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Archaeometallurgical residues from the N7 Castletown to Nenagh scheme, Camlin 1 (E3579), Co. Tipperary

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Abstract

The assemblage from Camlin 1 comprised 59kg of residues, all of which, except 1.1kg of largely indeterminate material, was derived from the fill of the ringfort ditch. The majority of the material was identifiable as residue from smithing (smithing hearth cakes, SHCs), with a few pieces tentatively identified as being from smelting. The majority of fragments in the collection were quite large – probably reflecting the manual disposal of lumps of residue either into the ditch, or perhaps more likely onto a bank that was subsequently levelled into the ditch.

The high degree of fragmentation, despite the large size of the fragments, meant that the original weight was measurable or estimatable for very few of the SHCs. The number so determinable is revised down from 42 in the assessment to just 11. Such a small number means that statistical comparison with assemblages from other sites is not practical, but it is noteworthy that the smallest SHC recorded was 498g and the largest 2275g – a range suggesting that the site was involved with the refining of iron, but less conclusively with the end use of iron. In contrast, 50% of the SHCs in the assemblage from Camlin 3 weighed less than 498g.

The analytical programme was restricted in its scope, but involved chemical analysis of two pieces initially interpreted as being from smelting and four pieces of smithing slag, with samples taken across the size-range of examples. Of the smithing lags, two were then selected for investigation of their microstructure on the SEM.

Chemical analysis confirmed the discrimination of the identified smelting slags from the other samples. Although the smelting system at this site shares a distinctive chemistry with that at Camlin 3, some minor differences suggest that there were subtle differences between the ore exploited at the two sites and possibly with the ores exploited at Camlin 1. A strong inheritance of smelting residue into the smithing slags indicates that these slags were from the bloom refining process – in agreement with the interpretation based on SHC size. Possible mechanisms of bloom refining are discussed.

Contents

Methods

From the materials examined for the evaluation report (Wallace 2011), a selection of six samples (Table 2) was taken forward for detailed analysis. Once the selected six pieces had been slabbed for bulk chemical analysis, inspection of the cut blocks guided the selection of two of the six for investigation under the SEM. The process of specimen selection allowed for some update and revision of the catalogue, which is presented here as Table 1.

Electron microscopy was undertaken on the LEO S360 analytical electron microscope in the School of Earth and Ocean Sciences, Cardiff University. Microanalysis was undertaken using the system's Oxford Instruments INCA ENERGY energy-dispersive x-ray analysis system (EDX). All petrographic images presented in this report are backscattered electron photomicrographs. The polished blocks for investigation on the SEM were prepared in the Earth Science Department, The Open University. Chemical analysis was undertaken using two techniques. The major elements (Si, Al, Fe, Mn, Mg, Ca, Na, K, Ti, and P) were determined by X-Ray Fluorescence using fused beads on the Wavelength-Dispersive X-Ray Fluorescence (WD-XRF) system in the department of Geology, Leicester University (this also generated analyses for S, V, Cr, Sr, Zr, Ba, Ni Cu, Zn, Pb and Hf). Whole-specimen chemical analysis for minor and trace elements was undertaken using samples in solution on the ThermoElemental X-series Inductively-Coupled Plasma Mass Spectrometer (ICP-MS) in the School of Earth and Ocean Sciences, Cardiff University.

Throughout this report standard mineral terminology is applied to both natural and anthropogenic materials – although artificial phases are no longer strictly considered to be minerals.

The convention adopted in this report is to describe olivine bearing Fe, Mg, Ca and Mn in terms of an olivine on the forsterite-fayalite join (using the notation for instance of Fa95Fo5 for an olivine that is 95% fayalite and 5% forsterite; where Fe/(Fe+Mg) = 0.95) plus figures for the overall percentage replacement by calcium and manganese.

This project was undertaken for Valerie J Keeley Ltd.

Results

General description of the assemblage

The assemblage has already been through a stage of assessment and general description (Wallace 2011), but a few further comments on the materials, particularly in the light of the analytical studies, are needed.

In general, the assemblage shows a rather poor preservation, with abundant evidence in hand specimen for both leaching and for the deposition of secondary minerals. Great care was taken in the selection of materials for analysis in an attempt to investigate only the freshest of the material. Despite this, there are various unusually facets of the chemical analyses which suggests that there has been considerable elemental mobility.

Iron smelting slags: several highly manganese-rich pieces of ambiguous form were picked-out during the reinvestigation of the assemblage as possible smelting slags. There were no completely unambiguous examples of smelting slags based on morphological criteria, although a few pieces did show suggestive flow-lobed forms. The possible identification of residues from smelting based on other criteria is discussed further below.

Iron working slags: the majority of the macroscopic iron working (smithing) slags are fragments from smithing hearth cakes. A revised list of the more complete examples, for which the original weight may be measured or estimated, permits the construction of some descriptive statistics, but the downward revision of the number involved to just eleven sufficiently complete examples, reduces the potential or comparison with other sites (Table 3). The comparison with the assemblage from Camlin 3 is, however, striking, with 50% of SHCs from Camlin 3 weighing less than the smallest example now recorded from Camlin 1 (498g).

Details of analysed specimens

CMN1-1: <20> (c8) [chemical analysis only – sample from lower, denser part]

This sample was an extremely irregularly-shaped slag block (160mm x 150mm x 100mm deep, 1925g) with apparently Mn-rich corrosion. The surface shows some possible original slag margins with rounded components a few centimetres across, suggestive of flow lobes, or lobing on a non-wetting contact surface. Although the overall form is irregular, it is possible to interpret the cake as a rather deep SHC with denser slag layers in the bowl and on top, with a more charcoal-rich layer between, with the whole cake having a separate piece of slag attached to the side of the bowl.

In cut section, the 'bowl' section does indeed appear rather denser – and has a concavo-convex form, 50mm deep, with the slag 35mm thick in the centre. This bowl has mainly rounded vesicles, just a few of which show vertical elongation. The top of the bowl section is marked by a zone of very large, rounded, tabular vesicles, above which the slag is variable but is typically more charcoal rich. The section does not give any indication of internal cooling lobes or flow structures.

Despite external appearances, the structure of this piece is more similar internally to the wide, flat, CMN1-4 than would have been expected.

CMN1-2: <43> (c10) *[chemical analysis only – sample from typical denser part]*

This block of slag (130 mm x 130 mm x 90 mm, 1320g) shows an unusual crudely lobate surface structure (somewhat similar to that of CMN1-1). The surface shows strong secondary mineralisation, suggestive of a high manganese content. It is not clear to what extent the odd surface morphology might be associated with this high degree of overgrowth. The piece has a very irregular shape, but with one gently curved side that might be original.

In the cut face the slag is seen to be fairly dense, with a gradation of colour from a slate grey close to the possibly original face, to a paler grey elsewhere. The slag contains large rounded vesicles ranging up to about 7mm maximum dimension. There are some charcoal inclusions, and it appears that these increase in frequency on most of the margins of the piece. This morphology has no immediate easy interpretation.

CMN1-3: <7> (c6) [chemical analysis only – sample from central, denser part]
SHC 984g

This piece was a well-formed, regularly-shaped SHC, (145 mm x120 mm x55 mm deep, 984g). It has a smooth top over a 90mm diameter area, but becomes deeply dimpled distally. Part of smooth top collapsed into interior void, but a void 55mm long and 8mm deep extends from the proximal side towards the centre of the piece. The main dense slag bowl is about 10mm thick below the void, thickening to 20mm distally. The is layer has abundant vesicles, many of which are tubular. Where the base of this layer forms the base of the cake, it has a crudely dimpled to incipiently lobed appearance.

In the centre of the cake, however, the dense grey vesicular slag passes down into a brown-weathering, more irregular, charcoal-rich slag, up to 25mmthick. The base of this has a somewhat prilly appearance in places.

CMN1-4: <20> (c8) [sampled from typical part of bowl; Plate 1]
SHC >2995g.

This was a large cake (270mm x 160mm x 85mm thick). Externally it had the appearance of a typical 'thin-crust' SHC (*sensu* Young 2008) of very irregular shape. The piece weighed 2995g. On cutting, this form resolved into a somewhat asymmetrical (steep-sided proximally) bowl of dense, but vesicular slag, approximately 50mm thick and 120mm across, overlain by a rather oblique (in plan) slab of charcoal-rich slag with a friable (almost-fuel-ash slag-like) texture. The bowl shows some tubular vesicles in the basal 10mm, overlain by a dense slag with fine vesicles 20mm thick and then a 20mm thick zone of very large rounded cavities in a dense slag. These cavities are irregular, expanded and sometimes branching in the horizontal plane, up to 40mm in horizontal dimensions and about 8mm deep individually. The contact zone between the pale grey slag of the bowl and the browner, more rusty slag of the charcoal-rich zone is diffuse and irregular, but appears to rise over the bowl.

