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Archaeometallurgical Residues from  
Portwall Lane, Bristol (BSRMG 2006/17)

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## Abstract

*This site yielded a variety of both macroscopic and microscopic archaeometallurgical residues, indicating a protracted history of metalworking in the area.*

*Phase 1 yielded a small amount of evidence for both ferrous and non-ferrous metalworking. Both phases 2A and 2B show strong microresidue evidence from the garden soils for iron working (smithing) possibly associated with the property known to have been occupied by a smith in 1775. Phase 3 levelling deposits yielded further macroscopic slags from iron working. Detailed investigation of these microresidues showed chemical similarities with some of the microresidues from Victoria Street, interpreted previously as coal residues (clinkers). The investigation of the microresidues contributes to current debates on the origin of hammerscale and suggests that the silicate component of the hammerscale from Portwall Lane was mainly contamination from the coal fuel ash.*

*Material dumped on the site prior to glassworks construction (c1131), yielded a significant quantity of large crucible fragments which had been employed in reheating copper alloy for casting, although this activity may not have been local to the site. The crucibles had a complex assemblage of slags and droplets associated with their internal surfaces, but the least-altered droplets clearly indicated that the crucibles had been used for the melting of leaded antimony bronze. This unusual alloy was used almost exclusively in the late medieval and earlier post-medieval periods for the casting of large domestic vessels (cauldrons, posnets and skilletts). The large size of these artefacts meant they were usually cast directly from a reverberatory furnace, without the use of crucibles. The presence of the alloy in crucibles at Portwall Lane is therefore unusual. The only small artefact type which has been shown previously to be commonly cast in this alloy are manillas, and although no manillas from Bristol have yet been analysed to establish their manufacture from this alloy in the city, this remains a very likely use of the current crucible assemblage.*

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## Methods

All materials were examined visually with a low powered binocular microscope as part of the initial assessment (Young 2007) and a database of all materials produced. The assessment identified two particularly interesting facets of the assemblage: the large sherds of crucible used to handle copper alloy and the iron working and coal burning microresidues. A follow-up programme of analysis was designed to investigate these two groups residues in more detail.

Electron microscopy was undertaken on the LEO S360 analytical electron microscope in the School of Earth, Ocean and Planetary Sciences, Cardiff University. Microanalysis was undertaken using the system's Oxford Instruments INCA ENERGY energy-dispersive x-ray analysis system (EDX). All images of microstructures presented in this report are backscattered electron (BSEM) 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 Open University Earth Science Department's Wavelength-Dispersive X-Ray Fluorescence (WD-XRF) system.

Whole-specimen chemical analysis for minor and trace elements (Sc, Ti, V, Cr, Mn, Fe, Co, Zn, Ga, Rb, Sr, Y, Zr, Nb, Mo, Sn, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th and U) was undertaken using samples in solution on the ThermoElemental X-series Inductively-Coupled Plasma Mass Spectrometer (ICP-MS) in the School of Earth, Ocean and Planetary Sciences, Cardiff University. All sample batches for chemical analysis are run with internationally certified standards.

Preliminary investigation of examples of the crucible sherds was undertaken using the Eagle II ED-XRF system at English Heritage's laboratories at Fort Cumberland, Portsmouth.

During preparation of this report, it was discovered that supplementary material submitted by BARAS from the Victoria Road site after completion of the assessment for that site (Young 2006) had inadvertently been included within the assessment of the material from Portwall Lane (Young 2007). Consequently the two assessments have been amended and reissued as Young 2009b (Victoria Street) and Young 2009c (Portwall Lane).

The present report is the final report on the Portwall Lane assemblage and includes detailed analysis of typical samples of microresidues from ironworking from the site (PWL7, 8; from c1432), together with investigation of crucibles from a dump deposit (c1131). Five crucible sherds (PWL1-5) were selected (from c1131). These were cut to reveal sections through likely locations for metal droplets. Sherds 2 and 3 were cut twice; sherd 1 yielded no useful areas for analysis. Thus samples PWL2A, 2B, 3A, 3B, 4 and 5 were taken forward for detailed analysis. To assist with the interpretation of the ironworking microresidues from a deposit (c222) at Victoria Street were analysed for comparative data on clinker compositions and textures (PWL9, 10, 11).

Bulk compositional data are given in Table 4 and the EDS data in tables 6 and 7.

## Part 1: The Crucibles

The working of copper alloys was indicated by material from two contexts. In Phase 1b context 1734 produced several fragments from copper-alloy working: a dense disk of material probably representing metal spilled in the hearth, a piece of crucible slag, a piece of hearth slag, and a piece of vitrified hearth lining.

Context 1131 (Phase 2b) yielded a larger assemblage of residues including crucible sherds, hearth slags and clinker. The crucibles are represented by 38 sherds, many bearing indications of failure during use. There are relatively few joins between sherds and no complete profile has yet been reconstructed. The crucibles show variable, but typically thick bases (up to 35mm) with an external diameter of about 125mm. The internal diameter at the base is about 90mm. The sides of the vessels are straight and slightly splayed, thinning from 25mm near the base to about 10mm at the simple rim. The external diameter at the rim is approximately 150-170mm. One sherd shows a small simple out-turned spout. The original height of the crucibles has not been reconstructed, but the minimum height indicated is about 150mm, which would give the crucibles a minimum volume of 1400cm<sup>3</sup>.

Crucibles with only a slight use have a smooth exterior and a white to buff coloured hard fabric. In use the fabric turns dark towards the outside, particularly on the base. Very well used fragments show the fabric becoming pale grey, with a hint of lilac, with a bleached pale layer below the inner surface.

The inner surfaces of some basal sherds show accumulations of thick, dense residues rich in secondary copper minerals, whereas the sherds from near the rim show a thin inner smooth slag coating, becoming rougher with included dross material in the area below the spout.

The exterior surfaces show a deep, rich, dark brownish glaze on the upper parts and a thicker slag accumulation near the base. These basal accumulations typically have included burnt shale fragments from the coal fuel.

Two sherds were examined during the assessment using an ED-XRF (Table 3). The results suggested that the alloy was high in zinc, somewhat lower in lead, with very little tin. The analysis of the body of one of the sherds showing a grey/lilac colour indicated substantial zinc accumulation within the ceramic. More detailed investigations were then undertaken, using destructive analytical techniques, to clarify the nature of the alloy, and in particular to examine whether these crucibles were residues from the manufacture of brass.

## Results

### General

The droplets of metal without signs of a high degree of oxidation and with apparently primary textures showed compositions that were polymetallic. They were broadly classifiable as antimony-bearing leaded tin bronzes (= leaded antimony bronze; Cu 75-87wt%, 2-12% Sn, 7-13% Pb, 1-2% Zn, 0-3% Sb, 0-2% As, 0-1% Ag). The slag phase and the altered crucible fabric locally showed relatively high levels of zinc (as indicated by the ED-XRF investigation during the assessment), but there were no metal droplets with

sufficiently high zinc contents to be termed brass and the zinc had probably become concentrated in the silicates over multiple use cycles. The crucibles were not, therefore associated with brass manufacture, but with the casting of leaded antimony bronze artefacts.

The slag on the interior surface of the crucibles was mainly glassy, particularly, close to the ceramic of the crucible and in areas where there were no adhering droplets of metal. Where the simple slag phase had crystallised, the mineral assemblage included anorthite and zinc-bearing magnetite.

In other areas there were adhering slaggy materials that were rich in calcium and magnesium. These suggest alteration materials from dolomite or ankerite. Minerals in the slag in these areas include probable wolastonite and periclase in the relict particle itself, with zincian spinels, possibly copper-bearing olivine, gehlenite and zincian åkermanite. These melilite group minerals occur as members of the åkermanite – gehlenite solid solution, with compositions close to gehlenite in PWL2A area 13, but reaching close to 75% åkermanite in PWL5 area 11. Zincian iron-åkermanite occurs in PWL2A area 11.

Complex spinel group minerals were seen in many locations, but particularly around the margins of the ceramic fragments attached to the crucibles. They range from minerals close to spinel ss ( $MgAl_2O_3$ ) to up to almost 60% gahnite ( $ZnAl_2O_3$ ), with members on this solid solution also mixed with magnetite ( $Fe_3O_4$ ). A few analyses showed almost end-member magnetite. Most analyses showed significant zinc substitution.

Calcium- and magnesium-rich slags with åkermanite, gehlenite, anorthite and spinels recur in this project in the clinkers investigated in part 2 below. This suggests that the blebs present on the interior of the crucibles have a similar origin – and are fuel remnants. In other words, despite the apparently dolomitic primary mineralogy, these may be residues from the burning of coal which had a dolomitic or ankeritic carbonate cement.

