Newport Medieval Ship Project
Specialist Report: METALS AND SLAG

Site number: GGAT 467
Site location: NGR: ST 31286 88169 Kingsway, Newport, South Wales, UK.

Newport CITY COUNCIL
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Please note: Reports 1-6 were prepared by Dr. Gerry McDonnell in 2011-2012

The Newport Ship Project

Introduction

In 2002, during the construction of the Riverfront Theatre, on the banks of the River Usk in Newport, South Wales, an archaeological find of great significance was unearthed. In the summer of that year, while undertaking the excavations for the theatre's orchestra pit, the well-preserved remains of a 15th century clinker built merchant vessel were discovered.

The site, which was surrounded by a cofferdam, was being monitored by the Glamorgan Gwent Archaeological Trust at the time of discovery. The ship lay in what is locally known as a pill or small inlet, with its stern closest to the river and its bow facing into the inlet. The timbers were covered in thick alluvial mud, which created an ideal anaerobic environment for successful preservation. Seventeen strakes of planking remained on the port side and thirty-five on the starboard side of the ship. The vessel was approximately 30m in length.

A silver French coin was found purposely inserted into the keel of the vessel, dating the ship to after May 1447. Dendrochronological research has shown the hull planking to be from the Basque country and after 1449 in date.

After a much publicised 'Save Our Ship' campaign, it was decided that the ship would not be recorded and discarded but excavated with the aim to conserve. The riders, stringers, braces, mast step, frames and overlapping clinker planks and keel were dismantled one by one and lifted. Almost 2000 ship components as well as hundreds of artefacts were excavated.

This report examines and lists the faunal remains recovered during the Newport Medieval Ship excavation.

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Report on the Metallographic Examination of Iron Artefacts from the Newport Ship.

For: Toby Jones, Newport Ship Project

gerry mcdonnell archaeometals

Date: 18 October 2011

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Report on the Metallographic Examination of Iron Artefacts from the Newport Ship

1. Introduction

This report provides the results of the optical metallographic examination of 10 iron components of the Newport Ship. The results contribute to a better understanding of the Newport Ship, and to a broader understanding of medieval boat technology. The iron nails and other constructional material held the boat together, and the material must perform in certain ways. The iron must resist rapid corrosion, it must be tough and have fatigue strength, i.e. the ability to withstand continuously varying and alternating loads as the ship moved through the water, especially in rough seas. 'Nails' tend to be regarded as a low grade tool that could be manufactured from low grade iron, scrap etc. However the importance of the boat nail or rivet places this item as a critically important piece of technology, which if it failed, would result in the possible loss of the ship, its cargo and crew. Hence archaeometallurgical analysis can assess the quality and consistency of manufacture of these artefacts.

Wooden built ships held together by boat rivets or nails or other pieces of iron e.g. staples rely on the iron behaving in certain ways. Although iron is highly susceptible to corrosion, some irons are more susceptible than others. For example an iron with a high slag inclusion (volume) content , e.g. slag stringers will corroded faster than a clean iron. Thus an assessment of the slag inclusion content compared to the state of preservation of the iron will provide evidence regarding the quality of manufacture and the role of slag inclusions in iron corrosion. Phosphoric iron (iron containing between 0.15-1%P) is considered to have greater corrosion resistance than ferritic iron (iron containing no alloying elements). Analysis of the iron will demonstrate whether phosphoric iron was used and whether it was consistently used, i.e. are all sampled artefacts phosphoric and does the level of phosphorus vary within rivets and between artefacts
The archaeometallurgical analysis will enable the quality of the iron used in the manufacture of the ship and its repair to be assessed, and the consistency of composition. This can be achieved by assessing the variation on composition in the metal within and between samples. The volume per cent of slag inclusions is also an indicator of quality. The cleaner the metal the better the quality. However it is difficult to obtain detailed quantitative data of inclusion volume per cent due to the presence of corrosion in the samples.
The archaeometallurgical analysis will aid in determining the quantity of iron required to construct the Newport Ship, hence enhancing an understanding of the natural and human resources required to construct such a ship. This report will be supported by further reports detailing the hardness testing of the samples and the analysis using Scanning Electron Microscopy.

The aims of the analyses of the metal artefacts are:

- To assess the quality of the iron used in construction and repair of the ship.
- To assess whether specific alloys have been utilised, e.g. phosphoric iron

- Is there evidence for shock caused by hammer blows present in the nails?
- To compare the metallurgy of the original iron work with that used in the repair.
- Are the nails used in the repaired sections of the same quality compared to those used in the original construction?

2. Methodology

The artefacts were selected on the advice of Toby Jones. Each artefact was photographed, and a thick section was cut, and the section mounted in cold setting resin, ground and polished to ¼ micron finish. The mounted specimen was photographed using a low power magnifier. The specimens were examined in the as-prepared condition (unetched) using a metallurgical reflected light microscope, with magnification ranging from x4 objective to x40 objective lenses. Digital images at different magnifications were taken to record the slag distribution and corrosion penetration. Samples were etched in 3% Nital (Nitric Acid in ethanol) and re-examined using the reflected light microscope to reveal the metallic microstructure, digital images were recorded. In one case (MSG 2709) the nail was too corroded and no metal survived, in all other cases substantial metal survived enabling full metallurgical analysis to be undertaken.

3. Results

3.1. Bolts from Knee/Crossbeam

3.1.1. Sample MSG 1239, bolt from Knee/Crossbeam Structure

A bolt of approximately 30cm long and the shaft is 2.5cm in diameter (Plate 1). A wedge shaped cross-section was removed from mid-length of the bolt. In the unetched condition the section displays some corrosion penetration. There are slag inclusion distributed across the section, stringers are absent and the slag inclusion shape ranges from small round or sub-spherical inclusions to larger angular sub-rectangular inclusions (Plate 2). The majority of slag inclusions are dual-phased, some with iron oxide present. In the etched condition the section showed a varied carbon gradient ranging from near eutectoid steel (0.8%C) degrading across most of the section through pearlite plus ferrite to ferrite plus pearlite to a ferritic microstructure (ASTM Grain Size 3-4, Plates 3-5). The bolt is too big for it to have been carburised from one side, as the distance would have required many days of carburisation. This suggests the bolt was manufactured from a heterogeneous iron. The pearlite is coarse indicating that the bolt had cooled slowly, but widmanstatten ferrite is also present indicating a period of more rapid cooling. Finally, the pearlite shows evidence of breaking up and spherodising indicating that it was held at elevated temperature. This sequence could be achieved by being repeatedly heated and held at high temperature during the time the bolt was being forged to shape. It was then probably quenched to remove the initial heat, but then left to cool slowly to ambient temperature. The slow cooling would be enhanced by a pile of bolts being left to cool.

3.2. Keel Spike Nail

3.2.1. Sample MSG 2861 Spike Nail driven through garboard strake and into keel at S1_3

A long thin nail, c 13cm long, slightly bent at the thinned end (Plate 6). A complete cross-section was removed from the thinned end. In the unetched condition the section displays some corrosion penetration. There are slag inclusion distributed across the section, stringers are absent and the slag inclusion shape ranges from small round or sub-spherical inclusions to larger angular sub-rectangular inclusions (Plate 7). The majority of slag inclusions are dual-phased, some with iron oxide present. In the etched condition the microstructure is typical of phosphoric iron with the presence of variable grain size, ranging from ASTM 2-4 - and ghosting present in some area (Plate 8) .

3.3. Original Clench Nails

3.3.1. Iron nail sample from timber <2368> Clench Nail from S14_4

The nail survives as a very short length (2cm) of the shank (Plate 9). A complete transverse section was removed. The section showed heavy corrosion penetration, the surviving metal contained appeared clean of small inclusions but with two prominent bands of slag inclusions running across the section (Plate 10). The majority of inclusions appear as glassy phase with occasional fine precipitates present reminiscent of the glassy phase present in smithing and smelting slags. In the etched condition the microstructure was ferrite grains ((Plate 11), Grain Size ASTM 3-4) with no indication of the presence of phosphorus with one side having ferrite grains plus grain boundary pearlite (ASTM 5-6). The ferrite grains were irregular, but not deformed. There was no evidence of cold working.

3.3.2. Iron nail sample from timber <2180> Clench Nail from P6_4

The nail survives as a short length (3cm) of the shank (Plate 12). A complete transverse section was removed
In the unetched condition the section displays some corrosion penetration. There are slag inclusion distributed across the section, stringers are absent and the slag inclusion shape ranges from small round or sub-spherical inclusions to larger angular sub-rectangular inclusions (Plate 13). The majority of slag inclusions are multi-phased, some with iron oxide present. In the etched condition the microstructure is ferritic with no carbide present, nor was there any evidence for the presence of phosphorous. The grains were equiaxed with Grain Size ASTM 2-4, and show no evidence for deformation (Plate 14).

3.3.3. Iron nail sample from timber <895> Clench Nail from S9_2

The nail survives as a short length (3cm) of the shank (Plate 15). A complete transverse section was removed. The section showed heavy corrosion penetration, the surviving metal contained appeared clean of small inclusions but with a few larger inclusions distributed across the specimen (Plate 16). The inclusions appear to be single or dual phase, probably silicate/glassy phase. In the etched condition (Plate 17), the microstructure was predominantly ferritic (ASTM Grain Size 3-4) with some localised areas showing ghosting, indicating the presence of phosphorus. There is some age grain boundary precipitation or slight intergranular corrosion.

3.3.4. Iron nail sample from timber <2177> Clench Nail from P6_4

The nail survives as a short length (3.5cm) of the shank (Plate 18). A complete transverse section was removed

In the unetched condition the section displays some corrosion penetration. There are slag inclusion distributed across the section, two lines of stringers cross the section below one of them in one corner are large number of slag inclusions badly affected by corrosion penetration Plate 19). The inclusions in the two lines of stringers are multi-phased, whereas the isolated inclusions appear to be single or dual phased. In the etched condition the microstructure is ferritic (Plate 20, Grain Size ASTM 2-3), with occasional carbide at the grain boundary/and or age precipitation.

3.4. Repair Spikes

3.4.1. Iron nail sample from timber <2572> Repair Spike from S25_3

A near complete nail, approximately 7cm long (Plate 21). A complete section was removed from the thin end. In the unetched condition the section displays some corrosion penetration. There are slag inclusions distributed across the section. The majority are angular single or dual phase inclusions. Some inclusions form folded lines (Plate 22). In the etched condition the microstructure is varied with a small region of small ferrite grains plus grain boundary carbide (Grain Size ASTM 6), the majority of the nail is ferritic (Grain Size ASTM 3-4) but there is also ghosting in some areas indicating the presence of phosphorus (Plate 23, (Grain Size ASTM 2-3).

3.4.2. Iron nail sample from timber <2190> Repair Spike from P6_7

The nail survives as a short length (3.5cm) of the shank (Plate 24). A complete transverse section was removed. The nail had suffered severe corrosion penetration, and there were numerous slag inclusions distributed across the section Plate 25), some of which had suffered corrosion. The slag inclusions were either single or dual phase some of the latter appeared to contain iron oxide dendrites. In the etched condition the microstructure comprised small ferrite grains (Plate 26, Grain Size ASTM 5-6) with grain boundary carbide or pearlite and a second grain boundary phase.

3.4.3. Iron nail sample from timber <2690> Repair Spike from S14 8

The nail survives as a length (6.5cm) of the shank (Plate 27). A complete transverse section was removed
In the unetched condition the section displays some corrosion penetration. There are slag inclusions distributed across the section including lines of stringers, one of which appeared to form a fold in the section. The inclusions ranged from small spheroidal inclusions to larger more angular inclusions (Plate 28). The majority of inclusions were single phased, but with some dual phased inclusions present, none appeared to contain iron oxide. In the etched condition the microstructure was small grained ferrite and pearlite. The carbon content varied between c0.1-0.3% and the grain size was ASTM 6-7, in the higher carbon areas there was an indication of a third phase, possibly a phosphide precipitate (Plate 29).

3.4.4. Iron nail sample from timber <2461> Repair Spike from S18 7

The nail survives as a length (c. 9cm) of the shank, bent through c90^{o} midway along its length (Plate 30). A complete transverse section was removed
In the unetched condition the section displays extensive corrosion penetration. In some areas of corrosion remnant metallographic microstructures were present. There are numerous slag inclusion distributed across the section many of which are affected by corrosion penetration (Plate 31). In the etched condition the sample showed a varied microstructure ranging from near eutectoid (0.8%C) (Plate 32a) to ferrite plus grain boundary pearlite (Grain Size ASTM 7) to ferrite with one area of larger grained ferrite (Plate 32b, Grain Size ASTM 3) with ghosting indicative of the presence of phosphorus.

4. Discussion

The results of the metallographic analysis are summarised in Table 1, this shows that of the six original fixtures three are ferritic (MSG 2177, 2180 and 2368), two MSG 895 and MSG 2861) contain phosphorus and one MSG 1239), has a heterogeneous microstructure ranging from high carbon steel to ferritic iron. Two (MSG2177 and MSG 2368) of the ferritic artefacts also contained a very low carbon content forming grain boundary carbides. This demonstrates that the ship builders were accessing a number of different iron producers, and were not utilising one specific alloy type. The repairs are equally diverse, two (MSG 2190 and MSG 2572) of the four artefacts are ferritic, both of which contain grain boundary carbide. A third artefact (MSG 2461) is heterogeneous with pearlite, ferrite and phosphoric iron present. The fourth artefact (MSG 2690) has a ferrite and pearlite microstructure. This evidence shows that the shipwrights carrying out the repair are either re-sing the original nails or are accessing similar diverse iron suppliers.

Table 2 summarises the attributes of the non-metallic slag inclusions in the artefacts sections. Three artefacts (MSG 895, MSG 2177 and MSG 2690), were considered clean, i.e. having a low volume per cent of slag inclusions, all three having a ferrite or ferrite plus pearlite microstructure. The spike, MSG 2861 was moderately clean. The remaining artefacts were considered dirty i.e. having a large volume per cent of slag inclusions. All the specimens, save one (MSG 2690) contained one or more large inclusions, of the order of 3mm across or larger. In addition eight of the ten specimens (the exceptions being MSG 2177 and MSG 2690) contained angular inclusions.

MSG Code	Type	Location	Met Code	Original or Repair
895	Clench Nail	S9_2	ferrite plus some P	o
1239	bolt	Knee/Crossbeam Structure	Het	o
2177	Clench Nail	P6_4	Ferrite	o
2180	Clench Nail	P6_4	Ferrite	o
2368	Clench Nail	S14_4	Ferrite	o
2861	Spike Nail	garboard strake and into keel at S1_3	P-Fe	o
2190	Nail Spike	P6_7	Ferrite	r
2461	Nail Spike	S18_7	Het	r
2572	Nail Spike	S25_3	Ferrite	r
2690	Nail Spike	S14_8	Ferrite & Pearlite	r

Table 1 Summary of the metallurgy of the artefacts. Ferrite plus some P - mainly ferritic with some phosphoric iron present; Het - heterogeneous varying from pearlite to ferrite; Ferrite-ferritic iron; P-Fe- phosphoric iron; ferrite & pearlite - a ferrite and pearlite microstructure.

During the hot working of iron, .i.e. forging, the slag inclusions in the metal will become broken up, rounded in shape, elongated into stringers and reduced in size. Thus the presence of large inclusions and angular inclusions indicate very little working. Thus it can be argued that the nails and spikes are produced directly from the bloom with little working. This argues for dedicated ship nail producers. One repair artefact (MSG 2690)) lacks both angular inclusions and large inclusions, but was clean with few inclusions, but also lacked stringers. The other artefact with no angular inclusions (MSG 2177) is an original clench nail, but does include large inclusions and no stringers. The pattern of size and shape is the same in both the original and repair artefacts. This further suggests that the original nails were recycled during the repair phases, or alternatively the repair was carried out at the original shipyard at which the ship was built. The largest and smallest grain size measured in the samples is shown in Table 3. There are no samples with very large grains (ASTM 1) which do occur in archaeological iron, strongly associated with the occurrence of phosphoric iron. Three samples (MSG 2177, 2180 and 2861) have the largest grain size (ASTM 2) but only one (MSG 28610 contained features in the microstructure indicative of the presence of phosphorus, the other two were ferritic. The other sample with phosphoric iron (MSG 895) indicated by ghosting rather than increased grain growth, It is noticeable that the original ironwork has a slightly larger overall mean grain size (overall mean value 3.3) compared to the artefacts used in the repair (overall mean value 5.3). The smaller overall grain size of the repair ironwork could result from the original iron being re-heated and reworked prior to re-insertion into the ship's woodwork during the repair process.

5. <u>Conclusions</u>

The metallographic analysis of the ironwork recovered from the Newport Ship has shown that the shipwrights did not specify one iron alloy type for the constructional ironwork. Three types of iron were used, ferritic iron containing no alloying elements, although some samples did contain a small amount of carbon in the form of grain boundary carbides. A ferrite and pearlite alloy, i.e. overall a low carbon steel, but with wide ranges of carbon content within a sample varying from circa 0.8% Carbon, eutectoid composition to zero carbon content i.e. ferrite. The third alloy was phosphoric iron, although phosphorus was present in three artefacts, as indicated by the metallography and must be confirmed by SEM analysis, only one, the specialist item the spike nail inserted into the keel (MSG 2861), was wholly phosphoric. The other two items contained phosphoric iron and other alloys. The original ironwork and the repair iron work contained examples of all three alloy types. Therefore during the construction of the vessel the iron was being sourced from different iron producers, which is not surprising given that circa 4 tonnes of iron was required to construct the ship. There is broad similarity between the metallography of the original artefacts and the repair artefacts which suggests that original ironwork was re-used during the repair. This proposition will be further examined during the SEM study.

MSG Code	Type	Location	Met Code	clean or dirty?	angular inclusions present?	Massive inclusions	stringers?	single phase	dual phase	multi phase
895	Clench Nail	S9_2	ferrite plus some P	C	y	y	n	y	n	n
1239	bolt	Knee/Crossbeam Structure	Het	D	y	y	n	y	n	n
2177	Clench Nail	P6_4	Ferrite	C	n	y	n	y	y	y
2180	Clench Nail	P6_4	Ferrite	D	y	y	n	y	y	n
2368	Clench Nail	S14_4	Ferrite	D	y	y	n	y	y	y
2861	Spike Nail	garboard strake and into keel at S1_3	P-Fe	Med	y	y	y	y	y	y
2190	Nail Spike	P6_7	Ferrite	D	y	y	n	y	y	n
2461	Nail Spike	S18_7	Het	D	y	y	y	y	y	n
2572	Nail Spike	S25_3	Ferrite	D	y	y	y	y	y	n
2690	Nail Spike	S14_8	Ferrite & Pearlite	C	n	n	n	y	n	n

Table 2 Assessment of the non-metallic inclusions in the artefact sections. Clean/Dirty- assessment of volume per cent of slag inclusions present, angular - whether angular i.e. un-worked inclusions are present. Massive - large >3mm across; Stringers thin elongated slag inclusions; single, dual, and multi – number of phases present in the slag inclusions.

MSG Code	Type	Location	Met Code	Largest ASTM Grain size	Smallest ASTM Grain Size
895	Clench Nail	S9_2	ferrite plus some P	3	4
1239	bolt	Knee/Crossbeam Structure	Het	3	4
2177	Clench Nail	P6_4	Ferrite	2	3
2180	Clench Nail	P6_4	Ferrite	2	4
2368	Clench Nail	S14_4	Ferrite	3	6
2861	Spike Nail	garboard strake and into keel at S1_3	P-Fe	2	4
2190	Nail Spike	P6_7	Ferrite	5	6
2461	Nail Spike	S18_7	Het	3	7
2572	Nail Spike	S25_3	Ferrite	3	6
2690	Nail Spike	S14_8	Ferrite & Pearlite	6	7

Table 3 Largest and Smallest ASTm Grain Size measured in the samples.

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Report on the Analysis of the Metal and Slag Inclusion in Four Artefacts from Newport Ship.

For: Toby Jones, Newport Ship Project

gerry mcdonnell archaeometals

Date: Wednesday, 28th March 2012

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Report on the Analysis of the Metal and Slag Inclusion in Four Artefacts from Newport Ship.

1. Introduction

The metallographic analysis of 10 artefacts including five nail spikes, four clench nails and one bolt from the ship that showed that three alloys were present, ferritic iron, ferritic iron plus pearlite and ferritic iron plus phosphoric iron. The ferritic iron dominated the assemblage. Six of the artefacts derived from the original construction of the ship and four were derived from the repair of the vessel. There was no difference in the alloys used in the original construction and the repair of the ship. A sub-set of four artefacts were selected for analysis using Scanning Electron Microscopy to undertake elemental analysis of the metal and slag inclusions. The aims of the analyses of the metal artefacts were:

- To confirm the metallographic identification of phosphoric iron.
- To compare the composition of the slag inclusion from the original artefacts to those of the repair artefacts.
- To assess whether the repair artefact could have been manufactured from iron produced in the Newport area by comparison with the composition of the smelting slag recovered from below the ship.

2. Methodology

The mounted metallographic specimens were carbon coated and analysed using a JEOL 700F Scanning Electron Microscopy with wavelength dispersive x-ray analysis (running Oxford Instrument's Inca Wave technology) and energy dispersive x-ray analysis (running Oxford Instrument's Inca systems) in the Department of Metallurgy and Material Science at the University of Birmingham. The slag inclusions were analysed either in spot mode or by small area scan. The filament was at saturation and an accelerating voltage of 20kV was used. The samples were examined under backscattered electron imaging (BSE). The inclusions were analysed for 40 seconds livetime count. A target of c. 20 inclusions per sample were analysed. The resultant composition of an inclusion can be allocated to one of three broad groups. The first group are iron oxide, and includes all compositions with $FeO>80\%$. The silicate inclusions are dominated by iron oxide, silica, magnesia and manganese oxide with ($FeO+MgO+MnO$) ranging from c 20%-80%. The third group are described as glassy phase inclusions and are dominated by silica, alumina lime and potash, hence $FeO<20\%$.

3. Results

3.1. Original Artefacts

3.1.1. Clench nail MSG 895 from S9_2

The microstructure was predominantly ferritic with some localised areas showing ghosting, indicating the presence of phosphorus. Twenty two inclusions were analysed (Table 1), of which 10 were considered to be iron oxide inclusions, with FeO> 80%. The remainder were silicates as the glass forming oxides, alumina, potash and lime, were low in concentration. The silicate inclusions contained significant levels of manganese oxide (average of 7.8%), which indicates that the iron was smelted from manganese bearing ores. The inclusions were dominates by silica and iron oxide, with only a few inclusions containing more than 5% of another oxide, and the majority of these were containing more than 5% manganese oxide. Twelve of the inclusions contained sulphur at elevated levels, normally in archaeological iron it rarely exceeds detectable levels (c. 0.1%), however in some cases it reached nearly 8% (and are associated with higher levels of phosphorus pentoxide).

The metallographic analysis indicated the presence of some phosphorus and this was detected above the minimum detectable level at 0.2% in the area where the iron oxide, manganese oxide, sulphur and phosphorus pentoxide inclusions were present.

3.1.2. Clench nail MSG 2177 from P6_4

In the etched condition the microstructure was ferritic, with occasional carbide at the grain boundary/and or age precipitation. Seventeen inclusions were analysed (Table 2) of which three were considered to be iron oxide inclusions. The remainder were silicate as the glass forming oxides levels were low, with no oxide exceeding 5% with one exception, (Inclusion 11, Al_2O_3=5.4%). The manganese oxide content of the silicate inclusions was 2.4%, indicating that the metal was smelted from a low manganese bearing ore. The sulphur and phosphorus pentoxide contents are low.

No phosphoric iron was observed in the metallographic analysis and two random areas of metal were analysed, but no phosphorus was detected.

3.2. Repair Spikes

3.2.1. Nail Spike MSG 2190 from P6_7

In the etched condition the microstructure comprised small ferrite grains, with occasional grain boundary carbide or pearlite and a second grain boundary phase present. Thirty inclusions were analysed (Table 3), and none were iron oxide. This is probably due to the presence of the carbon in the microstructure which would reduce the iron oxide compounds.

This indicates that the bloom was low carbon, i.e. the iron was produced in a strongly reducing atmosphere and there was little smithing undertaken. The concentration of glass forming oxides was low, with only a few instances of either alumina or lime exceeding 5%. The levels of phosphorus pentoxide and sulphur were low. The manganese oxide content was high ranging from 5-14% with an average of nearly 7%. This indicates that the iron derived from a high manganese bearing ore.

The microstructure was ferrite with grain boundary phases, and six random areas were checked for the presence of phosphorus and it was detected at the minimum detectable levels in three of the analyses.

3.2.2. Nail Spike MSG 2461 from S18_7

In the etched condition the sample showed a varied microstructure ranging from near eutectoid (0.8%C) to ferrite plus grain boundary pearlite to ferrite with one area of larger grained ferrite with ghosting indicative of the presence of phosphorus. Thirty inclusions were analysed which displayed a wide range of compositions. Some inclusions (Plate 1) were cored, comprising a core (dark grey under BSE) and a rim (light grey under BSE), the analyses of these phases show the core is lower in iron oxide (Table 4), hence darker grey. Some of the inclusions had suffered the effects of corrosion, indicated by the presence of chlorine in the spectrum. These inclusions analyses were ignored in the subsequent analysis, as were the rim values for the cored inclusions, resulting in 24 valid inclusion analyses (Table 5). Seven inclusions were iron oxide inclusions, fourteen were silicates and the remaining three were classed as glassy phase inclusions i.e. rich in silica, alumina, lime and potash. The levels of phosphorus pentoxide (mean value 0.7%) and sulphur (mean value 0.2%) were low. The manganese oxide content of the silicate inclusions was low only 2.5%, but still indicative of the exploitation of a manganese bearing ore.
The metallographic analysis observed the presence of larger grains and some ghosting indicative of the presence of phosphorus. This area and other areas were spot analysed and phosphorus was detected at the minimum detectable level of c.0.1%, one of these area was analysed using the wavelength dispersive system (Inca Wave) and only 0.04% was measured. This indicates that the phosphorus content of the sample was exceedingly low and the larger grain size and ghosting was due in part to the working of the iron.

4. Discussion

The elemental analyses of the metal confirm the presence of phosphorus at low levels in three of the artefacts, in the original nail spike MSG 895 and the two repair artefacts MSG2190 and MSG 2461. However, the levels of phosphorus were very low.

Non-metallic slag inclusion in an archaeological iron artefacts may derive from three sources (McDonnell and Chabot in prep), firstly inclusions derived from the smelting process, secondly those derived from the refining (bloomsmithing) process that produces a workable billet, and thirdly inclusions derived from subsequent smithing operations, that include forging of the billet to a trade bar, forging the artefact from the bar and any subsequent repairs and re-forgings. Hence within any artefacts three groups of inclusion types/composition can be encountered. However a previous study (Chabot 2007), has demonstrated that artefacts do not contain three clear distinct groups of slag compositions relating to the three main processes and the composition variation is more complex. Inclusion data can be manipulated in a number of different ways and there have been a number of different approaches (e.g. Hedges and Salter 1979; McDonnell 1992, Buchwald and Wivel, 1998; Dillman and Hertier, 2007; Blakelock et al 2009). The approach is dependant to some extent on the questions being asked. In many cases there have been attempts at provenancing the iron (e.g. Hedges and Salter 1979; Buchwald and Wivel 1998) or determination of technology (Gordon 1997). The aim of this analysis is to compare the inclusion composition of the two original artefacts (MSG 895 and MSG 2177) to assess whether they derive from the same iron production process. Similarly to assess whether the two repair artefacts (MSG 2190 and MSG 2461) derived from the same production centres. Secondly the question as to whether the repair artefacts are re-used original artefacts or were manufactured in a different location. Thirdly to assess whether the repair artefacts inclusions indicated if they had been manufactured in the Newport region by comparison with the smelting slags recovered at the site. The data can be manipulated in a number of different ways, but the simplest method is to compare simple ratios if oxides. The most commonly used oxides (Dillman and Hertier, 2007; Blakelock et al. 2009) are those that derived from the inputs, the ore, slag-lining reactions and fuel ash that do not carry through to the metal. The major oxides of this group are MgO, Al2O3, SiO2, K2O, CaO, and MnO, of particular significance is MnO as this is not present in all ores, hence if it is present in the slag inclusions then (a) the slag inclusions derive from the smelting process, MnO was not carried through into the metal, and hence must derive from smelting slag (McDonnell 1988), and (b) the iron was smelted from a manganese bearing ore.

The plots of the oxides MgO/K_2O, SiO_2/MnO, Al_2O3/SiO_2, Al_2O_3/MgO, $Al_2O_3/K2O$ and Al_2O_3/CaO are presented Figures 1-6, and the mean ratios are presented in Table 6. The scatter plots of MSG 895 (Figure 1) shows two distinct groups, whereas those for MSG 2177 (Figure 2) show a general scatter, but there is an indication of two groups, similar to the pattern of MSG 895. However these two original artefacts do not have similar plots indicating they derive from different production centres. The scatter plots for MSG 2190 (Figure 3) show that MgO/K_2O and SiO_2/MnO form a tight group, whereas the plots against alumina show a more general spread of data. The plots for MSG 2461, (Figure 4) show strong trends for some plots. The oxides being considered can be ascribed either to silicate forming oxides, e.g. MgO, SiO_2 or to glassy phase oxides. By plotting the major silicate oxides against the major glassy oxides, summarises the other plots. These are presented in Figure 5, and confirm that all four sections display different characteristics. Further analysis of the mean values of the ratios (Table 6) are neither consistent within the original artefacts or the repair artefacts.

The inclusion data can be compared to similar data derived from the slag analyses. The ratios for the four slag samples are shown in Figure 7 and compared with the data of the metal artefacts in Figures 8 and 9. Clearly the two original artefacts (MSG 895 and MSG 2177) would not be expected to plot near the smelting slag, and they do not. Equally the two repair artefact (MSG 2190 and MSG2461) plot further away from the slag points than the two original artefacts.