The mounted sample showed a texture with primary wustite, possibly associated in part with plates of hyalophane (with the ratio of barium to barium plus potassium of 0.88 to 0.94). The hyalophane is locally intergrown with the wustite (e.g. Plate 1a, lower right). The main generation of fayalite is cotectic with wustite and locally overgrows the ends of the hyalophane plates (Plate 1a, c,e). This fayalite forms crystals at least 700 µm in length and 200-300 µm wide. The hyalophane typically bridges the interstitial spaces. These spaces are frequently very highly weathered, but where preserved there are interstitial assemblages including leucite, wustite, iron sulphide, probably barite and glass (Plate 1 a,c,f). In one area (Plate 1a) some of the spaces between adjacent hyalophane plates is filed by a barium phosphate.

CMN1-5: <36> (c89) [chemical analysis only – sample from central, dense part of bowl]
SHC? >795g

This piece was an incomplete slag block (110 mm x 110 mm x 55mm, 798g). It comprised a bowl-shaped dense lower section, with a raised lip on one side, which supported a 'flange' extending back over one side of the bowl – as if from a fracture upper layer.

The surface of the piece was altered and brown – with little preserved detail.

The cut section showed a very pale grey slag, with a variable fine vesicularity and a few larger tubular vesicles springing from both sides of the base of the bowl.

CMN1-6: <38> (c7) [sampled from typical dense vesicular slag; Plate 2]
SHC 1705g

This piece appears to be strongly asymmetrical SHC (170 mm x110 mm x75 mm, 1705g), that may just possibly be incomplete, but may just have had a steep proximal side.

The surface is strongly, if thinly, encrusted by pale brown concretion, which has contributed to the smooth appearance of the upper surface and the blebby appearance of the lower surface.

On the cut face the piece can be seen to include two horizons of denser slag (probably two distinct work-periods), separated by a charcoal-rich layer. Further charcoal-rich slag forms the base of the piece. The lower denser slag layer contains abundant rounded vesicles of up to about 7mm. The upper dense layer is similar, but has more tubular vesicles and a layer of tabular vesicles immediately below the top. The tabular vesicles are small (15 mm long by 4 mm deep). In part at least, the asymmetry of the piece may be due to a slight difference in position of the two denser slag layers.

This piece shows some textural similarities to CMN1-3 – but shows two work periods rather than one, but with the two phases less fully developed than in the smaller example.

In polished section the sample shows a patchy distribution of primary wustite (Plate 2a) associated with extant and former vesicles. The wustite varies from coarse rounded blebby dendrites, to finer, more developed dendrites. The vesicles are also associated with multiple generations of leucite rims (Plate 2a).

The main generation of olivine has an elongate to blocky habit and has a composition of between Fa_{100} and $Fa_{98}Fo_2$ with 6-9% calcium substitution and 7-8% manganese substitution.

The main phase olivine is commonly terminated, quite abruptly by the onset of growth of leucite – which may form a zone of discrete crystals, or of a leucite-wustite cotectic. Much of the interstitial space is typically occupied by a growth of a fayalite-leucite cotectic. The marginal olivine associated with the leucite and that in the subsequent well-developed leucite-fayalite cotectic both show a composition of Fa_{100} with 26-28% calcium substitution and 5% manganese substitution.

Chemical composition of analysed samples

The materials from Camlin 1 showed, in general, a rather high degree of weathering. This is probably reflected in some of the elemental abundances, which show some unusual patterns. This can be seen for instance in a graph of the manganese content of the main olivine phase (as a percentage substitution into the overall olivine) plotted against the bulk content of manganese in the slag (as wt% MnO; Figure 1). The analyses of most samples lie very close to a linear relationship, but the two from Camlin 1 well below this relationship It is also interesting to note that the barium:manganese ratio for the various samples from Camlin 3 is constrained in a narrow range (Figure 2), but the samples from Camlin 1 have a very variable ratio (or possibly have two distinct ratios). This could be due to the slags from Camlin 1 being produced in the chain of production of iron from different ore sources, but also might be due to an enhanced barium content in the secondary manganese minerals.

Despite these issues, the extremely high manganese and barium contents of the samples are a characteristic of both Camlin 1 and Camlin 3 – indicating a local bog iron ore source with a particularly high barium content. Barium is a common associate of manganese mineralisation - so called 'wad' (the manganese equivalent of an iron ochre) may be rich in psilomelane (a 'bucket' term for amorphous manganese and barium hydrous oxides, of which romanèchite,$(Ba,H_2O)_2(Mn^{+4},Mn^{+3})_5O_{10}$ is a common component).

The chemical composition of the two samples (CMN1-1 and CMN1-2) suspected of being smelting residues are different from each other in many aspects of their trace element content, despite some similarities in major element composition (not least the high manganese content).

The two samples show similar REE profiles – both rather flat (Figure 3), and with a very reduced negative cerium anomaly (compared with all smithing slags from Camlin 1 and Camlin 3, which show a small, but marked, negative cerium anomaly) and a strong positive europium anomaly (Figure 4). Despite the similarity in profile, then abundance of the REE is much lower in CMN1-1 (Σ REE = 20.2ppm) than CMN1-2 (Σ REE = 79.3ppm). That ratio of approximately 1:4 is also seen in many other trace elements. Uranium is much lower in CMN1-1 (0.49 ppm) than CMN1-2 (7.15), giving U:Th ratios of 0.77 and 5.79 respectively.

It is worth noting that although some of these features of the chemical composition allow discrimination of the specimens provisionally identified as smelting slags from those identified as smithing slags, the more clearly morphologically identifiable smelting slags from Camlin 3 do not show the same features. The europium anomalies of the slags from Camlin 3 (both smelting and smithing slags) are lower than the equivalent material from Camlin 1. At Camlin 3 the negative cerium anomaly of the smelting slags is greater than for many of the smithing slags (Figure 4). This provides evidence that the smelting systems (i.e. the ore – furnace clay – fuel system) was not precisely the same, although broadly similar, for the two sites.

The silica to alumina ratio for the samples is typically high than for equivalent materials at Camlin 3 (7.8 and 13.4 for the two smelting slags and 10.5 to 15.9 for the four smithing slags.

The samples interpreted as smithing slags show a very slightly more marked negative cerium anomaly and a much less well-developed positive europium anomaly, but are otherwise rather similar (Figures 3, 4). They show a wide range of total REE contents from 27.2ppm (CMN1-3) to 168.5ppm (CMN1-4). Other aspects of the chemistry of the smithing slags is also variable, obscuring any trends in the data, presumably because the original smelting chemistry was variable.

Interpretation

The chemical compositional data from Camlin 1 appear more variable than those from Camlin 3. This is interpreted, at least in part, as deriving from a higher degree of alteration in the analysed samples. However, it is clear from the chemical data that the two samples tentatively identified as smelting slags are indeed chemically distinct from those identified as smithing slags. Furthermore, despite the unusual bulk composition of the slags from Camlin 1 and Camlin 3, with their generally high manganese and barium contents (often leading to formation of hyalophane, for which the occurrences at Camlin are the first record in Ireland; see also Young 2011b), the trace element chemistry points to differences in the smelting system in detail. In practice, this is most likely to represent slight differences in the ore sources exploited.

The smithing slags contain a significant inheritance from the smelting system – based on the high manganese and barium contents and the similarity of the REE profile. This interpretation of the smithing slags as from the processes of bloom smithing/bloom refining is in agreement with the interpretation of the slags based on cake weight. The lack of SHCs below 500g suggests that Camlin 1 was not involved in the end use of iron – merely in its production. Indeed, despite the small size of the assemblage and the lack of very large SHCs, there are some similarities in the distribution shown on Table 3 with the 'specialist' bloom processing sites such as Borris (Young 2009d) and Lismore-Bushfield 1 (Young 2008a).

The pattern of disposal, with the slag blocks occurring in the ditch, appears different from that at Camlin 3, where the ditch contained very little residue. However, the bank deposit at Camlin 3 did contain a large number of large slag blocks. This means that filling of the ditch by levelling of the bank might produce the pattern observed at Camlin 1.

The total volume of slag from Camlin 1 is rather small, but it is difficult to extrapolate to the scale of the metalworking activity. It seems plausible that the scale of the activity was less at Camlin 1 than Camlin 3 – but if the enclosure ditches are compared on their own, then Camlin 1 produced substantially more slag than Camlin 3 from equivalent contexts.

Discussion

The assemblage from Camlin 1 is relatively small and relatively poorly preserved, but none the less provides clear evidence both for iron smelting and for the subsequent refining of the raw iron. The residues are primarily in fairly large blocks and occur in the ringfort ditch. It is a reasonable to interpret them as having been deposited initially on a bank that was subsequently levelled into the ditch. The deposition of manually-disposable blocks of residue onto the bank was a feature of the Camlin 3 assemblage.

Neither the smelting slags nor the smithing slags are particularly instructive as to the details of the technology employed.

The chemical evidence shows the resource exploited was a high manganese and high barium ore (even higher in the elements than that at Camlin 3). Precise determination of the composition of the original ore is not however possible on the present data.

