



**ARCHAEOLOGICAL STRIP, MAP AND
RECORD REPORT:
GREEN LANE WORKS,
KELHAM ISLAND,
SHEFFIELD,**



Report prepared By Elmet Archaeological Services Ltd
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Contents

Non-Technical Summary	3
Acknowledgements.....	3
Project Background	5
The Site, Location and Geology.....	5
Aims and Scope of the Works.....	10
Methodology.....	11
Strip, Map and Record Results	11
Discussion	19
References.....	21
<i>Appendix 1: Trench Descriptions</i>	22
<i>Appendix 2: Plates</i>	26
<i>Appendix 3: Post-excavation analysis of furnace residues from Green Lane/ Eagle and Horseman Works, Kelham Island, Sheffield</i>	30

Illustrations:	Illustration 1: Site location
	Illustration 2: Green Lane, Sheffield: Site Plan
	Illustration 3: South Facing Section: Mitigation Area
	Illustration 4: Green Lane, Sheffield: Phase 1
	Illustration 5: Green Lane, Sheffield: Phase 2
	Illustration 6: Green Lane, Sheffield: Phase 3
	Illustration 7: South-west Facing Section through Western Furnace

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Non-Technical Summary

Elmet Archaeological Services Ltd (hereafter 'Elmet') were commissioned by Berkeley Ltd ('the Client') to undertake an archaeological strip, map and record in advance of works at the Green Lane Works site, Kelham Island, Sheffield ('the Site' **Illustration 1**).

This report details how Elmet carried out that strip, map and record and has been prepared in accordance with current industry best practises (IfA 2008a and b) and in accordance with IfA Codes of Conduct (IfA 2010). The report will be submitted to South Yorkshire Archaeological Services (SYAS) for approval.

The strip, map and record revealed a largely intact cementation furnace from the 19th century with associated features. This feature has significance for the industrial heritage of the city of Sheffield.

The archive is held at Elmet's Wath-Upon-Dearne offices and will be deposited with Museums Sheffield in due course.

Acknowledgements

Elmet Archaeological Services Ltd were commissioned by Berkeley Ltd and thanks go to Paul Sanderson in this regard. The archaeological work was monitored by Dinah Saich of SYAS and thanks go to her for her input.

This report was compiled by Alex Sotheran and illustrations were prepared by Alex Sotheran, Justin Russell and Mike McCoy. The fieldwork was completed between October and November 2013 and was carried out by Alex Sotheran and Richard Jackson. Specialist consultation was carried out by Dr Roderick MacKenzie and the historical background to the site was produced as an archive assessment by Lauren McIntyre for Elmet Archaeological Services Ltd. (2013).

Project Background

Elmet Archaeological Services Ltd were commissioned by the Client to undertake an archaeological Strip, Map and Record in advance of development at the Green lane Works, Kelham Island, Sheffield (**Illustration 1**).

Following discussion with SYAS and the Client it was agreed that Elmet Archaeological Services Ltd would undertake an archaeological strip, map and record of an area of the site known to contain the remains of a 19th century cementation furnace a remnant of Sheffield's industrial heritage.

This report details how Elmet Archaeological Services Ltd conducted that strip, map and record and has been prepared in accordance with current industry best practises (IfA, 2008a and b) and in accordance with IfA Codes of Conduct (IfA, 2010). The report will be submitted to SYAS for approval.

The Site, Location and Geology

Underlying solid geology consists of Pennine Lower Coal Measures, overlain by superficial deposits of alluvium (British Geology Survey, 2013). This type of solid geology typically comprises interbedded grey mudstone, siltstone and pale grey sandstone, commonly with mudstone in the lower part and thicker coal seams in the upper part (British Geology Survey, 2013).

The area under investigation is bounded to the west by the Green Lane Works building and courtyard, to the north by the River Don, to the east by the Fat Cat public house (with associated garden and car park), to the south east by Alma Street, and to the south west by Green Lane. The archaeological strip, map and record was conducted in the northern portion of the Site to the immediate east of the upstanding Eagle Works building and consisted of an area approximately 225m square (**Illustration 2**).

Archaeological and Historical Background

General

The following historical background information is taken from an Archive Assessment conducted by Elmet Archaeological Services Ltd in November/December 2013 and concerns the greater area of Green Lane Works including the area of site investigated during the archaeological strip, map and record. It is suggested that this document is consulted in reference to the historical background described below.

Early Prehistoric Period to Late Medieval Period

There is no evidence for activity of this date within the area of investigation. Given the development of the area during the post-medieval period, it is highly unlikely that

any sub-surface remains from these early periods survive as archaeological deposits.

Post-Medieval to Modern Period

Eighteenth Century

All map evidence discussed in the Archive Assessment report (Elmet 2013, see this document for the full bibliography) show that the current investigation area is located within an area known as Long Croft from at least 1771, largely consisted of fields until the 1820s - 1830s. In the late eighteenth century, much of the surrounding land was owned by the Duke of Norfolk, with fields being rented out to a variety of occupants. The Sheffield Trade Directories from 1774 and 1781 do not yield any information pertaining to tradesmen working within or near the investigation area.

Given that there appears to be little in the way of structural evidence in the maps pertaining to this time, it is suggested that tradesmen mentioned in contemporary Trade Directories were based in the buildings that can be observed on the north side to Green Lane, to the west of the investigation area. These buildings are observable on the 1795 map, but don't appear on the 1771 map or even the 1788 enclosure map. However, the inclusion of tradesmen on Green Lane in the 1787 directory indicates that some small-scale industrial activity must have been happening in the area at this time.

The amount of industrial activity in this area appears to have increased by the end of the eighteenth century, as the number of tradesman entries for Green Lane in the 1797 Directory of Sheffield has increased. Again, it is uncertain how many of these individuals, if any, could have been working within the investigation area, rather than on other parts of Green Lane. No evidence has been found to suggest where the various house or building numbers might be situated.

Nineteenth Century

The first structural evidence in the investigation area is shown on the 1808 map, where a few small structures appear within the fields, one in close proximity to the area under investigation. There is no evidence pertaining to the function of this building. However, evidence from trade directories indicates that the number of tradesmen and variety of industry being undertaken in the Green Lane area continued increase. The 1811 Holden's Directory lists both Barlow and Deakin (still manufacturing scissors) and Boothby, Hole and Shaw ("merchants and manufacturers of all kinds of steel saws, stove grates, fenders, edge tools, joiners tools, iron candle sticks etc") as being based on Green Lane, although again, the exact location of the premises is unclear and they may not have been located within the investigation area.

By 1832, the field systems observed in earlier maps appear to have gone, and the number of buildings constructed within the investigation area had increased. The main body of the site, however, appears to still be open ground. The 1832 map is certainly the first map that depicts a more industrialised landscape in this area of Sheffield, as well as in the investigation area and the number of buildings observed

on the 1832 map suggests there was some degree of industry being undertaken in the area at this time.

The Eagle Works appears to have been constructed in the investigation area between 1834-5 for Charles and Samuel Peace. The Peace family had been involved in file production since the early 18th century, branching into crucible steel making in 1816. In 1825 they are listed as a saw, file, cut nail, truss maker and cast steel refiner with works at 5 Smithfield. The continued success of the business led to the company seeking new premises, and in 1835 they moved to new premises on Long Croft (more specifically, Russell Street) which they named the Eagle Works. The 1834 trade directory does not list the Eagle Works at all, therefore it could be assumed that the works were either constructed later, were still under construction, or had been built but was not operating at the time that information for this directory was compiled. However, the 1835 rate book rated the Eagle Works for an iron house and cellar, a steel furnace, a 12 double pot and cellar, a coke shed and a steel house, indicating that the works were operational by 1835. No workshops were listed in this rate book. This may indicate that the works had initially specialised in steel production, possibly using offsite workshops.

By 1837 the works had expanded with the rate book recording a weighing machine and office, two shops, coke sheds, file shops, converting furnace and shed, three double hearths, an iron house and cellar, a cast steel furnace with 12 double pots, a steel house, coke shed, hearths and a dwelling. The Pigot and Co. 1837 trade directory lists "Peace, Charles and Samuel and Co., Eagle Works, Russell Street" under steel converters and refiners, and also scythe, hay and straw knife manufacturers. This is the earliest conclusive written evidence that steel refining and converting was taking place within the study area.

By 1839 the investigation area and wider landscape were continuing to develop and become increasingly industrialised and more densely populated. The 15 entries for Green Lane continue feature metalworking trades, producing spring knives, scissors, brass and iron objects and so on (and Nicholson and Hoole continue to be listed as steel refiners and converters). Other entries for this area include grocers and shopkeepers, a shoe maker, a carpenter, a beer retailer, a milliner, and a slater.

As well as Peace and Co. at the Eagle Works (steel converters, saw, scythe and file manufacturers), a further 21 entries are included in the Trade Directories. These include a further two entries manufacturing or refining steel (Thomas Turton and Sons, and Drabble and Sanderson at the Ebenezer Works respectively), two milliners, six beer retailers, two joiners, one scissor and razor manufacturer, a horn button manufacturer, a stone mason, a shoe maker, a slate maker, a builder, a tailor, one blacksmith/shopkeeper and one entry with no listed trade. However it is difficult to quantify which and how many of these would fall within the investigation area.

Between 1837 and 1840 the rate books list the Eagle Works as owned by Ibbotson and Peace and Co. Robert Ibbotson, a saw maker, married into the family in 1845. By 1841, the trade directory indicates that the company returned once more to being Charles and Samuel Peace and Co.

By 1845, Charles and Samuel Peace and Co. had changed back to being Ibbotson, Peace and Co., and at this time employed approximately 50 men. The 1849 map is

the first to show the Eagle Works on the east side of the study area, as well as showing an extensive set of buildings on the remaining land to the west.