Strongly altered metallic blebs were also recorded with both oxide and sulphide mineralogies. These often showed demixing of the alloying elements copper, lead, tin and zinc into distinct oxide/sulphide blebs.

## Details of metal droplets

### PWL2A (Plates 1-3).

The sample cut the inner slagged margin of the crucible at a point where there was a large (10mm x 5mm) adhering to the inner face. Glassy slag, bearing small metal droplets, surrounded the adhering particle.

The droplets were polymetallic with very variable composition: Cu contents varied from 75-87wt%, with 2-12% Sn, 7-13% Pb, 1-2% Zn, 0-3% Sb, 0-2% As, 0-1% Ag. The adjacent ceramic and slag had moderately elevated levels of Zn, suggesting accumulation of volatilised zinc in these materials.

### PWL2B (Plate 4)

A relatively fresh droplet in this sample showed a composition of 90wt% Cu, 2% Zn, 3% Sn and 5% Pb. A nearby tiny droplet gave a rather similar analysis of 83wt% Cu, 1% Ni, 2% Zn, 5% Sn and 5% Pb.

### PWL3A (Plate 5)

This section proved to free of metal droplets.

### PWL3B (Plate 6)

A metal bleb trapped within rather vesicular slag had the bulk composition 83wt% Cu, 1% Ni, 7% Sn, 3% Sb and 6% Pb. Analyses of the copper-rich phase in the bleb gave 85-92 wt% Cu, 1% Ni, 0-1% Zn, 0-2% As, 4-9% Sn, 1-4% Sb and phase on the grain boundaries adjacent to the Pb-rich phase was up to 23-26wt% Sb, 10-12% Sn, 3-5% As, 6-7% Ni and 51-54% Cu.

### PWL4 (Plate 7)

This sample contained some highly altered metal blebs in an irregular quartz-rich slag lump. The blebs appear to have undergone segregation during oxidation and do not preserve primary textures.

### PWL5 (Plate 8)

The blebs in this sample have separated into distinct copper- and lead- rich zones. The glassy enclosing slag incorporates both complex Zn-bearing melilite group minerals and anorthite. One complex anorthite-dominated zone showed a tin-oxide rich area. This area shows the alloy unmixing as a result of oxidation.

## Interpretation

The crucibles had been used for handling leaded antimony bronze. The nature of small, often slightly oxidised, metal blebs that may have become incorporated into, or onto, the crucible fabric at various stages in the melt cycle, means that they do not necessarily provide a representative analysis of the bulk composition of the metal charge. In addition, the EDS analysis employed has high detection limits, so cannot provide an accurate measure of the trace element components of the metal. The analyses presented above vary in detail, but provide a broad picture of the metal composition as lying in the range Cu 75-87wt%, 2-12% Sn, 7-13% Pb, 1-2% Zn, 0-3% Sb, 0-2% As, 0-1% Ag.

The analyses indicating an antimony leaded bronze are compatible with metal compositions recorded as *caldarium* (Dungworth & Nicholas 2004, Figure 4), widely employed in the medieval and post-medieval periods for the casting of domestic vessels. They argued that this metal, with its high content of antimony and lead, modest tin content and traces of arsenic, nickel, iron and silver, was produced as a by-product of the liquation process of extracting silver from smelted *fahlerz* ores.

More specifically Dungworth & Nicholas describe the production of very particular types of vessel from this alloy: cauldrons, posnets and skillets. These vessels are all quite substantial in size, and they argue that the normal casting procedure was to run the molten metal from a refractory furnace into the moulds. Thus, for the production of these vessels, crucibles were not normally employed. The estimated volume of the crucibles (from 1400cm<sup>3</sup>) would be suitable for the handling of the amount of metal (from 200cm<sup>3</sup> upwards) required for skillets, but not for the larger vessels. There is currently no evidence from other sites for the handling of metal in crucibles for this purpose.

The use of this alloy for smaller artefact types is not well documented, although Craddock & Hook (1995) do describe its use for manillas, penannular rings exported from Europe to West Africa as currency during the slave trade. A mould for a manilla was also recovered from Birdall's Foundry in Exeter (Royal Albert Memorial Museum, accession no. 41/2005/5/1),

which is also known to have been casting cauldrons and skillets in antimony leaded bronze (Blaylock 2000). Manillas range in weight from around 200g for early examples to about 60g for late examples, so would be eminently suitable objects to cast from crucibles of the size seen here.

The source of the crucible sherds dumped in Portwall Lane is not known, but medieval foundries are known a short distance downhill in Redcliff Street (the 2 Redcliff Street site has produced evidence for the casting of skillets, and further casting evidence was obtained at 68-72 Redcliff Street; Jones 1983), so there may have been a local tradition in the production of such wares.

## Part 2: Ferrous residues and associated materials

### Results

#### *Macroscopic residues*

Smithing hearth cakes (SHCs), the normal dominant slag type produced in early smithing hearths, are not well represented in the assemblages. Two reasonably well-formed examples, indicative of original SHC weights of over 800g were recovered from Phase 3c context 1037. This provenance means they are not closely tied to on-site activity. Both showed evidence for the fuel employed being coal. A fragment from a much smaller SHC was found in Phase 1b context 1696. This piece had some adhering charcoal, and might just have been from a charcoal-fuelled hearth although the charcoal was not certainly originally attached to the slag (some charcoal is also sometimes found in coal-fired hearths from the remains of fire-lighting).

Small fragments of probable smithing slags were recovered from contexts 1453 and 1548, both showing evidence for coal use.

A crescentic block of coal-fired smithing slag from context 1365 was not a conventional SHC, but may have formed attached to the tuyère or blowhole area.

#### *Microresidues*

The forging of iron produces various microresidues in addition to the SHCs in the hearth. Two classes of microresidue are normally generated and deposited outside the hearth: flake hammerscale and spheroidal hammerscale. Flake hammerscale is generated through the superficial oxidation of the hot workpiece. The iron oxides to various iron oxides and differential thermal properties plus the changing shape of the iron during working cause the scale thus formed to spall off the workpiece. Flake hammerscale may accumulate in large quantities close to the smith's anvil. Spheroidal hammerscale is formed when the iron is worked very hot and the surface oxides (and possibly also the slag inclusions in the iron) melt. Working, particularly forge (= hammer-) welding, causes the molten material to be forcibly expelled from the workpiece. It chills and solidifies as spheres in flight, or may form irregular particles if it hits an object before solidifying. Other forms of microresidue (such as slag flats and slag blisters) may be more closely associated with slag and

other materials adhering to the surface of the hot workpiece, than to processes occurring within the workpiece.

The sieved residues from Portwall Lane included two broad suites of material: those attributable to iron-working with a high degree of confidence, and those which certainly involved the burning of coal, but for which a metallurgical origin is not proved.

Metallurgical particles include both flake and spheroidal hammerscale, together with blister-like slag films, slag flats (thin sheets of slag with a metal contact surface on one face, but showing an irregular and convex form on the other). Slag fragments also occur, but certain discrimination of iron-working slag and simple clinker is often difficult at this size. Good assemblages of this kind were recorded from contexts 1365, 1432, 1453, 1454, 1455, 1516, 1643, 1718, and 1735.

The coal-burning residues include fragments of coke (a highly vesicular, black, shiny material, largely carbon, generated during the incomplete burning of coal), clinker (a glassy slag material, typically with a maroon surface, formed from the melting of the impurities of the coal, and often including partially-melted shale fragments), burnt shale and highly magnetic burnt stone particles (iron-rich inclusions, probably originally either of pyrite or siderite, from with the coal seam or coal shale). Assemblages with significant quantities of fines from the burning of coal include those from contexts 1516, 1523, 1547 and 1627.

One interesting observation is the occurrence of slag spheroids, strongly resembling spheroidal hammerscale, within assemblages which otherwise have no evidence for metallurgical input. Spheroidal particles appear to be generated in several settings other than conventional spheroidal hammerscale from forge welding. In this instance it may be that spheroidal droplets of slag (clinker) formed within the coal-burning hearth. It is also possible, since some of these assemblages derive from contexts closely related to those with iron-working residues, that some sorting process has concentrated the spheroidal particles in these contexts without concentrating the flake hammerscale.

Investigation of the microresidues was pursued by the investigation of two samples, both from c1432, one of particles with flake morphology and one with particles of spheroidal morphology (PWL7 and PWL8 respectively). Samples of microresidues from a context at the nearby Victoria Road site which did not have certain ironworking residues according to the assessment report (Young 2007) were also analysed for comparative purposes. These samples also included one of particles of flake morphology and one of particles with a spheroidal morphology (samples PWL9 and PWL10 respectively), but also some irregular material which was more certainly formed of clinker (PWL11).