The SHC weight-frequency data (Table 3) indicate, despite a small assemblage, a striking difference between the assemblages at Camlin 1 and those at Camlin 3 or Parknahown 5. Indeed it is tempting to see a closer parallel with the assemblages from the apparent specialist bloom processing suites at Borris and Lismore-Bushfield 1.

In the past it has been assumed that all processing of raw bloom would have been undertaken solely by 'bloomsmithing' (the expulsion of slag from the raw iron by repeated hot-working), there is now a growing recognition that bloom remelting is also likely to have played a part in many refining traditions. A late survival of such a remelting process was described by Evenstad in the late 18th century (Jensen 1968; Wagner 1990) in Norway. Residues from this process have not yet been recognised in archaeological material, although considerable effort is on-going to replicate the process experimentally and to study the residues. Since the remelting residues are not (yet?) distinguishable from those of bloomsmithing, the term smithing hearth cake (SHC) is retained here. It is to be hoped that remelting hearth cakes will become a separately identifiable class of slag in the future. When such interpretations become available, then a more detailed interpretation of the Camlin 1 SHCs may be possible.

For now, at least, the Camlin assemblage can be attributed to iron smelting and refining of the raw blooms produced.

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Figure Captions

Figure 1.

Plot of the percentage substitution of manganese into the core of the main phase of olivine recorded for samples from Camlin 3 and elsewhere, against the bulk whole sample content of manganese (expressed as wt% MnO determined by XRF).

Figure 2.

Plot of the whole sample concentration of barium (expressed as wt% BaO determined by XRF) against that of manganese (expressed as wt% MnO determined by XRF).

Figure 3.
Upper crust-normalised REE profiles (normalisation after Taylor & McLennan 1981)

a. smelting slags
b. smithing slags
c. All samples renormalized on an iron-free basis.

Figure 4.
Bivariate plot of the cerium vs europium anomalies (upper crust-normalised after Taylor & McLennan 1981) for samples from Camlin 1 and Camlin 3.

Plate Captions

Plate 1
a. CMN1-4 SOI1. Scale bar 70µm.
b. CMN1-4 SOI2. Scale bar 600µm
c. CMN1-4 SOI3. Scale bar 200µm
d. CMN1-4 SOI4. Scale bar 1mm
e. CMN1-4 SOI5. Scale bar 400µm
f. CMN1-4 SOI6. Scale bar 70µm
g. CMN1-4 SOI7. Scale bar 1mm
h. CMN1-4 SOI8. Scale bar 70µm

Plate 2
a. CMN1-6 SOI1. Scale bar 1mm
b. CMN1-6 SOI2. Scale bar 100µm
c. CMN1-6 SOI3. Scale bar 600µm
d. CMN1-6 SOI4. Scale bar 300µm

Table 1: Summary Catalogue

sample	*context*	*context note*	*context wt. (kg)*	*Item wt (g)*	*no*	*description*	*Original SHC wt*
2	6	ringfort ditch fill	2.284	2280	15	all prilly fragments from large cakes - either thin crust type or furnace bottoms. The largest piece is quite dense so possibly from near burr?	
3	7	ringfort ditch fill	1.267	588	1	incomplete SHC with strongly raised margin	
				422	1	incomplete SHC with strongly raised margin	
				264	3	fragments of SHCs with moderately well formed, but vesicular crust	
4	6	ringfort ditch fill	3.758	1620	4	block of prilly/microprilly charcoal rich slag	
				486	1	block from centre of charcoal-rich SHC, 140mm wide x 55mm deep, dimpled top	
				970	1	crust from large thin crust cake with recurved profile	
5	6	ringfort ditch fill	0.511	508	1	dense SHC, very slightly incomplete, 120mm x 100mm x 45mm, just very edges missing	508
6	7	ringfort ditch fill	0.296	270	1	pale, very hard, thin crust attached to charcoal rich material, probably from a fairly small SHC to judge from curvature (plus fine bits)	
7	6	ringfort ditch fill	6.551	984	1	SHC, 145mm x 120mm x 55mm, smooth top over 90mm diameter area, distally deeply dimpled. Part of smooth top collapsed into interior void. Base microprilly over dimpled dense layer. (**CMN1-3**)	984
				660	1	rounded overgrown slag lump	
				1115	1	SHC	1115
				1205	1	SHC fragment	
				588	1	section from centre of thin-crust SHC	
				200		fine bits/debris	
				346		flow lobed dense slags, possibly from smelting	
				506	2	large blocks of charcoal-rich slag	
				458	4	indeterminate dense slag pieces	
				220	1	small piece from centre of small SHC	
				308	1	curious SHC-like piece, but with strong right angle profile, possibly formed at foot of blowing wall?	

sample	*context*	*context note*	*context wt. (kg)*	*Item wt (g)*	*no*	*description*	*Original SHC wt*
8	9	ringfort ditch fill	0.146	146	1	worn fragment of SHC crust - possibly most of a small SHC originally, but uncertain	
9	7	ringfort ditch fill	1.546	926	1	large chunk from core of double layer SHC, deep, dense, worn	
				424	1	very worn and weathered SHC piece	
				198	1	worn SHC fragment	
11	14	linear ditch	0.141	140	1	concretion over indeterminate dense slag	
12	11	ringfort ditch fill	0.56	562	1	eroded vesicular/charcoal-rich SHC, 120mm x 100mm x 70mm, uncertain proportion	
15	10	ringfort ditch fill	0.34	340	1	dished dense sheet lying on charcoal-rich material. Very rusty with some cracking, contains iron, dense. If this was a symmetrical SHC the proportion surviving is no more than 60%	
16	7	ringfort ditch fill	0.055	55	1	small rounded slag piece, contains iron	
17	10	ringfort ditch fill	0.304	216	1	weathered SHC crust fragment	
				64		tiny burr fragment and other bits	
19	10	ringfort ditch fill	0.964	944	1	very highly weathered probably deformed charcoal-rich SHC, slightly waisted form, ochreous	
20	8	ringfort ditch fill	5	1925	1	fragment of charcoal-rich slag cake, manganese-rich, has 90 degree bend in base and has curved plan at one end - probably the burr (**CMN1-1**)	
				2995	1	large piece of thin crust cake with irregular base, possibly bent (**CMN1-4**)	
				678	1	very neat plano-convex cake, 120mm x 100mm x 65mm, deeply impressed charcoal on upper surface	678
23	11	ringfort ditch fill	0.121	120	1	dense lobate or prilly fragment, covered with concretion	
24	6	ringfort ditch fill	0.584	580	1	part of fairly simple dense SHC with earlier crust fused to base	
25	10	ringfort ditch fill	0.367	370	1	irregular, slightly foliated mass of weathered charcoal rich slag	

sample	*context*	*context note*	*context wt. (kg)*	*Item wt (g)*	*no*	*description*	*Original SHC wt*
27	8	ringfort ditch fill	3.5	704	1	fragment from centre of flat dense SHC -possibly c. 80%	880
				598	1	small very dense iron-bearing SHC, probably essentially complete	598
				896	1	piece of double-layer SHC, upper dense sheet over lower microprilly	
				952	1	dense microprilly SHC fragment, top not preserved, crust mainly absent	
				302	9	mainly microprilly slag fragments, but one dense piece might be overgrown iron rod	
34	7	ringfort ditch fill	2.176	666	5	pieces of dense blebby/granular slags	
				162	1	slab of lining-influenced slag - dense - SHC top not tongue	
				522	1	broadly SHC-shaped block of microprilly slag	
				704	4	pieces of slag with dense lobes	
				292	1	irregular basal crust fragments, possibly with tubular vesicles	
35	7	ringfort ditch fill	1.137	278	1	lobate slag - possibly smelting?	
				646	1	fragment from centre of dense fresh SHC	
				62	1	small slag fragment with glassy lining slag on one side	
36	89	ringfort ditch fill	2.936	390	1	dense block - overgrown slag (or possibly ore?)	
				286	1	large corroded angled iron piece	
				460	8	blebby/microprilly/porous slag	
				708	1	slag/ore?	
				798	1	trough-shaped dense slag piece probably slightly incomplete SHC (**CMN1-5**)	
38	7	ringfort ditch fill	1.721	1705	1	strongly asymmetrical SHC, 170x110x75 - just possibly incomplete (**CMN1-6**)	1705
40	10	ringfort ditch fill	0.209	210	1	irregular block of manganese-rich slag, containing piece of exploding iron	
41	10	ringfort ditch fill	10	2935	1	large part of complexly multi-lobed thin crust cake	
				3840	15	pieces of charcoal-rich thin crust cake	
				1380	3	rounded masses of slightly denser slag than the 15 pieces above	
				1820	1	incomplete two-layer SHC, completeness hard to assess ?80%	2275