At Russell Street, Ibbotson, Peace and Co. are still listed at the Eagle Works. Several entries are the same as in 1845 (two shoemakers, a beer house, a smith, and Turton and Sons manufacturers). Additional entries comprise a further two beer houses, a joiner, a slater, three shopkeepers, a wool carder, two more manufacturers, a tailor and a grocer.

By 1853, the new building layout can be observed clearly within the study area, as well as the new road layout. The area appears to comprise a number of small workshops and probably domestic structures, some around central courtyards. The Eagle Works is observed as a set of buildings on a scale similar to the Green Lane Works to the west. The 1854 trade directory listings for Russell Street include Peace, Spafford and Co. (merchants and manufacturers of steel, files, saws, edge tools and table cutlery at the Eagle Works), indicating yet another name change for the company that started out as Peace and Co. Further listings for Russell Street include Joshua Moss and Gamble Bros. (steel converters and refiners, file, saw and edge tool manufacturers), three public houses, two beer retailers, three grocers, a hatter, a stonemason, two shoemakers, a carpenter, a slater, a file cutter, a cow keeper, and a builder. Although it is still difficult to ascertain the extent to which these individuals were located within the investigation area, the listings give a good indication as to the type and range of industries and occupations that are likely to have taken place within the observed workshops. Many of these listings can also be found in the 1856 directory, where the Eagle Works is again occupied by Peace, Spafford and Co.

The rate books for 1858-59 demonstrate that the Eagle Works had continued to grow, listing a coke shed and steel house, a warehouse, workshops, a steel warehouse, a grinding wheel, an engine house, a boiler seating and stack, converting furnaces, an iron house, a furnace, a steel house, sheds and appurtenances, and a dwelling. By 1859 the company had changed names yet again, being listed in that year's trade directory as W. K. Peace and Co. at the Eagle Works, 84 Russell Street.

In 1864, the Peace family are thought to have moved premises, along with the name Eagle Works, to Mowbray Street. However, there is no entry for any company under the name of Peace at the Eagle Works in the 1862 trade directory, only Ibbotson Bros. and Co. at the Globe Steel Works. Interestingly, the 1863 map still names the works in the eastern side of the study area as the Eagle Works. Whatever the case, the Peace family business does appear to have moved away from the study area at some point around the early to mid-1860's. Their new works at Mowbray Street employed around 150 workers and the company continued to produce a variety of tools, knives and other hardware.

The 1864 map clearly shows buildings (surrounding Cotton Mill Walk) labelled as the Globe Steel Works. This strongly indicates that Ibbotson Bros. and Co. were operating here by 1864. This renders subsequent labelling of these works as the Eagle Works on the 1868 and 1884-5 maps a little confusing, as other documentary evidence from contemporary writing and the trades directories continue to record the works as the Globe Works after 1864 (see below).

Neither Ibbotson Bros. and Co. nor the Globe Works are listed in the 1864 trade directory: it is possible that this is due to the works being damaged by the Sheffield Flood, which resulted from collapse of the Dyke Dale Dam in 1864. Buildings within the vicinity of the study area suffered affected by the flood included 164 dwellings, eight workshops and warehouses, five manufacturing tilts, five breweries and eight shops. Most of the damage in the area was limited to flooding rather than destruction. Some of the properties along the mill goit suffered the loss of walls fronting onto the watercourse and debris was swept into several works. The Globe Steel Works was also quite badly damaged by the flood, particularly due to an underground hot-air flue exploding due to the influx of water. This works is recorded as being the property of Messrs. Ibbotson.

Six people from Long Croft are listed as having died during the flood: Robert Ryder, aged 11; Priscilla Willett, aged 16; Christopher B. Arculus, aged 4; Christopher Colton, aged 32; Mary Colton, aged 32, and Christopher Colton, aged 4. Most of these deaths appear to have occurred as people were swept away by the water.

As previously stated, the 1868 map may be slightly inaccurate: the Globe Steel Works are labelled as the Eagle Works, even though other primary evidence discussed above suggests that the works were indeed the Globe Steel Works by this date. This is further evidenced by the inclusion of Ibbotson Bros. and Co. at the Globe Steel Works in the 1868 White trade directory, listed under Russell Street.

The next appearance of Ibbotson Bros. and Co. is in the 1883 trade directory, listed as “merchants and manufacturers of steel and saws” at the Globe Steel Works (Kelly, 1883: 102). The north side of Alma Street is listed as having a news agent and a hairdresser, and Cotton Mill Walk is listed as having a shoe maker, four shopkeepers, an umbrella maker, and a corn miller (Henry and William Ibbotson at the Britannia Mills). The 1883 map does not give any indication as to the precise location of any of these other tradesmen.

The 1884 trade directory lists the same tradesmen occupying Alma Street and Cotton Walk as in 1883, and many of the same tradesmen at Long Croft/Green Lane. However, Ibbotson Bros. and Co. are not listed: the occasional omission of this large company from the trade directories does suggest inconsistency in the manner of trade directory recording. As previously stated, the labelling of the eastern half of the study area as the Eagle Works on the 1884-5 map suggests that this map may also have been based on an earlier ordnance survey, and the change in the name of the works was missed. The fact that Ibbotson Bros. and Company are recording as operational in 1883 is another indication that the 1884 records may not be entirely accurate, unless the company for some reason decided not to trade during this year. Ibbotson Bros. and Co. make a return to the trade directories in 1889, listed under Long Croft at Green Lane.

The 1890 ordnance survey map shows the full extent of the Globe Steel Works within the study area. The Albion Cutlery Works, run by John Coe and Co., was also located within the study area to the west. Details of buildings at the Long Croft Works, occupied by A. Badger and Son, can also be seen. Some of the smaller structures shown are likely to represent smaller workshops and housing. The 1898 and 1902 Trade Directory entries for Long Croft Works are also very similar to those

listed in 1896 with Ibbotson Bros. and Co. still listed at Green Lane, under Alma Street/Russell Street in 1898.

Twentieth Century

The 1903 ordnance survey map shows that the Globe Steel Works expanded to cover most of the site of the present-day Horseman Works. This expansion therefore must have taken place at some point between 1890 and 1903. In 1903 there were still smaller structures, probably houses and workshops, fronting onto Green Lane to the southwest of the works. After 1898, Ibbotson Bros. and Co. do not feature in the trade directories until 1913, where they appear under the Alma Street/Green Lane listing as “merchants and manufacturers”. Various small tradesmen continue to be listed in the trade directories, similar in number and variety of occupations to those listed in the mid to late nineteenth century. By 1930, the smaller structures visible in the 1903 map had been demolished, and the Globe Steel Works covered the entire Site. The works were apparently still under the ownership of the Ibbotson Brothers.

In 1948, the Green Lane Works and Globe Steel Works were purchased by the Tyzack family. The factory contents were also purchased, as well as the “Globe” and “Ibbotson” trademarks; these were added to the Tyzack’s “Horseman” brand, and the factory was renamed as the Horseman Works. Products manufactured at the Horseman Works included harrow and plough discs, cultivator parts, chaff knives, and many other steel cutting and wearing parts for agricultural machines. W. A. Tyzack and Co. Ltd. appear in Kelly’s 1951 trade directory under Alma Street.

In mid to later twentieth century, many parts of the works fell into disrepair. Substantial demolitions, alterations and additions were carried out between 1980 and 2000, including the demolition of the Grade II listed office building to the east of the courtyard. By 1985, the Tyzack Company was still at the works, but had changed to the manufacture of agricultural and motor vehicle pressings. The works closed in 2007, although the Tyzack Company remained at the site until 2009.

Aims and Scope of the Works

The general aims of the strip, map and record investigation were to:

- Monitor the machine excavation of demolition overburden until the uppermost archaeological layers were encountered;
- assess the artefactual and environmental potential of any archaeological features and deposits encountered;
- sample and record any archaeological remains located within the area of the cementation furnace in accordance with current industry standards and practises;
- produce a site archive for deposition with an appropriate museum and to provide information for accession to the local SMR.

Methodology

Introduction

Work commenced on an area approximately 15m by 15m (225m square) located to the immediate east of the Eagle Works building (see **Illustration 2**). Initially areas were cleaned by hand to reveal the extent and characterise the existing archaeological deposits, but it was quickly realised that further work with a toothless bucket would be required.

The area to the south of the site was covered with demolition rubble and overburden which was removed by a four tonne 360 machine fitted with a 1.80m wide toothless ditching bucket working under the continual supervision of a suitably experienced archaeologist. The overburden was removed in spits down to the upper archaeological horizon after which all trenches were then hand cleaned to clarify the extent of the archaeological remains.

All recording took place in accordance with standard industry practises and methodology. All trenches were recorded on Elmet *pro forma* to a standard in accordance with the relevant Institute for Archaeologists' (IfA) Standard and Guidance, the IfA Code of Conduct and other current and relevant best practise (IfA, 2008a and b).

This report will be submitted to SYAS for approval and the archive will be deposited with Museums Sheffield in due course.

Strip, Map and Record Results

Introduction

The following section is a summary of the information held in the Site archive. The trench location is shown in **Illustration 2** and contexts are detailed on **Illustration 3**. The deposits encountered in each trench are summarised in **Appendix 1** and are referred to in the text in bold.

General

The strip, map and record revealed the extensive remains of a cementation furnace dated to the middle of the nineteenth century (the following descriptions can be referenced by consultation with **Illustration 3**). Although other archaeological remains were also encountered and recorded during the work it was the furnace which was the largest and most complete of the deposits. The cementation furnace was originally one single structure consisting of an eastern and western furnace, however the site work demonstrated that this single structure was split into two distinct areas due to the truncation by the drains **1049** and **1051**. These truncations occurred at almost the central point east to west and divided the site from north to south through the complete furnace structure; therefore each of these areas will be

dealt with separately below, beginning with the eastern furnace structure and its associated contexts then detailing the western furnace and its associated structures.