#### Portwall Lane: flake hammerscale (PWL7; Plates 11,12)

This has a typical flake hammerscale microstructure, with wustite commonly showing polygonal grain boundaries. EDS analysis of the interstitial areas near the surface of the analysed piece showed elevated levels of sulphur. The material is variably vesicular below the dense surface layer. The  $\text{SiO}_2:\text{Al}_2\text{O}_3$  ratio is

1.14 for the bulk sample. Within the single piece analysed in detail (Grain 17), the  $\text{SiO}_2\text{:Al}_2\text{O}_3$  ratio varied widely from 0.55 (in areas with tightly adjoining polygonal wustite, where  $\text{SiO}_2\text{:Al}_2\text{O}_3 = 0.64\text{wt}\%$ ) to 1.84 where there were slag films between the wustite grains (where  $\text{SiO}_2\text{:Al}_2\text{O}_3 = 2.79\text{wt}\%$ ).

The U:Th ratio is 0.45. The Upper Crust-normalised (after Taylor & McLennan 1981) rare earth element (REE) profile has a humped profile, which is very depleted compared with Upper Crust (Figure 1). The profile is almost identical to that from PWL9.

#### Portwall Lane: spheroidal hammerscale (PWL8; Plates 13-17)

**Bulk analysis:** The bulk analysis shows a very high iron total (91% expressed as FeO). All other elements are accordingly very diluted.

The Upper Crust-normalised REE profile has the humped profile common to all the samples (Figure 1), but shows a very slight positive cerium anomaly. The U:Th ratio is 0.46.

**Grain 1 (Plate 13a-c, Plate 15e-f):** This irregularly rounded grain is moderately vesicular and dominated by iron oxides. Internally, these are blebby and stubbily dendritic wustite. Towards the margin the wustite is largely replaced by equant euhedral magnetite with 11-23% hercynite. The  $\text{SiO}_2\text{:Al}_2\text{O}_3$  ratio by weight is approximately 1.0.

**Grain 2 (Plate 13d-g, Plate 15g-h, Plate 16a):** This grain is very highly spheroidal and has large internal vesicles. The microstructure is a glass bearing spinels. Where well-developed these show euhedral hercynite cores, overgrown by magnetite rims which extend into dendrites. The matrix is glass. There are a few small iron sulphide blebs. The  $\text{SiO}_2\text{:Al}_2\text{O}_3$  ratio by weight is approximately 1.4.

**Grain 3 (Plate 13h, Plate 14a-b, Plate 16b):** Is a rounded grain resembling two merged spheroids. It has a dense microstructure of wustite, including areas with polygonal grain boundaries as well as more dendritic growths. The microstructure shows a number of vesicles filled with later wustite. The  $\text{SiO}_2\text{:Al}_2\text{O}_3$  ratio by weight is approximately 1.1.

**Grain 4 (Plate 14c-f, Plate 16d):** Grain 4 has a complex shape, suggesting collapse of a partially brittle shell. It has a large cavity and some smaller vesicles. Internally there are several dense patches of wustite, some resembling flake hammerscale. The remainder of the interior is filled with a dendritic wustite. Near the margins, and locally internally, there is an angular magnetite with up to 30% hercynite. The  $\text{SiO}_2\text{:Al}_2\text{O}_3$  ratio by weight is approximately 1.1.

**Grain 5 (Plate 8g-h, Plate 16e-f):** This is a vesicular wustite-dominated spheroid with a large central cavity. The internal wustite shows up to 2% Al substitution, but the surface lacks Al. The  $\text{SiO}_2\text{:Al}_2\text{O}_3$  ratio by weight is approximately 0.9.

**Grain 6 (Plate 15a-b, Plate 16g-h):** This grain is close to spheroidal but has a slightly irregular margin, which bears several pieces of probable flake hammerscale. The grain is moderately vesicular. The internal microstructure is of small wustite dendrites in glass. Towards the margin, particularly close to the flake hammerscale fragments, there is widespread

development of euhedral magnetite, with up to 20% hercynite substitution. The  $\text{SiO}_2\text{:Al}_2\text{O}_3$  ratio by weight is approximately 1.7.

**Grain 7 (Plate 15c-d, Plate 17a-b):** This appears to have been a grain of high sphericity which has collapsed in brittle failure of the crust on one end. Textures resemble Grain 6, with areas resembling flake hammerscale, which are associated with zones of development of magnetite (with 15-25% hercynite). The  $\text{SiO}_2\text{:Al}_2\text{O}_3$  ratio by weight is approximately 1.4.

#### Victoria St.: flake particles (PWL9; Plates 18-19)

**Bulk analysis:** The sample is dominated by iron (82% when presented as FeO). All other elements are thus strongly diluted. The total of  $\text{SiO}_2\text{:Al}_2\text{O}_3$  is 6.2wt%; the total of MgO+CaO is only 2.2 wt%. The CaO:MgO ratio is 5.3; the  $\text{SiO}_2\text{:Al}_2\text{O}_3$  ratio is 1.65.

The Upper Crust normalised REE profile is almost identical to that of PWL7 (Figure 1). The U:Th ratio is 0.38.

**Grain 8 (Plate 18a, e-g):** This grain shows a somewhat foliated texture, which appears to reflect a varying density of fine grained quartz scattered through this otherwise iron oxide-dominated particle. The most dense parts of the iron oxide (e.g. Plate 18f, lower left) show polygonal grain boundaries suggest of oxidation of a coarse iron. In contrast the silica-rich areas (e.g. Plate 18g) show extremely fine grained granular oxides intimately mixed with neomorphic quartz (or a high-temperature polymorph).

**Grain 9 (Plate 18d, h):** This irregular grain shows an apparently concentric structure (although this may be due to the intersection of an uneven lamination with the plane of the section). The lamination is picked out by trains of small vesicles and also voids which appear to have pulled apart by contraction of the core of the sample. EDS analyses show very low silica and alumina contents, with alumina predominant over silica, probably due to its substitution into the iron oxide.

**Grain 10 (Plate 18b-c, Plate 19a):** As with Grain 9 this piece is almost entirely iron oxide, which bears both irregular and rounded voids. The pattern of alumina and silica is similar to Grain 9, with both very low, but with higher alumina.

#### Victoria St: spheroidal particles (PWL10; Plates 20-23)

**Bulk analysis:** The bulk chemical composition was determined solely by ICP-MS because the available sample was too small for fabrication of a fused bead for XRF. Elements were typically in concentrations of approximately 50% higher than in PWL12 – suggesting a reduced dilution by iron (present here at 36wt% expressed as FeO). If the Sr:Ca:Mg relationships are the same as in PWL11, it would suggest that CaO+MgO might be as high as 32%.

The Upper Crust-normalised REE profile is humped, as for the other samples (Figure 1), but has the highest concentration of the REE, with all elements well above parity. The profile is almost identical to that of PWL11,

and both profiles are slightly elevated at the HREE compared with the profiles of the other three samples. The U:Th ratio is 0.44.

**Grain 11 (Plate 20b-e, Plate 22a-d):** this grain has a very fine-grained mineral assemblage, including probable åkermanite associated with possible periclase, zones of magnetite-hercynite, blebs of iron sulphide, relict quartz grains, neomorphic anorthite, together with other unidentified phases, all set in a very heterogeneous glass.

**Grain 12 (Plate 20f-h, Plate 22e-h):** this is a very vesicular grain of irregular shape, rather like a typical fuel ash slag particle. Analyses of peripheral areas where there was a better-developed melt phase shows a glass bearing anorthite laths and small crystals of magnetite (with some hercynite substitution).

**Grain 13 (Plate 21a-c, Plate 23a-c):** this grain shows a morphology similar to that of some true spheroidal hammerscale particles, have a spheroidal main body, attached via a narrow neck to a tangentially-oriented piece of iron oxide-dominated material with a granular texture like flake hammerscale. The flake hammerscale-like area is probably formed of magnetite, with up to about 5% hercynite substitution. The neck is characterised by magnetite in a dendritic form. The main body of the particle shows angular equant magnetite often with a rather porous nature. On one side of the grain the magnetite is intimately associated with elongate crystals of an unidentified Fe-Mg-Ca aluminosilicate. The magnetite within the main body of the grain shows much higher levels of substitution by both Mg and Al than does the magnetite in the flake hammerscale attached to the neck.

**Grain 14 (Plate 21d-e, Plate 23d-f):** This neatly spheroidal grain is composed almost entirely of rather porous large (<1.5mm long) crystals of gehlenite. Secondary calcium (carbonate?) is present in the pore spaces. There is a thin iron oxide crust.