sample	*context*	*context note*	*context wt. (kg)*	*Item wt (g)*	*no*	*description*	*Original SHC wt*
42	10	ringfort ditch fill	1.642	1630	1	complexly deformed? Blebby, charcoal-rich slag	
43	10	ringfort ditch fill	1.32	1320	1	large possibly contorted block of blebby/microprilly slag with overgrowths. Very manganese-rich so possibly smelting slag (**CMN1-2**)	
44	10	ringfort ditch fill	0.495	496	1	elongate dense flat crust with pile of charcoal rich slag on top, proportion uncertain	
45	11	ringfort ditch fill	0.182	180	1	indeterminate charcoal rich slag with possible gravelly base	
46	74	hearth	0.314	310	2	highly concreted and iron mottled concretionary pieces. Do not contain metallic iron	
47	76	pit	0.096	90	1	unidentifiable slag in manganese-rich dense concretion	
52	10	ringfort ditch fill	0.872	860	1	fragment of probable SHC, c.80mm thick, vesicular, central fragment so size not determinable; originally much larger	
53	11	ringfort ditch fill	0.767	762	1	neat, SHC, 140mm x 110mm x45mm, fairly conventional	762
54	1	topsoil	0.464	460	4	variably dense manganese-rich slags, not well seen surfaces so smithing or melting.	
55	9	ringfort ditch fill	1.08	638	1	part of charcoal-rich SHC with concentric rings on top, no crust, probably c.50%	1276
				354	1	channel-shaped dense SHC fragment	
				84	1	charcoal-rich slag fragment	
56	10	ringfort ditch fill	0.898	890	1	rounded mass of charcoal rich slag with clear internal lobes in places	
57	11	ringfort ditch fill	0.493	496	1	large, possible bent block of slag, contains charcoal to 30mm - could be either smithing or smelting	
58	11	ringfort ditch fill	2.703	1150	1	rounded mass of prilly slag with charcoal - uncertain origin	
				1245	1	large base from the base of a thin crust cake	
				170		bits from thin crust cake	

sample	*context*	*context note*	*context wt. (kg)*	*Item wt (g)*	*no*	*description*	*Original SHC wt*
59	7	ringfort ditch fill	0.503	498	1	dense oval SHC, possibly small part missing	498
60	6	ringfort ditch fill	0.317	320	1	base of charcoal-rich cake, microprilly/micro-dimpled base with possible tool-mark	
61	11	ringfort ditch fill	0.402	400	2	rounded lumps of vesicular, charcoal-rich, but moderately dense slag	
62	102	ringfort ditch fill	0.295	294	2	worn pieces of very dense slag, with clotted/blebby texture	
70	7	ringfort ditch fill	0.127	124	1	worn, rather 'clotted' textured slag fragment, indeterminate	
71	backfill		0.129	130	1	small tongue, glossy top, dense prills below, attached to tiny remnant of tuyère tip	

Table 2: Analysed specimens

Sample	Context	Sample	summary description	Bulk chemistry	SEM
CMN1-1	8	20	Mn-rich charcoal -rich cake	Y	
CMN1-2	10	43	Mn-rich externally blebby slag, internally vesicular	Y	
CMN1-3	6	7	SHC 984g	Y	
CMN1-4	6	20	SHC >2995g	Y	Y
CMN1-5	89	36	SHC >795g trough shape	Y	
CMN1-6	7	38	SHC 1705g	Y	Y

Table 3: Comparison of the SHC assemblage with assemblages from other early medieval sites

Site	Gortnahown	Parknahown	Trumra	Clonmacnoise New Graveyard	Camlin 3	**Camlin 1**	Woodstown	Clomacnoise Waste Water	Clonfad	Borris	Lismore Bushfield
County	Cork	Laois	Laois	Offaly	Tipperary	**Tipperary**	Waterford	Offaly	Westmeath	Tipperary	Laois
Reference	*Young 2011a*	*Young 2009b*	*Young 2008b*	*Young unpublished data*	*Young 2011b*		*Young 2009c*	*Young 2005*	*Young 2009a*	*Young 2009d*	*Young 2008a*
Smelting present?	yes	yes	no	no	yes	**yes**	yes	yes	yes	no	no
No. of SHCs	98	89	57	258	34	**11**	140	38	375	88	23
Min wt (g)	78	86	92	54	87	**498**	68	124	60	154	426
Max wt (g)	3450	2898	3163	7815	3165	**2275**	6310	5540	11000	7440	4390
Mean wt (g)	498	564	727	762	767	**1025**	1060	1087	1177	1618	1737
% SHC <500g	68%	70%	47%	52%	50%	**9%**	40%	39%	30%	22%	4%
% SHC <850g	87%	79%	67%	73%	68%	**45%**	61%	63%	55%	36%	26%
% SHC >1000g	8%	16%	25%	22%	24%	**36%**	29%	32%	35%	59%	61%
% SHC >3000g	2%	0%	2%	3%	3%	**0%**	8%	8%	7%	16%	13%

Table 4: Major and selected trace elements (as wt% oxide) determined by XRF. LOI = loss on ignition (negative = weight gain).

Sample Name	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	Mn_3O_4	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	SrO	ZrO_2	BaO	LOI	Total
CMN1-1	10.59	0.04	0.79	68.24	15.89	0.24	2.20	0.04	0.39	0.090	0.140	0.005	0.002	0.796	-6.25	99.45
CMN1-2	14.13	0.07	1.82	55.48	22.83	0.10	1.60	<0.01	0.31	0.389	0.107	<0.003	0.004	3.208	-0.88	100.06
CMN1-3	16.08	0.05	1.01	74.75	7.08	0.16	1.31	<0.01	0.36	0.083	0.056	0.006	<0.002	0.378	-4.59	101.34
CMN1-4	21.36	0.06	1.86	59.86	12.33	0.09	1.23	<0.01	0.32	0.289	0.025	<0.003	0.005	2.049	-5.47	99.48
CMN1-5	25.62	0.12	2.44	59.82	5.35	0.21	3.68	0.06	1.32	0.394	0.083	0.003	0.010	0.702	-3.25	99.82
CMN1-6	17.01	0.06	1.50	75.06	2.37	0.15	2.23	<0.01	0.72	0.241	0.057	0.006	0.003	0.306	-2.90	96.79

Table 5: Major elements (as wt% oxides) determined by ICP-MS.

	MnO	FeO	TiO_2	P_2O_5
CMN1-1	13.68	59.61	0.04	0.09
CMN1-2	17.88	45.54	0.08	0.36
CMN1-3	5.10	58.21	0.06	0.08
CMN1-4	9.99	51.27	0.07	0.28
CMN1-5	4.93	58.49	0.11	0.36
CMN1-6	1.97	62.53	0.06	0.20

Table 6a: Minor and trace elements (as ppm element) determined by ICP-MS.

	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Mo	Sn	Cs	Ba
CMN1-1	1.2	5.7	9.0	0.4	27.1	58.5	42.6	3.7	6.2	59.1	4.7	32.0	0.98	1.92	1.03	0.26	9551.4
CMN1-2	2.2	35.6	13.2	32.7	6.6	30.4	41.5	5.1	7.7	29.2	15.5	80.3	1.81	3.10	0.95	0.79	36361.1
CMN1-3	1.0	7.2	2.7	13.8	8.9	40.2	40.9	2.6	6.9	29.8	5.0	62.8	1.18	1.70	1.08	0.37	3773.5
CMN1-4	2.7	31.3	10.7	24.6	7.0	15.0	62.4	4.0	7.4	25.6	35.1	84.2	1.80	3.05	0.85	0.58	24363.1
CMN1-5	2.2	25.4	8.4	3.1	12.3	110.4	47.3	5.2	31.1	39.0	15.1	74.6	2.90	1.21	1.01	1.24	7792.0
CMN1-6	1.3	8.8	7.7	2.1	10.1	15.9	27.7	2.3	12.9	33.4	9.2	39.0	1.40	2.57	0.93	0.62	2485.7

Table 6b: Minor and trace elements (as ppm element) determined by ICP-MS.

	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
CMN1-1	3.90	7.85	0.96	3.51	0.74	0.73	0.71	0.08	0.67	0.13	0.34	0.06	0.44	0.06	0.66	0.07	2.04	0.64	0.49
CMN1-2	15.62	30.54	3.68	14.40	3.02	2.59	3.18	0.44	2.43	0.47	1.33	0.19	1.20	0.18	1.65	0.26	2.58	1.24	7.15
CMN1-3	5.98	10.72	1.30	4.92	0.99	0.43	0.93	0.10	0.75	0.14	0.39	0.06	0.41	0.07	1.30	0.21	3.34	0.76	0.47
CMN1-4	33.97	64.81	8.01	31.19	6.61	2.86	6.84	1.05	5.66	1.02	3.01	0.42	2.63	0.39	1.81	0.28	2.85	1.76	7.30
CMN1-5	14.72	27.00	3.45	13.09	2.72	0.95	2.63	0.34	2.11	0.39	1.12	0.16	1.03	0.15	1.58	0.17	3.12	1.83	2.56
CMN1-6	8.79	15.80	2.01	7.47	1.45	0.60	1.46	0.20	1.35	0.24	0.72	0.12	0.73	0.11	0.88	0.09	1.66	1.00	2.05

Table 7: EDS microanalyses, expressed as wt% element. Oxygen by analysis.