Further, other archaeological deposits were identified which post-dated the furnace and are detailed in brief here. An archaeological link between both furnaces was identified in the demolition rubble **1072** which covered the entire site except in a few areas. In these places some structures were directly overlain by the modern concrete floor surface **1065** (as detailed appropriately below). Another archaeological context which linked both east and west furnaces was the large truncation cut **1029** to the south of the two furnaces which appeared to have grubbed out large portions of the centre of the furnace structure whilst heavily damaging the eastern furnace in the process. This cut was filled with the modern demolition rubble **1030**, which included large chunks of concrete, wood and metal in the matrix. These features were not excavated lower than the horizontal plane at which it was first located by the machine, but the cut **1029** was seen to be 4.50m north to south and 3.20m east to west. This cut truncated through the furnace features **1012**, **1013**, **1022**, **1023**, **1028**, **1039**, **1040** and **1041**, demonstrating the destructive effect this phase of truncation had on the remaining furnace structures.

The Eastern Furnace

The remains of the furnace flue opening consisted of the curvilinear wall **1032**, constructed with handmade red brick, bonded with white lime mortar and which resembled a D shape in plan (**Plate 1**). This wall had a height of 1.25m but the full length and width were not identifiable due to later construction and truncation. Keyed into the red brick wall **1032** was the sandstone plinth **1033**, which formed the arched shape of the lower part of the flue passage. This plinth also served as a foundation for the upper walls of the flue identified as **1034**. The sandstone blocks were dressed with a chamfered western edge whilst the southern extent was shaped to fit flush with the curve of the D of the furnace opening **1032**. The full length of the plinth was not recorded, but was assumed to be similar in construction to the sandstone plinths **1001/1003** in the western furnace (see below for details). The remains of the opposing red brick flue wall had been completely destroyed by truncation of the drains **1049** and **1051** so a full record of the furnace at this point was impossible.

The floor **1047** of the furnace flue opening was constructed of a mix of handmade red brick and sandstone slabs, which was enclosed by and butted against the wall **1032**. This would have provided an area of hard standing when filling the fire trench with fuel and could have been re-laid several times during the furnace's use and may have accounted for the different material used, although this was impossible to ascertain. The floor surface **1047** was just above the present ground water level and this appeared to be a deliberate consideration when the furnace was originally being constructed.

The southern extent of the furnace flue **1032** was augmented by the addition of the front wall of the furnace **1044** (**Plate 2**). This addition consisted of handmade red

brick with a height of 1.10m, a length of 2.40m and width of 0.12m with the eastern extent heavily truncated by later demolition. This structure formed the front of the furnace and indicated that the furnace was brick fronted. Immediately behind the front wall **1044** and the furnace wall **1032** was sandstone block packing **1043**, which consisted of rough cut sandstone blocks laid flat but in a rough and irregular manner. This sandstone packing formed the foundation of the eastern extent of the eastern furnace structure and the chest remains **1034** and **1035**.

The remains of the eastern chest found **1035** was constructed of handmade red brick and had a visible length of 1.65m, a width of 1.17m and height of 0.31m. The bricks were pinkish in colour indicating that they had been heavily heat affected. This structure was truncated by the modern ceramic drain cut **1048** to the west. There was a small gap noticeable running between **1035** and **1037** which could have been the remains of a previous flue that had gone out of use and indicated that **1035** may have been part of a later rebuild within the overall furnace structure.

The remains of a flue wall **1037** sat on top of the chest foundation **1035** which was constructed with handmade red brick. This structure demonstrated possible heat damage in the form of metaliferous deposits along its western edge which may have been due to the possible flue gap noted in **1035**, mentioned above. A small rebuild phase of fire brick **1036** butted against the western edge of **1037**, which covered the fire damaged edge of the possible flue channel and indicated a later rebuilding within the flue super structure. It measured 1.90m long, 0.61m wide and 0.11m in height and was also heavily truncated to the west and north by the ceramic drain cut **1048**.

The eastern flue structures **1035**, **1036** and **1037** of the eastern furnace were enclosed by the handmade red brick wall **1038** which was bonded with white lime mortar. This wall was butted by the sandstone foundations **1043**, to the south but was also truncated by the drain **1048** to the north, so only a length of 1.53m remained.

The remains of the eastern chest in the eastern furnace were also heavily truncated and modified by later additional structures. On the southern front wall a substantial sandstone wall **1046** had been added to the furnace front wall **1044**. This wall was orientated north to south and had a length of 2.66m with a height of 1.36m. This abutted the front wall **1044** and was a later addition to the furnace, possibly as a bunker for fuel or a similar structure. Further evidence of this role was the handmade red brick springer **1045** adjoining both **1044** and **1046** and possibly used as an arched roof for the possible bunker, but later demolition of this feature made it difficult to ascertain this role.

A large modern truncation had removed a large portion of the eastern edge of the furnace which consisted of a rectangular frogged red brick construction **1052** surrounding a similarly rectangular fire brick structure **1053**. This structure had an overall length of 7.60m and width of 1.50m and was a possible flue foundation but was of unknown use or date. Sections within the structure had been partitioned by

two lengths of fire brick **1054** and **1055**. These enclosed three separate areas which had been back filled with a mix of rubble, concrete, red brick and gravel **1056** and may have served as the foundations for machine bases or were the result of infilling of flue voids to provide a hard standing for the later modern concrete surface **1065**.

At the northern extent of the site, the modern concrete surface **1065** also overlaid the small radial wall **1042**, which appeared to be the interior remains of the northern D of the eastern flue which consisted of handmade red brick bonded with white lime mortar. However, this structure was not investigated further due to modern truncation and the health and safety concerns of this area. This wall and the other remains of the eastern furnace, **1035**, **1036**, **1037** and **1038** were all truncated to the west by the modern ceramic drain **1049** and the drain cut **1048**. This drain was over 3.30m in length, 0.69m in width and 0.30m in depth and was overlaid by the modern concrete surface **1065**.

Lying to the west of the drain **1049** was the sandstone capped drain **1051** within the cut **1050**. This structure was over 3.50m long, 0.75m wide and 0.68m deep. At its southern extent were the remains of the access chamber constructed with frogged red brick. This drain truncated the remains of the eastern furnace and provided an arbitrary delineation between the eastern and western furnaces discussed above.

Structural elements of the eastern furnace were also truncated by the drain cut **1050**, these included the western chest remains **1039**, **1040** and **1041**, also the sandstone furnace foundation **1028** and the northern wall sandstone foundation **1025**. These elements will be detailed as part of the western furnace.

The remains of the western chest of the eastern furnace were identifiable in the fire brick chest pier foundation **1039**, which was 1.96m long, 0.48m wide and had a depth of 0.14m. Flue residue material was noted as a deposit on the upper surface of this structure and it was heavily truncated to the east by the drain **1050**. The foundation **1039** was butted to the west by the possible fire brick chest retaining wall **1040**. This structure would have bounded the western chest of the eastern furnace, retaining the ganister piers in place. The western chest structure was retained by the red brick outer wall **1041**, which was 2.54m long, 0.50m wide and bonded with white lime mortar. This small structure was truncated to the south by the large modern demolition cut **1029** and also truncated by the modern drain cut **1050** to the east and the structural elements described above represented the total remains of the western chest of the eastern furnace.

The Western Furnace

The western furnace was identifiable through a more complete set of remains than those of the eastern furnace (**Plate 3 & Illustration 7**). The handmade red brick walls **1000** and **1002** represented the east and west walls of the western furnace fire trench and also formed the D shaped stoking area, similar to the one described above. The western wall **1000** stood to a height of 0.90m, was 0.47m wide and had a length of approximately 7.30m. The western wall **1002** mirrored the wall **1000** in

construction but had a height of 1.04m with eleven courses of brick work remaining. Both walls were bonded with white lime mortar. A small buttress **1026** of handmade red brick was butted against the southern extent of the wall **1000** and represented the outer facing of the furnace. This buttress was similar to the structure **1044**, on the eastern furnace frontage. The buttress **1026** was also mirrored on the eastern frontage by **1073** butting against the wall **1003** and in turn was truncated by the concrete pad **1061**.

Butted between the two walls **1000** and **1003** was the flue working surface **1031**, which was constructed of handmade red brick and sandstone slabs to the south. This feature was similar to the floor remains **1047** in the eastern furnace, but was heavily truncated in the centre so it was impossible to ascertain if the feature had been remodelled and if other material had been used in its construction. The floor surface was just above the present ground water level and this appeared to be a deliberate level reached when the furnace was first being constructed, a practise also noted in the eastern furnace.

Keyed into the eighth course of the brickwork of **1000** was the sandstone plinth course **1001**, this structure was mirrored on the western wall by **1003**, which was keyed into the wall **1002** at the same level (**Plate 4**). The sandstone plinths measured 0.67m wide, 0.24m high and had a length that ran to over 6.00m, but was not fully recorded as the extents were not visible. Both plinths were chamfered on their outer edges to create the arch of the fire trench, whilst the southern extent was shaped to fit the curve of the firing area D. The two sandstone plinths, **1001** and **1003** provided a footing for the western and eastern fire brick walls of the fire trench, **1004** and **1011** respectively. The fire trench wall **1004** was at least 1.57m long with a width of 0.22m and a height of 0.25m, whilst **1011** had a visible length of 1.62m, similar width and a height of 0.40m. The bricks of both structures were laid in an alternate bond of stretcher and header.