The mean manganese oxide compositions of the slag inclusions and the slags are presented in Table 7. These data clearly demonstrate that the slag inclusions in all the artefacts are rich in manganese oxide. The lowest amount is in repair spike MSG2461 at 2.0% but this is still ten times the amount present in the Newport slags. Hence the repair artefacts were not manufactured in the Newport region.

5. Conclusions

The elemental analysis of the metal demonstrate that although phosphorus was present in three of the artefacts (original clench nail MSG 895, repair nail spike MSG 2190 and MSG 2461) it was at very low levels. Hence phosphoric iron was not preferentially selected for the manufacture of ship's nails.

The analyses of the inclusions demonstrate that it is almost certain that all four artefacts derive from different iron production centres. It can be confirmed, both on the basis of the manganese content and the scatter plots that the repair artefacts were not manufactured in the Newport region, and could possible either derive from a stock of iron held on the ship or were original artefacts re-used.

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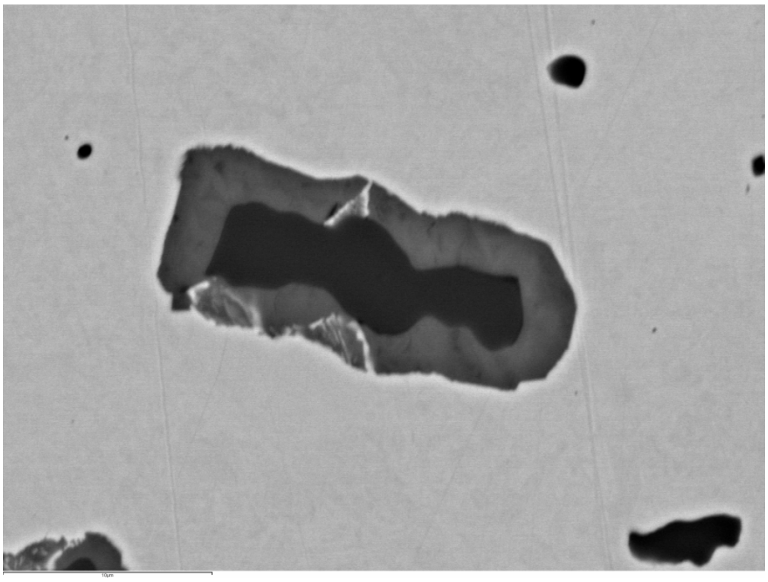

Plate 1 Sample MSG 2451, SEM BSE image of Inclusion 1 showing central dark (low Z) and rim (grey, higher Z) Scale bar 10microns   (see Table 5 for analyses)

ref	Na2O	MgO	Al_2O_3	SiO_2	P_2O_5	S	K_2O	CaO	TiO_2	V_2O_5	Cr_2O_3	MnO	FeO	CoO	NiO	CuO	BaO
incl 1	n.d.	0.1	n.d.	0.2	7.8	3.7	n.d.	n.d.	n.d.	0.1	n.d.	2.9	84.8	0.3	n.d.	0.1	0.1
incl 2	0.2	n.d.	n.d.	0.2	3.6	1.4	n.d.	n.d.	n.d.	n.d.	n.d.	3.0	91.3	0.5	n.d.	0.2	0.2
incl 3	0.1	0.1	0.1	n.d.	0.1	3.7	n.d.	0.1	n.d.	n.d.	n.d.	2.1	92.9	0.6	0.1	0.1	0.1
incl 4	0.7	0.1	0.2	1.0	0.6	n.d.	0.1	0.3	n.d.	n.d.	0.1	n.d.	95.0	0.9	n.d.	1.2	0.1
incl 5	0.1	0.9	2.4	36.2	0.4	0.2	2.7	4.9	0.1	n.d.	0.1	8.0	44.0	0.1	0.1	n.d.	n.d.
incl 6	0.1	0.9	2.4	36.2	0.4	0.2	2.7	4.9	0.1	n.d.	0.1	8.0	44.0	0.1	0.1	n.d.	n.d.
incl 7	0.2	0.9	2.5	36.4	0.5	0.3	2.7	4.6	0.2	n.d.	0.1	7.6	43.9	0.3	n.d.	n.d.	n.d.
incl 8	0.2	0.8	2.9	37.2	0.6	0.5	3.1	4.9	0.2	n.d.	n.d.	7.9	41.9	0.3	n.d.	n.d.	n.d.
incl 9	0.3	1.0	2.8	35.2	0.8	0.4	2.4	4.6	n.d.	0.1	0.1	7.4	44.3	0.3	n.d.	0.2	0.1
incl 10	0.2	1.1	2.4	35.2	0.7	0.2	2.5	4.4	0.2	n.d.	n.d.	7.5	45.4	0.2	n.d.	0.2	n.d.
incl 11	0.2	0.8	2.1	27.1	1.1	0.4	2.3	4.0	0.1	0.1	n.d.	7.3	54.0	0.5	0.1	0.1	n.d.
incl 12	n.d.	n.d.	n.d.	8.5	0.9	1.1	n.d.	n.d.	n.d.	n.d.	n.d.	2.2	87.0	0.3	0.1	0.2	n.d.
incl 13	0.4	1.0	3.0	37.4	2.1	1.9	3.1	4.8	0.2	n.d.	n.d.	8.0	37.8	0.3	0.2	n.d.	n.d.
incl 14	0.2	1.0	2.6	36.6	1.2	1.3	2.8	4.7	0.1	n.d.	n.d.	7.8	41.5	0.3	n.d.	n.d.	0.2
incl 15	0.3	1.0	2.7	35.0	1.7	1.5	2.7	4.5	n.d.	n.d.	n.d.	7.6	42.7	0.2	0.2	n.d.	0.2
incl 16	0.1	1.1	2.9	39.8	0.8	0.7	3.2	5.2	0.2	n.d.	n.d.	8.6	37.4	0.4	n.d.	n.d.	n.d.
incl 17	0.3	1.0	2.9	40.1	1.0	1.0	3.2	5.2	0.1	n.d.	n.d.	8.1	36.4	0.4	n.d.	0.1	0.2
incl 18	n.d.	0.1	n.d.	0.1	0.4	0.3	n.d.	n.d.	n.d.	n.d.	n.d.	2.2	96.7	0.6	n.d.	n.d.	0.1
incl 19	0.1	0.1	n.d.	0.1	1.1	1.9	n.d.	n.d.	n.d.	n.d.	n.d.	3.1	93.4	0.7	n.d.	n.d.	n.d.
incl 20	n.d.	0.1	n.d.	0.1	3.7	2.5	n.d.	n.d.	n.d.	0.1	n.d.	3.4	89.4	0.6	n.d.	0.2	0.1
incl 21	0.1	n.d.	0.1	0.3	2.8	7.6	n.d.	n.d.	n.d.	n.d.	0.1	2.4	86.4	0.4	n.d.	0.2	n.d.
incl 22	0.1	n.d.	n.d.	0.2	1.5	7.9	n.d.	n.d.	n.d.	0.1	n.d.	1.9	87.6	0.6	n.d.	0.2	0.1
mean	0.2	0.5	1.5	20.1	1.5	1.8	1.5	2.6	0.1	0.1	0.1	5.3	64.4	0.4	0.1.	0.1	0.1

Table 1 Sample MSG 895 slag inclusion analyses (weight%), n.d. - not detected

Ref	Na2O	MgO	Al_2O_3	SiO_2	P_2O_5	S	K_2O	CaO	TiO_2	V_2O_5	Cr_2O_3	MnO	FeO	CoO	NiO	CuO	BaO
incl 1	0.2	0.3	1.0	6.1	0.7	0.3	0.7	1.5	0.0	0.1	0.0	0.7	87.9	0.6	0.1	0.0	0.2
incl 2	0.2	0.6	3.6	25.5	5.5	0.8	2.0	2.8	0.2	0.0	0.0	2.0	56.5	0.2	0.1	0.1	0.0
incl 3	0.2	0.6	2.9	18.0	1.7	0.6	0.9	1.8	0.0	0.0	0.0	1.5	71.5	0.6	0.0	0.0	0.1
incl 4	0.1	0.7	3.7	26.0	0.3	0.1	1.9	2.9	0.2	0.1	0.0	2.3	61.5	0.4	0.0	0.2	0.0
incl 5	0.0	1.0	5.0	35.8	0.6	0.0	2.8	4.1	0.2	0.0	0.0	2.7	47.6	0.4	0.0	0.0	0.1
incl 6	0.2	0.8	5.0	35.3	1.0	0.1	3.0	3.7	0.1	0.0	0.0	3.0	47.2	0.3	0.3	0.2	0.0
incl 7	0.2	0.7	3.7	25.9	1.4	0.2	1.9	3.1	0.0	0.0	0.0	2.0	60.2	0.5	0.1	0.1	0.0
incl 8	0.2	0.7	4.8	31.9	1.2	0.1	2.3	3.7	0.0	0.0	0.1	2.7	52.0	0.5	0.0	0.0	0.0
incl 9	0.1	1.0	4.9	31.1	1.1	0.1	2.9	3.8	0.2	0.0	0.0	2.6	52.2	0.3	0.0	0.0	0.0
incl 10	0.5	0.8	5.0	33.4	1.7	0.3	2.6	3.8	0.1	0.0	0.0	2.7	48.7	0.2	0.1	0.0	0.3
incl 11	0.0	0.7	5.4	36.5	1.1	0.1	3.0	5.0	0.0	0.0	0.0	2.9	44.7	0.3	0.0	0.0	0.4
incl 12	0.0	0.7	4.3	28.4	0.8	0.1	2.3	3.4	0.1	0.1	0.0	2.6	56.9	0.5	0.0	0.0	0.0
incl 13	0.6	0.3	0.2	0.7	0.2	0.5	0.0	1.0	0.0	0.0	0.0	0.0	95.9	0.5	0.1	0.2	0.3
incl 14	0.2	0.8	4.1	28.6	0.6	0.3	2.3	3.1	0.1	0.1	0.0	2.4	56.6	0.6	0.2	0.1	0.0
incl 15	0.2	0.6	2.7	22.1	1.7	0.2	1.3	1.8	0.0	0.2	0.1	3.2	65.6	0.3	0.0	0.0	0.2
incl 16	0.6	0.4	0.0	0.2	0.0	0.3	0.0	0.8	0.0	0.0	0.0	0.0	97.0	1.0	0.2	0.0	0.0
incl 17	0.4	0.7	3.9	28.8	0.6	0.2	2.3	3.3	0.2	0.1	0.1	2.4	56.8	0.4	0.0	0.1	0.0
	0.2	0.7	3.5	24.4	1.2	0.3	1.9	2.9	0.1	0.0	0.0	2.1	62.3	0.4	0.1	0.0	0.1

Table 2 Sample MSG 2177 slag inclusion analyses (weight%) n.d. - not detected

Ref	Na2O	MgO	Al_2O_3	SiO_2	P_2O_5	S	K_2O	CaO	TiO_2	V_2O_5	Cr_2O_3	MnO	FeO	CoO	NiO	CuO	BaO
incl 1	n.d.	2.4	1.9	27.1	0.1	n.d.	1.2	2.5	n.d.	n.d.	n.d.	6.2	58.0	0.3	n.d.	n.d.	0.3
incl 2	0.2	2.4	2.0	29.8	n.d.	0.1	1.3	2.7	n.d.	0.1	n.d.	6.8	54.2	0.6	n.d.	n.d.	
incl 3	0.2	4.0	0.5	33.5	0.1	n.d.	0.2	1.4	n.d.	n.d.	n.d.	8.9	51.1	0.4	0.1	n.d.	n.d.
incl 4	0.5	1.5	4.7	36.7	0.4	n.d.	2.4	6.3	n.d.	0.2	n.d.	8.2	38.8	0.1	0.1	0.1	0.3
incl 5	0.4	1.4	3.9	35.1	0.3	0.3	2.7	4.5	0.2	n.d.	n.d.	6.3	44.8	0.3	n.d.	n.d.	n.d.
incl 6	0.2	1.2	4.1	32.2	0.3	n.d.	2.5	4.3	n.d.	0.1	n.d.	6.1	48.5	0.3	0.1	n.d.	0.3
incl 7	0.4	1.4	4.7	38.0	0.4	0.1	3.1	5.0	n.d.	0.1	n.d.	6.7	39.8	0.3	n.d.	n.d.	0.2
incl 8	0.3	1.3	4.5	35.4	0.6	n.d.	2.8	4.8	0.3	n.d.	n.d.	6.5	43.5	0.2	n.d.	0.2	n.d.
incl 9	0.3	1.2	4.9	38.1	0.3	0.1	3.4	5.0	0.2	n.d.	n.d.	6.4	40.1	0.2	n.d.	n.d.	0.1
incl 10	0.4	1.1	5.0	34.9	0.4	0.1	3.0	5.2	0.1	0.1	n.d.	5.5	43.9	0.1	n.d.	n.d.	0.3
incl 11	0.3	1.4	3.6	31.4	0.2	0.3	2.1	4.1	0.2	n.d.	n.d.	6.1	50.7	0.1	n.d.	n.d.	n.d.
incl 12	0.2	1.5	4.1	34.3	0.4	0.3	2.5	4.7	0.2	n.d.	n.d.	6.6	45.0	0.5	n.d.	n.d.	n.d.
incl 13	0.1	1.1	3.4	29.7	0.4	0.2	1.7	3.7	0.2	n.d.	n.d.	7.3	52.1	0.3	0.1	n.d.	n.d.
incl 14	n.d.	n.d.	n.d.	25.8	0.3	0.3	0.1	0.1	0.1	n.d.	n.d.	14.1	59.0	0.2	0.1	n.d.	0.1
incl 15	0.3	1.1	3.7	30.9	0.8	0.3	2.0	4.1	0.2	n.d.	n.d.	6.0	50.4	0.4	0.1	n.d.	0.1
incl 16	0.1	1.1	2.9	26.6	0.6	0.3	1.7	2.9	0.1	0.1	n.d.	5.3	57.6	0.7	0.1	n.d.	0.1
incl 17	0.2	1.3	4.3	36.8	0.3	0.2	2.7	4.9	0.2	n.d.	n.d.	6.4	41.9	0.5	0.1	0.2	0.1
incl 18	0.4	1.5	4.5	36.7	0.4	0.2	2.7	4.5	n.d.	0.1	n.d.	6.5	42.2	0.4	n.d.	n.d.	0.1
incl 19	0.5	1.2	3.4	30.9	0.2	0.2	2.0	3.8	0.2	n.d.	n.d.	6.1	51.1	0.4	n.d.	n.d.	0.1
incl 20	0.1	1.3	3.5	30.9	0.4	0.2	1.9	3.7	0.2	0.2	n.d.	6.2	51.6	0.3	n.d.	n.d.	n.d.
incl 21	0.5	1.1	4.1	32.4	0.5	0.1	3.0	4.8	0.1	n.d.	n.d.	6.4	46.6	0.4	n.d.	n.d.	0.1
incl 22	0.3	1.5	4.7	38.0	0.2	0.1	3.1	4.7	n.d.	n.d.	n.d.	6.1	41.1	0.2	n.d.	n.d.	0.4
incl 23	0.4	1.0	4.2	33.4	0.3	0.3	2.5	4.5	0.1	n.d.	n.d.	5.2	47.5	0.2	0.1	0.1	0.2
incl 24	0.3	1.3	4.4	36.7	0.3	0.3	2.8	4.6	n.d.	0.2	n.d.	6.4	42.4	0.2	0.1	n.d.	0.3
incl 25	0.3	1.2	4.4	36.9	0.1	0.2	2.8	4.9	0.1	n.d.	0.1	6.5	41.6	0.5	n.d.	0.1	0.3
incl 26	0.5	1.1	4.2	36.3	0.1	0.3	2.7	4.6	0.1	n.d.	n.d.	6.6	43.3	0.3	0.1	n.d.	n.d.
incl 27	0.3	1.1	3.0	24.6	1.2	0.2	2.3	3.7	n.d.	0.1	n.d.	6.7	56.5	0.1	n.d.	n.d.	0.2
incl 28	0.5	1.6	4.8	40.9	n.d.	0.1	3.4	5.2	0.2	0.1	0.1	8.1	34.8	0.2	n.d.	n.d.	0.1
incl 29	0.4	1.6	4.8	40.6	0.2	0.2	3.1	5.5	n.d.	n.d.	n.d.	7.9	35.5	0.2	n.d.	n.d.	0.2
incl 30	0.2	1.2	4.2	34.7	0.8	0.3	2.8	5.9	0.2	0.1	n.d.	7.4	42.0	0.3	n.d.	n.d.	0.2
	0.3	1.4	3.7	33.6	0.4	0.2	2.3	4.2	0.1	n.d.	n.d.	6.8	46.5	0.3	n.d.	n.d.	0.1

Table 3 Sample MSG 2190 slag inclusion analyses (weight%) n.d. - not detected

Ref	Na2O	MgO	Al_2O_3	SiO_2	P_2O_5	S	K_2O	CaO	TiO_2	V_2O_5	Cr_2O_3	MnO	FeO	CoO	NiO	CuO	BaO
incl1	0.2	2.5	8.3	57.1	0.2	0.0	6.6	9.7	0.6	0.0	0.0	3.3	11.4	0.1	0.0	0.1	0.0
incl 2	0.3	2.3	7.0	47.8	0.0	0.2	5.5	8.9	0.1	0.0	0.2	4.0	23.4	0.0	0.1	0.0	0.4
incl 3	0.9	0.3	0.2	0.9	0.4	0.3	0.2	1.2	0.0	0.0	0.0	0.1	94.6	0.8	0.0	0.1	0.0
incl 4	0.3	2.6	8.6	52.5	0.2	0.2	5.8	9.2	0.3	0.0	0.1	2.5	17.4	0.2	0.0	0.0	0.1
incl 5	0.3	0.2	0.6	5.2	0.4	0.1	0.7	1.2	0.0	0.0	0.0	0.6	89.3	0.7	0.1	0.6	0.1
incl 6	0.3	0.2	0.6	5.2	0.4	0.1	0.7	1.2	0.0	0.0	0.0	0.6	89.3	0.7	0.1	0.6	0.1
incl 7	0.3	0.2	0.6	5.2	0.4	0.1	0.7	1.2	0.0	0.0	0.0	0.6	89.3	0.7	0.1	0.6	0.1
incl 8	0.4	1.1	3.2	24.8	0.7	0.3	3.1	3.6	0.0	0.0	0.1	2.7	59.1	0.4	0.1	0.1	0.2
incl 9	0.4	1.6	5.2	35.7	2.0	0.5	4.5	5.7	0.2	0.0	0.0	3.6	40.6	0.1	0.0	0.0	0.2
incl 10	0.4	1.5	5.2	35.7	1.2	0.4	4.4	5.4	0.2	0.0	0.0	3.6	41.8	0.1	0.0	0.0	0.2
incl 11	0.2	1.3	4.5	30.3	3.0	0.5	4.3	5.1	0.1	0.0	0.0	4.0	46.2	0.3	0.0	0.1	0.0
incl 12	0.8	0.2	0.1	0.9	0.2	0.2	0.3	1.0	0.0	0.1	0.1	0.0	95.1	0.9	0.2	0.3	0.1
incl 13	0.3	2.2	7.9	55.8	0.2	0.1	7.2	8.9	0.4	0.0	0.0	3.5	13.5	0.0	0.0	0.0	0.2
incl 14	0.3	2.8	10.1	33.4	1.9	0.4	2.8	11.1	0.3	0.1	0.0	3.0	33.2	0.2	0.0	0.0	0.3
incl 15	0.2	2.8	9.7	33.3	2.9	0.4	2.7	10.9	0.3	0.0	0.0	3.2	33.6	0.1	0.0	0.0	0.2
incl 16	0.4	1.6	5.0	35.4	0.8	0.0	4.3	5.4	0.2	0.1	0.1	3.7	42.6	0.3	0.0	0.0	0.2
incl 18	0.3	1.3	11.2	62.1	0.1	0.0	3.4	7.9	0.5	0.0	0.0	3.0	10.2	0.0	0.0	0.0	0.3
incl 19	0.2	1.7	4.6	24.7	0.2	0.1	3.7	4.2	0.4	0.0	0.1	0.5	59.7	0.2	0.1	0.0	0.0
incl 20	0.1	1.1	3.1	18.3	0.3	0.0	2.4	3.2	0.1	0.0	0.0	0.6	70.2	0.5	0.1	0.0	0.0
incl 21	0.0	0.6	1.8	14.4	0.2	0.1	1.9	2.6	0.0	0.1	0.1	0.8	76.9	0.5	0.2	0.0	0.1
incl 22	0.0	0.0	0.4	2.5	0.2	0.1	0.5	0.5	0.0	0.0	0.0	0.0	95.3	0.4	0.0	0.1	0.0
incl 23	0.0	0.6	2.0	13.2	0.3	0.1	2.1	3.0	0.1	0.0	0.0	0.6	77.8	0.4	0.0	0.1	0.0
incl 24	0.3	0.3	0.1	1.8	0.3	0.3	0.1	1.7	0.1	0.0	0.2	0.1	94.3	0.7	0.1	0.1	0.0
incl 25	0.3	1.9	7.0	48.9	0.8	0.3	5.8	7.9	0.5	0.1	0.0	2.2	24.6	0.2	0.0	0.0	0.0
mean	0.3	1.3	4.5	26.9	0.7	0.2	3.1	5.0	0.2	0.0	0.0	2.0	55.4	0.3	0.0	0.1	0.1

Table 4 Sample MSG 2461 slag inclusion analyses (weight%) n.d. - not detected

	Na2O	MgO	Al_2O_3	SiO_2	P_2O_5	S	K_2O	CaO	TiO_2	V_2O_5	Cr_2O_3	MnO	FeO	CoO	NiO	CuO	BaO
incl1 core	0.2	2.5	8.3	57.1	0.2	n.d.	6.6	9.7	0.6	n.d.	n.d.	3.3	11.4	0.1	n.d.	0.1	n.d.
incl1 rim	0.4	0.5	2.1	11.7	n.d.	0.2	1.0	1.4	0.3	n.d.	n.d.	0.3	81.9	0.5	n.d.	0.2	n.d.

Table 5 EM EDS analysis of the core and rim of Inclusion 1 in Sample MSG 2461 (weight %)

MSG	Original/Repair	MgO/K_2O	SiO_2/MnO	Al_2O_3/SiO_2	Al_2O_3/MgO	Al_2O_3/K_2O	Al_2O_3/CaO
895	O	0.75	2.71	0.27	1.69	1.36	0.40
2177	O	3.07	10.19	0.14	5.01	1.99	1.11
2190	R	1.29	5.08	0.11	2.89	1.59	0.84
2461	R	0.59	17.39	0.15	3.15	1.31	0.73

Table 6 Ratio's of oxides

		MnO
Tap Slag	MSG707	0.3
Tap Slag	MSG1175	0.1
Type 2 Slag	MSG707	0.2
Type 2 Slag	MSG1175	0.2
Furnace Slag	MSG1175	0.2
original nail	MSG895	5.3
original nail	MSG2177	2.1
repair spike	MSG2190	6.8
repair spike	MSG2461	2.0

Table 7 Comparison of the mean values of MnO derived from the slag and the inclusion analyses

Report on the X-ray Fluorescence Analysis of the Copper Alloy Metal from the Newport Ship

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For: Toby Jones, Newport Ship Project

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Monday, 26th September 2011

1. Introduction

The non-ferrous artefacts recovered from the Newport Ship were analysed using hand-held x-ray fluorescence to determine the composition of the artefacts.

2. Methodology

The instrument used was a Bruker S1 Turbosdr hand-held XRF instrument operating at 40kV. Samples were analysed for 30 live seconds, the spectrum is stored and a normalised composition determined using a bespoke Bruker Fundamental Parameters Programme (FP). All elements heavier than calcium (Ca, Z=20), can be detected. The calculated two-sigma error on each element was calculated and overall shows values of the order of +/- 0.2%. The data was generated in a comma delimited file and then exported to an Excel spreadsheet, where the data was examined and relevant tables were generated. Brass may suffer de-zincification, i.e. loss of zinc, during the natural corrosion process in a burial environment. XRF is a surface technique (depth of penetration ~<10μm) hence the spectrum gained is dominated by the corrosion layer composition. Therefore, iron (Fe) is routinely detected but it derives from the corrosion layer. The value obtained for iron is included in the tables as an indicator of the degree of corrosion but is not included in the normalised totals. Therefore the data produced by XRF may under-estimate the Zinc (Zn) content of the alloy, but this cannot be quantified, but may of the order of 10%.

3. Results

Thirteen examples of copper alloy wire were analysed (Table 1), and the low iron content detected suggests minimum corrosion. The wires were either brasses (6 examples with Pb<0.5%) or leaded brasses (7 examples Pb>0.5%). The zinc content ranged from 17-26%, which assuming some de-zincification has occurred, probably rises to 25-30%. In modern brass wire technology the 70/30 (Cu/Zn) brass wire composition is noted for its colour and with addition of low levels of arsenic have enhanced corrosion resistance compared to other brass wires. This is not to suggest that the arsenic was deliberately added but its presence helped to preserve the wire. The addition of lead would be slightly detrimental if the wire was subjected to extensive cold working. This suggests that the leaded wires were drawn hot.

Two rods were analysed (Table 2), the first MSG 1075 showed a high iron content indicative of heavy corrosion, and was a low zinc brass, but the value of 6.5% is an underestimate due to de-zincification. The second rod, MSG 193, appeared to be made from two pieces of alloy, a central core with a sheath wrapped around the core. Two measurements were taken of the surface (Analyses Rod a and Rod b, Table 2), which was the sheath and showed that it was tin with a few per cent of copper and lead. The third analysis was of the end of the rod, to attempt to obtain most of the signal from the central core. This showed the analysis to contain tin and lead. This suggests that the copper formed the sheath, however this is uncertain and a metallographic section is the only way to resolve the manufacture of this rod.

One fragment of sheet alloy (MSG 1079) was analysed (Table 3), and shown to be brass with only minor levels of other elements present. The copper alloy helmet strips (MSG 171 and MSG 172 Table 4) were manufactured from brass containing a minor level of lead.

Seven coins were analysed, one the French Petit Blanc (MSG173) found in the keel was manufacture from a silver alloy containing, copper and low levels of tin and lead. One coin (MSG 182, a French Jetton) was manufactured from a brass. The other five coins were stamped from copper with traces of other lead e.g. As, and Pb. These included two other Ceitils of Alfonso the 6th (MSG 178 and MSG 180). These copper coins would be extremely soft.

Two lead artefacts were analyses, a sheet acting as a patch (MSG 183) and a weight (MSG 1118). The patch was made from pure lead Table 5). The weight had suffered significant corrosion or was in contact with iron artefacts as indicated by the iron content of the XRF analysis and was manufactured from a lead/tin alloy containing a low tin content.

4. Discussion

The wire fragments were manufactured from either brass or leaded brass. In modern leaded brass wire, the lead content does not exceed c. 3% as higher levels can cause failure when drawing due to the relative softness of the lead as it remains as isolated particles in the metal microstructure and this is reflected in the compositions of the leaded brass wire recovered from the ship. The c. 3% Pb level is a self-limiting higher percentage that enables the wire to be drawn. The wire composition is approximately 70/30 Cu/Zn and is the optimum for wire drawing. One rod (MSG 193) was manufactured in a complex way, presumably for a specific purpose, and requires further study to determine its function. The second rod (MSG 1075) was a low zinc brass, and was the most corroded of the brasses as indicated by the iron content (Table 6). The helmet strip was unleaded as expected but had a lower zinc content than the wire (Table 6), but the brass sheet contained a low zinc content (9.5%, Table 6). All the brasses did not contain alloying elements other than zinc and lead. The brass used to manufacture the French Jetton (MSG 182) was a high zinc brass with a minor lead content (0.5%). The results of the other coin analyses show that two of the Portuguese Ceitil coins (MSG 178 and MSG 180) are both effectively copper with minor alloy additions (As and Ag), which is not deliberate alloying and accords with other published data (Barrandon et al 1994). The lead weight was manufactured from a low tin/lead alloy and the patch was pure lead.