			Wt%														
			O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	Ba	Total
CMN1-4	SOI 1	#1	29.68				13.86					0.73		13.18	40.24		97.68
CMN1-4	SOI 1	#2	29.67				13.74					0.65		12.89	40.34		97.30
CMN1-4	SOI 1	#3	30.18				14.14					2.73	0.00	10.99	39.92		97.96
CMN1-4	SOI 1	#4	33.85	0.00		12.61	16.39				2.22	0.33		0.52	2.75	30.16	98.84
CMN1-4	SOI 1	#5	33.38			0.22	14.29	0.25				6.24	0.15	9.55	36.17		100.25
CMN1-4	SOI 1	#6	20.70				0.19						0.14	4.65	70.16		95.83
CMN1-4	SOI 1	#7	26.79	0.00		0.32	1.12	10.20			0.27	2.46		0.32	2.17	45.64	89.29
CMN1-4	SOI 1	#8	28.30	0.00		0.50	0.86	10.45	0.52		0.23	3.56		0.29	2.11	41.75	88.57
CMN1-4	SOI 3	#1	28.21				13.19					0.60		13.18	38.11		93.29
CMN1-4	SOI 3	#2	27.57		0.24		12.56					0.50		12.96	36.83		90.67
CMN1-4	SOI 3	#3	29.48				13.14					0.77		12.00	38.57		93.96
CMN1-4	SOI 3	#4	29.16				13.57					0.62		13.72	39.86		96.94
CMN1-4	SOI 3	#5	27.87				13.03					0.76		11.97	38.47		92.10
CMN1-4	SOI 6	#1	20.18										0.30	2.90	67.81		91.19
CMN1-4	SOI 6	#2	20.52										0.36	2.92	68.06		91.86
CMN1-4	SOI 6	#3	29.29				13.15					5.25		10.01	34.58		92.28
CMN1-4	SOI 6	#4	34.00			10.29	15.28	0.39			2.99	1.31		1.81	7.22	21.64	94.93
CMN1-4	SOI 6	#5	28.41				12.74	0.17				2.63		10.68	36.33		90.96
CMN1-4	SOI 6	#6	16.15			0.27	3.18	1.98	20.58		0.32	1.40		0.58	41.05	17.21	102.72
CMN1-4	SOI 6	#7	34.90	0.74		13.08	16.65				16.85	0.70		0.85	3.21	1.60	88.59
CMN1-4	SOI 6	#8	28.95				13.03	0.19				8.62		8.24	32.49		91.53
CMN1-4	SOI 6	#9	19.53										0.30	2.90	67.51		90.24
CMN1-4	SOI 6	#10	31.02			12.09	15.61				2.14	0.50		0.45	2.42	28.64	92.87
CMN1-4	SOI 6	#11	31.79			2.23	9.54	2.02		0.32	0.16	1.21		2.34	30.30	3.13	83.06
CMN1-4	SOI 6	#12	36.50			2.98	13.41	0.97		0.27		1.39		1.38	30.02	2.67	89.59
CMN1-4	SOI 8	#1	33.88			0.69	9.34	0.16		1.18		0.19		0.47	40.80		86.72
CMN1-4	SOI 8	#2	27.50				12.94	0.16				1.05		10.96	38.69		91.29
CMN1-4	SOI 8	#3	34.28			1.38	12.02			0.60		0.31	0.18	0.30	35.93		85.01
CMN1-4	SOI 8	#4	33.15				1.21	0.15		0.16				0.48	53.49		88.65
CMN1-4	SOI 8	#5	35.12				6.61			1.75				0.20	44.58		88.26
CMN1-4	SOI 8	#6	31.51			12.27	14.99				1.69			0.37	3.54	28.47	92.83
CMN1-4	SOI 8	#7	32.90			12.49	15.59				2.09				5.93	26.66	95.66
CMN1-4	SOI 8	#8	22.79				0.19						0.21	4.09	68.73		96.00
CMN1-4	SOI 8	#9	32.68			1.32	10.61			0.67		0.20		0.31	37.12		82.91

			Wt%														
			O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	Ba	Total
CMN1-6	SOI 2	#1	33.50		0.32		13.94					3.48		3.68	46.92		101.85
CMN1-6	SOI 2	#2	34.41		0.25		14.15					4.47		3.70	45.99		102.97
CMN1-6	SOI 2	#3	35.34		0.15		14.52					10.85		2.94	39.55		103.35
CMN1-6	SOI 2	#4	36.53	0.33			14.64	0.26				11.76		2.88	39.20		105.61
CMN1-6	SOI 2	#5	23.86			0.00	0.21							1.14	75.71		100.92
CMN1-6	SOI 2	#6	33.25		0.39		13.63					2.46		3.67	46.43		99.82
CMN1-6	SOI 4	#1	32.84		0.45		13.71					2.31		4.39	46.51		100.21
CMN1-6	SOI 4	#2	32.62		0.35		13.64					2.38		4.28	46.29		99.56
CMN1-6	SOI 4	#3	33.00		0.29	0.18	13.82					2.48		4.29	46.57		100.65
CMN1-6	SOI 4	#4	33.30		0.27		14.02					3.52		4.11	46.54		101.76
CMN1-6	SOI 4	#5	36.77				15.18					9.37		3.15	43.67		108.15
CMN1-6	SOI 4	#6	46.91	0.45		13.05	26.80				18.30				1.00	1.48	107.99
CMN1-6	SOI 4	#7	37.34				15.19	0.22				12.20		3.19	40.61		108.75
CMN1-6	SOI 4	#8	22.91											1.20	75.03		99.14

Table 8: EDS microanalyses as normalised atom%, with interpretation.

					Atom%													
					O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	Ba
CMN1-4	SOI 1	#1	olivine	Fa100 Ca2 Mn25	55.75				14.83					0.55		7.21	21.66	
CMN1-4	SOI 1	#2	olivine	Fa100 Ca2 Mn24	55.91				14.75					0.49		7.07	21.77	
CMN1-4	SOI 1	#3	olivine	Fa100 Ca7 Mn20	55.93				14.93					2.02	0.00	5.93	21.19	
CMN1-4	SOI 1	#4	hyalophane	93% Ba	60.28	0.00		13.31	16.63				1.62	0.24		0.27	1.40	6.26
CMN1-4	SOI 1	#5	olivine	Fa100 Ca16 Mn18	58.09			0.23	14.17	0.23				4.33	0.09	4.84	18.03	
CMN1-4	SOI 1	#6	wustite		48.93				0.25						0.11	3.20	47.51	
CMN1-4	SOI 1	#7	barium phosphate		66.96	0.00		0.47	1.60	13.17			0.28	2.46		0.23	1.55	13.29
CMN1-4	SOI 1	#8	barium phosphate		67.68	0.00		0.71	1.17	12.92	0.62		0.23	3.40		0.20	1.45	11.63
CMN1-4	SOI 3	#1	olivine	Fa100 Ca2 Mn26	55.62				14.81					0.47		7.57	21.53	
CMN1-4	SOI 3	#2	olivine	Fa99 Ca1 Mn26	55.80		0.32		14.48					0.41		7.64	21.35	
CMN1-4	SOI 3	#3	olivine	Fa100 Ca2 Mn24	56.90				14.44					0.59		6.74	21.33	
CMN1-4	SOI 3	#4	olivine	Fa100 Ca2 Mn26	55.49				14.71					0.47		7.60	21.73	
CMN1-4	SOI 3	#5	olivine	Fa100 Ca2 Mn24	55.63				14.82					0.60		6.96	22.00	
CMN1-4	SOI 6	#1	wustite		49.76										0.25	2.08	47.91	
CMN1-4	SOI 6	#2	wustite		50.06										0.29	2.08	47.57	
CMN1-4	SOI 6	#3	olivine	Fa100 Ca14 Mn20	56.66				14.49					4.05		5.64	19.16	
CMN1-4	SOI 6	#4	hyalophane	88% Ba	60.87			10.92	15.58	0.36			2.19	0.93		0.94	3.70	4.51
CMN1-4	SOI 6	#5	olivine	Fa100 Ca7 Mn21	56.46				14.42	0.18				2.09		6.18	20.68	
CMN1-4	SOI 6	#6	iron sulphide (+Ba?)		36.68			0.37	4.11	2.32	23.31		0.30	1.27		0.38	26.70	4.55
CMN1-4	SOI 6	#7	leucite		57.04	0.84		12.68	15.50				11.27	0.46		0.40	1.50	0.30
CMN1-4	SOI 6	#8	olivine	Fa100 Ca23 Mn16	56.08				14.38	0.19				6.67		4.65	18.03	
CMN1-4	SOI 6	#9	wustite		49.05										0.25	2.12	48.57	
CMN1-4	SOI 6	#10	hyalophane	93% Ba	59.29			13.70	16.99				1.67	0.38		0.25	1.33	6.38
CMN1-4	SOI 6	#11	glass		63.56			2.65	10.86	2.09		0.29	0.13	0.97		1.37	17.36	0.73
CMN1-4	SOI 6	#12	glass		64.72			3.13	13.54	0.89		0.22		0.98		0.71	15.25	0.55
CMN1-4	SOI 8	#1	dark-w		65.00			0.79	10.21	0.16		1.02		0.15		0.26	22.42	
CMN1-4	SOI 8	#2	bright-w		55.39				14.85	0.16				0.84		6.43	22.33	
CMN1-4	SOI 8	#3	dark-w		64.95			1.55	12.98			0.52		0.23	0.11	0.17	19.50	
CMN1-4	SOI 8	#4	bright-w		67.03				1.39	0.16		0.15				0.28	30.98	
CMN1-4	SOI 8	#5	dark-w		66.89				7.17			1.50				0.11	24.33	
CMN1-4	SOI 8	#6	hyalophane	94% Ba	60.07			13.87	16.28				1.31			0.20	1.93	6.32
CMN1-4	SOI 8	#7	hyalophane	93% Ba	59.98			13.50	16.20				1.56				3.10	5.66
CMN1-4	SOI 8	#8	wustite		51.97				0.25						0.16	2.71	44.91	
CMN1-4	SOI 8	#9	dark-w		64.57			1.54	11.95			0.60		0.16		0.18	21.01	