Keyed in to the walls of the fire trench **1004** and **1011** were at least two iron fire rod supports **1060**. It was possible that there more of these but they were not visible due to later demolition rubble and infill of the fire trench from firing material. The supports measured 0.55m long, 0.08m wide at the top and 0.05m wide at the base in an inverted trapezoidal shape. Although these metal rods were keyed into the walls of the fire trench, they were not bonded and there was no apparent material to hold them in place besides the weight of the fire rods themselves. The supports were laid perpendicular to the fire trench in an east to west axis. The supports **1060** bore the weight of the fire rods **1059**, which lined the fire trench and numbered seven in total (**Plate 5**). These rods were laid longitudinally along the fire trench, north to south and were square in shape with an average size of 0.03m square and a length of over 5m. Both the northern and southern extents of the rods were twisted out of shape due to later demolition. To the north the fire rods were covered with **1067**, the remains of the final firing of the furnace, which was a black friable mix of soot, ash and charcoal. This material was also present in the southern end of the fire trench at ground level and indicates that the furnace was not cleared before finally going out of use.

Butted to the outer face of each of the fire trench walls **1004** and **1011** were the red brick supporting structures **1005** and **1012** respectively. The handmade red brick structure **1005** butted against the western face of the fire trench wall **1004** and was 0.43m wide with a height of 0.30m. This structure was bonded with white lime mortar and the bricks were laid in a header bond. The two lengths of brick work also served as the foundation platform for the western chest lining **1006**. This structure was mirrored on the eastern side of the fire trench by **1012**, which was similar in all respects to **1005**, but with a height of 0.40m and a width of 1.17m. The structure **1012** also served as the foundation for the eastern chest lining **1014**. Both **1005** and **1012** had been heavily truncated to the south and north by modern disturbance so their full original extents were not recorded. Below **1012** was the sandstone foundation packing material **1013**, which was 2.20m in length and truncated by the modern cut **1029** to the east. The full depth of **1013** was not known as it was only exposed in the horizontal plane. This deposit would probably have been built at the same time as the wall **1012** and was used as retaining material to strengthen the entire furnace structure.

The remains of the western chest of the western furnace was made up of several elements, the base lining **1006** and the traverse ganister flue piers **1007**, **1008**, **1009** and **1010**. The roofing of the chest had been truncated and was no longer in evidence. The base lining of the chest **1006** consisted of handmade fire brick laid in a header bond along the axis of the flue chambers and no bonding material could be discerned. The top surface of the lining was heavily heat affected which was indicated by the brickwork being blistered. Four lateral flue chambers were identified, but further similar structures could have been truncated, so the original number would have been greater. The remains of the traverse flues of the chest were identifiable by the remains of four ganister piers, **1007**, **1008**, **1009** and **1010**, which ranged between 1.04m and 0.52m in length and had an average width of 0.23m with various remaining heights. Each of these structures was badly fragmented from heat damage but appeared to be made of a single block of ganister in each case.

The remains of two ganister flue arches, **1062** and **1063**, which originally spanned the fire trench, were identifiable attached to the eastern extents of the piers **1007** and **1008** respectively. The flue arch **1062** was in very fragmentary state and had a length of no more than 0.13m. The pier which it would have joined on the eastern side had been truncated by modern disturbance. The flue arch **1063** was in an almost complete state and joined the flue piers **1008** and **1015** on the eastern chest structure.

The remains of the eastern chest structure were largely intact despite being truncated to the north and south by modern disturbance (**Plates 6 & 7**). The base lining **1014** was similar to **1006** in that it was constructed with fire brick in a header bond the upper surfaces of which displayed heat affected blistering. The base lining had a length of 3.30m, a width of 1.30m and a height of 0.12m. On the upper surface of **1014** six ganister piers were identified as **1015**, **1016**, **1017**, **1018**, **1019** and **1020**. These piers ranged in length from 1.30m to 1.28m and each had an average width of

0.23m and a height of 0.17m. A further flue arch **1064** was heavily truncated but spanned the gap between the piers **1010** and **1017**. Although the piers were heat affected and friable they were largely intact due to a large extent of the upper surface **1021** of the eastern chest having survived modern truncation. This surface **1021** was constructed of a sandstone slab with a height of 0.18m and a width of 1m. The surviving length of the structure was 2.60m having been truncated at both the northern and southern extents. The sandstone was very friable due to the process of heating and cooling and process residues were notable on the interior of the traverse flues. A sample of this material was removed from **1021** for post-excavation analysis in order to assess the chemical compound of the material (see **Appendix 3** for more detail). The analysis revealed that the interior of the flues were coated in an unusual type of vitrified clay (Mackenzie, 2014). This clay was used to seal any cracks that appeared in the ganister material during the firing processes. The northern extent of the flue chest upper surface **1021** was overlain directly by the modern concrete surface **1065**.

The eastern extent of the eastern chest structures were bounded by the retaining wall **1022** that was constructed of fire brick and which had evidence of metaliferous residue on its western face. This residue indicated that the structure was connected to the heating processes in the chest and that it was part of the larger flue system throughout the furnace. The remaining length was 3.10m with a width of 0.24m and the wall had been truncated to the south by the modern cut **1029**. Butted to the eastern face of **1022** was the handmade red brick wall **1023** which was bonded with white lime mortar and was four skins thick. This structure retained the eastern chest structures and its associated flues and had a length of 3.40m. The wall **1023** was mirrored on the eastern furnace by the wall **1041** and between these two structures the sandstone packing material **1028** had been placed. This was irregularly coursed, but the extents which butted against the walls **1023** and **1041** were roughly aligned to fit these structures. The packing **1028** would have provided weight and cohesion to the entire furnace structure but was also used as a foundation for the furnace's brick cone as indicated by the overlying sandstone curvilinear structure **1024**.

The sandstone structure **1024** was 1.30m long, with a width of 0.42m and consisted of a single course of no less than three sandstone slabs (**Plate 8**). It was curved in plan and interpreted as the base structure of the western furnace cone, which was probably brick made above this foundation level. However, no evidence for these bricks was seen, but other cementation furnaces of a similar date may be used as a comparison. The remaining sandstone blocks lay directly below the modern concrete surface **1065**. Directly to the north of **1024** and butted against the foundation material **1028** was the massive sandstone wall **1025**. This structure measured 2.65m long and 0.60m wide and was orientated east to west and it is probable that these blocks represented the exterior northern wall foundation of the furnace. It consisted of no less than two sandstone slabs overlying smaller sandstone blocks with a rubble core. The full extents of this possible foundation were obscured by the modern concrete surface **1065** to the west.

At the southern extent of the western furnace there appeared to be a series of structures which indicated that the southern limits of the furnace had been rebuilt or reused as a possible fuel bunker or similar structure. This was also mirrored by similar remodelling on the eastern furnace. A single handmade red brick column **1027**, stood as high as 1.10m with each side measuring 0.38m wide. This structure was thought to be a structural support for a roof of an arched bunker which was further evidenced by the short stretch of sloping wall **1058**. This sloping wall was constructed with machine made frogged bricks and bonded with black ash mortar and only four courses of this wall remained, but it appeared to have been a later addition to the front of the furnace. Further modification of the southern front of the furnace was evidenced by the large concrete structure **1057**, this massive block may have served as the roof of a fuel bunker, or may have been the result of infilling of the void left by a similar bunker. The construction method appears to have been poured layers and was at least four layers thick with a total depth of 1.54m. The flat top measured 3.10m long by 2.57m wide and may have also served as a machine base or foundation for the later factory floor. There was little evidence to conclude definitely the purpose of this structure.

Further modern intrusive elements were identified to the west of the western furnace in the form of the modern concrete pad **1061**. This surface was constructed of poured and tamped concrete with a thickness of 0.15m. It had a length of over 5.70m and a maximum width of 0.58m. This structure either served as a foundation pad for the wall **1066**, or was used as a path, although the small width between the remains of the flue chest and the wall **1066**, make this unlikely. The wall **1066** had a height of 0.71m and eight courses, a length of 4.63m and was at least two skins thick. The bricks were machine made frogged red brick bonded with black ash mortar, so was much later in date than the bricks evidenced in the construction of the furnace. The purpose of this wall was unclear but represented a later remodelling of the area after the furnaces had gone out of use and had been demolished to their present level.

Evidence for modern rebuilding in the immediate area of the furnaces was evidenced in the south west corner of the site with the fire brick surface **1068**. This was a small area of bricks measuring 2.17m in length by 0.80m wide and was possibly a standing surface of a later factory floor or had been used as bedding for the modern concrete surface **1065**. This surface overlaid the red brick surface **1069**, constructed with machine made brick which had been stamped with 'Robinson Sheffield'. This area measured 2.16m long by 2.01m wide and had at least two layers of brickwork laid in alternate header and stretcher bonds. Both **1068** and **1069** were butted to the east by the short wall **1070**, which also included a concrete threshold pad. The wall was constructed of machine made brick stamped with 'Ron Woodside' and was 3.50m long and had a two skin thickness. Butted to the south of the red brick surface **1069**, was the square structure **1071**, possibly a chimney base. This measured 1.37m long by 1.21m wide and was made of a combination of red brick and fire brick, both of which were modern machine made bricks. A sooty residue in the centre of this

structure led to the conclusion it had been used for firing or a similar activity. It appeared that the construction of these modern structures was responsible for the truncation of the western part of the western furnace, as it appeared that this area had been grubbed out before construction began of these modern features.

Discussion

General

The strip, map and record investigation uncovered the substantial remains of a cementation furnace that has implications for the industrial heritage of the city of Sheffield. Other structural elements were also identified which belonged to later industrial activity centred on the Eagle Works. Three distinct phases of construction were identified during the investigations (**Illustrations 4, 5 & 6**). Phase one of construction on the site was identified as the cementation furnace (**Illustration 4**), phase two covered the later intrusions occurring after the furnace had gone out of use, the date of which was difficult to ascertain (**Illustration 5**) and the final phase three saw the laying of the modern concrete floor surface **1065**, which sealed the entire site (**Illustration 6**).