References

Jean-Noël Barrandon, J-N, Guerra, M.F., and Magro, F.A. 1994 Les ceitis portugais (XVe - XVIe siècles) : composition des alliages utilisés et problèmes numismatiques. *Revue Numismatique* Volume 6 Numéro 36 pp. 199-219

MSG Code	Type	Fe	Cu	Zn	As	Ag	Sn	Sb	Pb	Total
MSG 185	wire	0.7	75.0	21.5	0.3	0.2	0.2	n.d	2.8	100
MSG 186	wire	0.2	73.5	25.6	0.1	0.1	n.d	n.d	0.7	100
MSG 187	wire	0.3	73.3	25.4	0.1	0.1	n.d	n.d	1.1	100
MSG 188	wire	0.4	73.2	25.5	0.2	0.1	n.d	n.d	1.0	100
MSG 189	wire a	0.3	78.3	21.2	0.3	0.2	n.d	n.d	n.d	100
MSG 189	wire b	0.2	78.2	21.4	0.2	0.1	n.d	n.d	0.1	100
MSG 189	wire c	0.4	78.7	20.8	0.3	0.2	n.d	n.d	0.1	100
MSG 190	wire	0.2	73.2	26.3	0.1	0.2	n.d	n.d	0.2	100
MSG 195	wire a	0.7	79.6	17.8	n.d	0.1	n.d	n.d	2.5	100
MSG 195	wire b	0.7	80.7	17.2	n.d	0.1	n.d	n.d	2.1	100
MSG 195	wire c	0.6	78.4	19.5	n.d	0.0	n.d	n.d	2.0	100
MSG 196	wire a	0.4	75.2	23.8	0.3	0.3	n.d	n.d	0.4	100
MSG 196	wire b	0.4	77.5	21.9	0.2	0.3	n.d	n.d	0.1	100
Average		0.4	76.5	22.2	0.2	0.2	n.d	n.d	1.1	
Standard Deviation		0.2	2.7	3.0	0.1	0.1	n.d	n.d	1.0	
Max Value		0.7	80.7	26.3	0.3	0.3	0.2	n.d	2.8	
Min Value		0.2	73.2	17.2	0.1	n.d	0.2	n.d	0.1	

Table 1 XRF Analyse of Wire Samples (weight %)

MSG Code	Type	Fe	Cu	Zn	As	Ag	Sn	Sb	Pb	Total
MSG 193	rod	2.1	2.4	n.d	0.3	n.d	95.3	n.d	2.1	100
MSG 193	rod b	2.8	2.9	n.d	0.3	0.0	95.1	n.d	1.7	100
MSG 193	rod end on	5.5	0.3	n.d	n.d	0.1	95.0	0.5	4.1	100
MSG 1075	rod	11.7	92.5	6.5	0.5	0.4	n.d	n.d	0.1	100

Table 2 XRF analyses of the rod samples (weight %)

MSG Code	Type	Fe	Cu	Zn	As	Ag	Sn	Sb	Pb	Total
MSG 1079	sheet	2.6	89.4	9.5	0.5	0.3	n.d	n.d	0.3	100

Table 3 XRF analyses of the sheet (weight %)

MSG Code	Type	Fe	Cu	Zn	As	Ag	Sn	Sb	Pb	Total
MSG 171	front	0.6	79.9	19.7	n.d	0.1	n.d	n.d	0.3	100.0
MSG 171	rear	0.6	79.7	19.9	n.d	0.1	n.d	n.d	0.3	100.0
MSG 172	strip	1.2	80.8	18.9	n.d	0.1	n.d	n.d	0.3	100.0
MSG 175	helmet corr	89.3	57.7	26.5	0.1	2.0	6.0	7.7	0.1	100.0

Table 3 XRF analyses of the helmet strip and associated corrosion (weight %)

MSG Code	Type	Fe	Cu	Zn	As	Ag	Cd	Sn	Sb	Au	Pb	Bi	Total
MSG 173	coin	2.7	18.8	n.d	0.2	76.0	0.1	1.5	0.1	0.2	2.9	0.1	100
MSG 197	coin	0.1	98.6	n.d	0.7	0.3	n.d	n.d	0.3	n.d	0.1	n.d	100
MSG 178	coin	0.2	99.6	n.d	0.3	n.d	n.d	n.d	n.d	n.d	n.d	n.d	100
MSG 179	coin	0.3	98.6	n.d	0.6	0.5	n.d	n.d	0.1	n.d	0.2	n.d	100
MSG 180	coin	0.3	98.5	n.d	0.9	0.5	n.d	n.d	n.d	n.d	n.d	n.d	100
MSG 182	coin	0.1	73.1	26.2	0.1	0.1	n.d	n.d	n.d	n.d	0.5	n.d	100
MSG 181	coin	0.3	99.4	n.d	n.d	0.1	n.d	n.d	n.d	n.d	0.5	n.d	100
MSG 177	Cor. around coin	95.2	95.8	1.8	2.3	n.d	n.d	n.d	0.1	n.d	n.d	n.d	100

Table 4 XRF analyses of the coins and soil containing corrosion products associated with the coins (MSG177), (weight %)

MSG Code	Type	Fe	Cu	Zn	As	Ag	Sn	Sb	Au	Pb	Bi	total
MSG 183	Pb patch	0.4	n.d	n.d	0.6	n.d	0.2	n.d	0.5	98.5	0.1	100.0
MSG 1118	Pb weight	14.6	n.d	0.1	0.3	n.d	2.8	n.d	0.5	96.2	0.1	100.0

Table 5 XRF analyses of the lead artefacts (weight %)

	Fe	Cu	Zn	As	Ag	Sn	Sb	Pb
Brass Wire	0.3	76.9	22.6	0.2	0.2	n.d	n.d	0.1
Leaded Brass Wire	0.5	76.2	21.8	0.1	0.1	n.d	n.d	1.7
Brass Rod	11.7	92.5	6.5	0.5	0.4	n.d	n.d	0.1
Sheet	2.6	89.4	9.5	0.5	0.3	0.0	0.0	0.3
Helmet	0.8	80.1	19.5	n.d	0.1	n.d	n.d	0.3
Jetton Brass	0.1	73.1	26.2	0.1	0.1	n.d	n.d	0.5

Table 6 Average brass composition by artefact type (weight %)

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Report on the Analyses of the slags from the Newport Ship.

For: Toby Jones, Newport Ship Project

gerry mcdonnell archaeometals

Date: Friday, 2nd March 2012

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Report on the Analyses of the slags from the Newport Ship

1. Introduction

The slag was quantified by Scott (2010) and showed a total of 109 kg had been recovered. Of this total, 73.9kg was recovered from contexts outside the ship and interpreted as earlier than the ship, 3.8kg was recovered from within the ship and 22.9kg is regarded as having been deposited later than the ship. A further 6.7kg was regarded as unrelated to the ship or unstratified. The slag therefore represents activities in Newport predating the ship and post-dating it. The slag within the ship is enigmatic as it is unlikely to represent ironworking in the ship, e.g. repairing the ship. It may represent ballast and therefore it is important to understand what else was recovered from the interior contexts (Contexts: 120, 128, 130, 152 and 171). The slags were visually examined and a database created. Three distinct types of slag were identified, all were considered to be smelting slags. The majority (insert weight from database) was described as Tap Slag, this is the distinctive characteristic medieval iron smelting slag. It is characterised by a smooth ropey flowed upper surface, a fine grained fracture, often with vesicles of different sizes scattered throughout the slag section. The basal surface is normally fused droplets. The second morphological group described as Type 2, which lacks the ropey flowed texture, but is dense with a similar fracture to the Tap Slag. . The third type occurs as massive lumps and is described as Furnace Slag and is probably the slag left in the base of a furnace at the end of a smelting campaign. Five samples of slag were selected as representative samples of the material recovered from the excavation. Two samples (one sample of tap slag and one of Type 2 slag) were selected from MSG707, from the bow area of the ship. Three samples from MSG 1175 (one sample of tap slag, one of Type 2 slag and one sample of Furnace slag), were from beneath the ship. This report presents the results of the analyses of the samples

2. Methodology

A thick section was removed from each slag and mounted in Buehler VariDur 200 cold-setting resin. The mounted sample was ground on silicon carbide papers and polished to a one micron finish using Buehler diamond paste. They were briefly examined under a Leica Reflected Light Microscope to assess their mineralogy.

The samples were carbon coated and examined using a FEI Quanta 400 Scanning Electron Microscope under high vacuum using 20kV accelerating voltage, filament at saturation and a working distance of 11mm. Back Scattered Electron imaging was used to observe the samples providing enhanced atomic number (Z) contrast. Energy dispersive x-ray analysis was used to obtain quantitative elemental data from five randomly selected areas across the sample to provide bulk area compositions which were averaged. The areas were raster scanned at x400-x600 magnification, presenting an area approximately 0.5 x 0.5mm square. Individual phases were analysed in spot mode. Pure cobalt was used for spectrum calibration. The data was collected using Oxford Instruments Inca software, calculated as oxide values and normalised, and transferred into Microsoft Excel for manipulation. The results are presented to one decimal place and the error on most elements is c. 0.1%.

The morphology of each hand specimen is described, followed by a description of the mineral texture, i.e. the shape of the crystals present in the slag. The texture description is supported by the volumetric phase percentage of each of the phases. The bulk area and phase analyses are discussed.

3. Results

3.1. Sample MSG 707 Tap

A classic piece of flowed tap slag with a smooth ropey flowed upper surface, which has oxidised during cooling to produce a slight red colour to the surface. The basal surface is frozen droplets. In cross-section the slag is black in colour and highly vesicular towards the upper surface. The polished section (Plate 1) showed blocky silicate (70%) with globular iron oxide (12%) and some eutectic iron oxide in a glassy matrix (18%). The area bulk analyses (Table 1) show the slag is dominated by silica and iron oxide, all other oxides being low. In particular the phosphorus pentoxide and manganese oxide levels are low. The silicate phase (Table 2) is also relatively rich in silica and has minor levels of magnesia (MgO) and lime (CaO) substituted in the structure. The glass phase (Table 2) is rich in silica, alumina, potash and lime. Two iron oxide dendrites were analysed the first showing elevated levels of alumina and titania indicating a spinel (magnetite) structure.
The analyses of Sample MSG 707 Tap show that the slag derived from an efficient process, the mineral texture indicates a relatively fast cooling regime for the slag.

3.2. Sample MSG 707 Type 2

A rounded nodule of slag with granulated surfaces. There is no apparent upper or lower surfaces. In cross-section the slag is black in colour with some vesicularity present. The mounted section (Plate 2) displays a blocky to massive silicate microstructure (71%) with globular dendritic free iron oxide (17%) in a glassy matrix (12%). The bulk area analyses (Table 3) show the slag is dominated by the silica and iron oxide, all other oxides being low. In particular the phosphorus pentoxide and manganese oxide levels are low. The silicate phase (Table 4) is also relatively rich in silica and has minor levels of magnesia (MgO) and lime (CaO) substituted in the structure. The glass phases (Table 4) are rich in silica, alumina, potash and lime. Three iron oxide dendrites were analysed and are relatively clean with very minor level of alumina and titania.
The slag derives from a reasonably efficient iron smelting process, as indicated by c. 17% free iron oxide remaining in the slag. The variation in the microstructure and the morphology of the silicate indicates a relatively slow cooling rate, slower than the tap slag.

3.3. Sample MSG 1175 Tap

A classic piece of flowed tap slag, c 40mm thick, with a smooth ropey flowed upper surface., and with a basal surface formed by frozen droplets. Trapped in the basal surface are iron corrosion products, either derived from prills entrapped within the slag or from contact with metal during the tapping process. In cross-section the slag is black in colour and highly vesicular towards the upper surface. The polished section showed blocky silicate (59%) with globular iron oxide (21%) in a glassy matrix (20%). Occasional iron prills are present (Plate 3). The area bulk analyses (Table 5) show the slag is dominated by the silica and iron

oxide, with minor levels of magnesia, alumina and lime. In particular the phosphorus pentoxide and manganese oxide levels are low. Under Electron Back Scattered imaging (Plate 4) the silicate phase shows zoning (coring) during crystallisation with edges of the silicate phase lighter than the initial crystallised core of the crystal. This should indicate that the core has a lower mean atomic number (Z Number) than the periphery, which is confirmed by the phase analyses (Table 6). These analyses show that the darker silicate zone is richer in magnesia (MgO) and lower in iron oxide (FeO) than the lighter zones. Overall the silicate is dominated by the silica and iron oxide with substitution of magnesia and a little lime.
The glass phase (Table 7) is rich in silica, alumina, potash and lime. Two iron oxide dendrites were analysed (Table 8) the first showing elevated levels of alumina and titania indicating a spinel (magnetite) structure. Two metal prills were analysed (Table 9) and show that all other elements other than iron were measured at detectable levels. In particular although Prill 2 presents phosphorus at 0.1% examination of the spectrum suggest it was present at levels lower than this and was calculated as n.d.8% +/- n.d.7%. This strongly argues that the product of the smelting slag was ferritic iron.
The analyses of Sample MSG 1175 Tap show that the slag derived from an efficient process. The mineral texture indicates a relatively fast cooling regime for the slag.

3.4. Sample MSG 1175 Type 2

The sample is an irregular shaped lump that appears to be a slag frozen in a channel. The slag lacks smooth flowed surfaces and has the morphology of fused droplets, possibly from the freezing of a viscous slag. The cross-section is highly vesicular and grey in colour. The polished section displayed a varied microstructure (Plate 5); the silicate laths occurred as either laths or blocky laths (59%) in a glassy matrix (41%). There was no free iron oxide and occasional iron prills were present. The bulk area analyses (Table 10) show that the slag contains significant magnesia, alumina and lime contents. The analyses of the silicate phase (Table 11) show zoning in the silicate with the darker zones enriched in magnesia and depleted in iron oxide. The glass phase (Table 12) is typically rich in the alkali oxides. The analysis of a single metal prill (Table 13) again shows no significant alloying element and examination of the phosphorus level indicate a level c. n.d.5% maximum.

Overall the slag is silica rich with a mineral texture indicative of relatively fast cooling, but the slag lacks the morphology associated with such a microstructure, i.e. free flowing fast cooling tap slag.

3.5. Sample MSG 1175 Furnace Slag

A large lump of slag some 30cms in diameter with a curved surface indicating that the slag was attached to the furnace wall or base. One corner of the slag was sectioned. The microstructure (Plate 6) was dominated by massive silicate (66%) with globular dendritic iron oxide (19%) in a glassy matrix (16%). The bulk analyses (Table 14) show minor levels of magnesia, alumina and lime. The silicate phase analyses (Table 15) show low levels of magnesia and a little lime substituting in the microstructure. The glass phases (Table 16) show typical range of alkali oxides, and some iron oxides show elevated levels of silica, alumina and titania (Table 17). Another mineral hercynite was also identified in images (Plate 7, Table 18). In some areas another phase was identified (Plate 8) and analyses (Table 19) show that phase is rich in iron oxide and lime and probably derives from the clay lining of the furnace.

The mineral texture is consistent with a slow cooled slag and the presence of an 'exotic' mineral probably derives from unreacted clay in the furnace lining.

4. Discussion

The slag samples selected were representative of the Newport Ship assemblage. Two samples of tap slag were examined which displayed the characteristic features this type of slag in particular the smooth ropey flowed upper surface and the fused droplets forming the basal surface. The second morphological group appeared to be a more viscous slag, lacking the flowed surfaces and having an agglomerated texture. The third type was described as a furnace slag and probably derived from slag cooled within the furnace. The curvature of the piece suggests that it derived from the furnace wall or base. The mineral texture of the slags are compared in Table 20, and show that there are no significant differences between the types of slag, there appears to be more differences between the slags found in different context. MSG 707 derived from the bow area and MSG1175 from beneath the boat. It is therefore possible they represent two phases of deposition. The bulk analyses are summarised in Table 21 and the results show that all slag samples display low manganese oxide and phosphorus pentoxide values. This demonstrates that the ores used were low in manganese oxide and low or relatively low in phosphorus. The slags are low in magnesia alumina potash and lime, however the data indicates that the tap slag and Type 2 slag from MSG1175 are slightly richer in these oxides compared to the samples from MSG707. The Furnace Slag (MSG 1175 Furnace Slag) bulk analysis is slightly enriched in oxides derived from the lining e.g. alumina and lime, in particular lime due to the presence of the lime/iron oxide phase. The silicate phase analyses (Table 22) show that all the slags have some substitution of magnesia and lime into the silicate phase. Again it is noticeable that the samples from MSG707 and MSG1175 do differ in the level of these oxides, MSG1175 being slightly greater than MSG707. The iron oxides show some substitution of other elements but no pattern is apparent (Table 23). The glass phases analyses (Table 24) reflect the differences in the bulk analyses between MSG707 and MSG1175, with the glass phases in both samples from MSG1175 lower in alumina and potash, but higher in lime compared to those from MSG707.

The analyses of the slag samples from the Newport Ship are consistent with the smelting of ores from the Bristol Channel region (Thomas 2000, 54), which are characterised by low phosphorus and low manganese. These data provide a bench mark for comparison with slag inclusion data derived from the nail analyses. Furthermore the analyse of the metal prills within the slag show the metal produced was low in phosphorus.

5. Conclusions

The analyses of slag samples from the Newport Ship are consistent with exploitation of ores from the Bristol Channel Region. The ores were low in manganese and the phosphorus, hence it can be argued that one of the nails from the repair (MSG 2461) which includes phosphoric iron was not locally manufactured. The other three nails from the repair section could be of local manufacture based on the metallography and the absence of phosphoric iron in those nails. The iron smelting technology used in the generation of the slags is of reasonable efficiency but is not of the highest quality, i.e. in three of the four tap or Type 2 slags free iron oxide remained in the slag that was available for reduction. The microstructure of the slags was variable e.g. one sample contained no free iron oxide (MSG1175 Type 2) and one contained hercynite and an odd lime/iron oxide phase (MSG1175 Furnace slag). Although two tap slag samples were sectioned and the morphology of these slags was typical, their mineral texture was of slower cooling slags because they lacked the long thin lath silicate crystals typical of fast cooling slags.

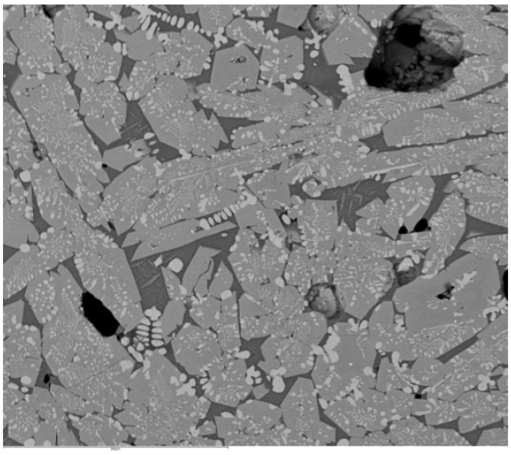


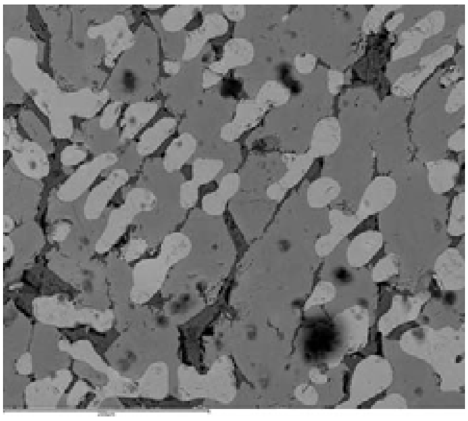
Plate 1 Back Scattered Electron Image of Sample MSG707 Tap Bulk Area 2, light grey - silicate; dark grey - glass phase with fine crystalites present. Scale Bar 20microns, approximate WoF=470microns.

	Area 1	Area 2	Area 3	Area 4	Area 5	Mean
Na_2O	0.3	0.5	0.1	0.4	0.5	0.4
MgO	1.2	1.3	1.5	1.0	0.5	1.1
Al_2O_3	3.8	4.6	3.3	4.8	6.9	4.7
SiO_2	27.5	27.5	27.3	27.7	28.8	27.7
P_2O_5	0.3	0.2	0.1	0.5	0.2	0.2
S	0.2	0.2	0.1	0.1	0.2	0.2
K_2O	0.9	1.1	0.7	1.2	1.7	1.1
CaO	1.4	1.9	1.2	2.0	2.8	1.9
TiO_2	0.2	0.2	0.1	n.d.	0.1	0.1
V_2O_5	n.d.	n.d.	n.d.	0.1	n.d.	n.d.
Cr_2O_3	n.d.	n.d.	n.d.	0.1	0.1	n.d.
MnO	0.2	0.3	0.3	0.5	0.2	0.3
FeO	63.7	62.0	65.4	61.4	57.5	62.0
CoO	0.5	0.3	0.4	0.2	0.3	0.3
NiO	n.d.	n.d.	n.d.	n.d.	0.1	n.d.
CuO	n.d.	0.1	n.d.	0.1	n.d.	n.d.
BaO	n.d.	n.d.	n.d.	0.1	0.2	0.1
	100.3	100.2	100.2	100.1	100.1	100.2

Table 1 Bulk Area Analyses of Sample MSG707 Tap (oxide weight %)

	area 6 silicate 1	area 6 glass 1	area 6 FeOx	Area 6 FeOx 2
Na_2O	n.d.	1.9	0.2	0.3
MgO	2.0	0.1	0.1	0.4
Al_2O_3	0.1	21.8	1.4	0.7
SiO_2	31.1	37.2	0.4	2.0
P_2O_5	n.d.	0.9	n.d.	0.1
S	0.1	0.3	n.d.	0.1
K_2O	n.d.	5.8	n.d.	n.d.
CaO	0.6	7.5	0.1	n.d.
TiO_2	n.d.	0.1	0.5	0.2
V_2O_5	n.d.	n.d.	0.1	0.2
Cr_2O_3	n.d.	n.d.	0.2	0.1
MnO	0.3	0.2	n.d.	n.d.
FeO	65.6	23.5	96.7	95.3
CoO	0.5	0.2	0.3	0.3
NiO	n.d.	0.1	n.d.	0.2
CuO	n.d.	n.d.	0.1	n.d.
BaO	n.d.	0.5	0.1	0.3

Table 2 Phase Analyses of Sample MSG707 Tap (oxide weight %)



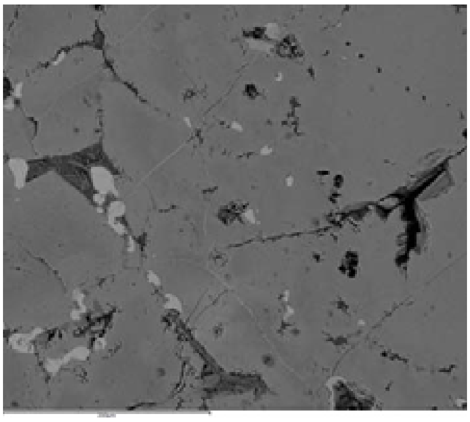


Plate 2 SEM BSE image of sample MSG707 Type 2 Area 3 (left) and Area 4 (right). White - free iron oxide; light grey - silicate laths; dark grey - glass. Scale 400 microns, WoF~900 microns

	Area 1	Area 2	Area 3	Area 4	Area 5	Mean
Na_2O	0.3	0.4	0.4	0.2	0.4	0.3
MgO	1.8	2.9	2.2	4.0	2.2	2.6
Al_2O_3	3.4	0.9	3.1	1.2	2.9	2.3
SiO_2	22.2	26.8	24.9	31.8	25.1	26.1
P_2O_5	n.d.	n.d.	0.2	n.d.	0.1	n.d.
S	0.1	0.1	n.d.	0.1	0.1	0.1
K_2O	1.4	0.2	0.8	0.1	0.7	0.6
CaO	0.7	1.2	1.9	1.4	1.3	1.3
TiO_2	0.2	0.1	0.1	0.1	0.1	0.1
V_2O_5	0.2	n.d.	0.1	0.1	0.1	0.1
Cr_2O_3	n.d.	0.1	n.d.	n.d.	n.d.	n.d.
MnO	0.1	0.3	0.2	0.2	0.2	0.2
FeO	69.9	67.1	65.8	60.9	66.0	65.9
CoO	0.1	0.3	0.4	0.2	0.4	0.3
NiO	n.d.	n.d.	n.d.	n.d.	0.1	n.d.
CuO	n.d.	0.1	n.d.	0.2	0.2	0.1
BaO	n.d.	n.d.	0.1	n.d.	0.2	0.1
	100.3	100.2	10n.d.	100.3	10n.d.	100.2

Table 3 Bulk area analyses of Sample MSG707 Type 2 (oxide weight %)

	Area 6 silicate	Area7 Silicate	Area 6 FeOx	Area 6 FeOx 2	Area 7 Feox	Area 6 glass	Area 7 Glass
Na_2O	0.3	0.1	0.1	0.5	0.1	2.5	2.0
MgO	2.2	6.2	0.2	0.3	n.d.	0.1	n.d.
Al_2O_3	0.1	n.d.	1.0	0.6	0.2	17.5	23.2
SiO_2	31.2	32.9	0.6	0.6	1.5	44.7	40.8
P_2O_5	0.1	0.1	0.3	n.d.	0.1	0.4	0.6
S	n.d.	n.d.	n.d.	0.5	0.4	0.2	0.3
K_2O	n.d.	n.d.	n.d.	0.1	n.d.	11.9	8.6
CaO	1.1	0.6	n.d.	0.2	0.1	0.4	10.5
TiO_2	n.d.	n.d.	0.4	0.5	n.d.	0.3	0.2
V_2O_5	0.1	0.1	n.d.	n.d.	n.d.	n.d.	n.d.
Cr_2O_3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.1
MnO	0.2	0.1	n.d.	0.1	0.1	0.1	n.d.
FeO	64.1	60.1	96.6	96.8	97.0	22.3	13.6
CoO	0.3	n.d.	0.6	0.4	0.5	n.d.	0.1
NiO	0.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
CuO	0.2	n.d.	n.d.	0.1	0.1	n.d.	0.1
BaO	0.1	0.2	0.1	n.d.	0.2	0.1	0.2

Table 4 Phase analyses of Sample MSG707 Type 2 (oxide weight %)

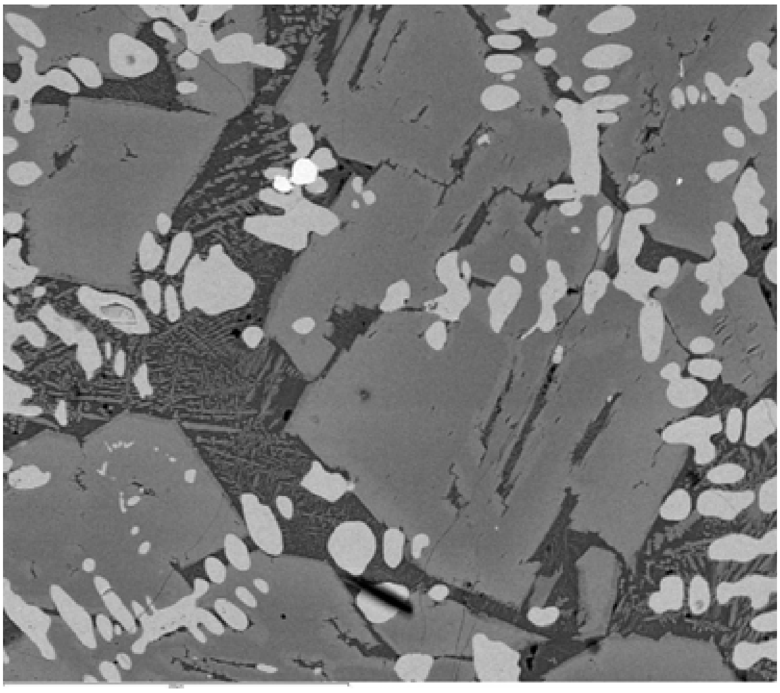


Plate 3 SEM BSE image of sample MSG1175 Tap Area 4. Bright white (top centre, metallic prill; White - free iron oxide; light grey - silicate laths; dark grey - glass. Scale 400 microns, WoF~900 microns

	Area 1	Area 2	Area 3	Area 4	Area 5	Mean
Na_2O	0.5	0.3	0.4	0.5	0.5	0.5
MgO	3.0	3.4	3.2	3.3	3.6	3.3
Al_2O_3	5.7	5.1	5.4	4.7	4.1	5.0
SiO_2	28.5	27.3	27.9	27.4	23.6	27.0
P_2O_5	0.2	0.1	0.2	n.d.	n.d.	0.1
S	n.d.	0.2	0.1	0.3	0.1	0.1
K_2O	1.1	1.1	1.1	1.0	0.8	1.0
CaO	5.7	4.8	5.2	4.9	4.0	4.9
TiO_2	0.4	n.d.	0.2	n.d.	0.1	0.1
V_2O_5	n.d.	0.1	n.d.	n.d.	n.d.	n.d.
Cr_2O_3	0.1	n.d.	0.1	n.d.	0.1	0.1
MnO	0.2	0.1	0.1	0.2	0.2	0.1
FeO	54.5	56.9	55.7	56.8	62.3	57.3
CoO	n.d.	0.3	0.1	0.5	0.2	0.2
NiO	n.d.	n.d.	n.d.	0.1	n.d.	n.d.
CuO	n.d.	n.d.	n.d.	n.d.	0.1	n.d.
BaO	0.3	0.4	0.3	0.5	0.3	0.4
	100.1	100.1	100.1	100.2	10n.d.	100.1

Table 5 Bulk area analyses of sample MSG1175 Tap (weight % oxide)

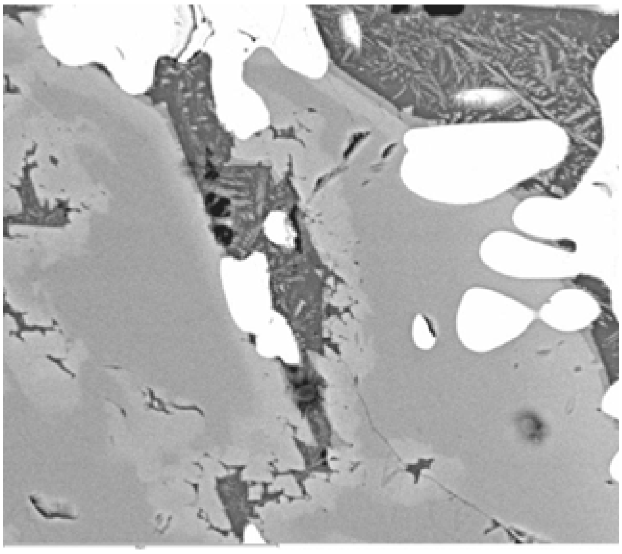


Plate 4 Sample MSG1175 Tap showing zoning in the silicate phase, centre dark grey, edges light grey; white - iron oxide; dark grey - glass with crystallites. (Scale 60 microns)

silicate	area 1 silicate 1	area 1 silicate 2	area 2 silicate	area 4 silicate	area 5 silicate dark	area 5 silicate 2 dark	area 5 silicate 3 light	mean silicate
Na_2O	0.2	n.d.	n.d.	n.d.	n.d.	n.d.	0.1	n.d.
MgO	3.1	9.9	6.3	5.8	9.4	11.1	4.5	7.2
Al_2O_3	n.d.	0.2	n.d.	n.d.	0.1	n.d.	1.3	0.2
SiO_2	31.6	32.8	31.9	31.8	32.4	32.9	31.0	32.0
P_2O_5	0.1	0.1	0.1	0.1	n.d.	0.1	0.2	0.1
S	0.1	n.d.	n.d.	0.1	0.1	n.d.	0.1	n.d.
K_2O	0.1	0.1	n.d.	n.d.	0.1	n.d.	0.3	0.1
CaO	3.2	1.3	1.7	2.0	1.3	1.2	3.9	2.1
TiO_2	0.1	n.d.	n.d.	n.d.	0.1	n.d.	0.1	0.1
V_2O_5	n.d.	0.1	0.2	0.1	n.d.	n.d.	n.d.	0.1
Cr_2O_3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
MnO	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.2
FeO	60.9	55.3	59.2	60.1	56.8	54.8	57.8	57.8
CoO	0.4	0.2	0.4	0.1	0.1	0.1	0.4	0.2
NiO	0.2	0.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
CuO	0.1	n.d.	0.1	n.d.	n.d.	0.1	0.2	0.1
BaO	n.d.	n.d.	0.1	0.3	n.d.	n.d.	0.2	0.1