					Atom%													
					O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	Ba
CMN1-6	SOI 2	#1	olivine	Fa98 Ca9 Mn7	58.21		0.37		13.80					2.41		1.86	23.35	
CMN1-6	SOI 2	#2	olivine	Fa99 Ca11 Mn7	58.65		0.28		13.74					3.04		1.84	22.46	
CMN1-6	SOI 2	#3	ol. Marg	Fa99 Ca26 Mn5	58.68		0.16		13.73					7.19		1.42	18.81	
CMN1-6	SOI 2	#4	ol i/s	Fa100 Ca28 Mn5	58.92	0.37			13.45	0.22				7.57		1.35	18.11	
CMN1-6	SOI 2	#5	wustite		51.88			0.00	0.25							0.72	47.15	
CMN1-6	SOI 2	#6	olivine	Fa98 Ca6 Mn7	58.72		0.45		13.71					1.73		1.89	23.49	
CMN1-6	SOI 4	#1	olivine	Fa98 Ca6 Mn8	58.15		0.52		13.83					1.64		2.26	23.60	
CMN1-6	SOI 4	#2	olivine	Fa98 Ca6 Mn8	58.16		0.41		13.86					1.69		2.22	23.65	
CMN1-6	SOI 4	#3	olivine	Fa99 Ca6 Mn8	58.15		0.34	0.19	13.87					1.75		2.20	23.50	
CMN1-6	SOI 4	#4	olivine	Fa99 Ca9 Mn7	58.02		0.31		13.91					2.45		2.09	23.23	
CMN1-6	SOI 4	#5	olivine i/s	Fa100 Ca22 Mn5	58.74				13.82					5.98		1.47	19.99	
CMN1-6	SOI 4	#6	leucite		60.01	0.40		9.90	19.53				9.58				0.37	0.22
CMN1-6	SOI 4	#7	olivine i/s	Fa100 Ca28 Mn5	58.77				13.62	0.17				7.66		1.46	18.31	
CMN1-6	SOI 4	#8	wustite		51.20											0.78	48.02	

Figure 1

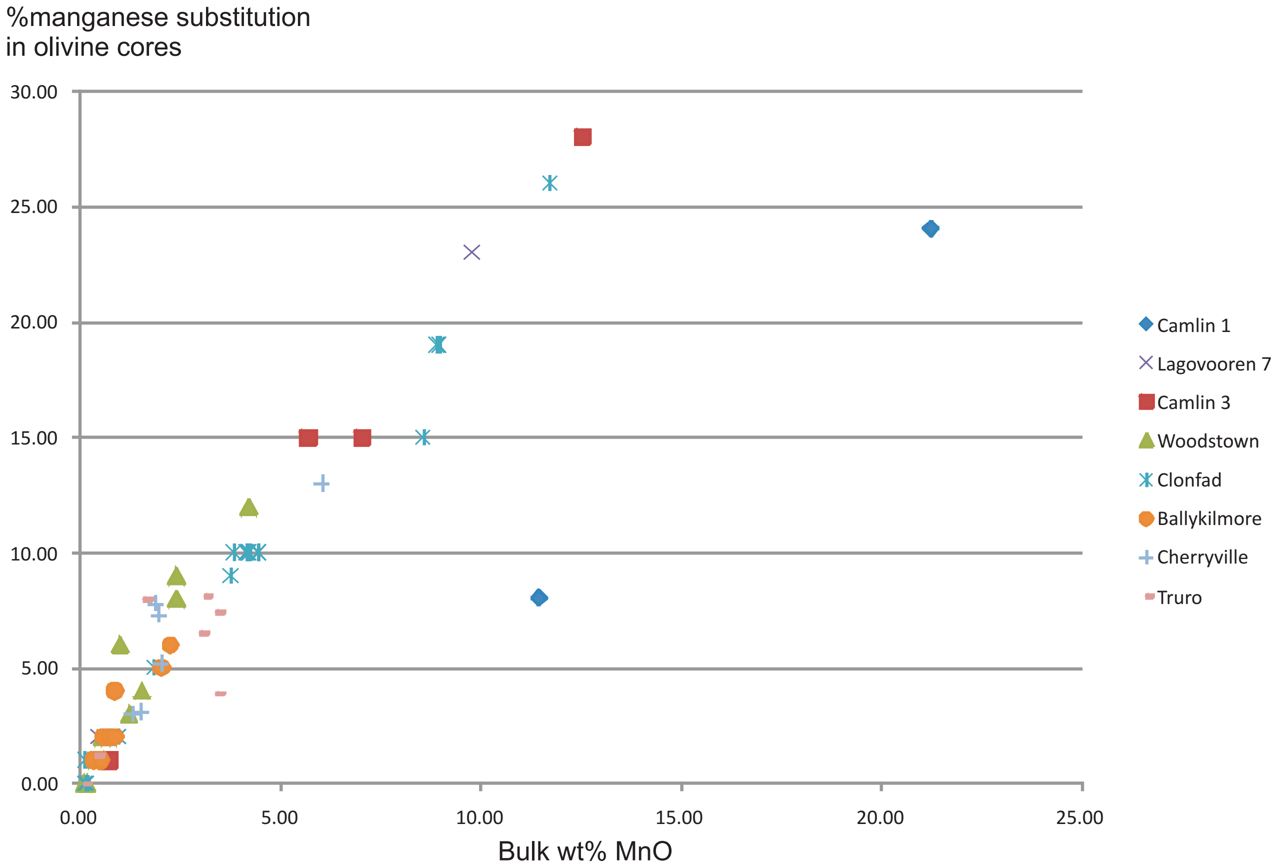
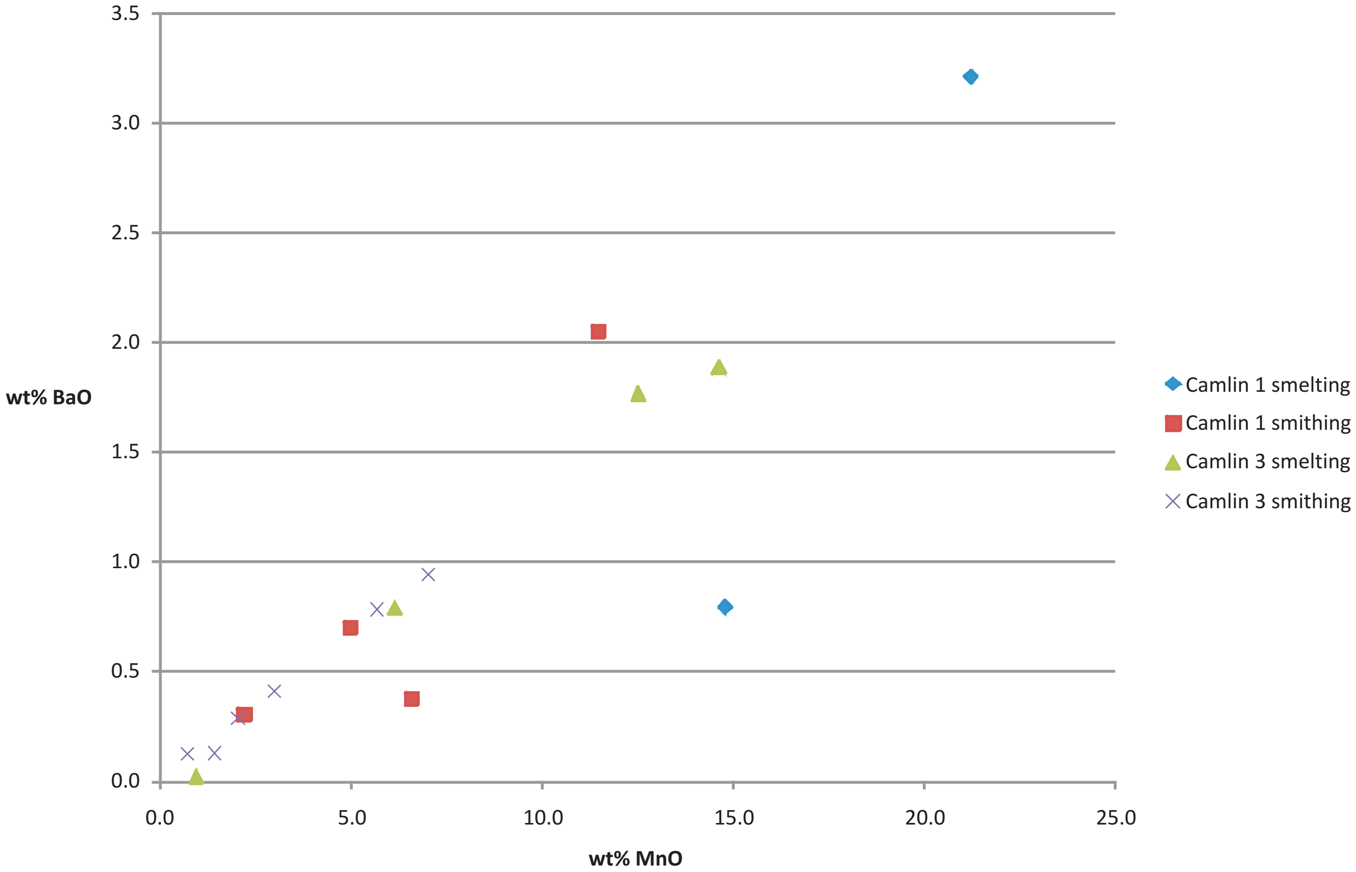
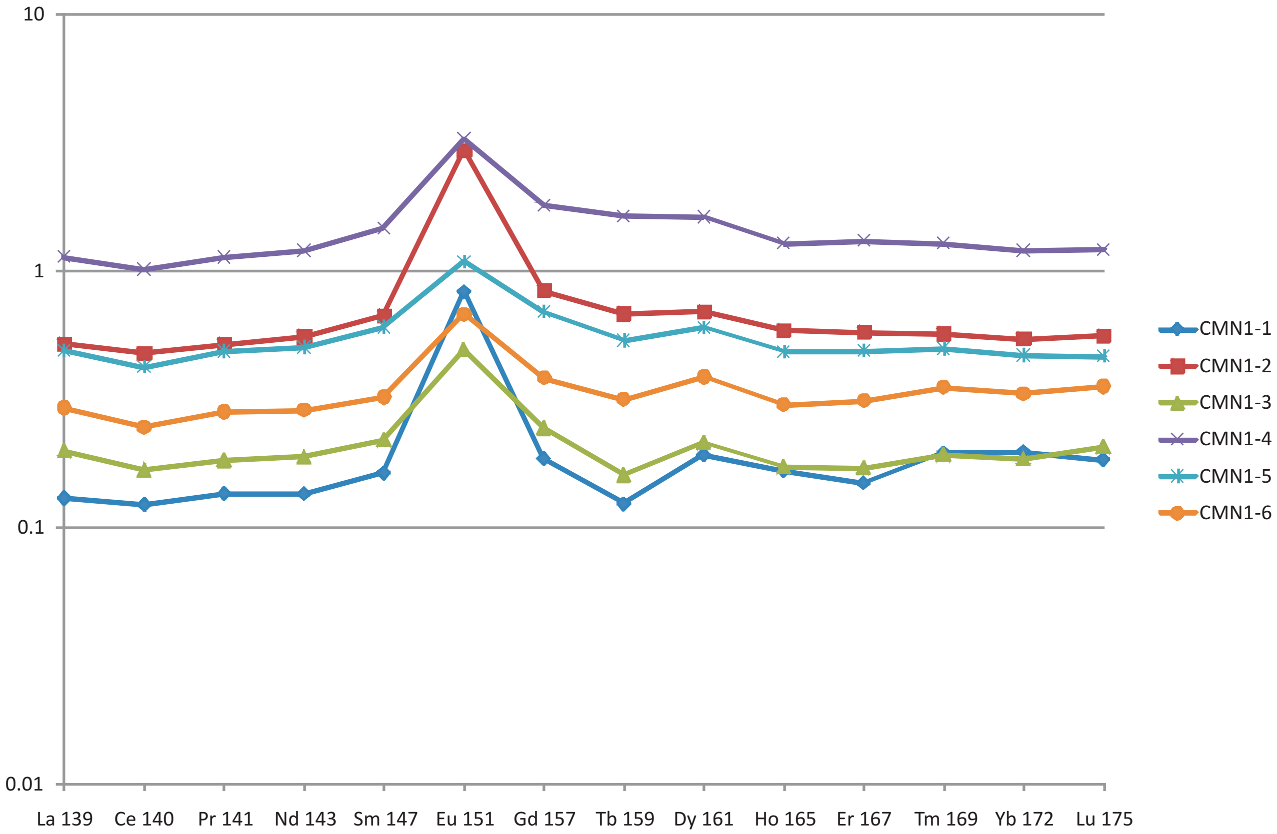