Cementation Furnace

It appears that the cementation furnace remains (**Illustration 4**) uncovered in the strip, map and record investigation belonged to W. K. Peace and Co. or the later I. Ibbotson Bros. and Co. or a combination of the two firms. Given that the Peace Company moved premises around the mid 1860s this may account for the disuse of the furnace and its subsequent demolition and may give a date to the structure of the mid nineteenth century (Elmet, 2013). The bricks used in construction of the furnace are handmade and dates the construction to the early part of the nineteenth century, although an exact date is impossible, however the first documentary evidence of steel production on the site is from the Rate Book of 1835 (Elmet, 2013). There is no mention of the furnace in the 1834 Rate Book, leading to the conclusion that the structure was still in the process of construction or had yet to begin functioning (Elmet, 2013). To further compound the problem of exact dating, no tangible and dateable artefactual evidence was recovered from any secure contexts within the fabric of the furnaces. This is not unusual as it would be unlikely that material not directly relating to the furnace workings would be in evidence on what would have been an industrial work area. However, adding weight to the evidence from the Rate Books, McKenzie (2013) has also noted that this particular furnace type is likely from the 1830's.

Barraclough notes that in 1843 Sheffield was producing 90 percent of the total British steel output and almost 50 percent of the European steel output through cementation furnaces such as the one located at Eagle Works (Barraclough, 1976: p.12). However, the 1856 Bessemer Process overtook the cementation process of steel production and furnaces such as the one uncovered at Green Lane fell into disuse by 1870 as the new process took hold across the steel industry (Barraclough, 1976: p.14). In fact, the cementation process had reached its peak by the invention of the Bessemer process and was already on the decline as demonstrated by the erection of the River Don Works in 1862, which had no cementation furnace associated, yet

had a capacity of steel output larger than any in Sheffield at the time (Barraclough, 1974: p.3). This is not to say that the cementation process disappeared entirely, with the last recorded cementation operation being carried out in Sheffield in 1951, however, the larger furnaces fell into disuse (Barraclough, 1974: p.3). This date range gives the most probable time frame that the furnace at Green Lane was in use, i.e. 1835 to the mid 1860s.

The last instance that a square chimney furnace was recorded was in a 1798 drawing by Gustav Broling and all the later evidence is of conical brick chimneys, of which the furnace identified during these works is a type (Barraclough, 1974: p.2). The brick cone chimney structure, the foundation of which was identified as the sandstone block course **1024**, may have stood somewhere between 35ft (10.66m) and 60ft (18.28m) high (Barraclough, 1976: p.12). Obviously, with the occurrence of demolition this height was impossible to ascertain, but it gives an impression of the size of these structures and how they would have appeared in Sheffield's early industrial skyline.

The chest area of the furnaces were crucial in the employment of the structures for converting the raw material of Swedish iron into blister steel, which was used elsewhere for further processing (Barraclough, 1974: p.4). To create blister steel, the Swedish iron was placed within the chests and heated. This process was carried out by two men firing the furnace for between five and nine days to produce the required temperature for blister steel (Barraclough, 1974: p.4). A report produced by Professor Le Play after a visit to Sheffield in 1836 and 1842 gave a mathematical formula for the output of steel based on the size of the chests of two furnaces he examined, both of which had a length of 11ft 2in (3.40m) (Barraclough, 1974: p.3). Le Play went on to describe a cementation furnace that would have had an output of 10 ton (10t 160.47kg) from an internal chest length of 9ft 2in (2.79m) (Barraclough, 1974: p.3). This particular sum is intriguing given that the remains of the chests upper area, **1021**, measured 2.60m in length, therefore, from Le Play's calculation it can be surmised that the furnace at the Eagle Works was capable of at least 10 ton (10t 160.47kg) of cementation output.

From the evidence gathered during the investigation it is clear that the demolition of the furnace occurred in several phases, at least one phase being the upstanding structures reduced to the highest level noted during the investigation, possibly to provide a hard standing for later factory floors and working surfaces. This was notable on the northern extent of the remains. A second phase of demolition appears to have been the truncation of the southern frontage of the furnace; the reasons for this phase of truncation remain unknown but may be identified as the modern cut **1029** which grubbed out a large section of the furnace frontage.

Later Structures

Large areas of the furnaces appear to have been used for later unknown purposes, possibly as areas of hard standing for further remodelling of the Globe Works for unknown purposes (**Illustration 5**). Notable amongst these was the rectangular structures **1052**, **1053**, **1054** and **1055**, which all appear to have been built directly on the solid structural foundation provided by the eastern furnace, though at a much later date as evidenced by the frogged brick.

Further modification of the furnace was evident on the western extent with the addition of the concrete path or foundation **1061** and the wall **1066** and **1070**. Both of these features were much later than the furnace, given the machine made frogged brick used in the construction of the wall and the modern concrete used for the path. It appears that **1066** and **1070** were retaining walls for later working surfaces, evidenced as **1068** and **1069**. All of these structures belonged to a later phase of construction that appeared to be completely unconnected with the furnaces and demonstrated a change in use of the Horseman Works after the furnace had gone out of use. It was impossible to correctly phase these later structures, as the only link between them was the coverage of modern demolition rubble **1072** and they have therefore been placed in a single phase of development.

The final phase of development was evidenced in the modern concrete floor surface **1065**, which utilised upstanding remains of the furnace in the northern portion of the site as bedding for construction (**Illustration 6**). This final phase of activity on the Green Lane site is the very reason that the furnaces were preserved at such a high level during the investigations on the site.

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Appendix 1: Trench Descriptions

Context Number	Description	Dimensions (L, W, H/D in M)
1000	East wall of west furnace, unfrogged red brick (0.24 x 0.12 x 0.07m), header bond, lime mortar bonding material.	7.30, 0.47, 0.90
1001	Sandstone plinth of east wall of west furnace, dressed sandstone blocks (1.10 x 0.67 x 0.24m), western edge arched for flue entrance, lime mortar bonding material.	6.00+, 0.67, 0.24
1002	West wall of west furnace, unfrogged red brick (0.24 x 0.12 x 0.07m), header bond, lime mortar bonding material.	6.00+, 0.47, 1.04
1003	Sandstone plinth of west wall of west furnace, dressed sandstone blocks (1.10 x 0.67 x 0.24m), western edge arched for flue entrance, lime mortar bonding material.	6.00+, 0.67, 0.24
1004	West wall of west flue, fire brick (0.22 x 0.12 x 0.07m), stretcher bond, no bonding material.	1.57+, 0.22, 0.25
1005	Foundation of chest, west flue, red brick (0.24 x 0.12 x 0.07m), header bond, lime mortar bonding material.	0.73+, 0.43, 0.30
1006	Lining of traverse flue chambers in western chest, west furnace, fire brick (0.23 x 0.12 x 0.07m), header bond, no bonding material.	2.06, 0.88, 0.38
1007	Ganister pier of west chest, west furnace, single block, no bonding material, runs east to west.	0.65, 0.22, 0.10
1008	Ganister pier of west chest, west furnace, single block, no bonding material, runs east to west.	0.88, 0.38, 0.24
1009	Ganister pier of west chest, west furnace, single block, no bonding material, runs east to west.	1.04, 0.24, 0.24
1010	Ganister pier of west chest, west furnace, single block, no bonding material, runs east to west.	0.52, 0.23, 0.12
1011	West wall of west flue, fire brick (0.22 x 0.12 x 0.07m), stretcher bond, no bonding material.	1.62+, 0.22, 0.40
1012	Foundation of chest, west flue, red brick (0.24 x 0.12 x 0.07m), header bond, lime mortar bonding material.	2.20+, 1.17, 0.40
1013	Foundation for western furnace, irregular undressed sandstone blocks (0.39 x 0.32 x 0.07m), lime mortar bonding material.	2.20, 0.78, depth not visible
1014	Lining of traverse flue chambers in eastern chest, west furnace, fire brick (0.23 x 0.12 x 0.07m), header bond, no bonding material.	3.30, 1.30, 0.12
1015	Ganister pier of east chest, west furnace, single block, no bonding material, runs east to west.	1.30, 0.25, 0.17
1016	Ganister pier of east chest, west furnace, single block, no bonding material, runs east to west.	1.11, 0.23, 0.17
1017	Ganister pier of east chest, west furnace, single block, no bonding material, runs east to west.	1.28, 0.17, height not visible
1018	Ganister pier of east chest, west furnace, single block, no bonding material, runs east to west.	Not fully visible
1019	Ganister pier of east chest, west furnace, single block, no bonding material, runs east to west.	Length not visible, 0.40, 0.20