**Grain 15 (Plate 21f-h, Plate 23g-h):** This grain is highly spheroidal. It shows a rather heterogeneous internal texture. On the left side of the view in Plate 23g it shows patches of dense iron oxide, resembling hammerscale. These appear to be of wustite. The background glass bears substantial laths of anorthite (up to about 400µm in length), plus a very fine dendritic phase in the area around the iron oxide.

#### Victoria St.: clinker particle (PWL11; Plate 24)

**Grain 16 (Plate 24a-g):** This very irregularly shaped particle was approximately 5mm across. On one side (the lower right margin of Plate 24a, g) the particle bears a strongly foliated material which is probably a relict shale fragment. The clast is dominantly alumina-silicate with SiO<sub>2</sub>:Al<sub>2</sub>O<sub>3</sub> ratio (by weight) of 1.26. The average of the measurements for the same ratio for the adjacent slag is 1.25. The bulk iron content is high (47.1wt% expressed as FeO), with SiO<sub>2</sub>+Al<sub>2</sub>O<sub>3</sub> at 25.6wt% and CaO+MgO at 19wt%.

The trace elements are typically present in somewhat lower concentrations than in PWL10 (typically by around 70%). The U:Th ratio (by weight) is 0.35. The Upper Crust-normalised REE profile (Figure 1) shows a humped shape, similar to that of the other samples, with almost all elements (except La and Ce) present above parity.

The slag has three main phases: anorthite, spinel (with cores at about 60%spinel ss/40%hercynite and rims close to magnetite) and an Fe-bearing åkermanite. The åkermanite is particularly abundant near the left edge (as seen in Plate 24), where it is large and equant, toward the right it is more dendritic and is interstitial to the large anorthite laths. The primary phase is the spinel, which seems dominantly magnetitic in the åkermanite-dominated areas, but has spinel-hercynite cores in the anorthite-dominated areas.

## Interpretation

The particles described in detail above show a wide spectrum of properties, from material identical to previously studied hammerscale, through to material of unusual compositions that may be interpreted as being dominated by clinker.

The spheroidal hammerscale is typically dominated by wustite, with minor peripheral magnetite. None of the hammerscale samples showed a composition rich in iron silicates (a marked contrast with some older hammerscale assemblages such as Coolamurry, Young 2008, or Trowbridge, Young 2009a) .

The particles that may be interpreted as clinker show a mineralogy dominated by spinels and melilite group minerals (gehlenite and åkermanite). Some of the clinker-dominated particles show clusters of wustite that may be indicative of hammerscale particles, suggesting that some of the clinker-dominated particles may have been generated during iron working.

Despite this diversity, they show a striking degree of chemical coherency: they have a constant REE profile (Figure 1), they have similarities in their silica:alumina ratio and in their uranium to thorium ratio and in the plots of elemental proportion in EDS analyses of areas within individual particles (Figure 2), there is a remarkable trend of analyses through the hammerscale samples and into the more clinker-dominated particles.

The observations on the hammerscale are similar to those made on Roman hammerscale from sites in South Wales (Young 2009a), particularly in terms of the REE profile, the Si:Al ratio and the U:th ratio.

Two conclusions flow from these observations:

- firstly that it is possible the clinker-dominated assemblages may, at least in part, have been generated during iron-working, rather than being simply residues from non-metallurgical use of coal (although it is equally likely that the iron-rich materials within them are derived from ankeritic, sideritic or pyritic coal)

-secondly, that the material "contaminating" the oxidised iron in the hammerscale probably had the same origin as the clinker – that is to say it is the fuel ash from the burning of coal fuel.

This second observation is important, for some recent studies (e.g. Dungworth and Wilkes 2009) have suggested that spheroidal hammerscale is largely the result of expulsion of slag inclusions from the workpiece. Although one could argue that in some cases coal residues might contribute to the slag inclusions, the present data are more easily

interpretable in terms of the silicate component of the hammerscale being largely provided by surface contamination on the work piece from the fuel ash (clinker).

The clinker compositions observed in this study have proved to be surprisingly calcium- and magnesium-rich. This suggests that the coal being utilised was rich in dolomite or ankerite. The clinkers observed here were very similar to the adhering slags on the inside of the Portwall Lane crucibles, suggesting a similar coal source was involved sets of operations.

## References

- Blaylock, S.R. 2000. Excavation of an early post-medieval bronze foundry at Cowick Street, Exeter, 1999-2000. *Proceedings of the Devon Archaeological Society*, **58**, 1-92.
- Craddock, P.T. & Hook, D.R. 1995. Copper to Africa, evidence for the international trade in metal with Africa, in: D.R.M. Gaimster & D.R. Hook, (eds). *Trade and discovery, The scientific study of artefacts from post-medieval Europe and beyond*. 181-193.
- Dungworth, D. & Nicholas, M., 2004. Caldarium? An antimony bronze used for medieval and post-medieval cast domestic vessels. *Historical Metallurgy*, **38**, 24-34.
- Dungworth, D. & Wilkes R. 2009. Understanding hammerscale: the use of high speed film and electron microscopy. *Historical Metallurgy*, **43**, 33-46.
- Jones, R.H. 1983. Excavations at 68-72 Redcliffe Street, 1982. *Bristol and Avon Archaeology*, **2**, 37-39.
- Taylor, S.R. & McLennan, S.M. 1981. The composition and evolution of the continental crust: rare earth element evidence from sedimentary rocks. *Philosophical Transactions of the Royal Society*, **A301**, 381-399.
- Young, T.P. 2006. Evaluation of archaeometallurgical residues from Victoria Street, Bristol. *GeoArch Report 2006/20*. 3pp.
- Young, T.P. 2007. Evaluation of archaeometallurgical residues from Portwall Lane, Bristol (BSRMG 2006/17). *GeoArch Report 2007/10*. 7pp.
- Young, T.P. 2008. Archaeometallurgical residues from Coolamurry 7, 04E0323. *GeoArch Report 2006/10*. 46pp.
- Young T.P. 2009a. Archaeometallurgical residues from Crickhowell Road, Trowbridge, Cardiff. *GeoArch Report 2009/02*. 11pp.
- Young, T.P. 2009b. Evaluation of archaeometallurgical residues from Victoria Street, Bristol (revised version), *GeoArch Report 2009/35*, 4 pp.
- Young, T.P. 2009c. Evaluation of archaeometallurgical residues from Portwall Lane, Bristol (BSRMG 2006/17) (revised version), *GeoArch Report 2009/36*, 6 pp.

## Glossary of mineral terms

- Åkermanite – a melilite group mineral:  $\text{Ca}_2[\text{MgSi}_2\text{O}_7]$
- Ankerite – a carbonate  $\text{Ca}(\text{Mg,Fe,Mn})(\text{CO}_3)_2$
- Anorthite – a calcium plagioclase feldspar  $\text{CaAl}_2\text{Si}_2\text{O}_8$
- Calcite – a carbonate mineral  $\text{CaCO}_3$
- Dolomite – a carbonate mineral  $\text{CaMg}(\text{CO}_3)_2$
- Fahlerz – copper ores with the copper sulfosalts tennantite ( $\text{Cu}_{12}\text{As}_4\text{S}_{13}$ ) and/or tetrahedrite ( $\text{Cu}_{12}\text{Sb}_4\text{S}_{13}$ )
- Gahnite - a spinel group mineral  $\text{ZnAl}_2\text{O}_3$
- Gehlenite – a melilite group mineral  $\text{Ca}_2[\text{Al}_2\text{SiO}_7]$
- Hercynite – a spinel group mineral  $\text{FeAl}_2\text{O}_3$
- Magnetite - a spinel group mineral  $\text{Fe}_3\text{O}_4$
- Melilite – a melilite group mineral  $(\text{Ca,Na})_2[(\text{Mg,Fe,Al,Si})_3\text{O}_7]$
- Olivine – a group of silicate minerals  $(\text{Fe,Mg})_2[\text{SiO}_4]$
- Periclase – a magnesium oxide  $\text{MgO}$
- Pyrite – an iron sulphide  $\text{FeS}_2$
- Siderite – a carbonate mineral  $\text{FeCO}_3$
- Spinel – a member of the spinel group  $\text{MgAl}_2\text{O}_3$
- Wollastonite – a calcium silicate  $\text{Ca}[\text{SiO}_3]$
- Wustite – an iron oxide  $\text{FeO}$

## Illustration Captions

Figure 1. Upper Crust-normalised rare earth element profiles for samples PWL7-11. Normalisation factors after Taylor and McLennan (1981).

Figure 2. Variation diagrams showing trends between particles. Data are EDS analyses of representative areas of individual particles. Data as per Table 7.

