragment
4034	w.b.	144	4 pieces of clinker - 2 substantial - one is from a 30mm thick sintery sheet
evals			
15026	tr22	30	rusty dense dimpled slag nub
15075	tr38	6.52	4 pieces of coke
15114	tr67	9.23	3 pieces of coke
21/18			
10285	21/18	1.11	highly vesicular, highly vesicular, white to pale grey slag , 2 pieces
10034	21/18	25.16	coarsely vesicular, highly vesicular lump, vitrified impure limestone??
.7/18			
13111	.7/18	9.03	glazed, slagged and vitrified thin sandstone fragment
13111	.7/18	24.07	coarsely vesicular pale highly vesicular slag, cf .10034 above
13111	.7/18	26.51	iron concretion attached to shale fragment
13010	.7/18	60	vitrified and slagged (clinker?) stone fragment
13001	.7/18	202	3 pieces of sheet like iron concretion on shale core
13001	.7/18	1.66	coke

Table 3: Summary catalogue for materials for other sites on PNK06

GeoArch

geoarchaeological, archaeometallurgical & geophysical investigations

54 Heol y Cadno,
Thornhill,
Cardiff,
CF14 9DY.

Mobile: 07802 413704
Fax: 08700 547366
E-Mail: Tim.Young@GeoArch.co.uk
Web: www.GeoArch.co.uk