1020	Ganister pier of east chest, west furnace, single block, no bonding material, runs east to west.	Length not visible, 0.23, 0.20
1021	Base of east chest in western furnace, ganister block, no bonding material.	2.60, 1.00, 0.18
1022	Rear wall of eastern chest in the western furnace, fire brick (0.24 x 0.12 x 0.07m), header bond, bonding material difficult to determine due to heating.	3.10, 0.24m, 0.60+
1023	Eastern wall of western furnace, red brick unfrogged (0.24 x 0.12 x 0.07m), four skins thick, header and stretcher bond, white lime mortar bonding material.	3.40, 0.50, 0.60+
1024	Sandstone foundation for furnace cone of western furnace, roughly dressed sandstone slabs, white lime mortar bonding material.	1.30m, 0.42, 0.08
1025	Sandstone wall, running east to west, white lime mortar bonding material.	2.65, 0.60, 0.20+
1026	Buttress end of flue wall, red brick unfrogged (0.24 x 0.12 x 0.07m), header bond, white lime mortar bonding material.	0.85, 0.63, 1.20
1027	Square column, red brick (0.24 x 0.12 x 0.07m), stretcher bond, black ash mortar bonding material.	0.38, 0.38, 1.10
1028	Sandstone rubble packing, bonding material lime with sand inclusions.	4.00, 1.15, 0.60+
1029	Modern truncation cut to south of the furnaces, approximately rectangular in plan.	4.50, 3.20, unexcavated depth
1030	Modern rubble fill of 1029 , comprises concrete, metal, wood, etc. in a black silty matrix	4.50, 3.20, unexcavated depth
1031	Floor of west furnace D, red brick (0.24 x 0.12 x 0.07m) and sandstone, brick laid on edge and bonded with white lime mortar, sandstone blocks to south bonded with white lime mortar.	-
1032	Eastern wall of eastern furnace, red brick unfrogged (0.24 x 0.12 x 0.07m), white lime mortar bonding material.	Length/width unknown, 1.25
1033	Sandstone plinth of east wall of east furnace, dressed sandstone blocks (length unknown x 0.55 x 0.22m), western edge arched for flue entrance, lime mortar bonding material.	Length unknown, 0.55, 0.22
1034	Remains of truncated eastern chest in eastern furnace, fire brick (0.23 x 0.12 x 0.07m) and remains of ganister, fire brick header bond, with no apparent bonding material.	3.25, 0.35, 0.50+
1035	Red brick surface, possible flue or chest foundation in the eastern furnace, red brick unfrogged (0.23 x 0.12 x 0.07m), alternate bond of header and stretcher, no discernible bonding material.	1.65, 1.17, 0.31
1036	Fire brick rebuilding phase in eastern furnace, fire bricks (0.24 x 0.11 x 0.07m) header bond, bedded on edge, no discernible bonding material.	1.90, 0.61, 0.11
1037	Possible flue foundation, red brick unfrogged and heat affected (0.23 x 0.12 x 0.07m), header and stretcher bond, no discernible bonding material.	2.50, 0.25, 0.20
1038	L shaped wall for eastern chest of eastern flue, red brick unfrogged (0.23 x 0.12 x 0.07m), stretcher bond, white lime mortar bonding material.	4.00, 1.53, 0.38+

1039	Foundation material for western chest, eastern flue, fire brick (0.22 x 0.10 x 0.05m), header bond, no discernible bonding material.	1.96, 0.48, 0.14+
1040	Possible footings for eastern furnace west flue chest, fire brick (0.25 x 0.12 x 0.08m), stretcher bond and header bond on alternate levels, no discernible bonding material.	2.40, 0.25, 0.12
1041	Outer chest wall of western chest eastern furnace, red brick unfrogged (0.24 x 0.12 x 0.08m), stretcher bond, three skins thick, white lime mortar bonding material.	2.54, 0.50, 0.20
1042	Radial brick wall, red brick, unfrogged (0.24 x 0.12 x 0.08m), header bond, white lime mortar bonding material.	0.72 x 0.28 x 0.24
1043	Sandstone packing material, sandstone blocks (0.39 x 0.32 x 0.09m), irregular undressed blocks, rough lime mortar bonding material.	2.30, 1.60, 1.10
1044	Front wall of eastern furnace, red brick unfrogged (0.23 x 0.12 x 0.08m), thirteen courses high, stretcher bond, white lime mortar bonding material.	2.40, 0.12, 1.10
1045	Springer off 1044 , red brick unfrogged (0.24 x 0.12 x 0.07m), stretcher bond, white lime mortar bonding material.	0.37, 0.18, 0.16
1046	Sandstone wall, sandstone blocks (0.35 x 0.32 x 0.12m), irregular undressed sandstone, white lime mortar bonding material.	2.66, 0.66, 1.36
1047	Floor of east furnace D, red brick (0.23 x 0.12 x 0.07m) and sandstone, brick laid on edge and bonded with white lime mortar, sandstone blocks to south bonded with white lime mortar.	1.25, 1.00+, unknown depth
1048	Modern ceramic drain cut.	3.30, 0.69, 0.30
1049	Modern ceramic drain pipe in 1048 .	3.30, 0.69, 0.30
1050	Sandstone capped drain cut.	3.50+, 0.75, 0.68
1051	Sandstone capped drain in 1050 .	3.50+, 0.75, 0.68
1052	Modern intrusion, red bricks frogged (0.23 x 0.11 x 0.07m), machine made brick, mixed stretcher and header bond, sandy cement bonding material	7.60, 1.50, depth not visible
1053	Modern intrusion, fire bricks (0.24 x 0.11 x 0.08m), machine made brick, mixed stretcher and header bond, sandy cement bonding material.	7.50, 1.02, depth not visible
1054	Modern intrusion, fire bricks (0.24 x 0.11 x 0.08m), machine made brick, stretcher bond, sandy cement bonding material.	0.91, 0.25, depth not visible
1055	Modern intrusion, fire bricks (0.24 x 0.11 x 0.08m), machine made brick, mixed header and stretcher bond, sandy cement bonding material.	0.77, 0.26, depth not visible
1056	Mixed rubble including cement, red bricks, concrete, pebbles and cobbles.	2.14, 0.81, depth not visible
1057	Concrete slabs, possible machine base or roof of bunker for fuel.	3.10, 2.57, 1.54
1058	Red brick wall, red brick frogged (0.23 x 0.11 x 0.08m), stretcher bond, black ash mortar bonding material.	2.08, 0.28, 0.48
1059	Iron fire rods in furnace flue, 0.03m square ends, 5.40+m long, seven bars.	-

1060	Iron supports for fire rods.	0.55 x 0.08 x 0.05
1061	Modern concrete pad.	5.70+, 0.58, 0.15
1062	Ganister flue arch, no discernible bonding material.	0.13, 0.21, 0.20
1063	Ganister flue arch, no discernible bonding material.	0.22, 0.22, 0.27
1064	Ganister flue arch, no discernible bonding material.	0.23, 0.15, 0.18
1065	Modern concrete.	Covers site, 0.23
1066	Modern wall, red brick frogged (0.23 x 0.11 x 0.08m), machine made brick, stretcher bond, black ash mortar bonding material.	4.63, 0.19, 0.71
1067	Friable, ash deposit in western furnace flue, mixed ash, soot and charcoal, 90% charcoal inclusions.	5.00+, 0.55, 0.22
1068	Possible brick surface, fire brick (0.23 x 0.11 x 0.08m), machine made brick, bedded on side in stretcher bond, black ash mortar bonding material.	2.17, 0.80, 0.11
1069	Red brick surface, red brick frogged (0.23 x 0.11, 0.08m), stamped with 'Robinson Sheffield', machine made brick, mixed bond, stretcher and header, black ash mortar bonding material.	2.16, 2.01, 0.15
1070	Red brick wall foundation and concrete threshold pad, red brick frogged (0.23 x 0.11 x 0.08m), stamped with 'Ron Woodside', two skin thick and stretcher bond, black ash mortar bonding material, plus poured concrete threshold pad (0.99 x 0.43 x 0.11m)	3.50, 0.23, 0.15+
1071	Chimney foundation, red brick and fire brick, modern machine made frogged brick, black ash mortar bonding material.	1.37, 1.12, depth not visible
1072	Modern demolition rubble, below modern concrete 1065 .	Covers site
1073	Buttress end of flue wall, red brick unfrogged (0.24 x 0.12 x 0.07m), header bond, white lime mortar bonding material.	0.85, 0.63, 1.20

Appendix 2: Plates



Plate 1: Eastern furnace showing extent of truncation and in situ remains. Facing north-east. Scales 2 x 1m.



Plate 2: Southern frontage of eastern furnace showing D wall **1032**, floor surface **1047**, furnace front wall **1044**, sandstone packing **1043** and sandstone wall **1046**. Facing north. Scales 2 x 1m.



Plate 3: Western furnace remains showing extent of truncation and in situ remains. Facing north-west. Scales 2 x 1m.



Plate 4: Fire trench chamber showing the various contexts used in construction. Facing north. Scales 2 x 1m.



Plate 5: Fire rods in situ in fire trench of the western furnace. Facing west. Scale 1 x 1m.



Plate 6: Western furnace chest structure showing extent of in situ remains and level of truncation. Facing east. Scales 2 x 1m.



Plate 7: Western furnace chest structure showing extent of in situ remains and level of truncation. Facing west. Scales 2 x 1m.



Plate 8: Northern extent of both furnaces, showing curvilinear sandstone foundation **1024** for the furnace cone and northern sandstone exterior wall **1025**, along with chest foundation remains. Facing south-west. Scales 2 x 1m.

Appendix 3: Post-excavation analysis of furnace residues from Green Lane/ Eagle and Horseman Works, Kelham Island, Sheffield

by Roderick Mackenzie BSc PhD

Introduction

The post-excavation assessment of the metallurgical residues from the site recommended metallurgical analysis of the slag-like material from the inner surface of the conversion chest of the former cementation furnace.

The assessment suggested that the aim of the analysis should be to try and determine whether the slag-like material found in the chests was an incidental by-product of the steelmaking process, or the result of intentional addition by the furnacemen prior to loading the cementation chests; and if it was an intentional addition, whether its composition was designed to give specific behaviour/properties whilst the furnace was in use.

Background on Cementation Steelmaking

An explanation of the cementation method of steelmaking was given in the post-excavation assessment, so only a brief summary of the process is given below to provide context for the results. It should be noted that the cementation method described below is the specific version of the process that was in common use in Sheffield between the 18th and mid-20th century. In the Sheffield area, the cementation method of steelmaking was often referred to as the 'converting' or 'conversion' process.

The local Sheffield term describes the process very well, as iron bars with a low carbon content, are carburised, which converts the iron into steel. Before the advent of 'bulk steelmaking' methods, such as the Bessemer process, the cementation method was the only way to produce large quantities of steel in bulk. Because of the local availability of raw materials for the process, and access to high quality imported iron, Sheffield became a national centre for cementation, and later, crucible steelmaking.