Plate 1: BSEM images of crucible fragment, PWL2a

- a. Area 1 Scale bar 1mm.
- b. Area 2 Scale bar 1mm.
- c. Area 3 Scale bar 600 $\mu$ m.
- d. Area 4 Scale bar 200 $\mu$ m.
- e. Area 5 Scale bar 700 $\mu$ m.
- f. Area 6 Scale bar 8mm.
- g. Area 7. Scale bar 300 $\mu$ m.
- h. Area 8 Scale bar 100 $\mu$ m.

Plate 2: BSEM images of crucible fragment, PWL2a

- a. Area 9 Scale bar 6mm.
- b. Area 10 Scale bar 6mm.
- c. Area 11 Scale bar 400 $\mu$ m.
- d. Area 12 Scale bar 400 $\mu$ m.
- e. Area 13 Scale bar 200 $\mu$ m.
- f. Area 14 Scale bar 1mm.
- g. Area 15. Scale bar 1mm.
- h. Area 16 Scale bar 1mm.

Plate 3: BSEM images of crucible fragment, PWL2a

- a. Area 17 Scale bar 200 $\mu$ m.
- b. Area 18 Scale bar 10mm.
- c. Area 19 Scale bar 100 $\mu$ m.

Plate 4: BSEM images of crucible fragment, PWL2b

- a. Area 1 Scale bar 1mm.
- b. Area 2 Scale bar 100 $\mu$ m.
- c. Area 3 Scale bar 200 $\mu$ m.

Plate 5: BSEM images of crucible fragment, PWL3a

- a. Area 1 Scale bar 600 $\mu$ m.
- b. Area 2 Scale bar 1mm.

Plate 6: BSEM images of crucible fragment, PWL3b

- a. Area 1 Scale bar 600 $\mu$ m.
- b. Area 2 Scale bar 600 $\mu$ m.
- c. Area 3 Scale bar 100 $\mu$ m.

Plate 7: BSEM images of crucible fragment, PWL4

- a. Area 1 Scale bar 2mm.
- b. Area 2 Scale bar 300 $\mu$ m.
- c. Area 3 Scale bar 900 $\mu$ m.
- d. Area 4 Scale bar 2mm.

Plate 8: BSEM images of crucible fragment, PWL5

- a. Area 1 Scale bar 600 $\mu$ m.
- b. Area 2 Scale bar 600 $\mu$ m.
- c. Area 3 Scale bar 600 $\mu$ m.
- d. Area 4 Scale bar 300mm.
- e. Area 5 Scale bar 70 $\mu$ m.
- f. Area 6 Scale bar 100 $\mu$ m.
- g. Area 7. Scale bar 100 $\mu$ m.
- h. Area 8 Scale bar 200 $\mu$ m.

Plate 9: BSEM images of crucible fragment, PWL2a

- a. Area 9 Scale bar 700mm.
- b. Area 10 Scale bar 80mm.
- c. Area 11 Scale bar 1mm.
- d. Area 12 Scale bar 60 $\mu$ m

Plate 10: BSEM images of crucible fragment, PWL6

- a. Area 1 Scale bar 4mm.
- b. Area 2 Scale bar 4mm.

Plate 11: BSEM images of microresidues, PWL7

- a. Area 1, Grain 17, Scale bar 4mm.
- b. Area 2, Grain 17, Scale bar 600 $\mu$ m.
- c. Area 3, Grain 17, Scale bar 100 $\mu$ m.
- d. Area 4, Grain 17, Scale bar 100 $\mu$ m.
- e. Area 5, Grain 17, Scale bar 100 $\mu$ m.
- f. Area 6, Grain 17, Scale bar 100 $\mu$ m.
- g. Area 7, Grain 17, Scale bar 300 $\mu$ m.
- h. Area 8, Grain 17, Scale bar 400 $\mu$ m.

Plate 12: BSEM images of microresidues, PWL7

- a. Area 9, Grain 17 Scale bar 400 $\mu$ m.

Plate 13: BSEM images of microresidues, PWL8

- a. Area 1, Grains 1-7, Scale bar 8mm.
- b. Area 2, Grain 1, Scale bar 1mm.
- c. Area 3, Grain 1, Scale bar 100 $\mu$ m.
- d. Area 4, Grain 2, Scale bar 1mm.
- e. Area 5, Grain 2, Scale bar 200 $\mu$ m.
- f. Area 6, Grain 2, Scale bar 100 $\mu$ m.
- g. Area 7, Grain 2, Scale bar 100 $\mu$ m.
- h. Area 8, Grain 3, Scale bar 1mm.

Plate 14: BSEM images of microresidues, PWL8

- a. Area 9, Grain 3, Scale bar 400 $\mu$ m.
- b. Area 10, Grain 3, Scale bar 100 $\mu$ m.
- c. Area 11, Grain 4, Scale bar 1mm.
- d. Area 12, Grain 4, Scale bar 200 $\mu$ m.
- e. Area 13, Grain 4, Scale bar 70 $\mu$ m.
- f. Area 14, Grain 4, Scale bar 100 $\mu$ m.
- g. Area 15, Grain 5, Scale bar 1mm.
- h. Area 16, Grain 5, Scale bar 200 $\mu$ m.

Plate 15: BSEM images of microresidues, PWL8

- a. Area 17, Grain 6, Scale bar 1mm.
- b. Area 18, Grain 6, Scale bar 100 $\mu$ m.
- c. Area 19, Grain 7, Scale bar 1mm.
- d. Area 20, Grain 7, Scale bar 300 $\mu$ m.
- e. Area 21, Grain 1, Scale bar 600 $\mu$ m.
- f. Area 22, Grain 1, Scale bar 80 $\mu$ m.

- g. Area 23, Grain 2, Scale bar 600µm.
- h. Area 24, Grain 2, Scale bar 80µm.

Plate 16: BSEM images of microresidues, PWL8

- a. Area 25, Grain 2, Scale bar 70µm.
- b. Area 26, Grain 3, Scale bar 600µm.
- c. Area 27, Grain 4, Scale bar 600µm.
- d. Area 28, Grain 4, Scale bar 70µm.
- e. Area 29, Grain 5, Scale bar 600µm.
- f. Area 30, Grain 5, Scale bar 100µm.
- g. Area 31, Grain 6, Scale bar 600µm.
- h. Area 32, Grain 6, Scale bar 100µm.

Plate 17: BSEM images of microresidues, PWL8

- a. Area 33, Grain 7, Scale bar 400µm.
- b. Area 34, Grain 7, Scale bar 100µm.

Plate 18: BSEM images of microresidues, PWL9

- a. Area 1, Grain 8, Scale bar 4mm.
- b. Area 2, Grain 10, Scale bar 4mm.
- c. Area 3, Grain 10, Scale bar 4mm.
- d. Area 4, Grain 9, Scale bar 4mm.
- e. Area 5, Grain 8, Scale bar 2mm.
- f. Area 6, Grain 8, Scale bar 200µm.
- g. Area 7, Grain 8, Scale bar 100µm.
- h. Area 8, Grain 9, Scale bar 2mm.

Plate 19: BSEM images of microresidues, PWL9

- a. Area 9, Grain 10, Scale bar 2mm.

Plate 20: BSEM images of microresidues, PWL10

- a. Area 1, Grains 11-15, Scale bar 7mm.
- b. Area 2, Grain 11, Scale bar 2mm.
- c. Area 3, Grain 11, Scale bar 100µm.
- d. Area 4, Grain 11, Scale bar 100µm.
- e. Area 5, Grain 11, Scale bar 100µm.
- f. Area 6, Grain 12, Scale bar 1mm.
- g. Area 7, Grain 12, Scale bar 100µm.
- h. Area 8, Grain 12, Scale bar 100µm.

Plate 21: BSEM images of microresidues, PWL10

- a. Area 9, Grain 13, Scale bar 1mm.
- b. Area 10, Grain 13, Scale bar 400µm.
- c. Area 11, Grain 13, Scale bar 400µm.
- d. Area 12, Grain 14, Scale bar 1mm.
- e. Area 13, Grain 14, Scale bar 200µm.
- f. Area 14, Grain 15, Scale bar 1mm.
- g. Area 15, Grain 15, Scale bar 200µm.
- h. Area 16, Grain 15, Scale bar 200µm.

Plate 22: BSEM images of microresidues, PWL10

- a. Area 17, Grain 11, Scale bar 700µm.
- b. Area 18, Grain 11, Scale bar 100µm.
- c. Area 19, Grain 11, Scale bar 90µm.
- d. Area 20, Grain 11, Scale bar 70µm.
- e. Area 21, Grain 12, Scale bar 1mm.
- f. Area 22, Grain 12, Scale bar 100µm.
- g. Area 23, Grain 12, Scale bar 200µm.
- h. Area 24, Grain 12, Scale bar 100µm.