%manganese substitution
in olivine cores
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
5.00
10.00
15.00
20.00
25.00
Bulk wt% MnO
Camlin 1
Lagovooren 7
Camlin 3
Woodstown
Clonfad
Ballykilmore
Cherryville
Truro

Figure 2



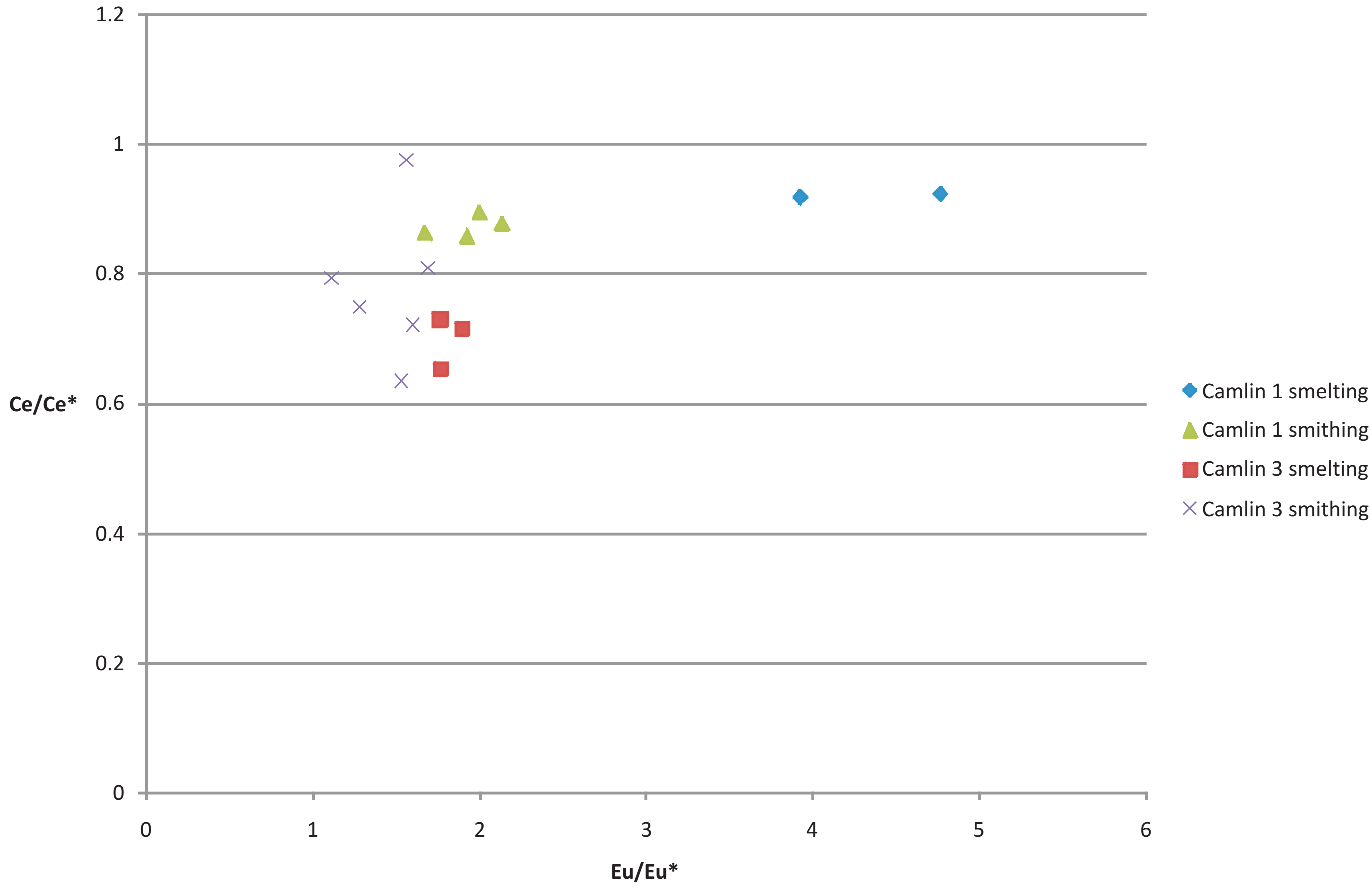
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
wt% BaO
0.0
5.0
10.0
15.0
20.0
25.0
wt% MnO
Camlin 1 smelting
Camlin 1 smithing
Camlin 3 smelting
Camlin 3 smithing