The conversion process involved packing alternating layers of bars of iron and crushed charcoal into large sarcophagus-like stone chests within a coal fired furnace. Once the stone chests were full, they would be sealed with thick layer of a refractory paste, which was a by-product of the cutlery and tool grinding trade. The furnace would be gradually brought up to its full operating temperature (c.1100^oC), to dry and harden the refractory paste, and avoid damaging the inner structure of the furnace through heat expansion.

With the furnace at operating temperature, the bars of iron inside the chests would gradually absorb carbon from the charcoal that surrounded them. The amount of carbon absorbed by the bars was largely dependent on the amount of time that the

furnace was kept at full heat. Once the bars of iron had absorbed more than approximately 0.25 weight percent of carbon, they would be categorised as steel. Typical firing times were anywhere between 5 and 8 days (Barraclough 1976, 12; 1984, 41), excluding a period of 24 to 36 hours to bring the furnace up to temperature and up to a week for it to cool down enough to be unloaded. By varying the length of time that the furnace was at full heat, various grades or types of steel could be produced, from softer 'spring steels' with around 0.6% carbon to high carbon steel with around 1.6% carbon content; the latter would form the feedstock for crucible furnaces.

As mentioned by the author in the assessment report, it was very important that air did not enter the sealed chests during the firing of the furnace, as this would inhibit the carburisation process and, in the worst case, the charcoal packing would burn out and the bars of iron within the chests would start to fuse together.

The material used to construct the chests had to be highly refractory to resist the sustained high temperature and erosion from the flames and corrosive fuel ash slag of the coal fire within the furnace.

Historical accounts of cementation steelmaking in Sheffield mention that a type of refractory stone called 'ganister' was used to construct cementation furnace chests (Barraclough 1984, Appendices etc), and the archaeological evidence from several furnaces in Sheffield confirms this. Ganister is a type of dense carbonaceous sandstone, and it is one of the most refractory natural stones available; substantial deposits of ganister were found under the coal measures in the Sheffield area. The melting point of ganister exceeds 1600°C (Havard, 1912, p33), so it was entirely capable of resisting the 1100°C operating temperature of cementation furnaces.

From a cementation steelmakers perspective, the main problem with ganister was its tendency to expand and contract considerably when heated and cooled, and Havard (1912, p33) mentions how it would split and crack unless heated very carefully and gradually. The particular way that cementation furnaces were built (with transverse stone 'sleepers' and flue voids underneath the base and to the sides of the chests) meant that it would be difficult to prevent localised heating of the stone slabs of the chests.

Methodology

The approach taken to the analysis was to prepare specimens of the material in a way that would allow initial examination with a reflected light optical microscope, but that would also give the option for more detailed analysis using an analytical Scanning Electron Microscope (SEM-EDS) if required. Reflected light microscopy can be used to examine and interpret the microstructure of specimens of metal and metallurgical slag, however, to examine very fine microstructural features and obtain chemical analyses of them, an analytical SEM needs to be used.

Large samples of the material were selected and removed from the furnace in person by the author during the excavation. Two specimens of the material (approximately 0.8 cm³) were fractured off the large samples, and the specimens were mounted in 32mm diameter cold setting resin mounts.

The specimens were prepared for metallographic analysis using established methods, as described by Vander Voort (1999); 1 micron diamond compound was used for the final polishing stage. Following initial examination using a reflected light microscope, the surfaces of the specimens were carbon coated in readiness for SEM-EDS analysis.

In addition to the two resin mounted specimens, a further sub-sample was removed for exploratory X-ray diffraction analysis. X-ray diffraction can be used to identify minerals and crystalline phases within materials.

An indicative bulk chemical analysis of the material was obtained by performing an SEM-EDS scan of three areas of microstructure measuring approximately 900 by 600 microns.

Results

The SEM analysis found that the microstructure appears to consist of a matrix of an amorphous vitrified clay containing grains of silica. Areas of the specimen also contain slag minerals, provisionally identified as Fayalite (2FeO.SiO₂), Wustite/Magnetite (FeO/Fe₂O₃), Anorthite (CaO.Al₂O₃.2SiO₂) and possibly Hercynite (an intermediate phase between Wustite and Anorthite) and Leucite (Al₂Si₂O₆).

To corroborate the findings of the SEM analysis, an exploratory X-ray diffraction analysis was carried out on a powdered and solid sample of the material. The results of the XRD analysis suggest that the material is predominantly composed of a non-crystalline, amorphous clay based material.

The results of the SEM-EDS chemical analysis are given in Table 1 below.

	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	K ₂ O	CaO	MnO	FeO	SrO	TiO ₂
Sample 1											
Average	1.84	-	10.49	66.27	-	2.21	0.58	-	18.05	-	0.55
Std Dev	0.18		0.53	0.71		0.79	0.8		6.12		0.39
Sample 2											
Average	1.12	0.39	7.35	74.31	-	1.40	0.46	-	14.57	-	0.39
Std Dev	0.15	0.27	1.48	1.98		0.61	0.32		5.22		0.21

Table 1: Average composition of specimens of cementation furnace residue from Green Lane/Eagle & Horseman Works, Kelham Island Sheffield.

Discussion

The results of the microscopic and chemical analysis of the specimens reveal that the material is not a metallurgical slag. The composition and microstructure suggest that the material is an unusual type of vitrified clay. The slag mineral phases present in the material appear to have formed during the heating and cooling cycle, and they contain elements that would have been present in the clay, or contents of the chests (alkalis from charcoal wood ash and potentially flakes of iron oxide from the surface of iron bars).

The interface between the surface of the ganister and the slag-like material was examined and the surface of the ganister does not appear to have fluxed or reacted with the vitrified clay layer.

The composition of the specimens analysed and operating temperature of the furnace reveal that the vitrified material had not become fully molten during the firing cycle, although initial estimates of its potential melting point suggest that it may have become viscous when the furnace was at its full operating temperature. If the material did become viscous during the firing, the weight of the bars of iron above it would presumably help to force the material into any cracks that had opened up in the slabs of ganister that formed the base of the chests.

The archaeological evidence from the Eagle & Horseman/Green Lane Works furnace, together with that seen during the excavation of other furnaces in Sheffield, reveal that the ganister used to construct the chests was extensively cracked. It therefore seems obvious that some type of 'self healing' material that would soften enough during the firing cycle to fill cracks in the base of the furnace would have been highly beneficial, and if this practice was confined to Sheffield, it may have given a competitive advantage to the steelmakers there.

There are numerous contemporary accounts of cementation steelmaking during the 18th and 19th century, and to the authors knowledge, only one of these (Crookes & Rohrig 1870, 221) mention anything other than crushed charcoal mixtures being spread over the inside base of the cementation chests prior to loading and firing. The account given by Crookes and Rohrig mentions the addition of a layer of crushed brick to the inside of the base of the chests prior to loading, if made from normal earthenware type clay brick, would have vitrified at the operating temperature of a cementation furnace. Unfortunately, it is not clear whether Crookes & Rohrig are described the process at a works in Sheffield or in Germany.

In the author's opinion, the most likely explanation for the presence of the slag-like material is that a substance, such as crushed brick, was applied as a layer to prevent air and possibly flames/sulphurous smoke from penetrating the chests. Because the excavated furnaces have been truncated at a level below the vertical side panels of the chests, it is difficult to be certain whether the inner walls of the chests were coated or just the base.

Conclusion

Analysis has established that the material has an unusual microstructure and composition that is not typical of slag by-products from iron and/or steel production.

The composition of the material and operating temperature of the cementation process strongly suggest that the material did not form as an incidental by-product of the process; it therefore seems likely that it was a deliberate addition to the furnace chests prior to them being loaded. The purpose of the material appears to have been to act as a sealant, to prevent air, flames and hot gasses from entering the base of the chests during firing.

At this stage, with only material from one furnace analysed, it is impossible to state with any certainty that this was common practice in Sheffield.

It would be interesting to compare the composition of the material from the furnace at Green Lane/Eagle & Horseman Works to the similar residues recovered from other cementation steelmaking sites to see whether the same material was being added to the furnace or if there were variations between the works.

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Green Lane, Sheffield
 Site location
 Excavation, Nov 2013
 Illustration No. 1
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+ 435150, 388200

+ 435220, 388200

Kelham Island

Excavation area

+ 435150, 388100

+ 435220, 388100

Cotton Mill Walk

Alma Street

Green Lane, Sheffield
Site plan
Excavation, Nov 2013
Illustration No. 2





+ 435179, 388155

+ 435195, 388155



-  Red brick
-  Fire brick
-  Sandstone
-  Brick and sandstone
-  Ganister
-  Fire rod
-  Concrete
-  Ceramic pipe