Table 6 Silicate phase analyses of Sample MSG1175 Tap (weight % oxide)

glass	area 1 glass	area 2 glass	area 3 glass	mean glass
Na_2O	1.3	1.2	1.1	1.2
MgO	n.d.	0.1	0.1	0.1
Al_2O_3	19.7	14.4	21.5	18.5
SiO_2	39.7	36.6	39.4	38.5
P_2O_5	0.5	0.4	0.5	0.4
S	0.8	0.9	0.7	0.8
K_2O	4.8	3.8	5.7	4.8
CaO	12.7	13.8	11.2	12.6
TiO_2	0.2	0.3	0.5	0.3
V_2O_5	0.2	n.d.	n.d.	0.1
Cr_2O_3	n.d.	n.d.	n.d.	n.d.
MnO	n.d.	0.2	0.1	0.1
FeO	18.5	27.0	17.9	21.1
CoO	0.1	0.2	0.1	0.1
NiO	n.d.	0.1	n.d.	n.d.
CuO	n.d.	0.2	n.d.	n.d.
BaO	1.8	1.2	1.4	1.5

Table 7 Glass phase analyses of Sample MSG1175 Tap (weight % oxide)

iron oxide	area 1 iron oxide	area 2 iron oxide	mean iron oxide
Na_2O	n.d.	0.1	0.1
MgO	0.2	0.2	0.2
Al_2O_3	2.2	0.9	1.5
SiO_2	0.4	0.5	0.4
P_2O_5	0.1	0.1	0.1
S	0.1	n.d.	n.d.
K_2O	n.d.	n.d.	n.d.
CaO	0.2	n.d.	0.1
TiO_2	0.4	0.4	0.4
V_2O_5	0.2	0.1	0.1
Cr_2O_3	0.1	n.d.	n.d.
MnO	0.1	0.1	0.1
FeO	95.7	97.6	96.6
CoO	0.5	0.3	0.4
NiO	0.1	n.d.	n.d.
CuO	n.d.	n.d.	n.d.
BaO	0.3	n.d.	0.1

Table 8 Iron Oxide phase analyses of Sample MSG1175 Tap (weight % oxide)

metal	Area 2 prill	Area 4 prill
Si	0.1	0.1
P	n.d.	0.1
S	n.d.	n.d.
Ti	n.d.	n.d.
Mn	n.d.	0.1
Fe	99.5	99.8
Co	0.2	n.d.
Ni	n.d.	n.d.
Cu	0.1	0.1

Table 9 Analysis of the metal prill in Sample MSG 1175 Tap (weight %)

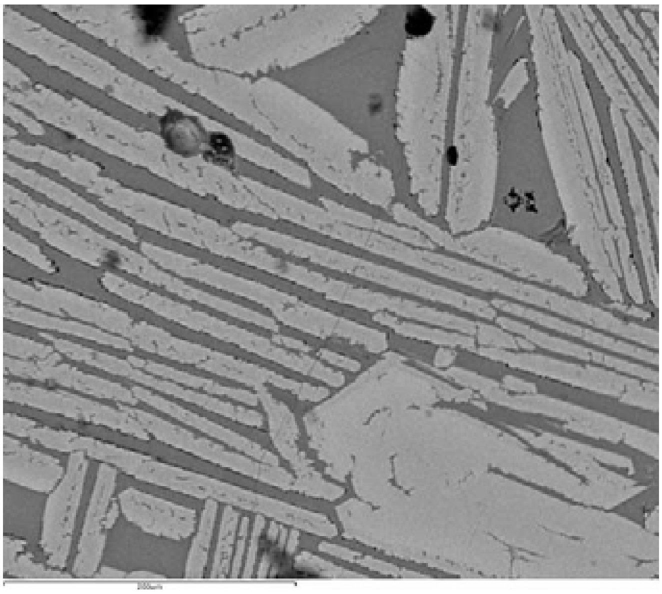


Plate 5 SEM BSE image of sample MSG1175 Type 2 Area 4. Light grey - silicate laths; dark grey - glass. Scale 200 microns, WoF~900 microns

	Area 1	Area 2	Area 3	Area 4	Area 5	Mean
Na_2O	0.5	0.4	0.5	0.6	0.9	0.6
MgO	2.8	4.7	3.5	3.4	1.0	3.1
Al_2O_3	6.6	4.8	4.5	5.5	9.4	6.2
SiO_2	37.1	35.6	35.7	36.3	39.1	36.8
P_2O_5	0.2	0.2	0.1	n.d.	0.3	0.2
S	n.d.	0.1	0.2	n.d.	0.1	0.1
K_2O	1.4	1.0	0.9	1.3	2.2	1.3
CaO	6.8	5.0	5.0	6.0	1n.d.	6.5
TiO_2	0.3	0.4	0.2	0.3	0.4	0.3
V_2O_5	0.1	n.d.	0.1	0.1	0.2	0.1
Cr_2O_3	n.d.	0.1	0.1	0.1	n.d.	0.1
MnO	0.3	0.1	0.2	0.2	0.2	0.2
FeO	44.0	47.9	48.8	46.0	36.0	44.5
CoO	n.d.	0.4	0.1	n.d.	0.2	0.2
NiO	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
CuO	n.d.	n.d.	n.d.	0.1	n.d.	n.d.
BaO	0.3	n.d.	0.4	0.2	0.2	0.2
	100.4	100.5	100.1	10n.d.	100.4	100.3

Table 10 Bulk area analyses of sample MSG1175 Type 2 (weight % oxide)

silicate	area 2 silicate 1 dark	area 2 silicate light	area 3 silicate	area 6 silicate (dark)	area 6 silicate (light)	mean silicate
Na_2O	n.d.	0.1	0.2	0.1	n.d.	0.1
MgO	11.2	5.1	6.9	9.6	1.9	7.0
Al_2O_3	n.d.	0.1	n.d.	n.d.	n.d.	n.d.
SiO_2	33.9	32.2	32.2	32.9	31.2	32.5
P_2O_5	n.d.	0.1	n.d.	n.d.	0.1	0.1
S	n.d.	0.1	0.1	0.1	n.d.	n.d.
K_2O	n.d.	0.1	0.1	n.d.	n.d.	n.d.
CaO	0.8	1.3	1.3	1.2	3.0	1.5
TiO_2	n.d.	n.d.	0.1	0.2	n.d.	0.1
V_2O_5	0.1	0.1	n.d.	n.d.	n.d.	n.d.
Cr_2O_3	n.d.	0.1	n.d.	0.1	0.1	n.d.
MnO	0.2	0.3	0.5	0.5	0.4	0.4
FeO	54.2	60.6	58.6	55.4	63.5	58.5
CoO	0.1	0.4	0.3	0.3	0.4	0.3
NiO	0.1	n.d.	n.d.	0.1	n.d.	n.d.
CuO	n.d.	n.d.	n.d.	n.d.	0.2	n.d.
BaO	n.d.	n.d.	n.d.	n.d.	0.1	n.d.

Table 11 Silicate phase analyses of sample MSG1175 Type 2 (weight % oxide)

	area 2 glass	area 3 glass 1	area 3 glass 2	Area 6 glass 1 (dark)	Area 6 glass 2	mean glass
Na_2O	0.6	1.0	1.0	1.1	1.1	1.0
MgO	0.1	0.1	0.2	n.d.	n.d.	0.1
Al_2O_3	12.5	12.3	13.3	15.8	17.0	14.2
SiO_2	43.2	41.9	44.9	45.3	46.6	44.4
P_2O_5	0.2	0.3	0.4	0.5	0.4	0.4
S	0.3	0.2	0.3	0.1	0.2	0.2
K_2O	2.6	2.5	2.7	7.5	4.5	4.0
CaO	16.2	16.1	16.5	12.6	14.2	15.1
TiO_2	0.7	0.8	0.9	0.8	0.7	0.8
V_2O_5	0.2	n.d.	n.d.	0.1	0.1	0.1
Cr_2O_3	n.d.	0.1	0.1	n.d.	n.d.	n.d.
MnO	0.2	0.2	n.d.	n.d.	n.d.	0.1
FeO	22.5	23.9	19.5	15.1	14.5	19.1
CoO	0.1	0.3	n.d.	0.2	n.d.	0.1
NiO	0.1	0.1	n.d.	0.2	n.d.	0.1
CuO	n.d.	n.d.	0.2	n.d.	0.1	0.1
BaO	0.7	0.2	0.5	0.8	0.7	0.6

Table 12 Glass phase analyses of sample MSG1175 Type 2 (weight % oxide)

metal	Area 7 prill
Si	n.d.
P	0.1
S	n.d.
Ti	n.d.
Mn	0.1
Fe	99.0
Co	0.3
Ni	0.2
Cu	0.2

Table 13 Analysis of metal prill in sample MSG1175 Type 2 (weight%)

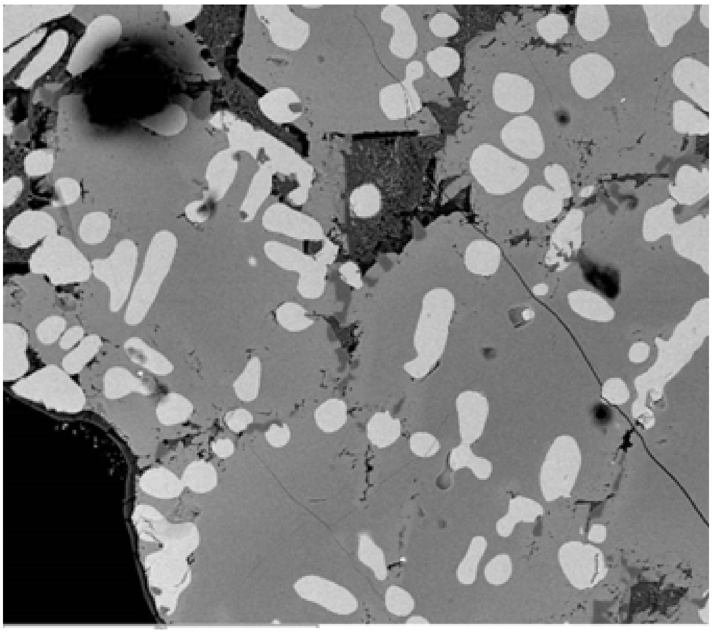


Plate 6 BSE image of sample MSG 1175 Furnace Slag White - free iron oxide; light grey - silicate laths; dark grey - glass. (scale bar 200 microns)

	Area 1	Area 2	Area 3	Area 4	Area 5	Mean
Na_2O	0.1	0.2	0.4	0.2	n.d.	0.2
MgO	3.9	4.8	3.2	3.9	7.7	4.7
Al_2O_3	3.2	1.9	4.2	2.7	1.2	2.6
SiO_2	27.9	28.6	25.2	26.4	28.3	27.3
P_2O_5	0.3	0.1	0.4	0.1	n.d.	0.2
S	0.2	0.3	0.2	n.d.	n.d.	0.1
K_2O	0.6	0.3	0.7	0.5	0.2	0.5
CaO	2.3	2.2	2.5	2.2	1.6	2.2
TiO_2	0.1	0.2	0.2	0.2	n.d.	0.1
V_2O_5	0.1	n.d.	n.d.	n.d.	0.1	n.d.
Cr_2O_3	0.1	n.d.	0.1	0.1	n.d.	n.d.
MnO	0.1	0.1	0.2	0.2	0.1	0.2
FeO	61.0	61.1	62.7	62.9	60.7	61.7
CoO	0.2	0.4	0.1	0.4	0.2	0.3
NiO	n.d.	n.d.	n.d.	0.1	n.d.	n.d.
CuO	n.d.	n.d.	n.d.	0.1	n.d.	n.d.
BaO	0.2	n.d.	0.1	0.1	n.d.	0.1
	100.2	100.2	100.1	10n.d.	100.2	100.1

Table 14 Bulk area analyses of sample MSG1175 Furnace Slag (weight % oxide)

silicate	area 1 silicate	area 2 silicate	area 4 silicate	area 5 silicate
Na_2O	n.d.	n.d.	0.1	n.d.
MgO	5.3	5.1	7.1	2.3
Al_2O_3	n.d.	n.d.	0.1	n.d.
SiO_2	32.3	32.1	32.4	31.7
P_2O_5	n.d.	0.2	n.d.	0.2
S	n.d.	0.2	n.d.	n.d.
K_2O	n.d.	n.d.	n.d.	n.d.
CaO	1.5	3.3	1.2	4.1
TiO_2	n.d.	n.d.	n.d.	0.1
V_2O_5	n.d.	0.1	n.d.	n.d.
Cr_2O_3	n.d.	n.d.	n.d.	0.1
MnO	0.3	0.1	0.3	0.2
FeO	60.9	58.4	58.5	61.5
CoO	0.2	0.2	0.2	0.4
NiO	n.d.	0.2	0.1	n.d.
CuO	n.d.	0.1	n.d.	n.d.
BaO	n.d.	n.d.	0.2	n.d.

Table 15 Silicate phase analyses of sample MSG1175 Furnace Slag (weight % oxide)

glass	area 1 glass	area 5 glass 1	area 5 glas 2
Na_2O	1.3	1.1	1.3
MgO	0.1	n.d.	0.1
Al_2O_3	20.2	19.7	17.9
SiO_2	37.9	40.4	37.9
P_2O_5	0.7	0.6	0.6
S	0.8	0.7	0.8
K_2O	5.3	5.6	5.4
CaO	10.5	10.6	11.9
TiO_2	0.1	0.2	0.1
V_2O_5	n.d.	n.d.	0.1
Cr_2O_3	0.1	n.d.	n.d.
MnO	n.d.	n.d.	0.2
FeO	21.9	19.7	22.2
CoO	n.d.	0.1	n.d.
NiO	0.1	n.d.	n.d.
CuO	n.d.	0.1	0.1
BaO	0.9	1.1	1.2

Table 16 Glass phase analyses of sample MSG1175 Furnace Slag (weight % oxide)

iron oxide	area 1 iron oxide	area 2 iron oxide	area 3 iron oxide light	area 3 iron oxide dark	area 5 iron oxide
Na_2O	0.4	n.d.	n.d.	0.3	0.2
MgO	0.3	0.5	0.2	0.4	0.2
Al_2O_3	0.5	0.9	0.5	1.4	0.8
SiO_2	0.5	4.6	0.6	5.8	0.4
P_2O_5	n.d.	1.1	0.2	0.3	n.d.
S	n.d.	0.1	n.d.	0.2	0.1
K_2O	n.d.	0.1	n.d.	0.1	n.d.
CaO	n.d.	0.9	0.1	0.5	0.1
TiO_2	0.3	0.8	0.6	0.7	0.5
V_2O_5	0.1	0.3	n.d.	0.1	0.2
Cr_2O_3	n.d.	0.1	0.1	n.d.	n.d.
MnO	n.d.	n.d.	0.1	n.d.	0.1
FeO	97.6	90.4	97.5	89.5	97.0
CoO	0.5	0.3	0.4	0.5	0.4
NiO	n.d.	n.d.	n.d.	n.d.	n.d.
CuO	n.d.	0.1	0.1	0.3	n.d.
BaO	0.1	n.d.	n.d.	n.d.	0.1

Table 17 Iron Oxide phase analyses of sample MSG1175 Furnace Slag (weight % oxide)

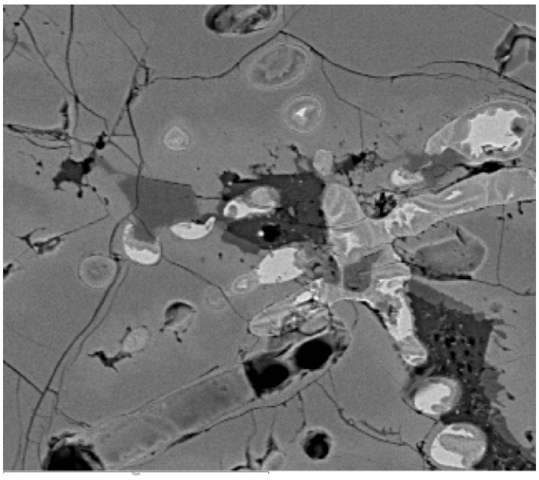


Plate 7 Sample MSG 1175 Furnace Slag showing white- iron oxide; light grey - silicate; dark grey (centre field) hercynite, darker grey glass (Scale Bar 70 microns)

hercynite	area 2 hercynite	area 5 hercynite
Na_2O	n.d.	0.1
MgO	1.2	0.6
Al_2O_3	51.0	49.3
SiO_2	0.5	1.6
P_2O_5	0.2	n.d.
S	n.d.	n.d.
K_2O	n.d.	n.d.
CaO	n.d.	0.6
TiO_2	0.6	0.4
V_2O_5	0.2	0.1
Cr_2O_3	n.d.	0.1
MnO	0.1	0.1
FeO	46.5	47.0
CoO	n.d.	0.2
NiO	n.d.	n.d.
CuO	n.d.	n.d.
BaO	n.d.	0.3

Table 18 Hercynite phase analyses of sample MSG1175 Furnace Slag (weight % oxide)

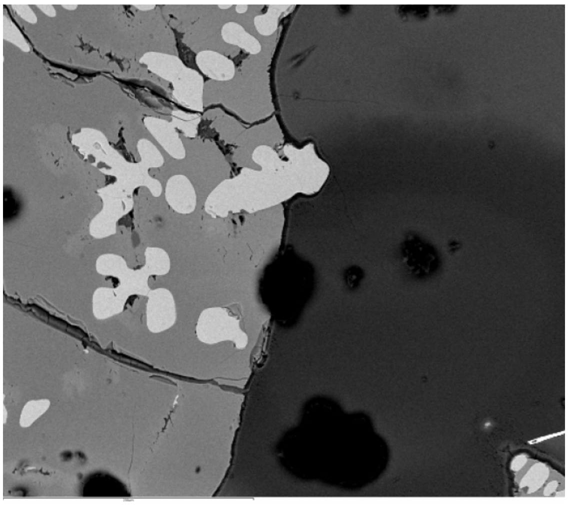


Plate 8 Sample MSG 1175 Furnace Slag showing silicate (grey) and free iron oxide dendrites (white) left hand side of image and calcium oxide -iron oxide phase, right hand side of image (Sacle Bar 200 microns).

Ca-Fe phase	area 2 ca-fe	area 3 ca-fe	area 4 ca-fe light	area 4 ca-fe dark
Na_2O	0.4	0.4	0.2	n.d.
MgO	0.7	0.6	2.3	3.7
Al_2O_3	0.1	0.2	n.d.	0.2
SiO_2	0.3	0.2	0.4	0.3
P_2O_5	1.0	0.3	0.4	0.2
S	0.1	n.d.	0.1	0.1
K_2O	n.d.	n.d.	n.d.	n.d.
CaO	11.2	8.2	30.6	75.4
TiO_2	n.d.	0.1	n.d.	0.1
V_2O_5	0.1	0.2	0.2	n.d.
Cr_2O_3	n.d.	-0.1	n.d.	0.1
MnO	0.3	0.2	0.2	1.5
FeO	85.7	89.2	64.9	18.0
CoO	0.4	0.5	0.4	n.d.
NiO	n.d.	n.d.	0.3	0.2
CuO	n.d.	0.1	0.1	n.d.
BaO	0.4	0.1	0.4	0.3

Table 19 Iron/Calcium rich phase analyses of sample MSG1175 Furnace Slag (weight % oxide)

Sample	Microstructure Texture					volumetric phase %		
	Silicate	Iron Oxide	Glass	Metal	Hercynite	silicate	Iron Oxide	Glass
NB 707-Tap	Blocky	Globular	matrix			70	12	18
NB707-Type2	Blocky to Massive	Globular	matrix			71	17	12
NB1175-Tap	Blocky to Massive	Globular	matrix	y		59	21	20
NB1175-Type 2	Lath to Blocky	absent	matrix	y		59	0	41
NB1175-Furnace	Massive	Globular	matrix		y	66	19	16

Table 20 Summary of the mineralogy of the slag samples

Bulks	Tap Slags		Type 2 Slag		Furnace Slag
	MSG707	MSG1175	MSG707	MSG1175	MSG1175
Na_2O	0.4	0.5	0.3	0.6	0.2
MgO	1.1	3.3	2.6	3.1	4.7
Al_2O_3	4.7	5.0	2.3	6.2	2.6
SiO_2	27.7	27.0	26.1	36.8	27.3
P_2O_5	0.2	0.1	n.d.	0.2	0.2
S	0.2	0.1	0.1	0.1	0.1
K_2O	1.1	1.0	0.6	1.3	0.5
CaO	1.9	4.9	1.3	6.5	2.2
TiO_2	0.1	0.1	0.1	0.3	0.1
V_2O_5	n.d.	n.d.	0.1	0.1	n.d.
Cr_2O_3	n.d.	0.1	n.d.	0.1	n.d.
MnO	0.3	0.1	0.2	0.2	0.2
FeO	62.0	57.3	65.9	44.5	61.7
CoO	0.3	0.2	0.3	0.2	0.3
NiO	n.d.	n.d.	n.d.	n.d.	n.d.
CuO	n.d.	n.d.	0.1	n.d.	n.d.
BaO	0.1	0.4	0.1	0.2	0.1

Table 21 Mean Bulk Area analyses of the slag samples (weight % oxide)

Silicate	Tap Slags		Type 2 Slag		Furnace Slag
	MSG707	MSG1175	MSG707	MSG1175	MSG1175
Na_2O	n.d.	n.d.	0.2	0.1	n.d.
MgO	2.0	7.2	4.2	7.0	4.9
Al_2O_3	0.1	0.2	0.1	n.d.	n.d.
SiO_2	31.1	32.0	32.0	32.5	32.1
P_2O_5	n.d.	0.1	0.1	0.1	0.1
S	0.1	n.d.	n.d.	n.d.	0.1
K_2O	n.d.	0.1	n.d.	n.d.	n.d.
CaO	0.6	2.1	0.8	1.5	2.5
TiO_2	n.d.	0.1	n.d.	0.1	n.d.
V_2O_5	n.d.	0.1	0.1	n.d.	n.d.
Cr_2O_3	n.d.	n.d.	n.d.	n.d.	n.d.
MnO	0.3	0.2	0.2	0.4	0.2
FeO	65.6	57.8	62.1	58.5	59.8
CoO	0.5	0.2	0.2	0.3	0.3
NiO	n.d.	n.d.	n.d.	n.d.	0.1
CuO	n.d.	0.1	0.1	n.d.	n.d.
BaO	n.d.	0.1	0.1	n.d.	n.d.

Table 22 Mean Silicate analyses of the slags (weight % oxide)

Iron Oxide	Tap Slags		Type 2 Slag		Furnace Slag
	MSG707	MSG1175	MSG707	MSG1175	MSG1175
Na_2O	0.2	0.1	0.2		0.2
MgO	0.3	0.2	0.2		0.4
Al_2O_3	1.0	1.5	0.6		0.8
SiO_2	1.2	0.4	0.9		2.9
P_2O_5	n.d.	0.1	0.1		0.4
S	0.1	n.d.	0.3		0.1
K_2O	n.d.	n.d.	0.1		n.d.
CaO	0.1	0.1	0.1		0.4
TiO_2	0.4	0.4	0.3		0.6
V_2O_5	0.1	0.1	n.d.		0.1
Cr_2O_3	0.1	n.d.	n.d.		n.d.
MnO	n.d.	0.1	0.1		n.d.
FeO	96.0	96.6	96.8		93.7
CoO	0.3	0.4	0.5		0.4
NiO	0.1	n.d.	n.d.		n.d.
CuO	0.1	n.d.	0.1		0.1
BaO	0.2	0.1	0.1		n.d.

Table 23 Mean Iron Oxide phase analyses of the slag samples (weight % oxide)

glass	Tap Slags		Type 2 Slag		Furnace Slag
	MSG707	MSG1175	MSG707	MSG1175	MSG1175
Na_2O	1.9	1.2	2.2	1.0	1.2
MgO	0.1	0.1	n.d.	0.1	0.1
Al_2O_3	21.8	18.5	20.3	14.2	19.3
SiO_2	37.2	38.5	42.8	44.4	38.7
P_2O_5	0.9	0.4	0.5	0.4	0.6
S	0.3	0.8	0.3	0.2	0.8
K_2O	5.8	4.8	10.2	4.0	5.5
CaO	7.5	12.6	5.5	15.1	11.0
TiO_2	0.1	0.3	0.3	0.8	0.2
V_2O_5	n.d.	0.1	n.d.	0.1	0.1
Cr_2O_3	n.d.	n.d.	0.1	n.d.	n.d.
MnO	0.2	0.1	n.d.	0.1	0.1
FeO	23.5	21.1	17.9	19.1	21.3
CoO	0.2	0.1	n.d.	0.1	n.d.
NiO	0.1	n.d.	n.d.	0.1	n.d.
CuO	n.d.	n.d.	0.1	0.1	0.1
BaO	0.5	1.5	0.1	0.6	1.1

Table 24 Mean Glass Phase analyses of the slags (weight % oxide)

References

Scott, I. 2010 *Newport medieval ship project. Updated research design*. Oxford Archaeology

Thomas G 2000 *A chemical and mineralogical investigation of bloomery iron-making in the Bristol Channel orefield U.K.* unpublished PhD Thesis Cardiff University

gerry mcdonnell archaeometals

Plate 1 Bolt MSG 1239, showing location of section

Plate 2 Sample MSG 1239 unetched condition showing a swirl of slag inclusions (black), (WoF 1mm)

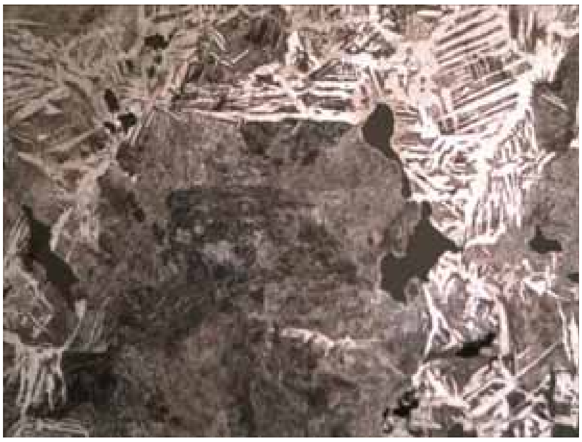


Plate 3 MSG 1239, Etched condition, high carbon area showing pearlite (grey centre of micrograph) with widmanstatten ferrite (white top right), (WoF 1mm).

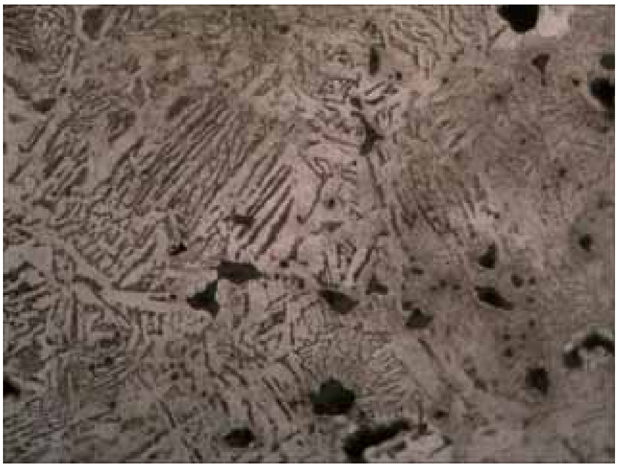


Plate 4 MSG 1239 Lower carbon region, showing widmanstatten ferrite (WoF 1mm)

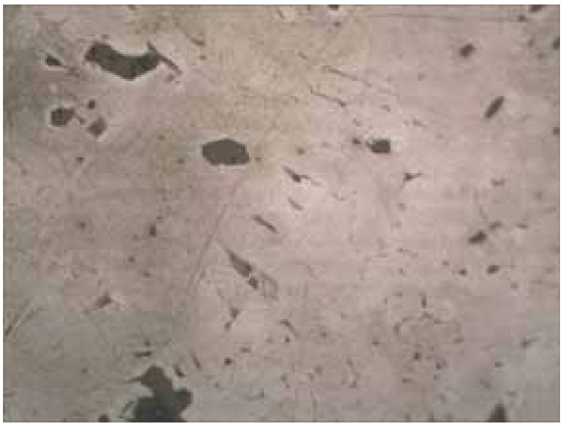


Plate 5 MSG 1239 etched, ferrite with some grain boundary pearlite (WoF 1mm)

Plate 6 MSG 2861, showing location of the section.