Figure 3



10
1
0.1
0.01
La 139
Ce 140
Pr 141
Nd 143
Sm 147
Eu 151
Gd 157
Tb 159
Dy 161
Ho 165
Er 167
Tm 169
Yb 172
Lu 175
CMN1-1
CMN1-2
CMN1-3
CMN1-4
CMN1-5
CMN1-6

Figure 4



1.2
1
0.8
0.6
0.4
0.2
0
Ce/Ce*
0
1
2
3
4
5
6
Eu/Eu*
Camlin 1 smelting
Camlin 1 smithing
Camlin 3 smelting
Camlin 3 smithing

Plate 1

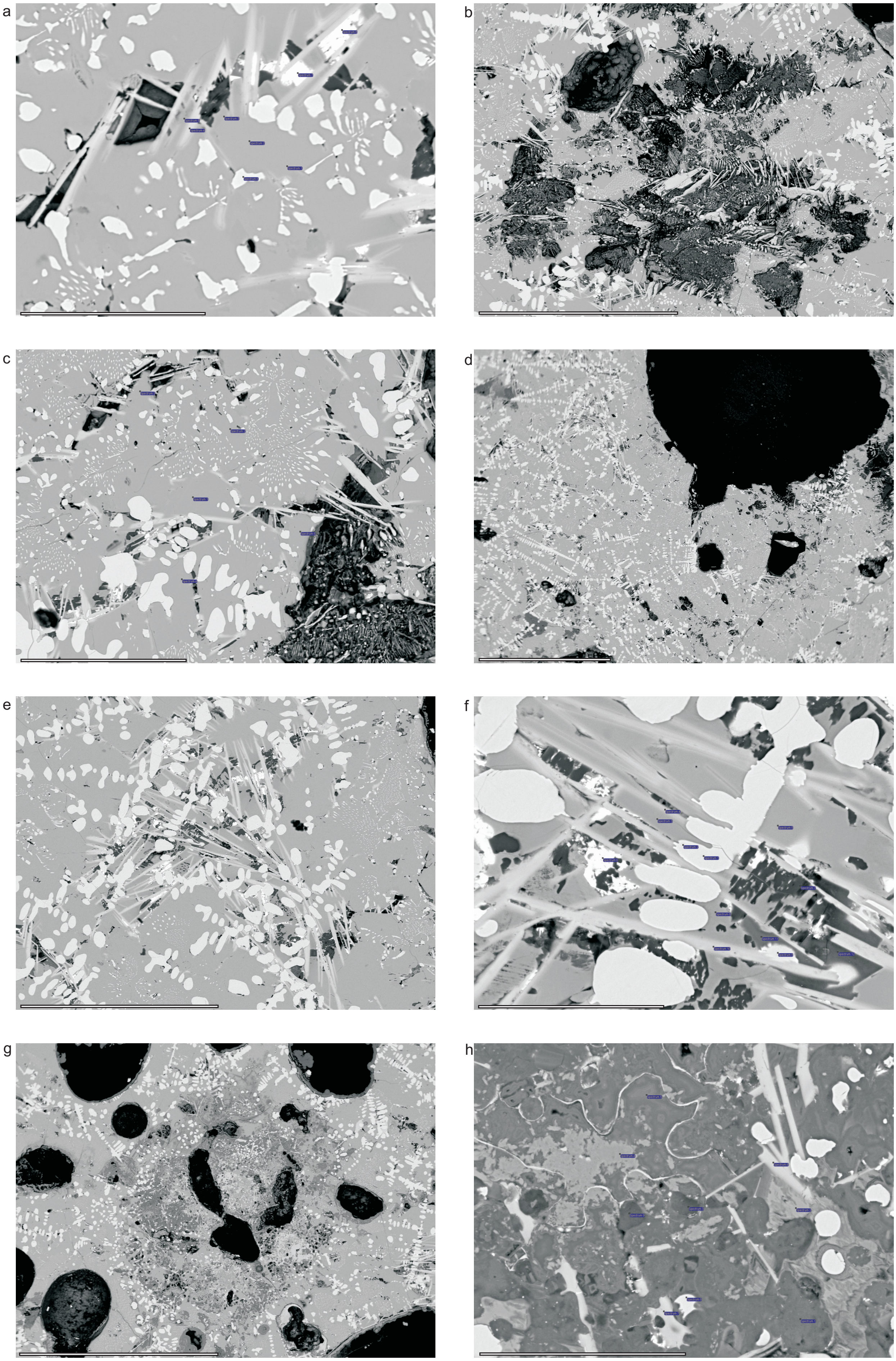
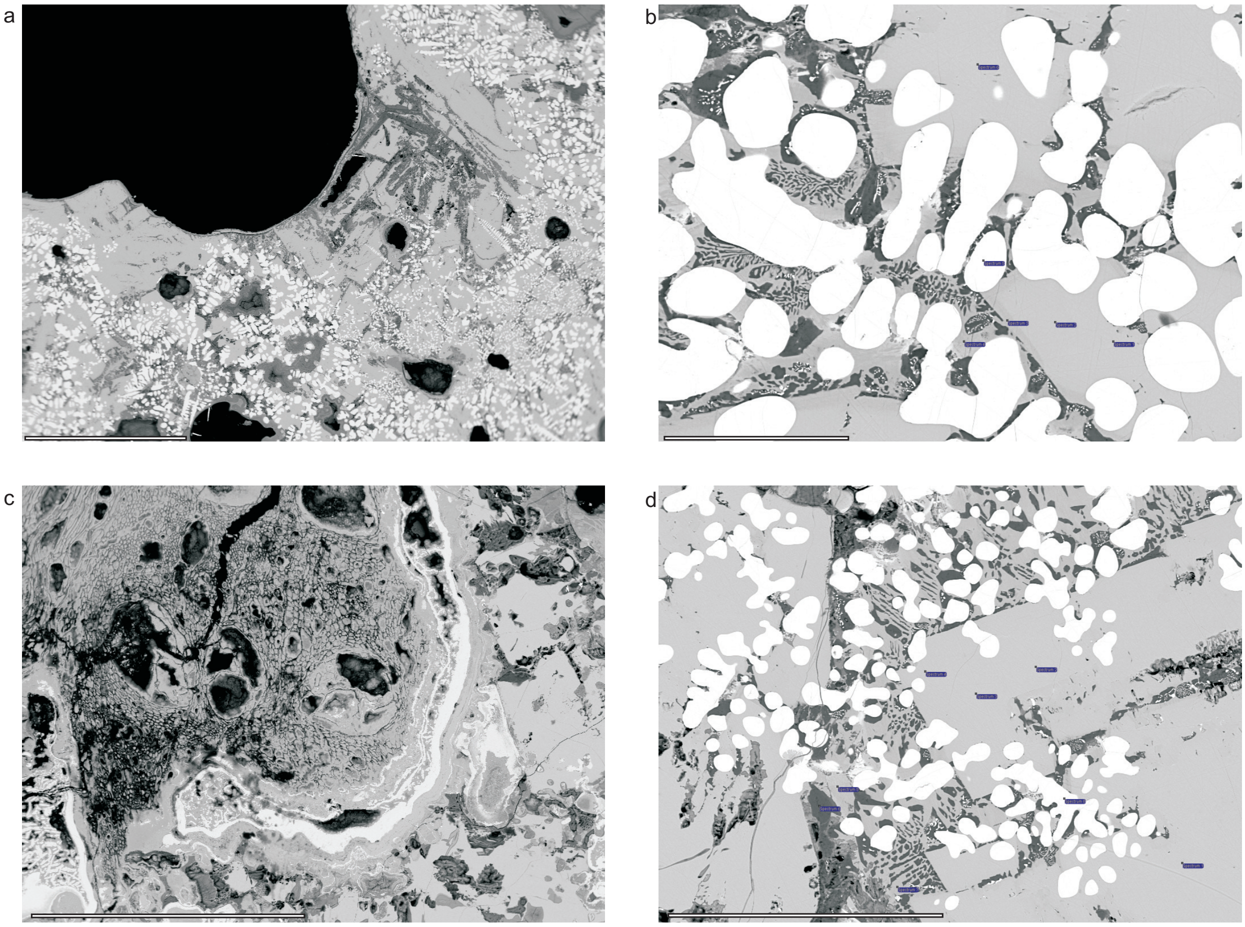


Plate 2



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