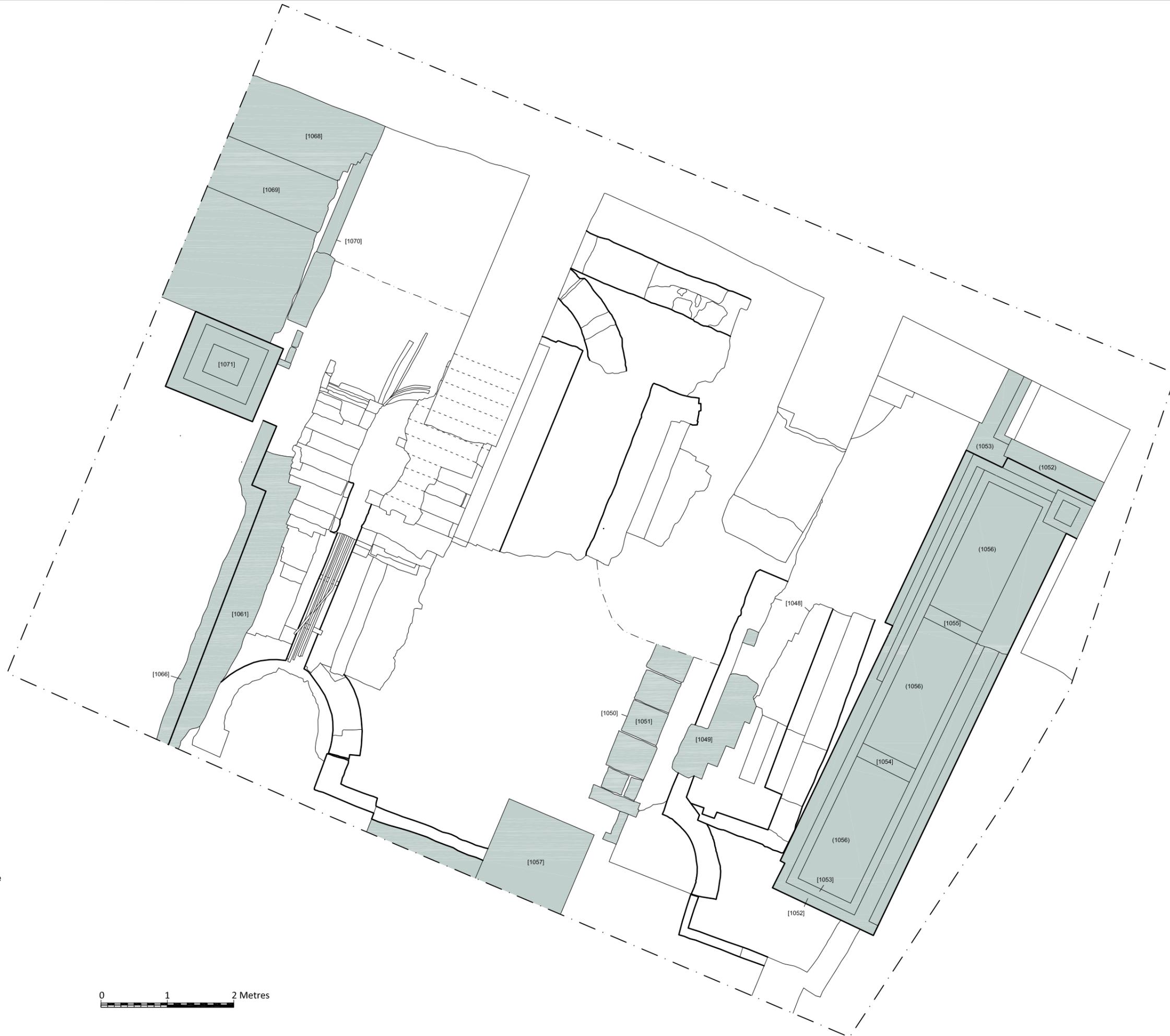


Green Lane, Sheffield
Plan: Mitigation area
Excavation, Nov 2013
Illustration No. 3



Green Lane, Sheffield
Plan: Phase 1
Excavation, Nov 2013
Illustration No. 4

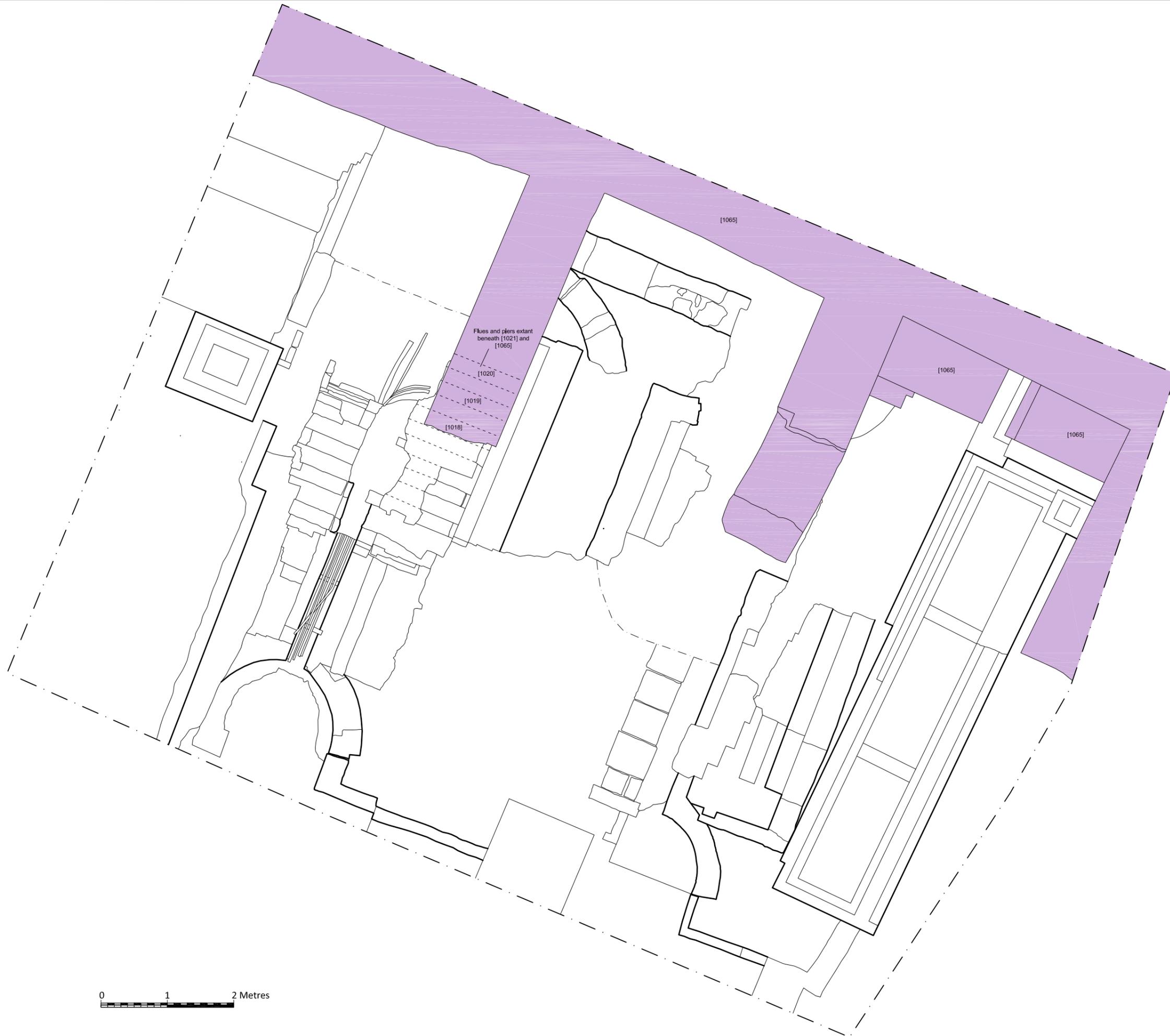




- Red brick
- Fire brick
- Sandstone
- Brick and sandstone
- Ganister
- Fire rod
- Concrete
- Ceramic pipe

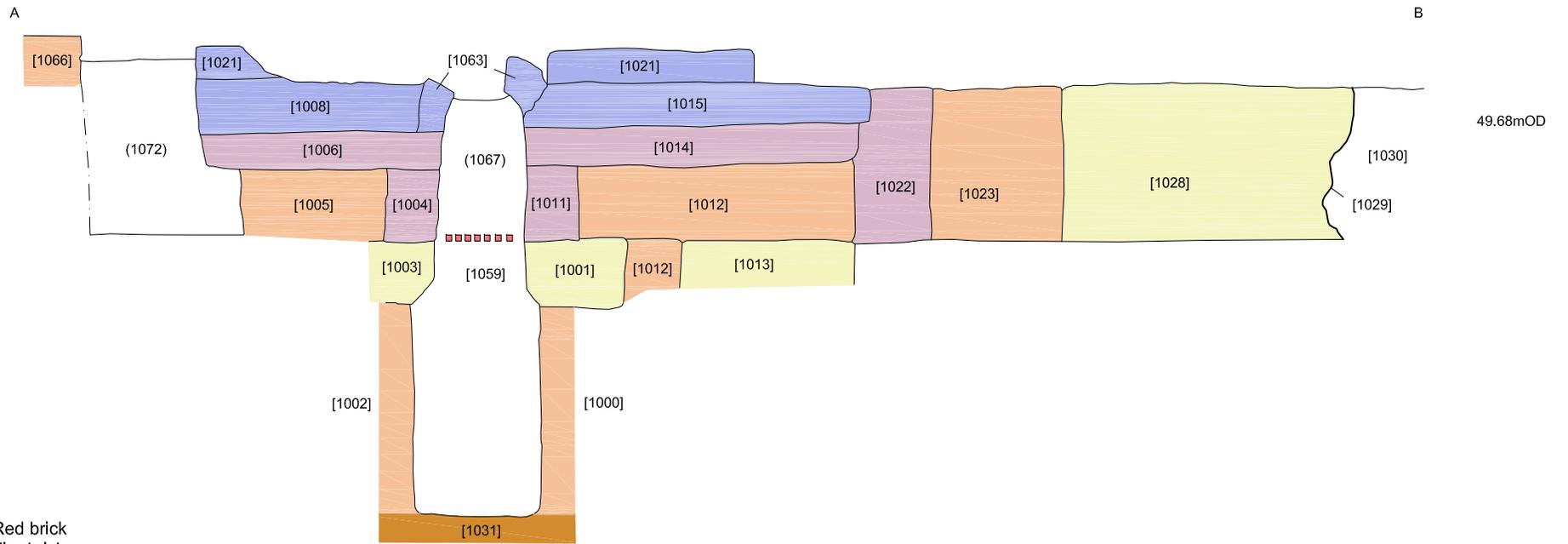
Green Lane, Sheffield
Plan: Phase 2
Excavation, Nov 2013
Illustration No. 5





Green Lane, Sheffield
Plan: Phase 3
Excavation, Nov 2013
Illustration No. 6





Green Lane, Sheffield
 South-west facing section
 through Cementation Furnace
 Excavation, Nov 2013
 Illustration No. 7