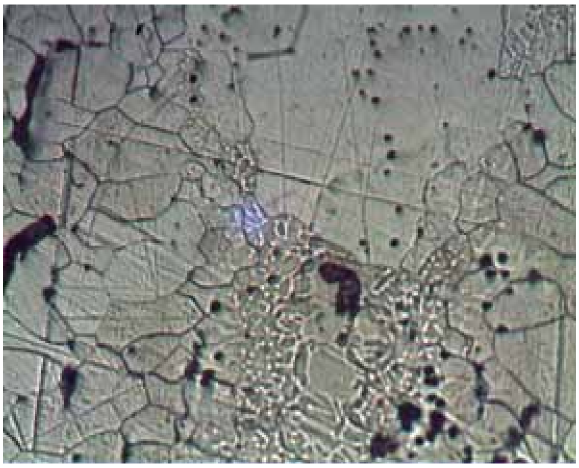
 replace with unetched image

Plate 7 MSG 2861 unetched (WoF 1mm)

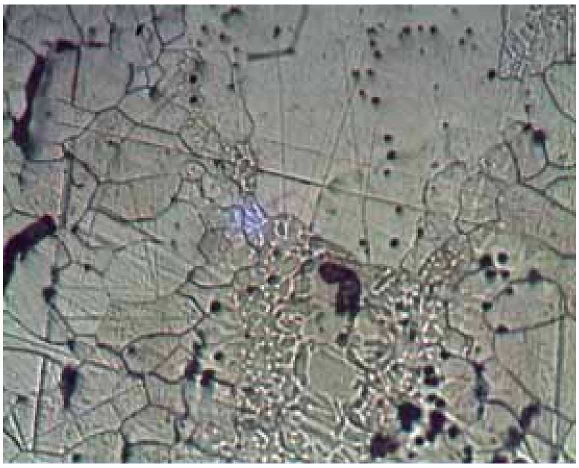


Plate 8 MSG2861 etched showing ferrite with ghosting indicative of phosphoric iron (WoF 1mm)

Plate 9 MSG 2368 showing location of section

Plate 10 MSG 2368 unetched showing angular slag inclusions (WoF 1mm)

Plate 11 MSG 2368 etched showing ferrite grains (WoF 1mm)

Plate 12 MSG 2180 showing location of section

Plate 13 MSG 2180 unetched showing large slag inclusions (WoF 1mm)

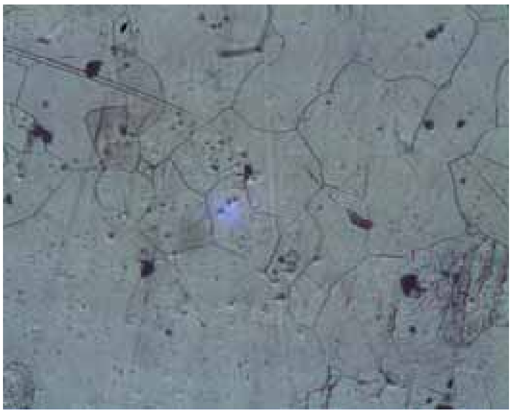


Plate 14 MSG 2180 etched showing ferrite grains (WoF 1mm)

Plate 15 MSG 895 showing location of section

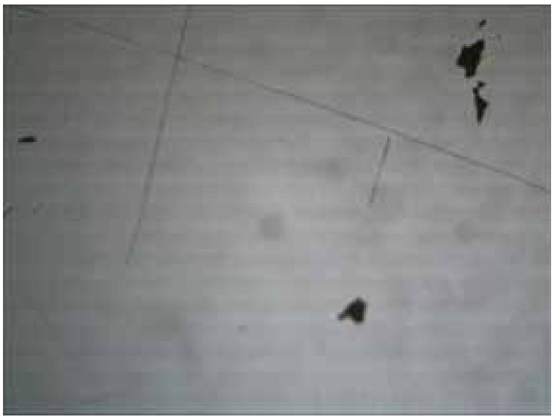


Plate 16 MSG 895, unetched showing angular slag inclusions (WoF 1mm)

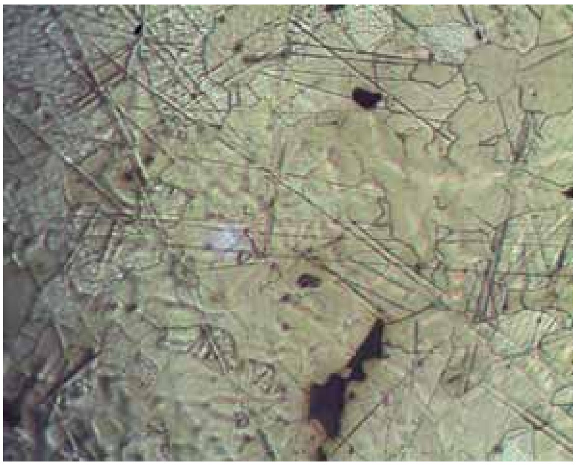


Plate 17 MSG 895 Etched showing Ghosting indicating phosphoric iron (WoF 1mm)

Plate 18 MSG 2177 showing location of section.

Plate 19 MSG 2177 Unetched condition showing slag inclusions and corrosion penetration (WoF 1mm)

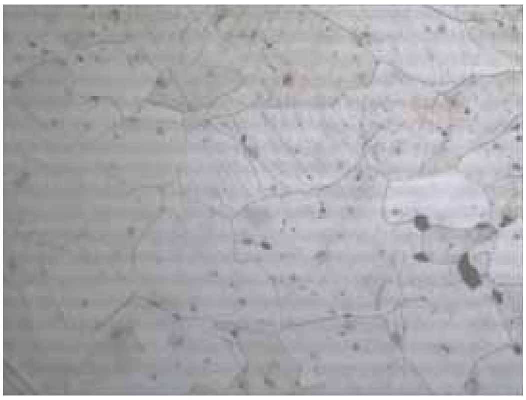


Plate 20 MSG 2177 Etched showing ferrite grains with small carbide precipitate at the grain boundaries. (WoF 1mm)

Plate 21 MSG 2572 showing location of section

Plate 22 MSG 2572 Unetched showing folded slag stringers (WoF 1mm)

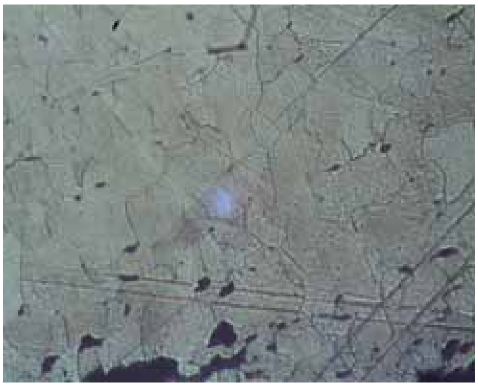


Plate 23 MSG 2572 Etched showing phosphoric ghosting.

Plate 24 MSG 2190 showing location of section.

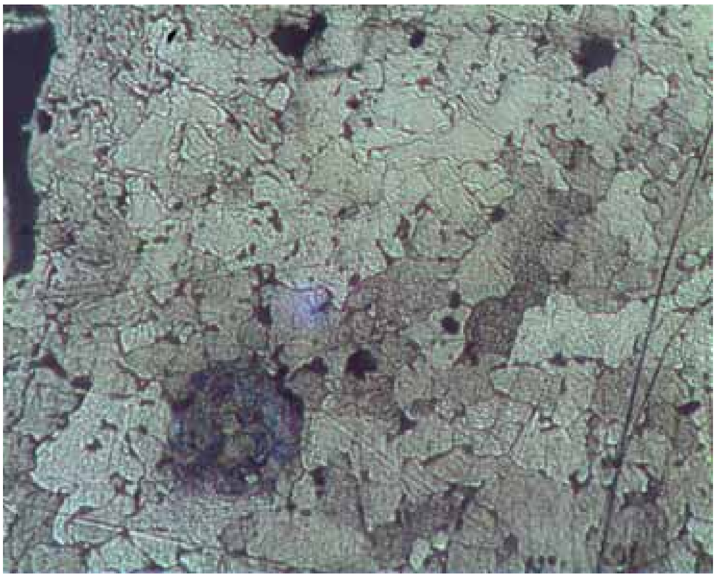
 replace with unetched image

Plate 25 MSG 2190 Unetched (WoF 1mm)

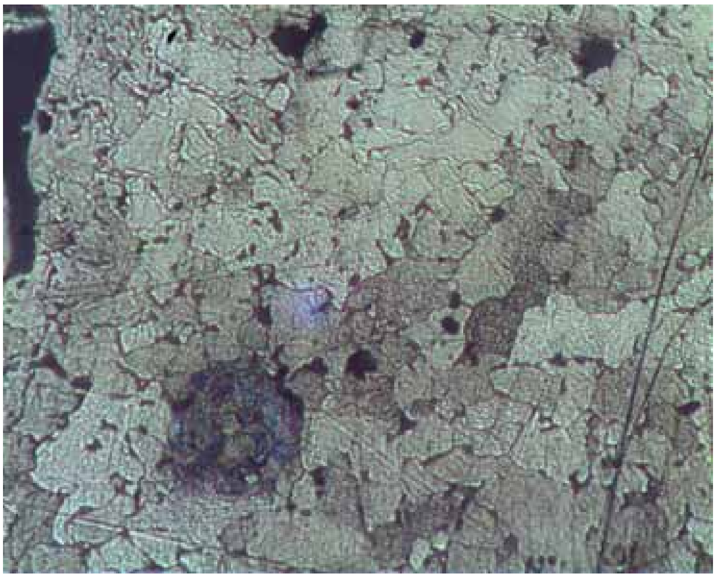


Plate 26 MSG 2190 Etched showing ferrite grains with grain boundary carbide (dark) and a second grain boundary phase (white). (WoF 0.7mm)

Plate 27 MSG 2690 showing location of section.

Plate 28 MSG 2690 Unetched showing the heavily slagged nature of the sample (WoF 1mm)

Plate 29 MSG 2690 Etched showing ferrite plus pearlite microstructure (WoF 0.7mm)

Plate 30 MSG 2461 showing location of section

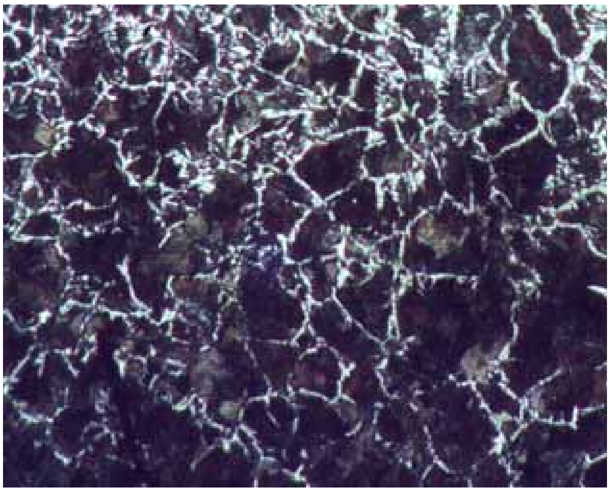
 replace with unetched

Plate 31 MSG 2461 Unetched

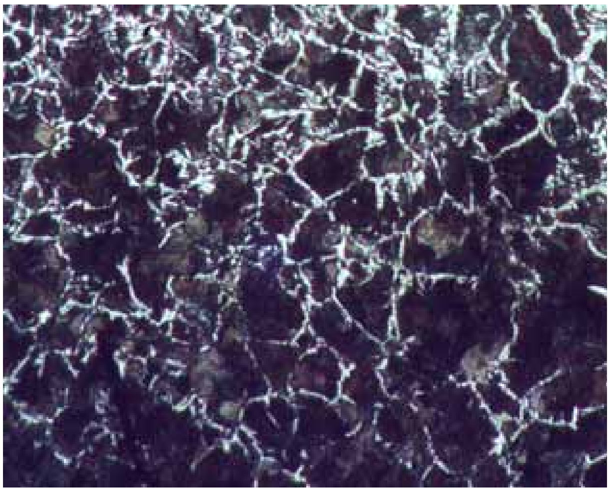


Plate 32a MSG 2461 Etched showing high carbon area the widmanstatten grain boundary ferrite (WoF 0.7mm)

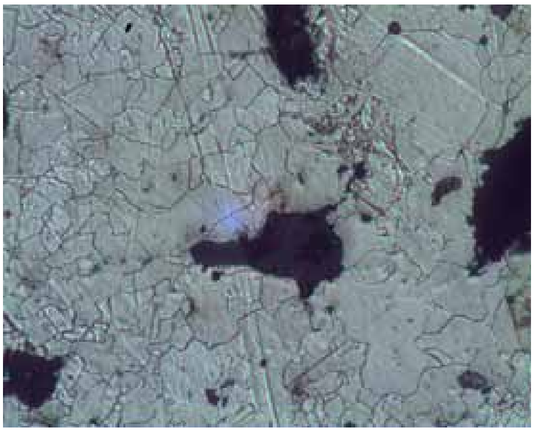


Plate 1 MSG 2461 Etched showing phosphoric iron with ghosting (WoF 0.7mm)

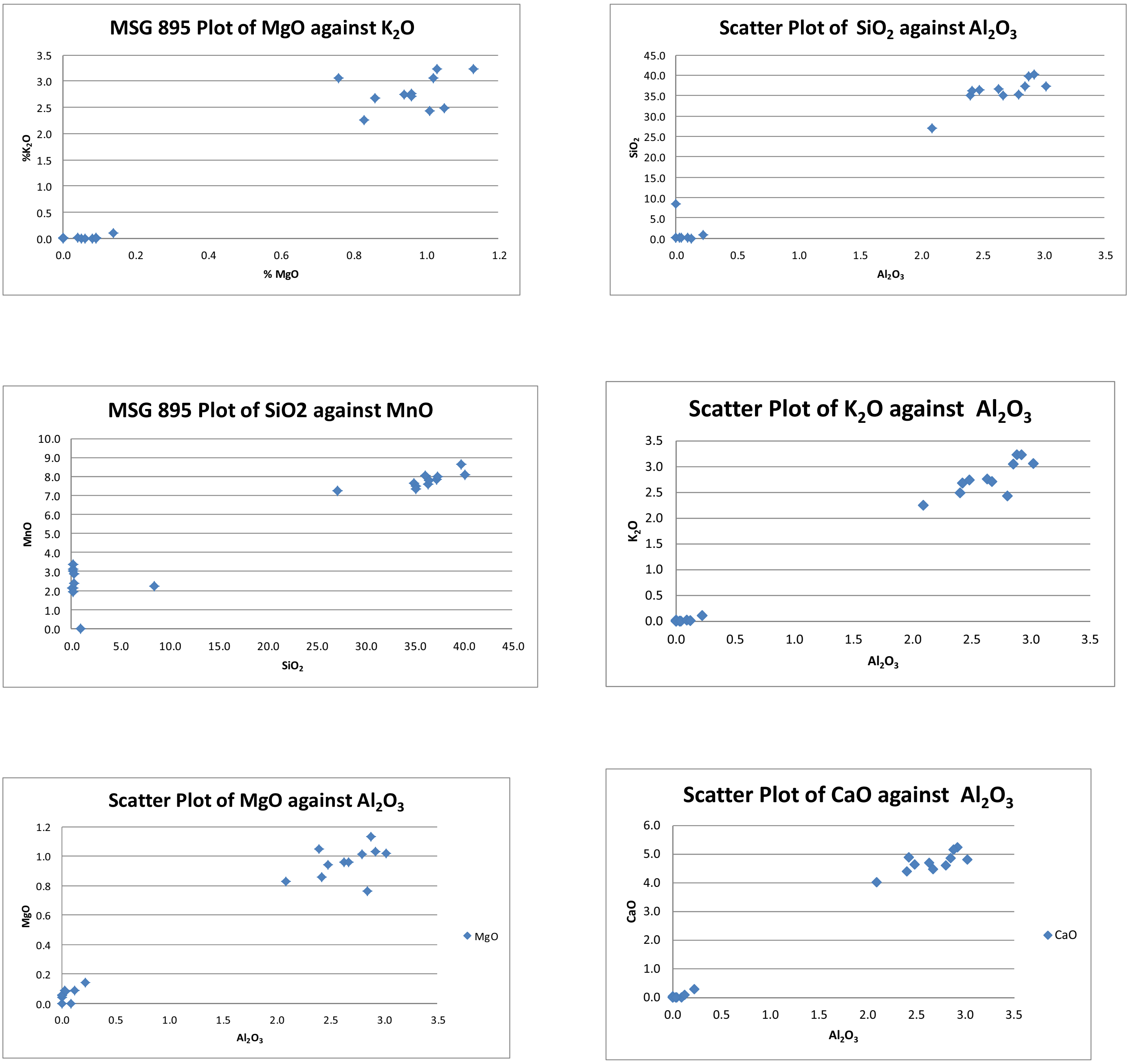


Figure 1 Scatter Plots for MSG 895

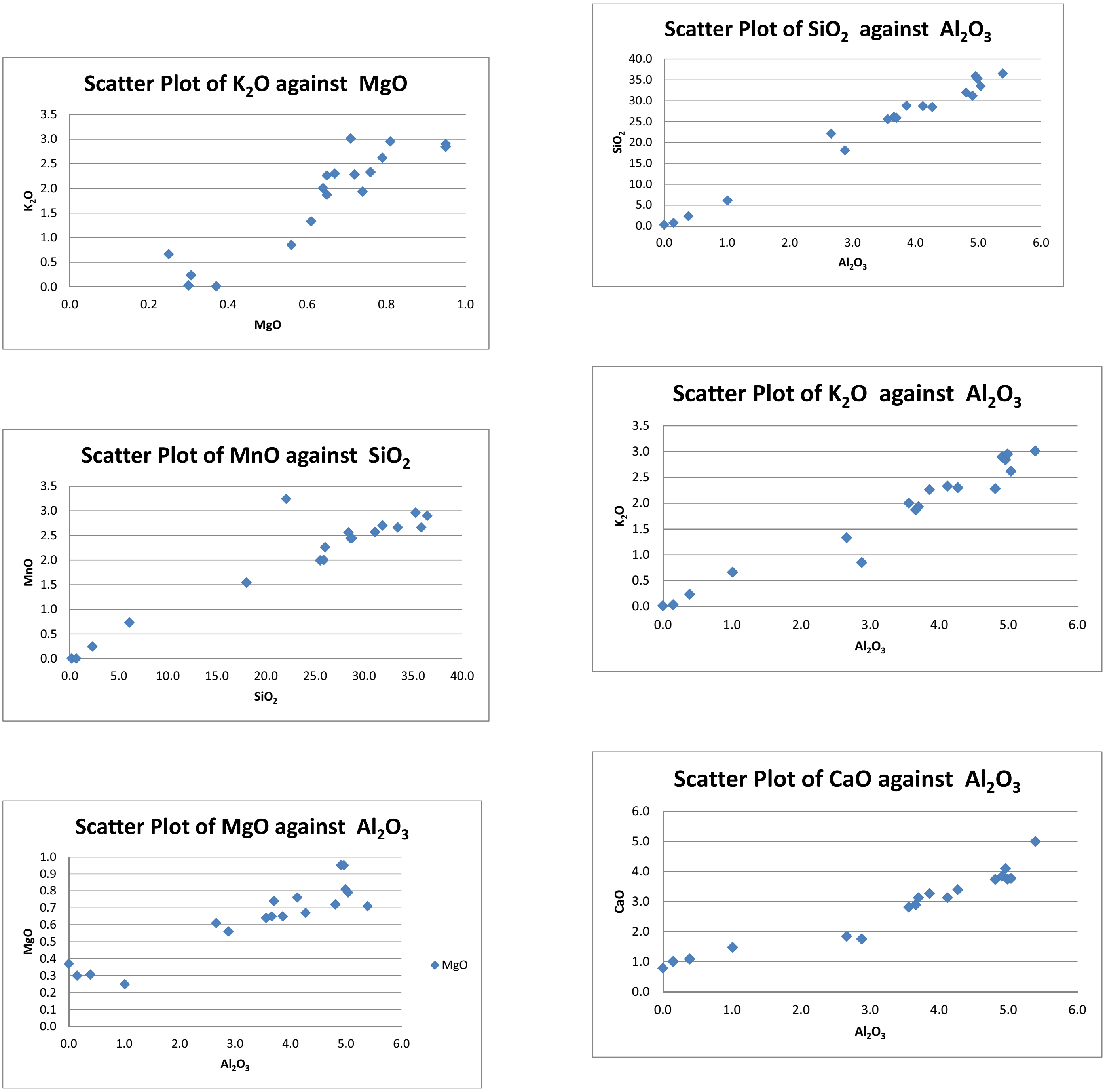
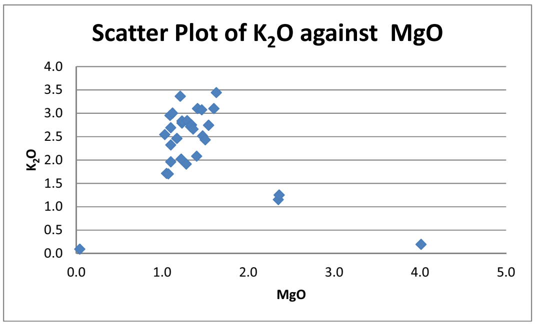
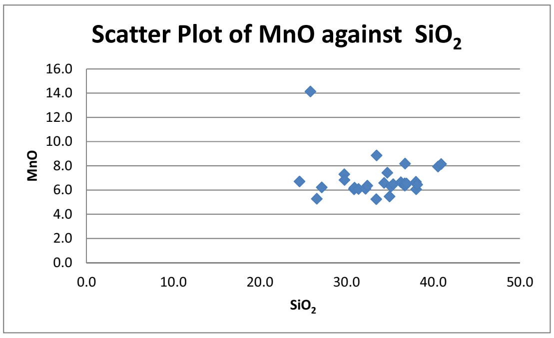
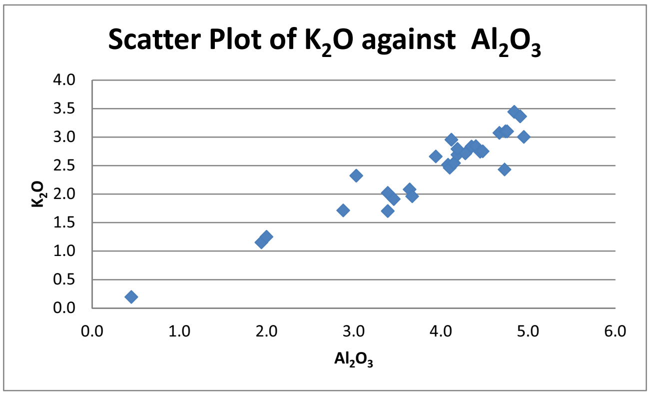
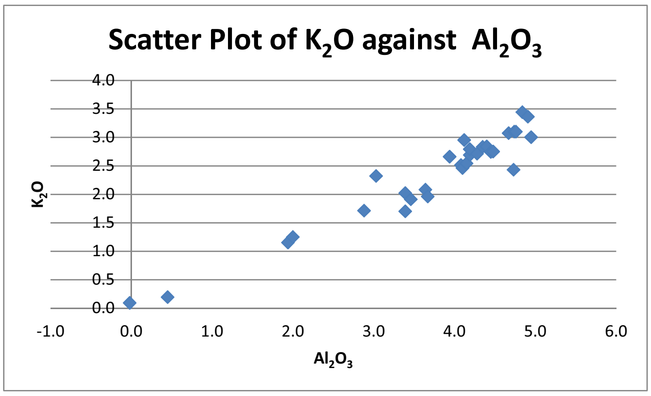


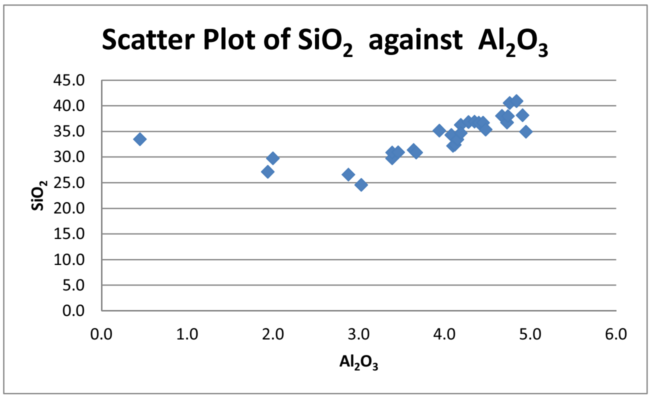
Figure 2 Scatter Plots for MSG 2177











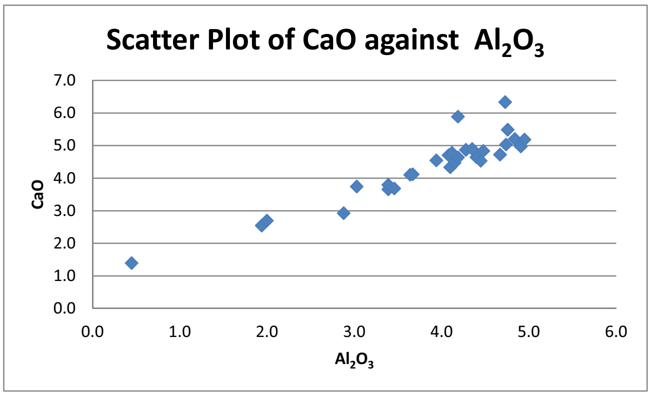


Figure 3 Scatter Plots for MSG 2190

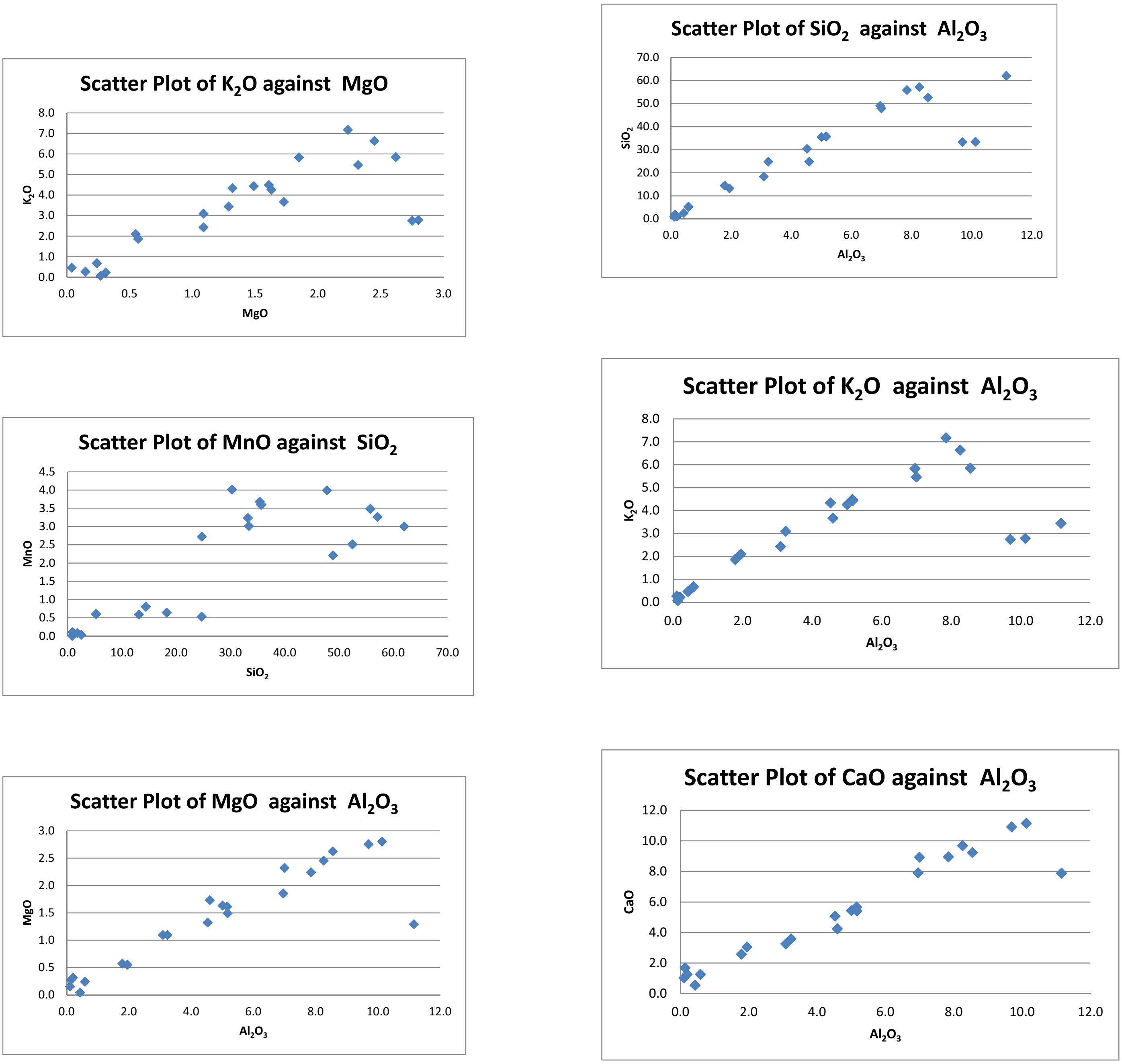
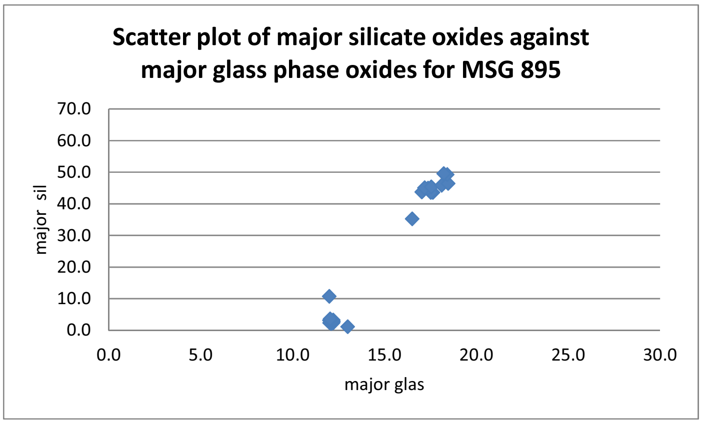
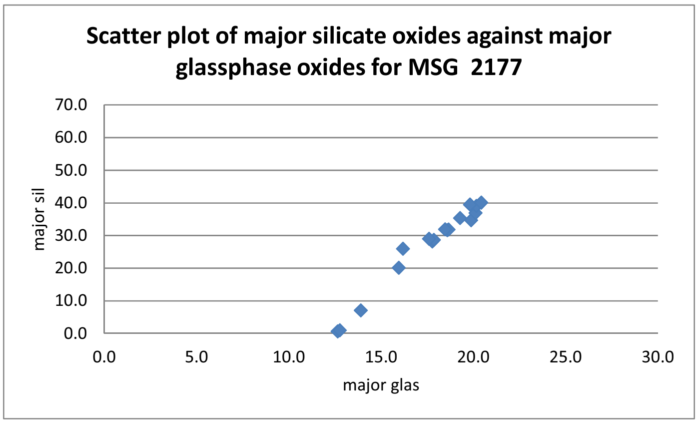
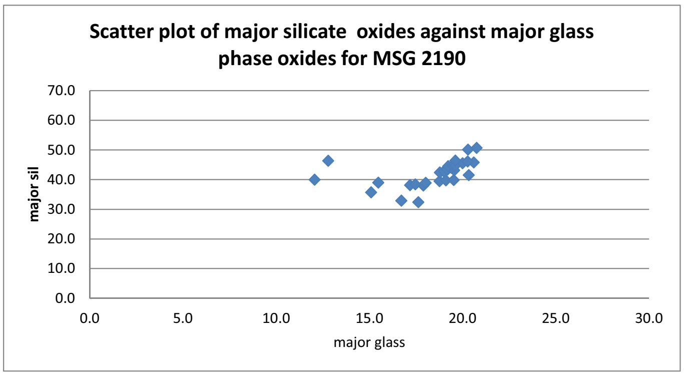


Figure 4 Scatter Plots for MSG 2461







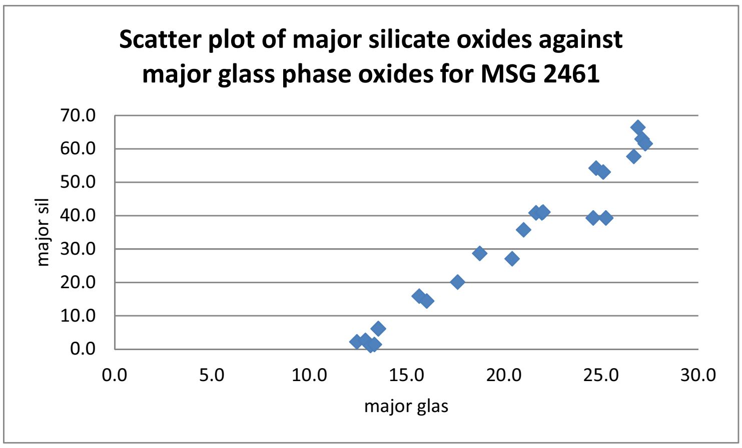


Figure 5 Scatter Plots for the major silicate and glass oxides for all samples.