Plate 23: BSEM images of microresidues, PWL10

- a. Area 25, Grain 13, Scale bar 300µm.
- b. Area 26, Grain 13, Scale bar 80µm.
- c. Area 27, Grain 13, Scale bar 1mm.
- d. Area 28, Grain 14, Scale bar 1mm.
- e. Area 29, Grain 14, Scale bar 200µm.
- f. Area 30, Grain 14, Scale bar 400µm.
- g. Area 31, Grain 15, Scale bar 1mm.
- h. Area 32, Grain 15, Scale bar 200µm.

Plate 24: BSEM images of microresidues, PWL11

- a. Area 1, Grain 16, Scale bar 5mm.
- b. Area 2, Grain 16, Scale bar 200µm.
- c. Area 3, Grain 16, Scale bar 200µm.
- d. Area 4, Grain 16, Scale bar 100µm.
- e. Area 5, Grain 16, Scale bar 600µm.
- f. Area 6, Grain 16, Scale bar 100µm.
- g. Area 7, Grain 16, Scale bar 1mm.

<i>context</i>	<i>sample</i>	<i>label</i>	<i>description</i>
<b>Microresidues</b>			
1365	21	hammerscale	large assemblage with good flake and spheroidal hammerscale, miscellaneous iron rich particles, magnetite rods, rusty concretions, shale, occasional coal
1432	22	hammerscale	good assemblage rich in flake and spheroidal hammerscale, along with slag fragments, shale and ashy white concretionary material
1453	25	hammerscale	dusty assemblage with abundant spheroids, some flake scale, lots of various coal residues
1454	23	hammerscale	abundant flake and spheroidal scale, also other slags films and lumps, fired clay, magnetite rods,
1455	24	hammerscale	abundant flake and spheroidal scale, also other slags films and lumps, fired clay, magnetite rods, charcoal, shale, coke
1516	32	magnetic residue	mainly fired stone and slaggy material, a few shiny flakes almost like hammerscale, but probably not
1516	32	slag	very shiny vesicular fragments - clinker?, also probable piece of coal
1516	32	hammerscale	burnt stone ,shale, clinker, cokes, slag, some flake scale rare spheroids
1518	31	clinker	large bag of coal residue, mainly coke
1518	31	hammerscale	very iron rich residue - lots of burnt stone, iron crusts, thin magnetite rods, possible flake hammerscale, occasional spheroid, some shale, a few angular slag fragments
1523	38	hammerscale	mainly burnt stone, but also abundant spheroids, some possible flake, shale, some rust particles
1547	34	hammerscale	lots of clinkery residue, white residue fragments, some spheres, some shiny flakes - at least some of which may be true flake scale
1548	35	hammerscale	some hammerscale but mainly shale, stone and glassy slag. Some elongate concretions, possible nail head
1627	42	slag	dark vesicular glass with maroon surface, 2 piece: clinker
1627	42	hammerscale	clinker droplets. Burnt stone, shale, probable flake hammerscale, abundant spheroids, crude magnetite rods,
1643	44	slag	red and black glassy clinkers
1643	44	hammerscale	mainly burnt stone and pale material (fired clay or ashy concretions - some rod like), has some flake scale and spheroids, some clinkery blebs
1662	41	hammerscale	some flake and spheroidal scale, clinker, slag, some very thin rods, stone
1718	49	hammerscale	mainly burnt stone and pale material (fired clay or ashy concretions - some rod like), has some flake scale and spheroids
1718	49	slag	small piece of greyish dimpled slag, small fragment, worn, of haematite ore, possible concretionary piece
1735	48	hammerscale	iron-rich coal fragments , possible rare flake and spheroidal scale, possible crucible slag fragment or clinker, magnetite rods, burnt stones
1744	47	hammerscale	mainly burnt stone, but some is slagged, also shale, some slag droplets
1744	47	slag	red and black glassy pieces with white grains - presumably clinker, other lumps may be concretionary
1751	50	clinker	coke (single small fragment)
<b>Macroresidues</b>			
1037	1556	slag	748g curving ferruginous block probable SHC fragment 155x110x60mm; 798g SHC (140)x105x65, both show evidence of coke and first has adhering ash and coal
1354	132	slag	large clinker block - now in several pieces
1354	32	slag	low density clinker in curved sheet
1365	108	slag	rusty crescent of dense clinkery slag. Probably from near tuyère in smithing hearth using coal
1436	76	slag	large block of shale-bearing coke
1453	22	slag	grey vesicular slag with shale fragments, rusted surface
1548	36	slag	dense slag with brownish surface and probable coke inclusions - coal fuelled smithing slag
1696	50	slag	small piece from small SHC, smooth maroon top, ?folded, base smooth with possible charcoal fragment, slightly concreted with freshwater? mussels
1734	130	Cu al slag	10g coke, 20g maroon crucible slag bearing corroded Cu-alloy droplets, 32g dense green glassy slag with Cu-alloy corrosion dimpled around coke fragments, 16 cu corrosion attached to piece of hearth wall - organic temper oxidised fired, 46g extremely dense probable Cu-alloy disk in slag reduced fired vitrified lining
1754	16	slag	
<b>Crucible Assemblage</b>			
1131	96	vitrified ceramic	2 pieces of slagged refractory material - possibly failed crucible fragments
1131	6880	crucibles	38 sherds of large crucibles
1131	790	Cu-alloy slag	11 pieces of slag. At least 4 pieces are effectively clinker, with large shale fragments, 1 is a piece of slagged crucible debris, 1 is a very dense block of iron-rich slag, the others are lower density slags with extensive development of secondary copper minerals.
1131	86	burnt stone	lightly vitrified shale with some Cu-alloy slag
1131	290	vitrified ceramic	2 blocks of vitrified shale strongly coated in slag including Cu-alloy material

Table 1: Summary catalogue by context

Context	Description	Phase	Assemblage
1735	fill of feature 1736	1a	coal burning residue, possible smithing
1751	fill of linear 1752	1a	coal-burning residue
1754	disturbed surface of alluvium	1a	hearth lining
1696	redeposited alluvium	1b	smithing
1718	redeposited alluvium	1b	indeterminate metalworking
1734	redeposited alluvium	1b	copper-alloy working, coal-burning residues
1744	redeposited alluvium	1b	coal-burning residues
1454	deposit	2a	smithing, coal-burning residues
1523	garden soil	2a	smithing, coal-burning residues
1643	garden soil	2a	smithing, coal-burning residues
1662	garden soil	2a	smithing, coal-burning residues
1718	fill of pit 1717	2a	smithing, coal-burning residues
1131	deposit	2b	Copper alloy working (casting), coal residues
1354	fill of shallow pit cut by old cone	2b	coal-burning residue
1365	garden soil	2b	smithing, coal-burning residues
1436	deposit	2b	coal-burning residue
1453	garden soil	2b	smithing, coal-burning residues
1518	fill of linear 1519	2b	smithing, coal-burning residues
1548	garden soil	2b	smithing, coal-burning residues
1627	dumped deposits	2b	smithing, coal-burning residues
1037	levelling over new cone	3c	smithing
1432	?	?	smithing, coal-burning residues
1455	?	?	smithing, coal-burning residues
1516	?	?	smithing, coal-burning residues
1547	?	?	smithing, coal-burning residues

*Table 2: Summary of interpretation of assemblages organised by phase and context. Records of coal-burning residue do not necessarily exclude a metallurgical origin for the residues. Stratigraphic and phasing details were not available for four contexts (1432, 1455, 1516 & 1547)*

	Portwall 1 brown residue	Portwall 1 green residue	Portwall 2 green corrosion on outside	Portwall 2 inner pale fabric
Oxide:	At%	At%	At%	At%
CaO	1.43	1.66	4.44	25.19
MnO	0.26	0.15	0.01	0.13
Fe <sub>2</sub> O <sub>3</sub>	72.15	48.54	2.66	8.18
CuO	17.04	36.96	83.32	2.11
ZnO	6.76	10.27	8.38	62.64
PbO <sub>2</sub>	1.85	2.18	0.83	0.52
SrO	0.08	0.11	0.09	0.31
ZrO <sub>2</sub>	0.35	0.03	0.15	0.74
SnO <sub>2</sub>	0.08	0.09	0.13	0.16
Oxide:	Wt%	Wt%	Wt%	Wt%
CaO	0.57	0.766	3.024	17.091
MnO	0.129	0.088	0.011	0.115
Fe <sub>2</sub> O <sub>3</sub>	82.11	63.629	5.168	15.799
CuO	9.659	24.134	80.531	2.029
ZnO	3.917	6.861	8.283	61.659
PbO <sub>2</sub>	3.155	4.283	2.416	1.511
SrO	0.063	0.093	0.115	0.388
ZrO <sub>2</sub>	0.31	0.03	0.22	1.11
SnO <sub>2</sub>	0.088	0.117	0.233	0.297