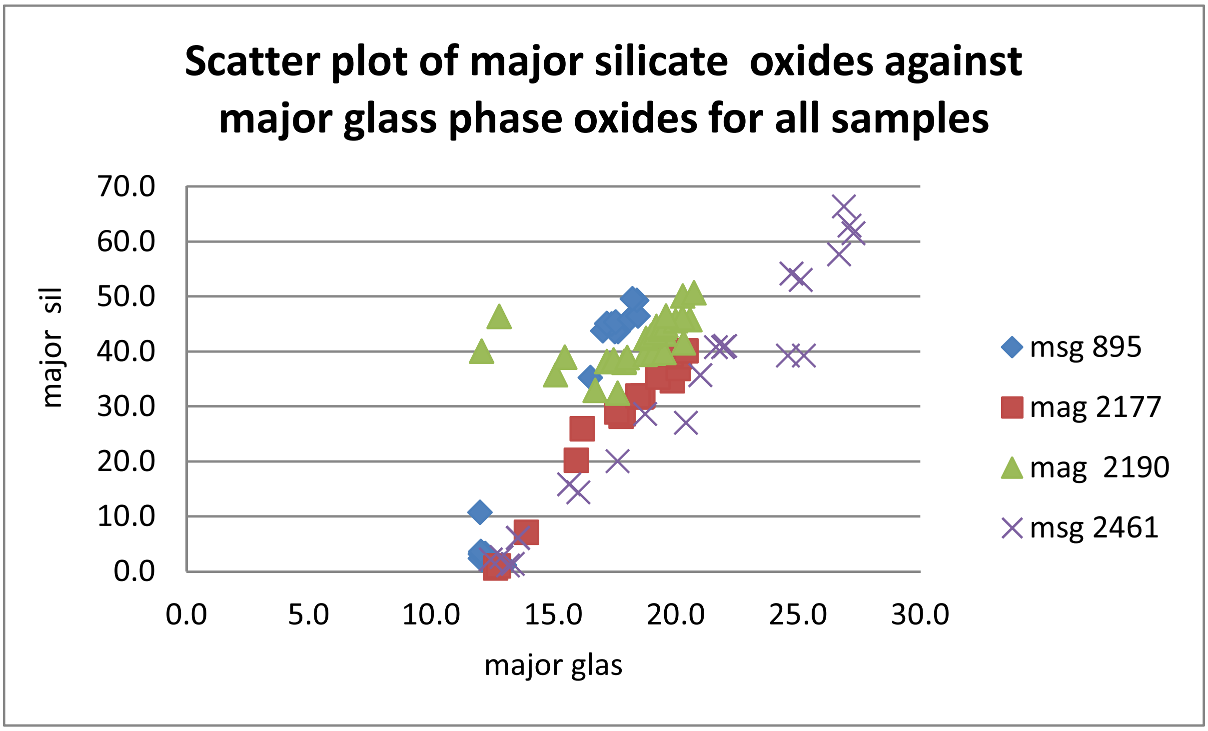
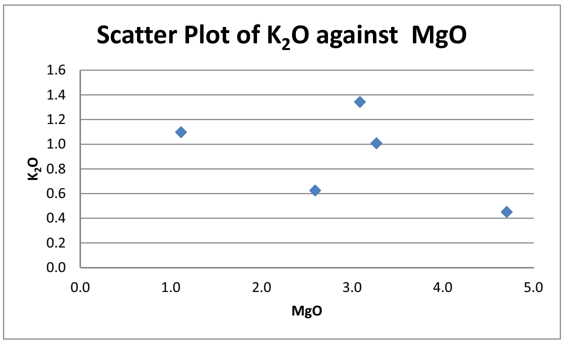
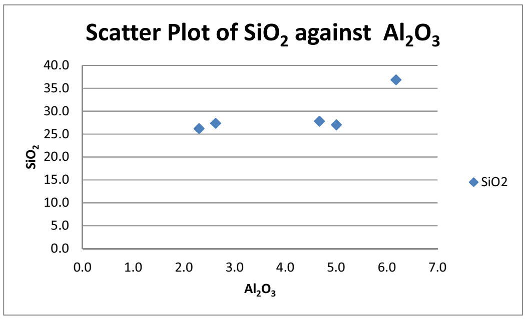
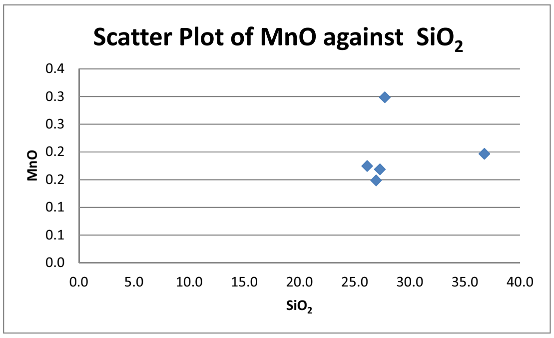
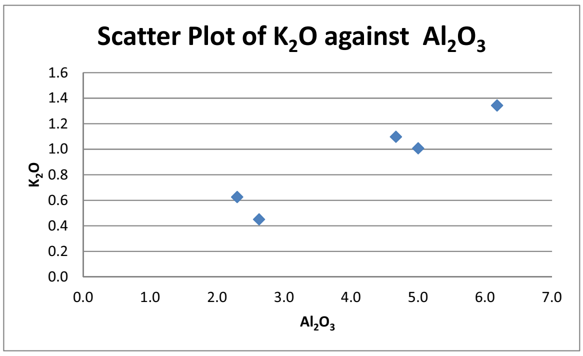


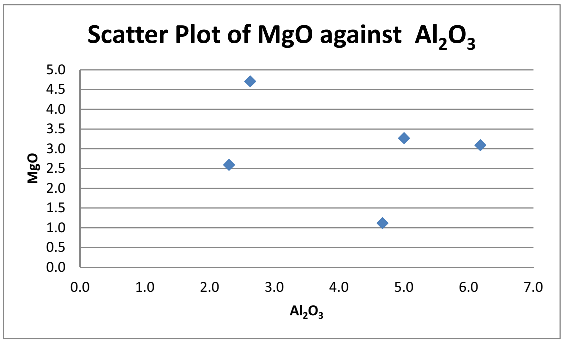
Figure 6 Scatter Plots for all samples











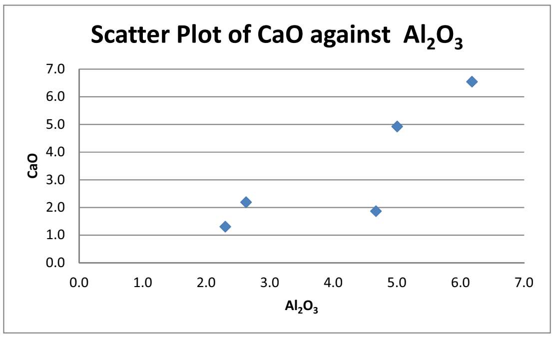


Figure7 Scatter Plots for the bulk area analyses of the slags

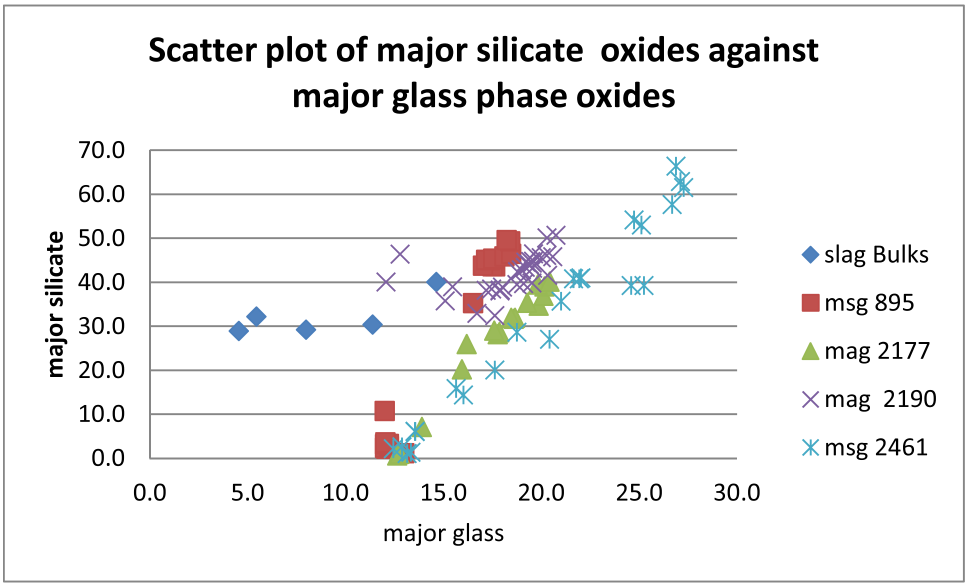


Figure 8 Scatter Plots for the slag and metal

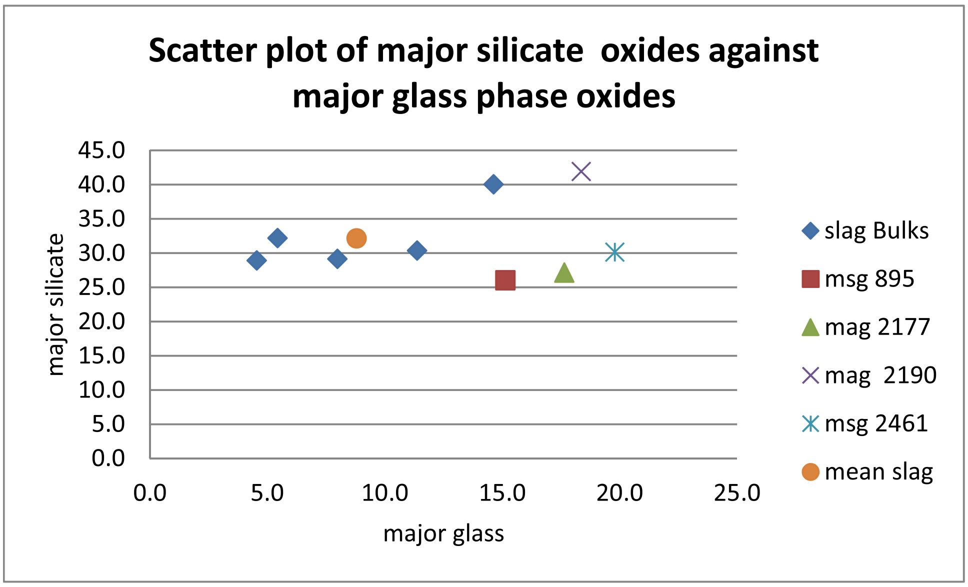


Figure 9 Scatter Plots for the major silicate oxides and glass oxides for the slags and the mean values of the slag inclusions in each metal sample.

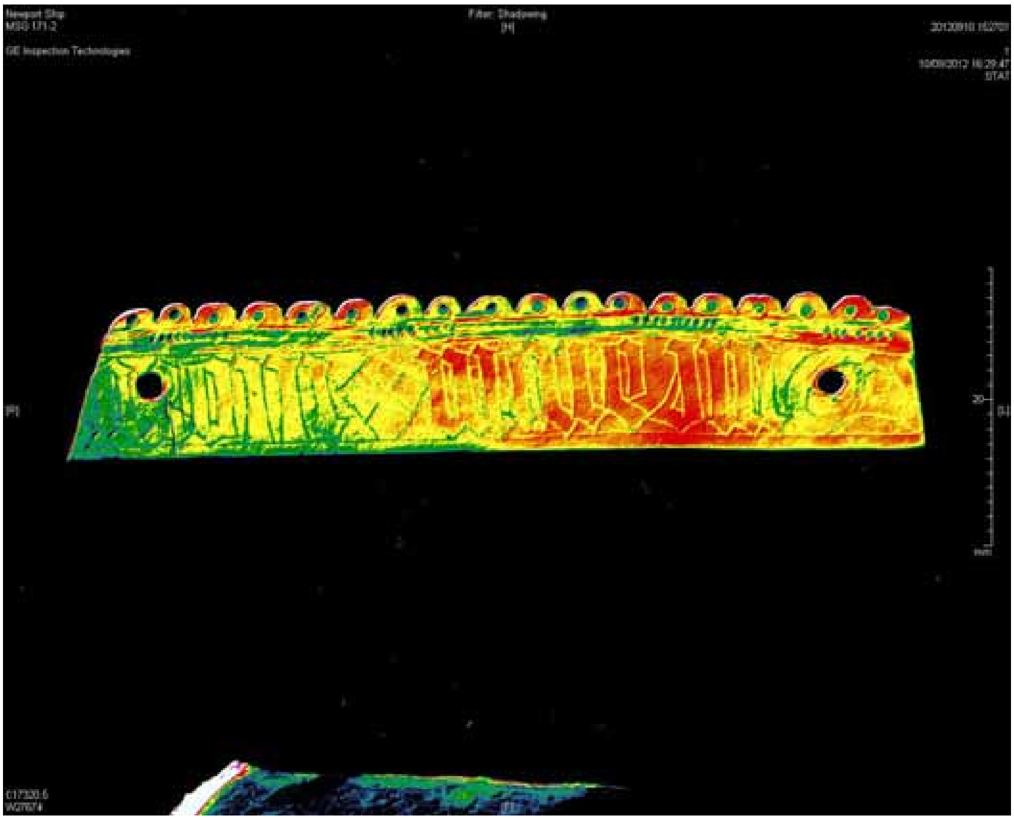
Artefact Type: Helmet strip

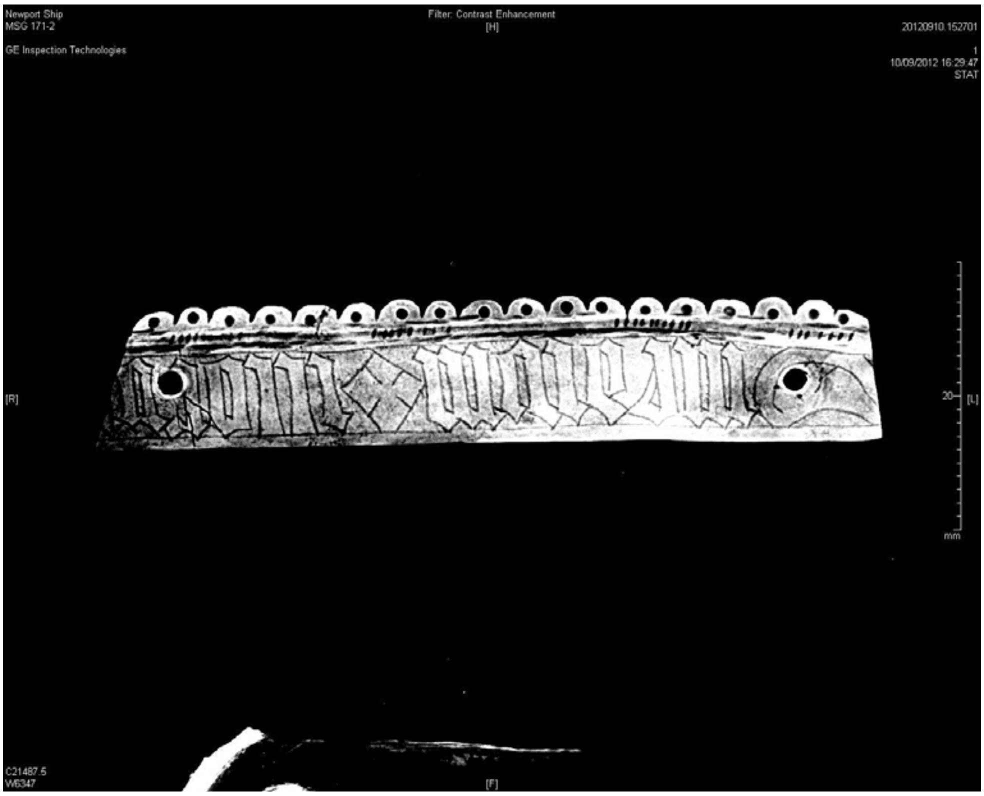
Material: CuA

Context: 152

Dimensions: 115mm x 19.7mm x .87mm. 13g.

Description: Helmet Strip, engraved. Rectangular in plan, three straight edges and one scalloped edge (18 scallops in total). Two holes present at either end for attaching to plate, 3.2mm in diameter. Two words MEDIUM ILLORUM are inscribed, in Gothic textura, separated by a diamond motif. The writing sits between two lines which run the length of the strip. Between the writing and the scalloped edge is a raised ridge, 2mm wide with four sets of notches inscribed at a slight angle. Piece is in good condition and gold in colour. See also Msg 172.





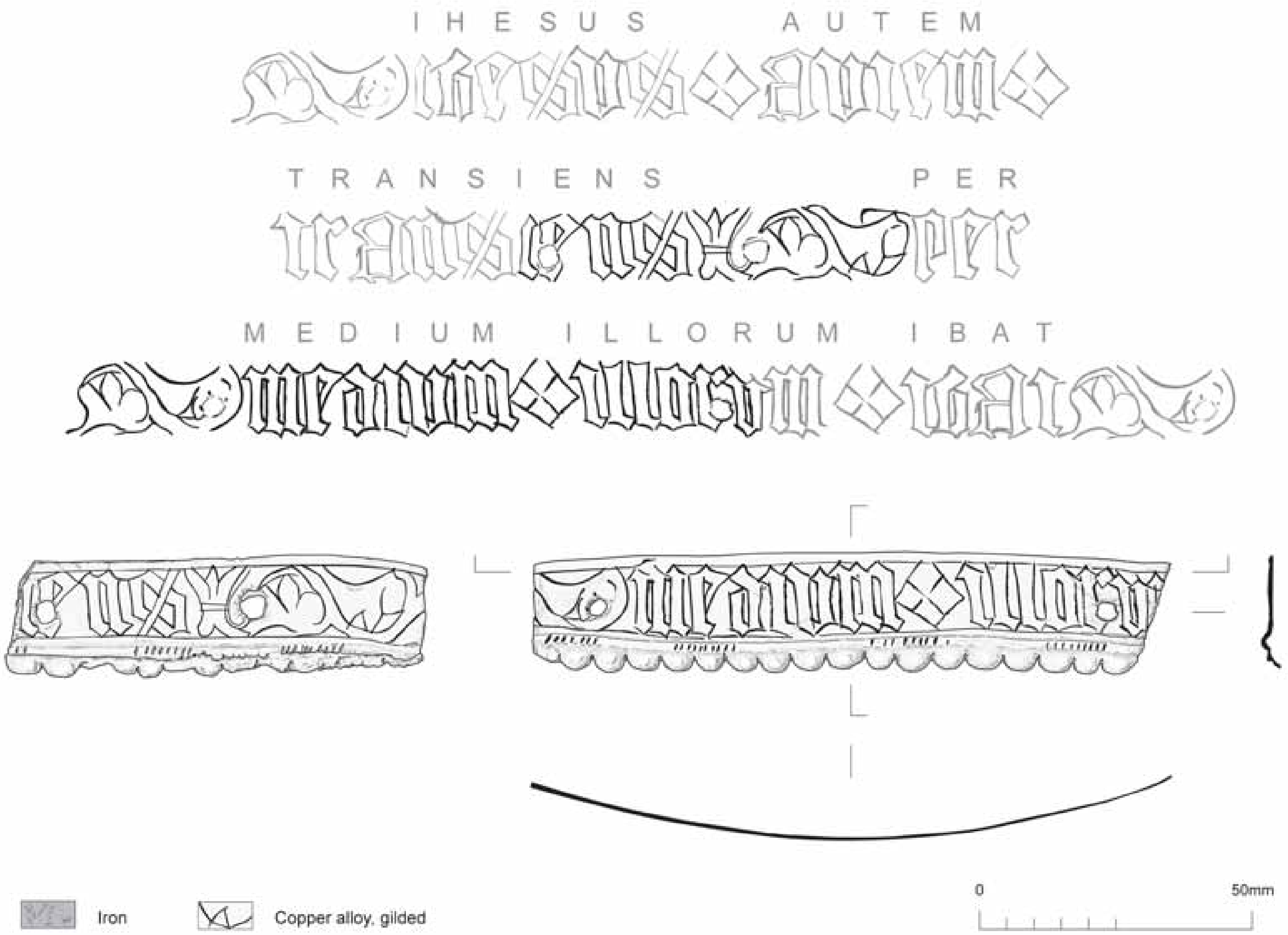
Artefact Type: Helmet strip

Material: CuA

Context: 152

Dimensions: 115mm x 19.7mm x .87mm. 13g.

Description: Helmet Strip, engraved. Rectangular in plan, three straight edges and one scalloped edge (18 scallops in total). Two holes present at either end for attaching to plate, 3.2mm in diameter. Two words MEDIUM ILLORUM are inscribed, in Gothic textura, separated by a diamond motif. The writing sits between two lines which run the length of the strip. Between the writing and the scalloped edge is a raised ridge, 2mm wide with four sets of notches inscribed at a slight angle. Piece is in good condition and gold in colour. See also Msg 172.



Artefact Type: Helmet strip

Material: CuA

Context: 152

Dimensions: 115mm x 19.7mm x .87mm. 13g.

Description: Helmet Strip, engraved. Rectangular in plan, three straight edges and one scalloped edge (18 scallops in total). Two holes present at either end for attaching to plate, 3.2mm in diameter. Two words MEDIUM ILLORUM are inscribed, in Gothic textura, separated by a diamond motif. The writing sits between two lines which run the length of the strip. Between the writing and the scalloped edge is a raised ridge, 2mm wide with four sets of notches inscribed at a slight angle. Piece is in good condition and gold in colour. See also Msg 172.

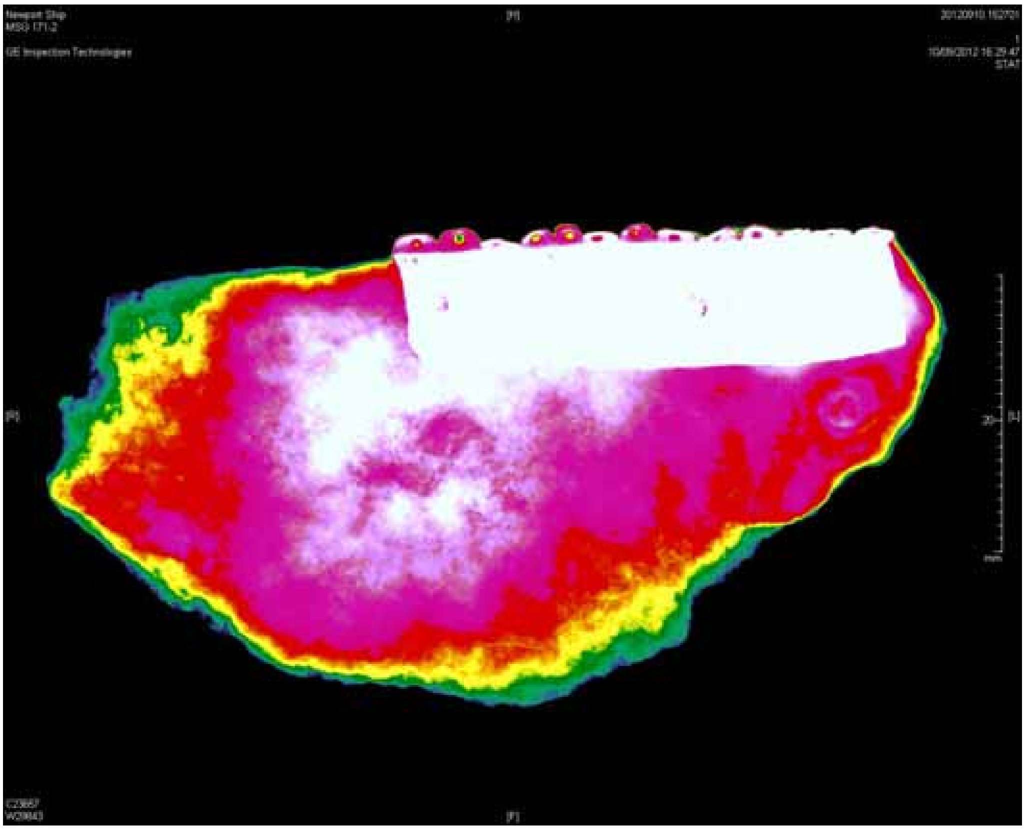
Artefact Type: Hemet fragment.

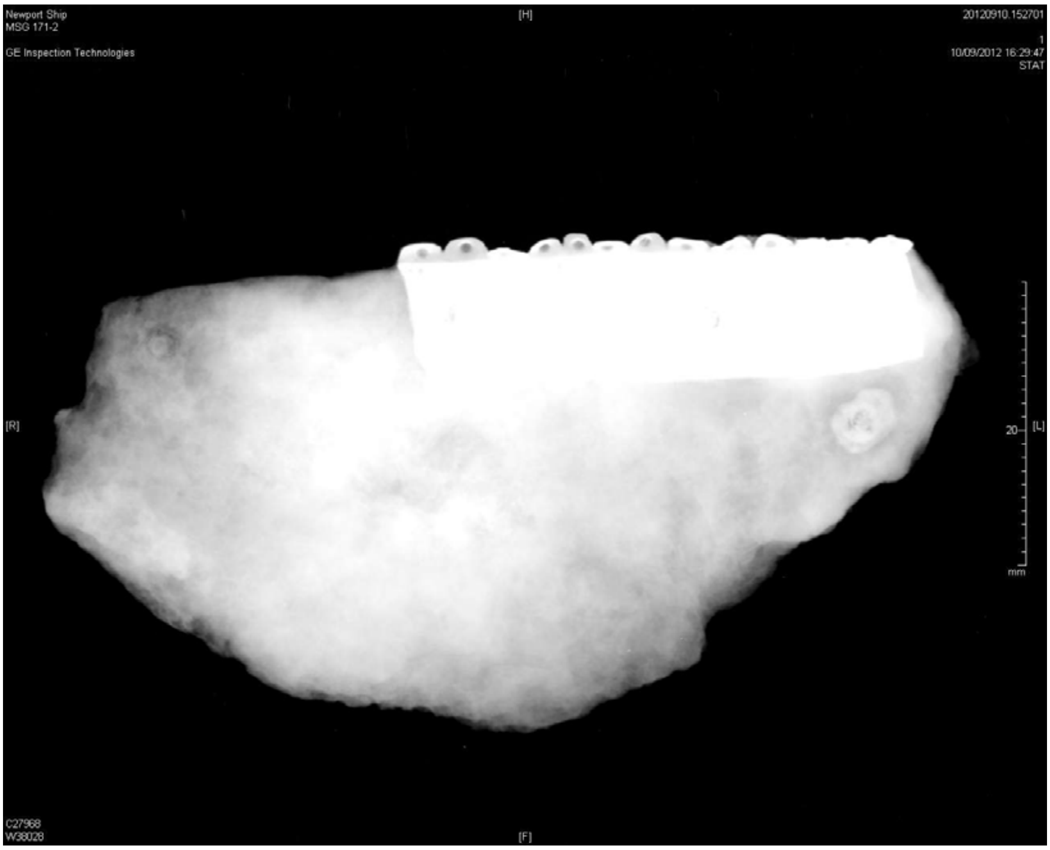
Material: Gilt CuA strip.

Context: 152

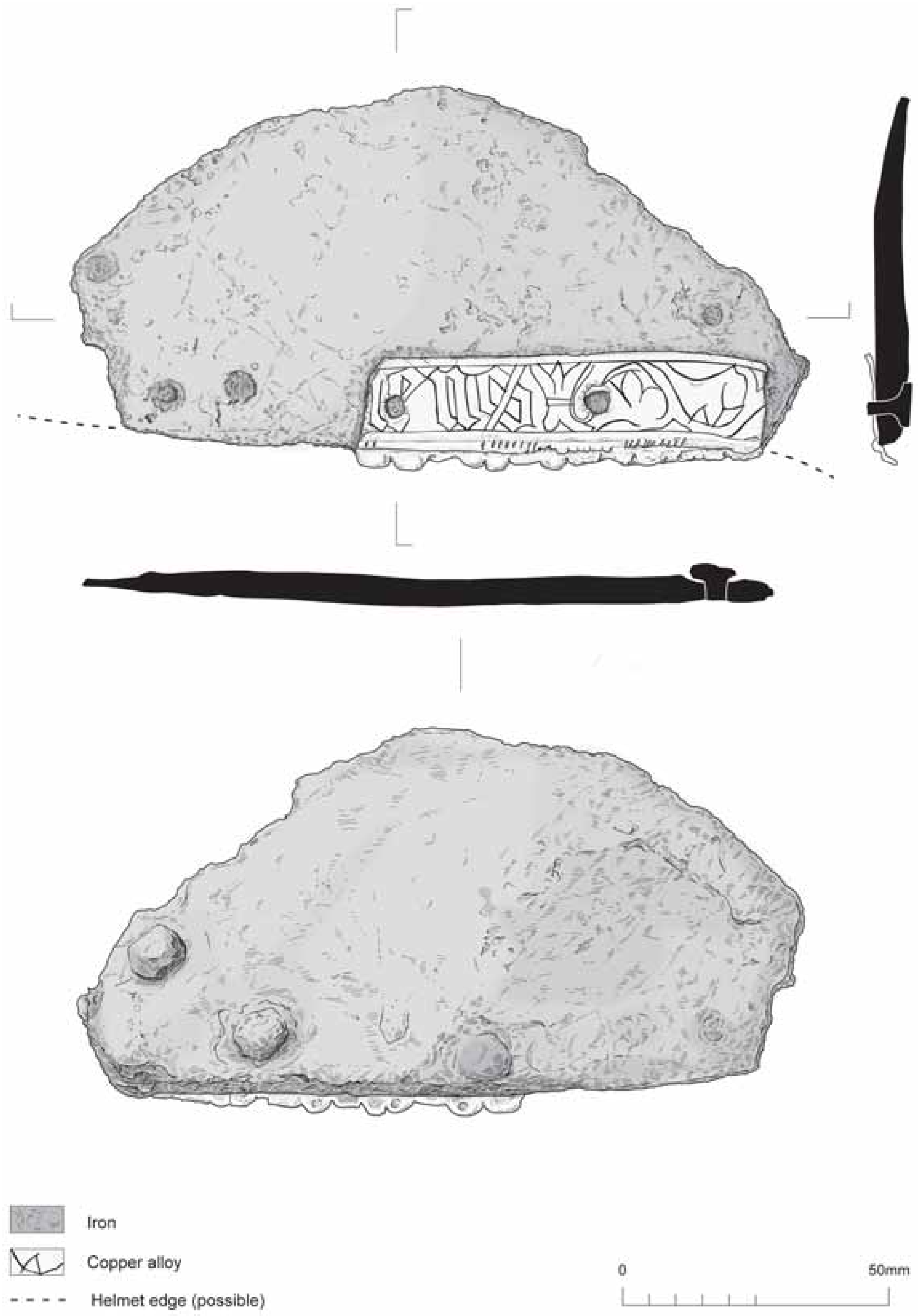
Dimensions: Plate is 148mm x 73mm x 4mm. The strip is 72mm x 22mm x 1mm.

Description: Helmet Fragment. One scalloped edge, three straight and two rivet attachments. It is engraved with Gothic textura (textualis quadrata) script. Inscribed are the letters ENS followed by a foliate/organic scroll, forming a break between words (Redknap 2010) Between the inscription and the scalloped edge is a raised ridge with decorative line motifs engraved at a slight angle. See also Msg 171.





Artefact Type: Hemet fragment.	Description: Helmet Fragment. One scalloped edge, three straight and two rivet attachments. It is engraved with Gothic textura (textualis quadrata) script. Inscribed are the letters ENS followed by a foliate/organic scroll, forming a break between words (Redknap 2010) Between the inscription and the scalloped edge is a raised ridge with decorative line motifs engraved at a slight angle. See also Msg 171.
Material: Gilt CuA strip.	
Context: 152	
Dimensions: Plate is 148mm x 73mm x 4mm. The strip is 72mm x 22mm x 1mm.	



Artefact Type: Hemet fragment.

Material: Gilt CuA strip.

Context: 152

Dimensions: Plate is 148mm x 73mm x 4mm. The strip is 72mm x 22mm x 1mm.

Description: Helmet Fragment. One scalloped edge, three straight and two rivet attachments. It is engraved with Gothic textura (textualis quadrata) script. Inscribed are the letters ENS followed by a foliate/organic scroll, forming a break between words (Redknap 2010) Between the inscription and the scalloped edge is a raised ridge with decorative line motifs engraved at a slight angle. See also Msg 171.

Artefact Type: Coin.

Material: Metal.

Context: From Keel.

Dimensions:

Description: French Coin (Petit Blanc).

Artefact Type: Coin.

Material: Metal.

Context: 128.

Dimensions: 1.89g

Description: 1 Coin, Portugal, Afonso V (1438-81); copper ceitil, Lisbon, 1.89g. cf A do 1115 etc.

Artefact Type: Coin.

Material: Metal.

Context: 130

Dimensions: 0.76g

Description: Portugal, Duarte I (1433-8), copper *real preto*, Lisbon, 0.76g. Cf. A do. A. 974.

Artefact Type: Coin.	**Description: Portugal, Alfonso V (1433-81), copper *ceitil* Lisbon, 1.44g. cf. A do. A. 1112?.**
Material: Metal.	
Context: 128.	
Dimensions: 1.44g	

Artefact Type: Coin.

Material: Metal.

Context: 128.

Dimensions: 1.47g

Description: 1 Coin, Portugal, Afonso V, copper ceitil, Lisbon, 1.47g.

Artefact Type: Coin.	**Description: Copper alloy jetton, 20mm, 0.61g. Obv: 'African' head to left, border of lozenges; rev: uncertain (folded), with border of fleurs-de-lys. 14th - 15th centuries.**
Material: Metal.	
Context: 128.	
Dimensions:	

Artefact Type: Tingle.	Description: Tingle with 25 visible nail holes of varying sizes. The largest nail hole is 5mm x 5mm, the smallest is 1.5mmx1.5mm. Nail head impressions remain. The inner surface has a thick layer of what looks like wool and horse hair. Nails were clearly hammered from the outside in toward the hair covered surface-(suggested by the head impressions on one surface and exit holes on the opposite surface)
Material: Lead.	
Context: 152.	
Dimensions: 190mm x 83mm x 2.43mm. 406g.	

Artefact Type: Binding.

Material: Metal - Cu Alloy.

Context: 128.

Dimensions: 22.1mm long x1.9mm in diameter. 0.24g.

Description: Gold colour in patches. Small hole, 0.5mm in diameter, perforates the piece's diameter 2.4mm from the end. A join runs the length of the piece- presumably from construction. Thie piece is wider at the end with a hole in it and tapers toward the opposite end.

Artefact Type: Binding.

Material: Metal - Cu Alloy.

Context: 128

Dimensions: 18.4mm in length x 1.72 diameter. 0.11g.

Description: Gold in colour. Join runs the length of the piece, presumably from construction. Metal strand runs through the centre of the wire. Damaged at one end.

Artefact Type: Binding.

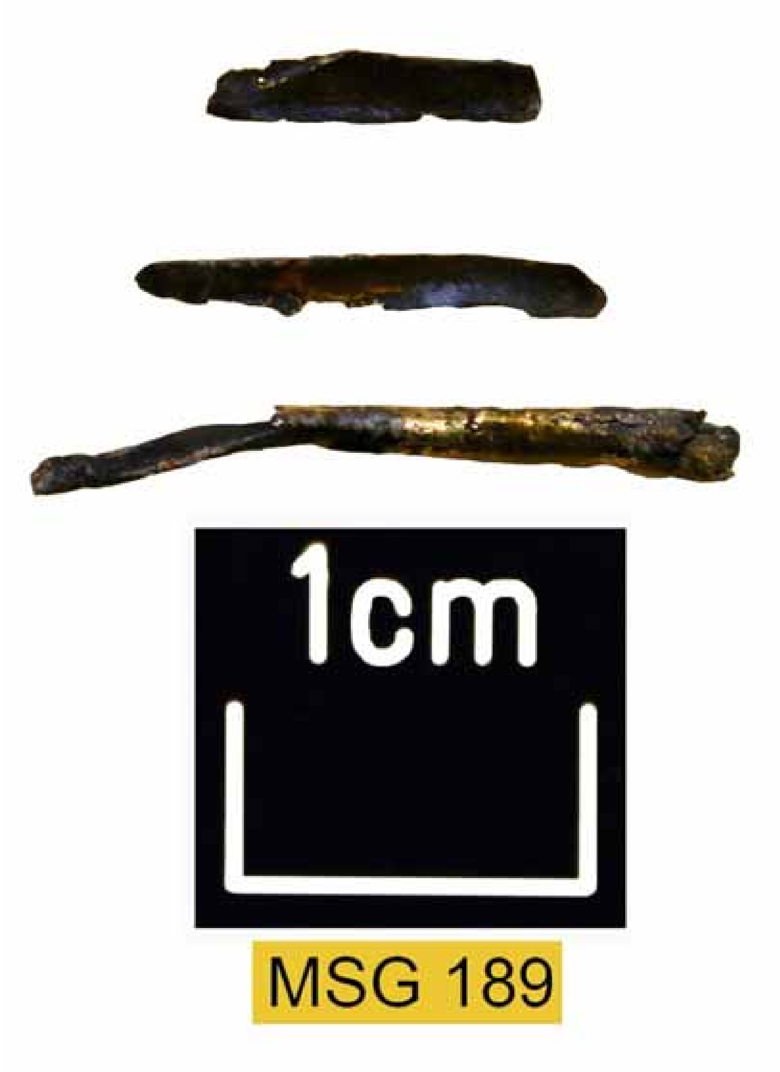
Material: Metal - Cu Alloy.

Context: U/S.

Dimensions: 33.4mm in length. 1.5mm in diameter. 0.13g.

Description: Gold in colour. Hollow with narrow gap or join running down the length of the piece-presumably from construction. Piece is slightly bent.

Artefact Type: Binding.	Description: Gold in colour, slightly bent. Appears to be hollow with a metal strand running through the centre- damaged end exposes central strand. Narrow gap running the length of the wire- presumably from construction.
Material: Metal - Cu Alloy.	
Context: 128.	
Dimensions: 20mm in length x 1.2 mm in diameter. 0.7g.	



Artefact Type: Binding.	**Description: Outer shell is gold in colour. Central strand runs through the outer shell.**
Material: Metal - Cu Alloy.	
Context: 128.	
Dimensions: Largest measures 19.4mm in length x 1.3 in diameter.	

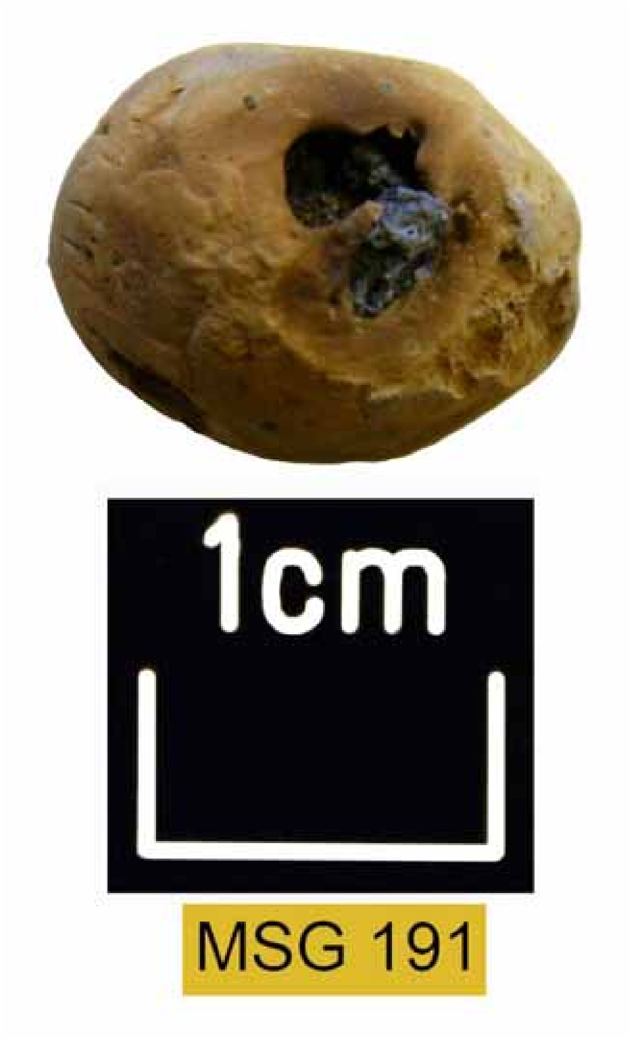
Artefact Type: Binding.

Material: Metal - Cu Alloy.

Context: 130.

Dimensions: 27.7mm in length. 1.69mm in diameter. 0.2g.

Description: Circular in section, gold in colour. Appears to have sediment within it. One end has a hole perforating through the wire. It appears to have the possible remains of a small pin, in situ, in the hole. A small gap runs the length of the wire, presumably a feature of its construction.



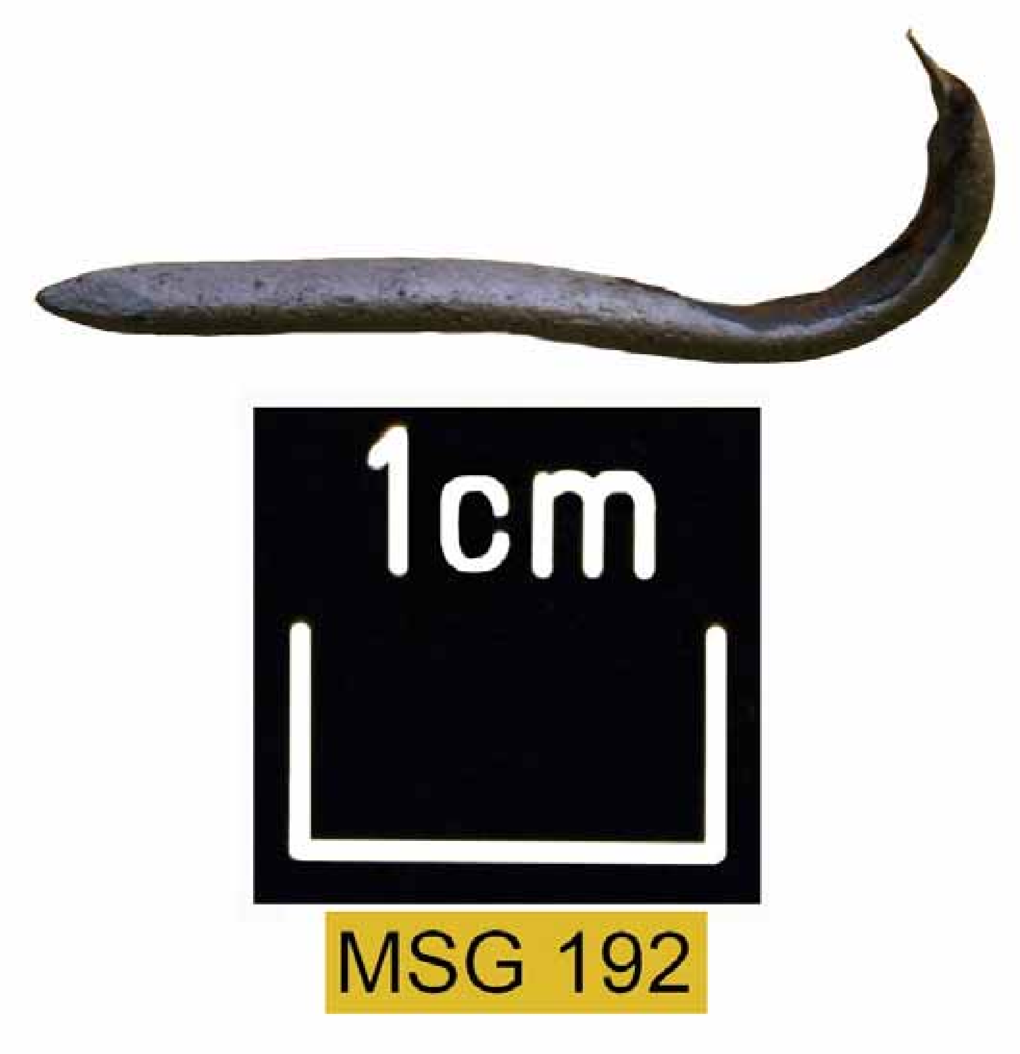
Artefact Type: Unknown.

Material: Metal - Fe..

Context: U/S.

Dimensions: 4.2mm diameter. 2g.

Description: Encased in a sediment concretion. Roughly globular in shape.



Artefact Type: Possible nail.

Material: Metal - Fe.

Context: 2027.

Dimensions: 30mm in length; 1.52mm in diam. 0.53g.

Description: Hooked in shape. Grey in colour. The tip is faceted. Opposite end ie the bent end is damaged. Possibly modern. Cardiff Uni No.:5939-05.

Artefact Type: Binding.	**Description: Appears to have been rolled with a join running the length of the piece. Concretion at one end. Piece tapers in thickness from one end to the opposite.**
Material: Metal - Cu Alloy.	
Context: 128.	
Dimensions: 48.2mm long. 7.1mm-5.8mm in diameter. 7.38g.	

Artefact Type: Wire.

Material: Metal - Fe.

Context: 130.

Dimensions: 15mm in length. Diameter of 1.6mm. 2.27g.

Description: Bent close to one end. Each end has been cut leaving two facets. (possibly modern).

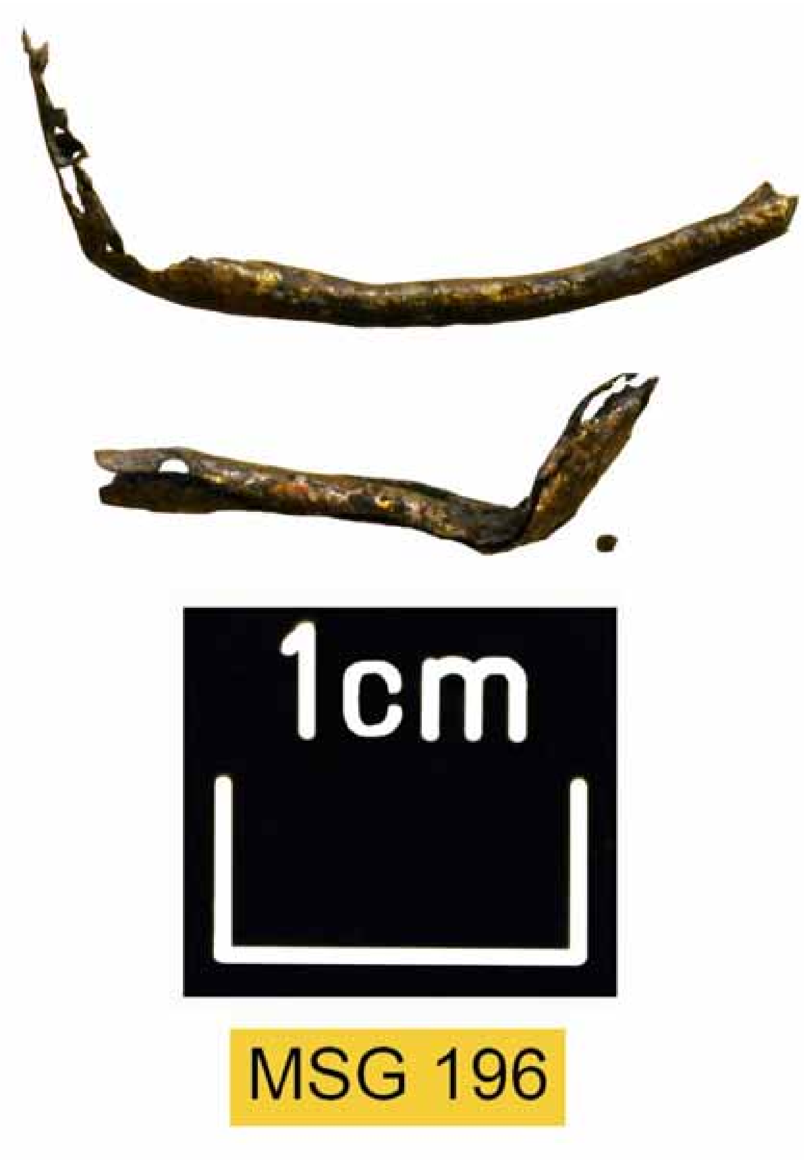
Artefact Type: Binding.

Material: Metal - Cu Alloy

Context: 128.

Dimensions: Combined length of 156mm. Diameter is 1.2mm (varies) Combined weight is 1.13g.

Description: 3 pieces Cu Alloy Binding. Gold in colour. Do not appear to be hollow.



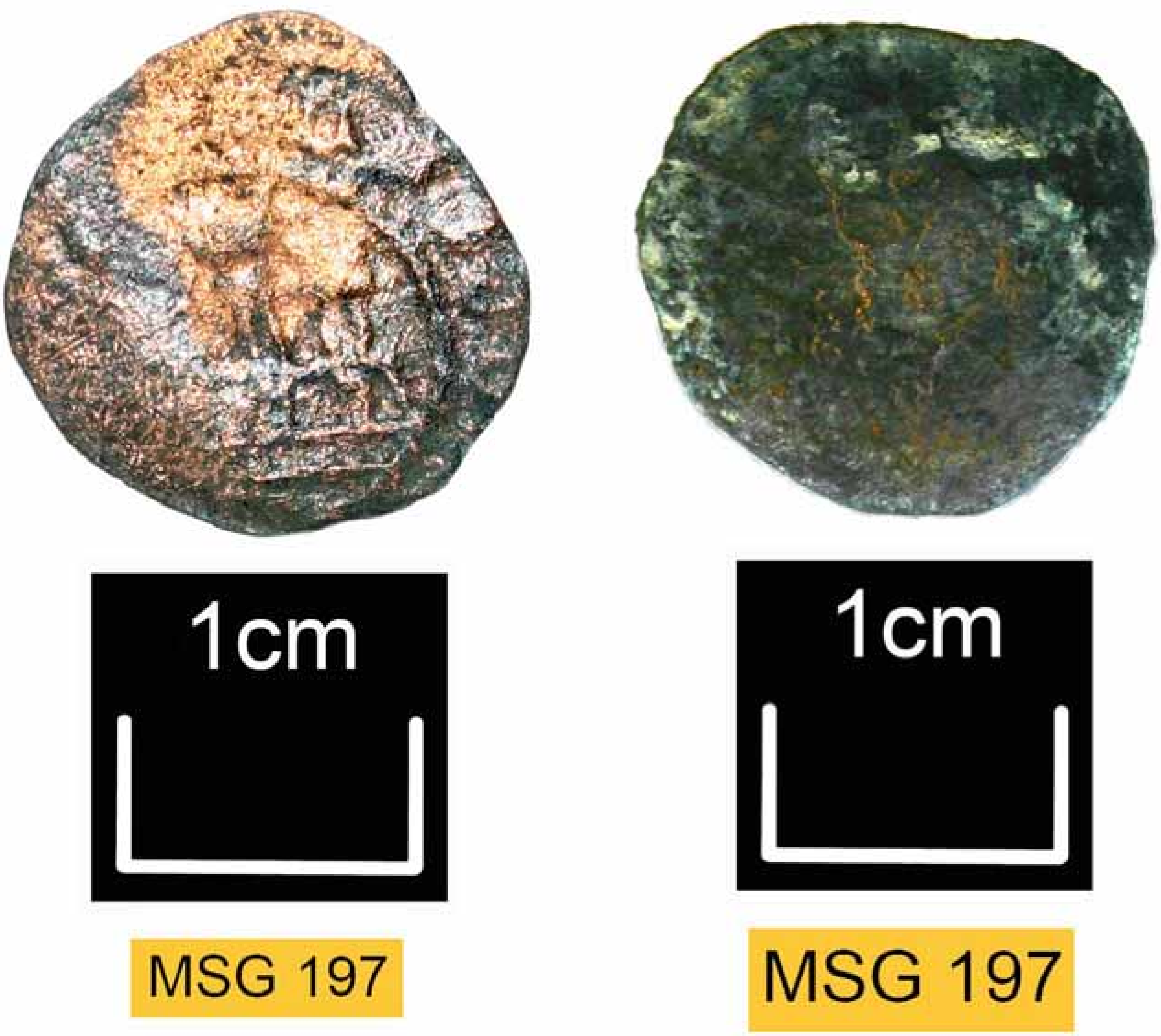
Artefact Type: Binding.

Material: Metal - Cu Alloy.

Context: 128.

Dimensions: longest is 30mm in length and 1.4mm in diameter. The two pieces combined weigh 11g.

Description: Both are gold in colour, hollow and bent. A join runs the length of the piece presumably from construction.



Artefact Type: Coin.

Material: Metal - Cu.

Context: 130.

Dimensions: 1.26g.

Description: Portugal, Afonso V, copper ceitil, Lisbon?, 1.26g. Cf Ado A 1165, general type. Rev: AFONS[...]?"

Artefact Type: Metal disc.

Material: Metal - Cu Alloy.

Context: 128.

Dimensions: --

Description:1 metal disc. No visible surface detail.

Artefact Type: Washer.

Material: Metal - Fe.

Context: U/S.

Dimensions: Outer diam is 58.6mm, inner diam is 33.9mm, depth is 9mm. Weight is 78.67g.

Description: Good condition.

Artefact Type: Washer.	Description: Good condition.
Material: Metal - Fe.	
Context: U/S.	
Dimensions: Outer diam is 58.6mm, inner diam is 33.9mm, depth is 9mm. Weight is 78.67g.	

Artefact Type: Washer.	**Description: Grey in colour, good condition. Some cracks present. No contextual info.**
Material: Metal - Fe	
Context: U/S.	
Dimensions: Outer diam is 57.2mm, inner diam is 32.6mm, depth is 10.9mm. Weight is 63.31g.	

Artefact Type: Washer.

Material: Metal - Fe.

Context: U/S.

Dimensions: Outer diameter is 57.9mm. Inner diam is 34.1mm, it's 9.2mm thick & weighs 90.4g.

Description: Part of the surface has fallen off. Circular in plan. Rust is visible where surface has fbroken away.

Artefact Type: Nail.

Material: Metal - Fe

Context: U/S.

Dimensions: 94.2mm in length. Shaft is 7mm x 7mm at head, tapering to 2.3mm x2 .3mm at the tip. 15.42g.

Description: Square in section with some surface damage. Head is flat and roughly circular in shape.

Artefact Type: Nail and rove.	Description: Nail is 64.8mm (including head). Shaft is square and measures 8mmx8mm. Head is subcircular with a dome and is approx 33.5mm in diameter. Rove is rectangular with a square hole in the centre measuring 7.5mm x 6.9mm. Both have beeen laser scanned. Note these items were found together however nail doesn't fit through the rove.
Material: Metal - Fe.	
Context: U/S.	
Dimensions: See description.	

Artefact Type: Nail and rove.

Material: Metal - Fe.

Context: U/S.

Dimensions: See description.

Description: Nail is 64.8mm (including head). Shaft is square and measures 8mmx8mm. Head is subcircular with a dome and is approx 33.5mm in diameter. Rove is rectangular with a square hole in the centre measuring 7.5mm x 6.9mm. Both have beeen laser scanned. Note these items were found together however nail doesn't fit through the rove.

Artefact Type: Unknown.	Description: Possibly one large bolt head.
Material: Metal - Fe.	
Context: U/S.	
Dimensions: Largest is 75mm x 61mm x 35mm.	

Artefact Type: Bolt.	Description Large Iron Bolt. Sureface concretions, active surface corrosion. Light orange flaky rust.
Material: Metal - Fe.	
Context: From knee 1638.	
Dimensions: 700mm in length Shaft diameter nr. Head is 32.5mm, middle is 32.7mm, end is 30.6mm. Wieghs 3320g.	

Artefact Type: Bolt.

Material: Metal - Fe.

Context: From knee 1638.

Dimensions: 700mm in length Shaft diameter nr. Head is 32.5mm, middle is 32.7mm, end is 30.6mm. Wieghs 3320g.

Description

Large Iron Bolt. Sureface concretions, active surface corrosion. Light orange flaky rust.

Artefact Type: Bolt.

Material: Metal - Fe.

Context: From Knee 1629.

Dimensions: 480mm x 30mm shaft diameter. Head = 67mm diam x 25mm thick. It weighs 1880g.

Description: Interesting concretion- small blooms on eruptions along surface of bolt shaft. Some timber trapped in concretion around bolt head. Bolt damaged on shaft end (away from head) during removal. Interesting iron grain feature on head of bolt - possibly indicating that the bolt head was formed over a ring. MSG 1239 &524=same bolt.

Artefact Type: Bolt.

Material: Metal - Fe.

Context: From Knee 1629.

Dimensions: 480mm x 30mm shaft diameter. Head = 67mm diam x 25mm thick. It weighs 1880g.

Description: Interesting concretion- small blooms on eruptions along surface of bolt shaft. Some timber trapped in concretion around bolt head. Bolt damaged on shaft end (away from head) during removal. Interesting iron grain feature on head of bolt - possibly indicating that the bolt head was formed over a ring. MSG 1239 &524=same bolt.

Artefact Type: 1 rove 8 nails.

Material: Iron - Fe.

Context: 128.

Dimensions: See description.

Description: The rove is 17g, 27mm x 27mm x 5mm. Concretion is present. The first nail is 30mm in length, has an irregular head 13mm across. The shaft is 5mm x 5mm and damaged. It's 4g. The second nail is55mm in length, domed head 35mm in diameter. The shaft is is 10mm x 10mm and weighs 21g. The third is 70mm in length, has an irregular head 25mm in diameter. The shaft is 6mm x 6mm and damaged towards the tip. It weighs 21g. The fourth nail is 72mm in length, no head. The shaft is 10mm x 10mm, 4g. The fifth is 45mm in length the head is 11mm in diameter. Shaft is 3mm x 3mm tapering to a point, 4g. The sixth is 30mm in length, the head is 30mm in diameter. The shaftis 6mm x 6mm tapering towards the tip. It is 11g. The 8th is 75mm in length, 15mm diameter head. The shaft varies in thickness, approx 4mm x 4mm and tapers to a point. The nail is bent 10mm below the head. It's 8g.

Artefact Type: 1 washer & 3 nails.

Material: Metal - Fe.

Context: 128

Dimensions: See description.

Description: Largest nail is 57mm in length, 6g. Head is circular with a diameter of 15mm. Shaft is 4mm x 4mm and tapers to a point. The smaller nail, 7g is 39mm in length and has a head diameter of 19mm. The shaft is 5mm x 5mm - tapering towards the point. The smallest nail is 1g, 25mm in length. The head is 10mm x 6mm. The shaft is 5mm x 5mm tapering to a point. The smallest nail is 1g, 25mm in length. The head is 10mm x 6mm. The shaft is 3mm x 3mm and tapers to a point. The washer is 68g. The outer diameter is 55mm, the inner diamketer is 30mm and is 7mm thick.