Table 3: Raw ED-XRF analyses (qualitative) from crucible sherds from context 1131.

			context	sample	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	MnO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	LOI 100% FeIII	LOI 100% FeII	total
PWL7	flake	Portwall Lane	1432	22	2.86	2.50	95.80	86.22	0.07	0.16	1.01	0.14	0.27	0.09	0.51	-5.70	3.88	97.70
PWL8	spheroids	Portwall Lane	1432	22	n.d.	n.d.	n.d.	<b>91.10</b>	<b>0.10</b>	n.d.	n.d.	n.d.	n.d.	<b>0.11</b>	<b>0.57</b>	n.d.	n.d.	n.d.
PWL9	flake	Victoria Street	222	6	3.84	2.33	91.60	82.44	0.06	0.35	1.86	0.12	0.17	0.10	0.65	-1.92	7.24	99.18
PWL10	spheroids	Victoria Street	222	6	n.d.	n.d.	n.d.	<b>35.99</b>	<b>0.40</b>	n.d.	n.d.	n.d.	n.d.	<b>0.48</b>	<b>1.54</b>	n.d.	n.d.	n.d.
PWL11	clinker	Victoria Street	222	6	14.36	11.22	52.29	47.06	0.75	7.32	11.63	0.18	0.52	0.35	1.00	-1.03	4.20	98.59

			Sc	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Mo	Sn	Cs	Ba
PWL7			5.20	31.27	10.82	66.70	108.95	142.53	185.02	9.30	11.32	124.18	10.88	19.93	1.63	8.02	1.71	1.03	678.89
PWL8			7.51	45.29	27.60	70.40	123.43	255.33	171.81	9.92	14.82	155.03	16.56	31.65	2.54	6.33	2.25	1.33	866.18
PWL9			5.76	37.02	12.72	86.99	197.45	122.62	137.57	16.12	7.00	162.63	10.77	24.11	2.51	7.65	2.28	1.51	501.94
PWL10			40.62	221.69	98.29	162.97	401.57	198.24	221.28	13.30	39.89	1075.27	74.85	135.01	12.15	14.26	0.91	6.82	3120.39
PWL11			31.32	89.84	64.45	111.26	309.81	81.32	93.98	6.25	23.01	657.32	49.43	79.87	7.21	5.91	1.17	3.55	1876.76

			La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
PWL7			7.85	16.34	2.04	7.90	1.86	0.46	1.96	0.30	1.62	0.29	0.84	0.12	0.72	0.11	0.48	0.10	98.97	1.75	0.78
PWL8			12.18	29.44	3.18	12.25	2.91	0.70	3.03	0.45	2.50	0.44	1.25	0.18	1.10	0.16	0.78	0.16	97.90	2.58	1.18
PWL9			7.88	15.88	1.93	7.45	1.85	0.45	2.08	0.33	1.75	0.30	0.82	0.12	0.71	0.10	0.61	0.16	28.89	1.78	0.67
PWL10			41.02	98.75	11.38	46.16	12.32	3.10	14.20	2.20	11.89	2.04	5.66	0.81	4.75	0.71	3.37	0.61	97.76	10.67	4.66
PWL11			27.06	56.96	7.46	30.39	8.03	2.01	9.36	1.47	8.01	1.38	3.79	0.55	3.20	0.48	2.05	0.41	10.39	6.78	2.39

Table 4. Chemical analyses of bulk samples

- a) Major elements, expressed as weight% oxides. Iron is shown as FeIII oxide and, alternatively, recalculated as Fe<sup>II</sup> (together with a recalculated loss on ignition). The alternative is given on a grey tone background. For PWL 7, 9, & 11 the analyses were undertaken on a fused bead by XRF. Small sample size prevented this approach for PWL8 & 10 for which a limited set of major elements were determined by ICP-MS. n.d. = not determined.
- b) Trace elements, expressed as elemental ppm, determined by ICP-MS.
- c) Trace elements, continued.