Artefact Type: 2 nails.

Material: Metal - Fe.

Context: 128.

Dimensions: See description.

Description: Larger nail, 7g, is 55mm in length. No head. Heavily concreted - approx 7mm x 7mm shaft, tapering to a point. The smaller nail is 7g, 37mm in length. Head is damaged and concreted, appears to be circular with a diameter of approx 22mm. The shaft is 4mm x 4mm and tapers towards the tip.

Artefact Type: Nails.

Material: Metal - Fe.

Context: 128.

Dimensions: See description.

Description: 3 Nails. 34g combined. Ferrous. Metallic iron present in two of the three. Some concretion present. First is 65mm in length with a circular head 23mm in diameter. Shaft is 7mm x 7mm tapering to 5mm x 5mm. Tip is damaged. Second is 65mm in length with a circular head 18mm in diameter. Shaft is 7mm x 7mm tapering to 5mm x 5mm with a damaged tip. The third is heavily concreted, 67mm in length. Shaft is approximately 5mm x 5mm. No metallic iron present. (5939/02)

Artefact Type: Clenched nail.

Material: Metal - Fe

Context: U/S.

Dimensions: See description.

Description

17g. Head is damaged, with a diameter of 20mm. Clenched into a 'U' shape. Concretion present. Attached to 1220. Ferrous. Metallic iron present.

Artefact Type: Nail

Material: Iron

Context: 128

Dimensions: 57mm in length, shaft is 7mm x 7mm. 16g.

Description: Ferrous. Metallic iron present. Tip is slightly bent. The head is concreted, shaft is tapering towards the tip.

Artefact Type: Nail and Iron fragment.

Material: Metal - Fe.

Context: 128.

Dimensions: 65mm x11mm x 5mm. 19g.

Description: Piece of iron. Metallic iron present. Rectangular in shape. Function unknown. Second piece appears to be a nail.

Artefact Type: **3 nails and 8 concreted fragments.**

Material: Metal - Fe.

Context: 128.

Dimensions: See description.

Description: Metallic iron present. Ferrous. Largest is 92g bent into an 'l' shape. Head is concreted and measures 24mm in diameter. Shaft tapers from 15mm x 15mm to 5mm x 5mm. Smaller nail is 18g, bent into an 'L' shape. Head is 10mm x 8mm. Shaft tapers from 7mm x 7mm and tapers to a point. Smallest nail is 7g, straight. The head is subcircular with a diameter of 15mm. Shaft tapers from 5mm x 5mm to a point.

Artefact Type: 2 Nails.	**Description: Metallic iron present. Larger is 70mm in length, 7g in weight. Head is damaged and concreted with 18mm diameter. Shaft is 6mm x 6mm tapering to a point. Smaller nail is 6g. Head is roughly square measuring 10mm x 11mm. Shaft is 5mm x 5mm tapering to a point.**
Material: Metal - Fe.	
Context: 128.	
Dimensions: See description.	

Description: Found in the bow. Metallic iron present. The rove is 39mm x 42mm x 7mm. Heavily concreted. Head and part of the shaft is in situ but concreted. The first nail is 50mm in length. It has a circular but bent head. The shaft is 6mm x 6mm, tapering towards the damaged tip and is bent. It is 14g. The second is 41mm in length and is a shaft with no head. It is 8mm x 8mm and is 16g. The third is 52mm in length, 4g, part of the head remains. Shaft is 4mm x 4mm tapering towards the tip. The fourth is 50mm in length, 2g. No head. 3mm x 3mm, tapering to a point. The fifth is 36mm in length. 14mm diameter head and weighs 2g. The shaft is 4mm x 4mm.

Artefact Type: 1 rove and 5 nails.

Material: Metal - Fe.

Context: 128.

Dimensions: See description.

Artefact Type: 2 nails and 6 iron fragments.

Material: Metal - Fe.

Context: 128.

Dimensions: See description.

Description: Ferrous. Metallic iron present. Larger nail is 75mm in length, 32g. Head is dome shaped with a diameter of 27mm approx. Shaft is square, 8mm x 8mm, tapering towards the tip. The second nail is 45mm in length. The head is 25mm in diameter. The shaft is 9mm x 9mm tapering towards the tip. Six iron fragments, 65mm (largest) 14mm (smallest) varying thickness, function unknown.

Description: Metallic iron present. The first is 51mm in length with a dome head 30mm in diameter. The shaft is 9mm x 9mm tapering to 6mm x 6mm. The second is 40mm in length, no head with a 4mm x 4mm shaft, slightly bent. The third is 36mm in length. The head is domed and broken with a 32mm diameter. The shaft is 7mm x 7mm tapering towards the tip. The fourth is 44mm in length with a bent tip. The head is six sided, approx 18mm across. The shaft is 4mm x 4mm, tapering to a damaged tip. The fifth is 78mm in length with a subcircular head, 20mm in diameter. The shaft is 5mm x 5mm, tapering to a point. It is slightly bent. The sixth is 44mm in length. The head is roughly circular, 10mm in diameter. The shaft is 3mm x 3mm tapering to a point. The final nail is 35mm in length with an irregular shaped head 19mm x 14mm. The shaft is 4mm x 4mm tapering and damaged towards the tip.

Artefact Type: 7 Nails.

Material: Metal -Fe.

Context: 128.

Dimensions: See description. 72g combined.

Description: From the bow. Metallic iron present. The rove is 8g, 25mm x 25mm x 1mm. The shaft hole is 5mm x 5mm. The first nail is 70mm in length, the head is 33mm in diameter. The shaft is is 10mm x 10mm and bent. It is 56g. The second is 50mm in length, the head is 20mm in diameter. The shaft is 8mm x 8mm, tapering towards the tip. It's 12g. The third is 27mm in length the head is 21mm in diameter. The shaft is 8mm x 8mm. It's 11g. The fourth is 30mm in length, the head is is 23mm in diameter. The shaft is 7mm x 7mm. It's 10g. The 5th nail is a shaft with no head, 36mm in length, 5mm x 5mm, 4g. The 6th is 74mm in length with a damaged head, 16mm in diameter. The shaft is 5mm x 5mm tapering to a point. It's 7g. The seventh is 54mm in length, no head. The shaft is 4mm x 4mm, tapering to a point. It's 4g. The 8th is 40mm in length, head is 23mm in diameter. The shaft is 4mm x 4mm tapering to a point. The 9th is 22mm in length. The head is 11mm in diameter, the shaft is 3mm x 3mm, 1g. The tenth is 33mm in length. No head. The shaft is 4mm x 4mm and is 5g.

Artefact Type: 10 nails and 1 rove.

Material: Iron - Fe.

Context: 128

Dimensions: See description.

Artefact Type: Possible horse shoe fragment.

Material: Metal - Fe.

Context: 128/130? Norht of mast step.

Dimensions: 60mm x 20mm x 10mm. 45g.

Description: Tapers in thickness from 10mm to 5mm. Slight curve along the length of the piece.

Description: Ferrous. Metallic iron present. First nail is 5g, 61mm in length. The head has concretion. The shaft is 5mm x 5mm tapering towards the tip. The second nail is 20g, 50mm in length. The head is concreted with a diameter of approx 25mm. The shaft is 10mm x 10mm tapering to 5mm x 5mm. The third nail is 3g, 44mm in length. The head is roughly square, 10mm x 10mm shaft is 4mm x 4mm, tapering to a point. The fourth nail is 17g. No head. Shaft is slightly bent and measures 6mm x 6mm tapering to a point. The fifth nail is an 'L' shape. 7g. Roughly square head, approx 8mm x 8mm. Shaft is 5mm x 5mm tapering to a point. The final object is a fragment of a possible horse or oxen shoe.. It is 115mm in length, 34mm wide tapering to 10mm. It's 4mm thick. Three holes, square, 4mm x 4mm, perforate the piece.

Artefact Type: 5 nails and 1 possible horse/ox shoe.

Material: Metal - Fe.

Context: 128.

Dimensions: See description.124g combined.

Artefact Type: Nail.	**Description: Head is damaged with approx diameter of 15mm. The shaft is 3mm x 3mm, tapering to a point. Metallic iron present.**
Material: Metal - Fe.	
Context: 128	
Dimensions: 28mm in length. 2g.	

Artefact Type: 1 nail and one washer.

Material: Metal - Fe.

Context: 130.

Dimensions: See description.

Description: Metallic iron present. Washer is 83g, 55mm in diameter, 30mm inner diameter. 8mm thick. Some concretion. See also MSG 199, 200, 201, 606, 654, 658, 690 and 770. The nail is 76mm in length. Concretion is present. The shaft is slightly bent and measures 6mm x 6mm and tapers to a point. No head. (5938/09)

Artefact Type: Nail.

Material: Metal - Fe.

Context: 130 F25-26.

Dimensions: See description.

Description: 3g. 35mm in length. Head diameter is approx 16mm. Shaft is 5mm x 5mm tapering to a damage tip. Tip is bent/clenched. Ferrous. Metallic iron present.

Artefact Type: Rove.	**Description: Ferrous. Metallic iron present. Nail head and part of shaft reamin in situ. Shaft is 7mm x 7mm.**
Material: Metal - Fe.	
Context: 130 F20-26.	
Dimensions: 33mm x 30mm x 4mm. 16g.	

Artefact Type: Washer.	**Description: Metallic iron present. Broken in to two pieces/ Outer diameter is approx 60mm. Inner diameter is approx 35mm in diameter. 7mm thick. See also MSG 199, 200, 201, 606, 626, 658, 690, 770.**
Material: Metal - Fe.	
Context: 129.	
Dimensions: See description. 52g.	

Artefact Type: One nail and one piece of iron.	**Description: Iron piece is ferrous, metallic iron present. 48g. Roughly rectangular. 44mm x 37mm x 8mm thick. Function unknown. The nail is 3g, Fe. 39mm in length. Head is broken. Shaft is 3mm x 3mm, tapering towards the tip. (5938/02)**
Material: Metal - Fe.	
Context: 109 F45 - 50.	
Dimensions: See description.	

Artefact Type: Washer.

Material: Metal - Fe.

Context: 130. F42 -43's.

Dimensions: See description.

Description: Metallic iron present. Broken in three pieces. Outer diameter is approx 64mm. Inner diameter is obscured by concretion but is 25mm diameter approx. See also MSG199, 200, 201, 690.

Artefact Type: Nail	**Description: Metallic iron present. Ferrous Head is slightly distorted with some concretion. Approximate head diameter is 30mm. Shaft is 10mm x 10mm tapering towards the tip. 5 Fragments now discarded.**
Material: Metal - Fe.	
Context: 1001.	
Dimensions: 65mm in length. 30g.	

Artefact Type: Washer.

Material: Metal - Fe.

Context: 120 F26_2.

Dimensions: Outer diameter is 80mm. Inner diameter is 30mm, 12mm thick.

Description: No metallic iron remains. Broken - in two parts. See also MSG199, 200 & 201.

Artefact Type: Rove.

Material: Metal - Fe.

Context: 2027.

Dimensions: 32mm x 32mm x 5mm. 34g.

Description: Ferrous, metallic iron present. Nail is still in situ with shaft 7mm x 7mm.

Artefact Type: Washer.

Material: Meatal - Fe.

Context: U/S.

Dimensions: See description.

Description: Outer diameter is 60mm. The inner diameter is 30mm. Washer is 10mm thick. See also MSG 199, 200, 201, 606, 626, 654, 658, 690.

Artefact Type: Nail.

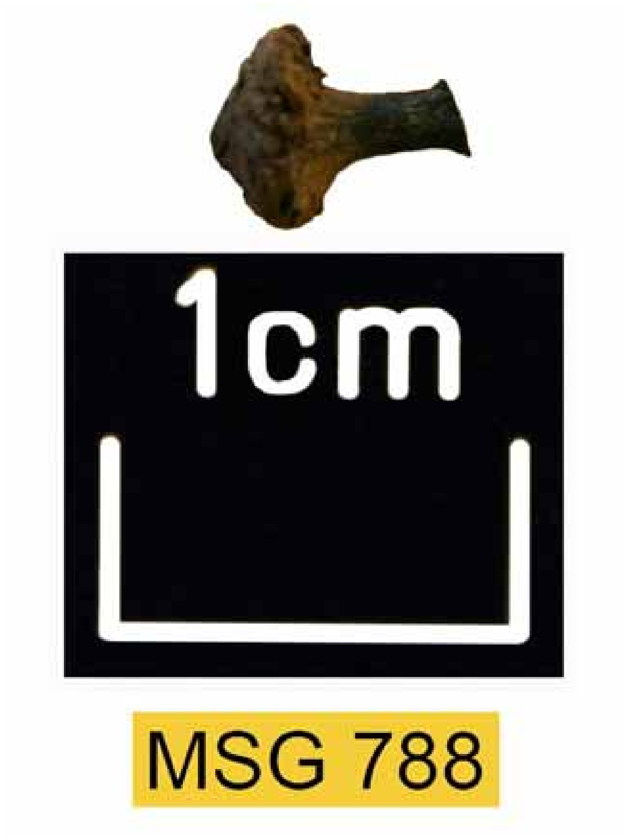
Material: Iron - Fe.

Context: 149.

Dimensions: >10 mm 4.23 g 36mm long, shaft is 4mm x 4mm.

Description: Concretion is present. Tapers toward the tip.

Artefact Type: Nail.	**Description: Some concretion. Packaged with the nail are several fragments.**
Material: Metal - Fe.	
Context: 120.	
Dimensions: >10 mm 3.59g 33.3mm in length (including head) shaft is 5mm x 5mm.	



Artefact Type: Nail.

Material: Metal.

Context: From leather.

Dimensions: See description.

Description: Nail from leather 2 of 2. 6.4mm including head. Shaft is 1.4mm x 2.1mm(diameter x 3.6mm in length. 4g. Broken shaft. Head is slightly concreted and has a diameter of 4.8mm. From leather.

Artefact Type: Nail.

Material: Metal - Fe.

Context: 1613.

Dimensions: 49.57mm long (including head. Shaft is 38mm long x 12mm x 12mm. Weighs 58.76g.

Description: Shaft is square. Rove is still in situ with concretion. Rove (including concretion measures 48mmx45mmx6.3mm.

Artefact Type: 3 nails.	**Description: Longest is 60.3mm including head, shaft is 5mmx5mm, 5.32g. The shortest is 38.9mm in length including head shaft is 3mmx3mm and 3.86g. The third nail is 47.2mm in length including head, the shaft is 6mmx6mm and is bent at the tip. All three taper towards the tip and have some concretion.**
Material: Metal - Fe.	
Context: 128.	
Dimensions: See description.	

Artefact Type: Binding.	**Description: Longest is 0.79g 37mm long x 2.3mm diameter and is heavily concreted. The shortest piece is 0.29g 29.1 in length x 1.6 diameter with some concretion. The third piece is 0.15g 31.4mm in length x 1.4mm diameter, gold in colour with join along its length. No concretion.**
Material: Metal.	
Context: 120	
Dimensions:See description.	

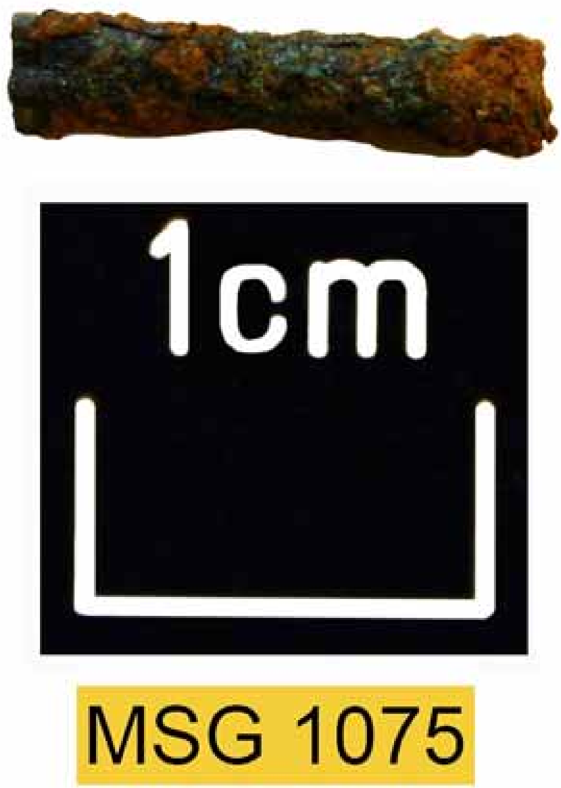
Artefact Type: Binding.

Material: Metal.

Context: 120.

Dimensions: 39.5mmx1.24mm 0.37g.

Description: Grey and gold in colour. Slightly bent. Function unknown.



Artefact Type: Pin / nail.

Material: Metal - Possibly Cu.

Context: 120.

Dimensions: 13.44mm x 2.3mm diameter. 0.11g.

Description: Quite flat at one end. Some concretion present.

Artefact Type: Binding.	**Description: Hollow rod, mostly gold in colour. A join runs the length of the piece. A small hole is visible at one end but doen not perforate right the way through.**
Material: Metal.	
Context: 130.	
Dimensions: 25.2mm x 2mm diameter 0.33g.	

Artefact Type: Binding.

Material: Metal.

Context: 130.

Dimensions: See description.

Description: metal rods. The longest is 38.6mm long x 2.2mm diameter & 0.79g, appears to be complete. A join runs the length of the rod. Gold in colour with uniform ridges across its width. One end has a small pin in situ through the diameter of the rod. The smaller piece is more fragile, bright gold in colour. Join runs along the length, slightly bent. It measures 26.5mm in length and 1.72mm in diameter. Appears to have a hole through the diameter at one end. Rod itself is hollow and weighs 0.11g.

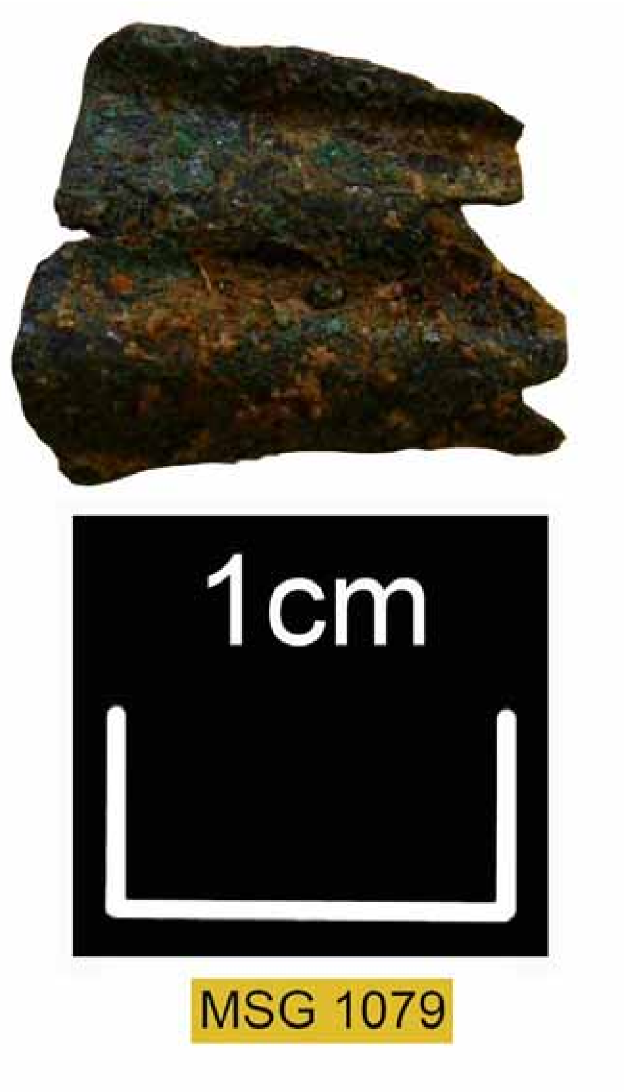
Artefact Type: Binding.

Material: Metal.

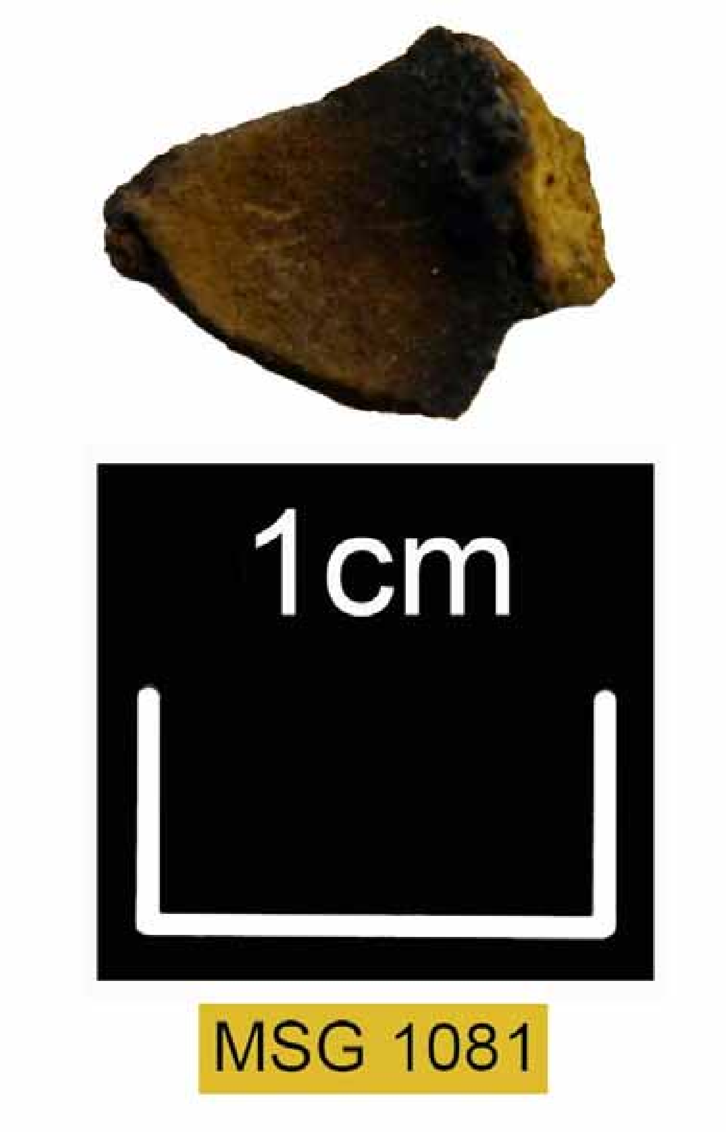
Context: 120.

Dimensions: 24.2mm in length 2.03 in diameter 0.2g.

Description: Possibly hollow. Some concretion attached.



Artefact Type: Corrugated fragment.	**Description: Copper fragment. Corrugated ridges running the length of the fragment. Appears to have two original edges.**
Material: Metal - Cu.	
Context: 120.	
Dimensions: 14.3mm x11.2mm x 0.6mm 0.36g.	



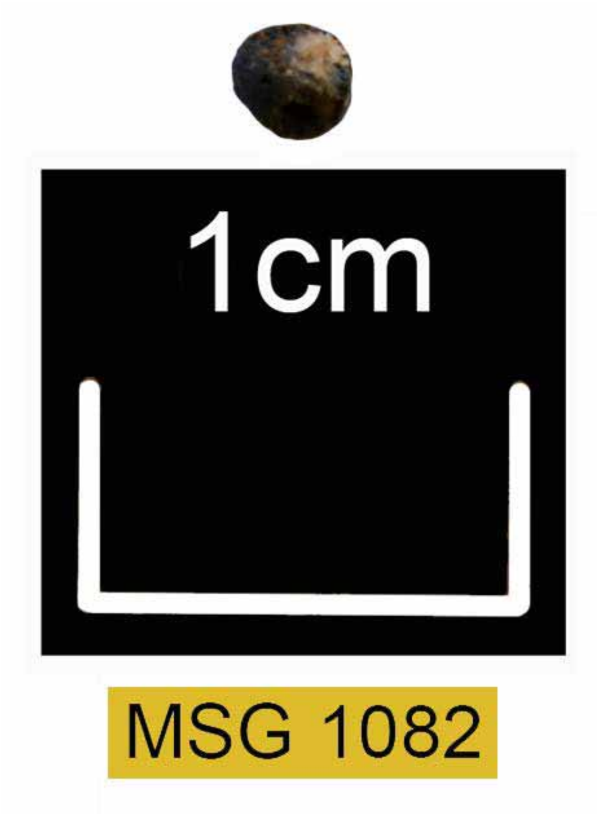
Artefact Type: Fragment.

Material: Possibly metal.

Context: 120.

Dimensions: 10.4mm x 8.8mm x 1.2mm. 0.2g.

Description: Small fragment, possibly metal. Charred.



Artefact Type: Possibly production waste.

Material: Metal - Fe.

Context: 120

Dimensions: 2.94mm in diameter. 0.02g.

Description: Tiny ball. Hole in the centre.

Artefact Type: Weight.

Material: Metal - lead.

Context: 130.

Dimensions: See description.

Description: Lead Weight, poss merchant weight (see small amount of lead removed from base) TNJ 11.11.10 Dome shaped. Base diameter=29.6mm height=26.1mm Weight=131.56g Hole, diameter 5.6mm perforates weight from top to base. Sub circular depression on base diameter=5.6mm. Cardiff Uni XRF ID'd composition as almost entirely lead with v. small amount of tin.

Artefact Type: Weight.

Material: Metal - lead.

Context: 130.

Dimensions: See description.

Description: Lead Weight, poss merchant weight (see small amount of lead removed from base) TNJ 11.11.10 Dome shaped. Base diameter=29.6mm height=26.1mm Weight=131.56g Hole, diameter 5.6mm perforates weight from top to base. Sub circular depression on base diameter=5.6mm. Cardiff Uni XRF ID'd composition as almost entirely lead with v. small amount of tin.

Artefact Type:	**Description: Nail Head and shaft fragment from Rider 3. No metallic iron present. Head is concreted, roughly circular, approx 70mm in diameter. 37mm thick. Shaft is visible and measures approx 13mm x 13mm. Fragment of concreted shaft has broken away from the head.**
Material: Originally Metal.	
Context: U/S.	
Dimensions: See description. 123g.	

Artefact Type: Bolt.

Material: Metal - Fe.

Context: From knee 1629.

Dimensions: 147mm x 31mm shaft. Head is 57mm wide x 27mm thick. 580g.

Description: Iron bolt with head. Ferrous - metallic iron present. Half of head has broken off. Substantial iron core remains intact and measures 21mm x 22mm. Concretion also intact.

Artefact Type: Bolt.

Material: Metal - Fe.

Context: From knee 1629.

Dimensions: 147mm x 31mm shaft. Head is 57mm wide x 27mm thick. 580g.

Description: Iron bolt with head. Ferrous - metallic iron present. Half of head has broken off. Substantial iron core remains intact and measures 21mm x 22mm. Concretion also intact.

Artefact Type: Bolt.

Material: Metal - Fe.

Context: From cross beam 001.

Dimensions: 288mm x 33mm. 1180g.

Description: Cylinderical. Hard iron core covered by corrosion product. Core is approximately 33mm x 27mm. Both ends are broken. Smaller end is slightly mush-roomed from removal process. Some wood grain patterns evident on the corrosion products.

Artefact Type: Bolt.

Material: Metal - Fe.

Context: From cross beam 002.

Dimensions: 266mm x 30mm diameter. 680g.

Description: Fragment of iron bolt. Most concretion has been removed leaving the hard iron core. Long grains of iron visiible. Original extents of fastener are present in the centre section. Some bent iron grains visibly damaged during bolt removal process. Core measures approximately 14mm x 21mm. MSG 1237 & 1240 & 1220 are all part of the same bolt.

Artefact Type: Bolt.

Material: Metal - Fe.

Context: From cross beam 003.

Dimensions: 286mm x 30mm. 740g.

Description: Cylinder bolt - Possibly a forelock bolt. Mushroomed at one end during removal. Hard iron core surrounded by concretion /corrosion product. Core varies between 19 and 23mm. Roughly square in section. MSG 1239 & 524 are the same bolt.

Artefact Type: Bolt.

Material: Metal - Fe.

Context: From cross beam 003.

Dimensions: 314mm x 30mm diameter. 920g.

Description: **Ferrous. Roughly square hard iron core surrounded by corrosion / concretion. Long iron grain is visible. Modern cut at one end. Core is approximately 17mm x 21mm. MSG 1237 & 1240 & 1220 are the same bolt.**

Artefact Type: Bolt.	**Description: Round iron bolt fragment. Hard core surrounded by concretion / corrosion. Core is 24.25mm square. Broken at both ends. MSG 1241 & 1236 are the same bolt.**
Material: Metal - Fe.	
Context: From cross beam 003.	
Dimensions: 228mm x 28-30mm diameter. 740g.	

Artefact Type: Fragments.

Material: Metal - Fe.

Context: From leather MSG 557 found in Bow (NE).

Dimensions: See description.

Description: Largest piece from leather MSG557 is 29mm in length x 5mm x5mm square shaft. It is 3.38g. The smaller piece-found in wood chips is 11.1mm in length x4.4mm. 0.2g Associated with 113.

Artefact Type: Nail.

Material: Metal - Fe

Context: U/S.

Dimensions: See description.

Description: Concreted nail from CT 2414. 40mm in length. Shaft is square in section 10mm x 10mm. Head is concreted..

Artefact Type: Nail.	**Description: Nail shaft from STRS 1.1A1 Damaged at both ends. Square in section.**
Material: Metal - Fe	
Context: U/S.	
Dimensions: 50mm x 10mm x 11mm.	

Artefact Type: Binding.

Material: Metal.

Context: 171.

Dimensions: 29mm x 2mm diameter. Less than 1g.

Description: From Sample 177. Seam runs the length of the wire. It is sealed at one end and open at the other. Black in colour with some gold in patches.

Artefact Type: Wire.

Material: Metal.

Context: 152.

Dimensions: 20mm in length x 5mm diameter.

Description: From Sample 149. Curled into a 'c' shape, encased in what appears to be concretion. Associated with MSG 1332 (feather was stuck to the concretion).