S	A	#	Texture/location	atom%																										
				O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	As	Br	Ag	Sn	W	Sb	Pb	Ba	Bi
<b>droplet on inner margin of slag</b>																														
2A	7	1	copper-rich phase	7.83	<	<	<	<	<	<	<	<	<	<	<	<	<	0.43	84.96	<	<	<	<	6.31	0.47	<	<	<	<	
2A	7	2	copper-rich phase	5.48	<	<	<	<	0.23	<	<	<	<	<	<	<	<	0.40	86.70	<	<	<	<	6.82	0.38	<	<	<	<	
2A	7	3	copper-rich phase	5.95	<	<	<	<	0.59	<	<	<	<	<	<	<	<	0.32	86.68	0.44	<	<	<	5.77	0.26	<	<	<	<	
2A	7	4	remains of lead phase	62.94	<	6.92	0.28	<	<	<	<	<	<	<	<	<	<	<	<	3.84	<	<	<	<	<	<	26.03	<		
2A	7	5	remains of lead phase	39.23	<	2.48	0.85	<	<	<	<	<	<	<	<	<	<	<	<	23.63	<	<	<	1.21	<	<	32.60	<		
2A	7	6	remains of lead phase	55.82	<	5.09	0.71	<	<	<	<	<	<	<	<	<	<	<	<	4.97	<	<	<	<	<	<	33.41	<		
2A	7	7	marginal globular bodies	29.70	<	<	0.38	<	<	34.88	<	<	<	<	<	<	<	<	<	8.48	<	<	<	<	<	<	26.56	<		
2A	7	8	marginal globular bodies	39.88	<	<	0.44	<	<	29.56	<	<	<	<	<	<	<	<	<	1.37	<	<	<	<	<	<	28.75	<		
2A	7	9	marginal globular bodies	41.88	<	<	<	<	<	28.90	<	<	<	<	<	<	<	<	<	1.21	<	<	<	<	<	<	28.01	<		
2A	7	10	bright phase around "pore"	62.84	<	<	<	<	17.66	<	<	<	<	<	<	<	<	<	<	0.92	<	<	<	<	<	<	18.57	<		
2A	7	11	bright phase around "pore"	63.92	<	<	<	<	17.05	<	<	<	<	<	<	<	<	<	<	0.79	<	<	<	<	<	<	18.24	<		
2A	7	12	bright phase around "pore"	64.03	<	<	0.21	<	16.23	<	<	<	<	<	<	<	<	<	<	0.85	<	<	<	<	<	<	18.68	<		
2A	7	13	altered outer material	64.94	<	1.49	0.34	<	8.79	3.32	<	<	<	<	<	<	0.21	<	0.93	<	<	<	<	3.15	0.37	16.45	<			
2A	7	14	dark rim of droplet	4.82	<	<	<	<	32.83	<	<	<	<	<	<	<	0.20	<	60.79	<	<	<	<	<	<	<	1.35	<		
2A	7	15	dark rim of droplet	2.13	<	<	<	<	34.17	<	<	<	<	<	<	<	<	<	63.21	<	<	<	<	<	<	<	0.49	<		
2A	7	16		61.59	<	5.09	<	<	1.22	28.11	0.32	<	<	<	<	<	<	<	1.62	<	0.80	<	0.24	<	<	1.02	<			
2A	7	17		51.69	<	36.59	0.71	0.14	0.96	4.76	0.30	<	<	<	<	<	0.30	<	1.60	<	<	2.35	0.22	<	<	0.38	<			
2A	7	18	botryoidal growth over droplet	58.90	<	<	3.33	1.77	0.22	<	1.00	<	<	<	<	<	0.48	<	28.93	4.66	<	<	<	<	<	0.69	<			
2A	7	19	botryoidal growth over droplet	54.55	0.31	<	3.73	6.08	1.48	0.34	2.91	<	<	<	<	<	0.63	<	24.17	3.80	<	<	<	<	<	2.00	<			
2A	7	20	botryoidal growth over droplet	50.13	0.30	<	15.51	3.21	0.64	0.24	2.01	<	<	<	<	<	1.23	<	22.81	3.10	<	<	<	<	<	0.82	<			
2A	7	21	botryoidal growth over droplet	57.18	0.26	<	20.42	1.51	0.22	0.23	1.38	<	<	<	<	<	0.65	<	15.76	1.93	<	<	<	<	<	0.45	<			
2A	7	22	bright layer inside dark rim	63.98	<	<	0.47	<	3.60	<	<	<	<	<	<	<	0.23	<	7.42	<	<	<	<	<	<	24.30	<			
2A	7	23	bright layer inside dark rim	62.98	<	<	<	<	16.40	<	<	<	<	<	<	<	<	<	2.12	<	<	<	<	<	<	18.51	<			
<b>droplet within ceramic</b>																														
2A	8	1	spot in inner drop	6.81	<	1.27	<	<	<	<	<	<	<	<	<	<	0.26	0.84	83.71	<	1.81	<	0.18	4.00	1.12	<	<	<		
2A	8	2	spot in lead phase	50.92	<	8.47	0.84	<	<	<	<	<	<	<	<	<	0.26	<	14.23	<	<	<	0.19	1.79	1.25	22.06	<	<		
2A	8	3	spot in lead phase	22.84	<	3.34	0.36	<	0.47	<	<	<	<	<	<	<	0.19	0.55	61.64	<	<	<	1.20	2.37	1.01	6.05	<	<		
2A	8	4	outer part of droplet	5.06	<	<	<	<	37.50	<	<	<	<	<	<	<	7.92	<	49.20	<	<	<	<	<	<	0.33	<	<		
2A	8	5	small droplet	8.09	<	<	0.28	<	36.97	<	<	<	<	<	<	<	17.14	0.19	35.20	1.63	<	<	<	<	0.11	0.39	<	<		
2A	8	6	bright phase in matrix	62.21	<	1.20	2.54	5.68	0.42	0.20	2.63	0.98	<	<	<	12.78	<	8.48	1.55	<	<	<	<	<	<	1.12	<			
2A	8	7	dark phase in matrix	62.77	0.30	8.93	22.36	<	0.07	<	2.41	0.14	0.76	<	<	0.60	<	0.09	1.58	<	<	<	<	<	<	<	<			
2A	8	8	area analysis of inner droplet	9.88	<	1.97	<	<	0.90	<	<	<	<	<	<	0.37	1.05	75.54	1.03	1.83	<	0.35	3.54	1.42	2.11	<	<			
2A	8	9	outer part of droplet	8.17	<	<	<	<	40.93	<	<	<	<	<	<	7.44	<	20.27	22.64	<	<	<	<	<	<	0.56	<	<		
2A	8	10	outer part of droplet	4.22	<	<	<	<	47.64	<	0.14	<	<	<	<	5.66	<	3.03	38.99	<	<	<	<	<	<	0.32	<	<		
2A	8	11	outer part of droplet	6.34	<	<	<	<	35.11	<	<	<	<	<	<	6.01	<	51.95	<	<	<	<	0.18	<	<	0.41	<	<		
<b>within wall</b>																														
2A	9	1	area of unaltered ceramic 6mm in	63.73	0.18	11.29	22.94	<	<	0.16	0.30	0.14	0.33	<	<	0.52	<	<	<	0.42	<	<	<	<	<	<	<	<		
<b>slag/wall contact</b>																														
2A	10	1	area of unaltered ceramic 2mm in	63.04	0.31	0.18	10.68	23.51	0.09	<	0.18	0.25	0.11	0.32	<	0.46	<	<	0.87	<	<	<	<	<	<	<	<	<		
2A	10	2	marginal slag	59.59	4.77	0.56	4.69	19.32	0.22	0.14	<	2.12	3.53	0.18	<	2.27	0.22	2.38	<	<	<	<	<	<	<	<	<	<		
2A	10	3	1mm out area	56.81	3.09	1.39	5.98	12.55	0.17	0.36	<	0.76	4.49	0.20	<	8.59	<	5.62	<	<	<	<	<	<	<	<	<	<		
2A	10	4	2mm out area	57.12	2.67	1.43	5.94	13.48	0.20	0.25	<	0.78	4.46	0.23	<	7.97	0.36	5.12	<	<	<	<	<	<	<	<	<	<		
2A	10	5	area of unaltered ceramic 1mm in	63.43	0.61	0.21	10.78	22.42	<	<	0.08	0.55	0.12	0.36	<	0.52	<	0.93	<	<	<	<	<	<	<	<	<	<		
2A	11	1		59.31	1.52	2.65	14.86	0.24	0.20	<	0.82	7.66	0.22	<	<	8.87	<	3.56	<	<	<	<	0.10	<	<	<	<			
2A	11	2		58.99	1.78	2.94	15.02	0.18	0.33	<	1.08	7.03	0.19	<	<	8.97	<	3.48	<	<	<	<	<	<	<	<	<	<		
2A	11	3		59.67	1.36	3.28	15.31	0.18	0.17	<	0.91	7.17	0.23	<	<	7.95	<	3.69	<	<	<	<	0.09	<	<	<	<			
2A	11	4		59.53	1.29	3.87	14.69	0.17	0.23	0.07	0.81	7.05	0.47	<	<	7.82	<	3.92	<	<	<	<	0.09	<	<	<	<			
2A	11	5		61.19	1.29	3.37	14.47	0.19	0.21	<	0.83	6.74	0.20	<	<	7.59	<	3.77	<	<	<	0.10	<	<	0.06	<	<			
2A	11	6		56.83	3.69	24.55	1.19	0.06	<	<	0.08	0.83	0.05	0.09	0.20	6.36	0.12	5.94	<	<	<	<	<	<	<	<	<			
2A	11	7		59.21	1.74	2.71	15.65	0.08	<	<	0.21	15.00	<	<	<	2.22	<	3.19	<	<	<	<	<	<	<	<	<			
2A	11	8		59.19	1.51	3.75	15.45	0.17	0.24	<	1.12	7.07	0.25	<	<	7.89	<	3.24	<	<	<	0.13	<	<	<	<	<			
2A	11	9	area of akermanite-spinel slag	58.82	2.16	7.20	12.67	0.15	0.21	<	0.82	5.71	0.21	<	<	7.85	0.15	4.05	<	<	<	<	<	<	<	<	<	<		

S	A	#	Texture/location	atom%																										
				O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	As	Br	Ag	Sn	W	Sb	Pb	Ba	Bi
2A	11	10	area analysis of inner droplet	12.68		<	3.13	<	<	0.53	0.40	<	<	<	<	<	<	0.25		76.19	1.84				1.60				3.37	
2A	11	11	area of sulphide outer droplet	6.16		<	0.28	<	<	32.05	<	<	<	<	<	<	<	0.46		56.74	2.67				<				1.64	
2A	11	12	copper phase of droplet	4.16		<	0.80	<	<	<	<	<	<	<	<	<	<	0.17		91.05	1.93				1.90			<		
2A	11	13	copper phase of droplet	4.09		<	0.74	<	<	<	<	<	<	<	<	<	<	0.20		90.94	2.29				1.73			<		
2A	11	14	lead phase of droplet	59.48		<	0.86	0.49	<	<	10.13	<	<	<	<	<	<	<		8.05	<				<			20.99		
2A	11	15	lead phase of droplet	53.21		<	12.19	0.68	<	<	<	<	0.29	<	<	<	<	<	<	4.84	<				<			28.78		
2A	11	16	spot in bright rim of inner droplet	61.38		<	<	0.29	<	10.18	4.09	<	<	<	<	<	<	<	<	1.93	<				3.30			18.83		
2A	11	17	spot in outer rim	4.16		<	<	0.23	<	33.08	<	<	<	<	<	<	<	0.34		61.86	<				<			0.33		
2A	11	18	spot in outer rim	2.72		<	<	<	<	33.55	<	<	<	<	<	<	<	0.23		63.00	<				<			0.50		
2A	12	1	area analysis of grain in SOI7	18.88			3.56			1.27	0.43								66.76		<			5.58				3.52		
2A	13	1	large grain on ceramic margin	58.76		0.43	15.04	7.80	<	<		<	16.59	0.05			<	1.17	<	0.08	<				0.08					
2A	13	2	large grain on ceramic margin	58.93		0.50	14.60	7.91	<	<		<	16.64	<			<	1.23	<	0.08	<				0.10					
2A	13	3	large grain on ceramic margin	59.37		0.34	14.50	7.99	<	<		<	16.59	<			<	1.21	<	<	<				<					
2A	13	4	contact zone	54.68		13.27	11.01	<	<	<		<	0.45	0.14		0.77	16.93	<	2.27	0.48				<						
2A	13	5	contact zone	56.05		9.94	9.67	<	<	<		<	0.43	0.19		0.67	21.27	<	0.19	1.57				<						
2A	13	6	contact zone	5.03		<	1.90	<	<	<		<	<	<		<	1.22	<	91.50	0.34				<						
2A	13	7	contact zone	5.92		<	2.02	<	<	0.39		<	0.27	<		<	0.98	<	90.03	0.39				<						
2A	13	8	contact zone	55.34		5.01	11.43	<	<	<		<	0.17	0.21		0.24	23.45	<	<	4.16				<						
2A	13	9	contact zone	53.47		6.57	9.49	0.11	<	<		<	0.16	0.19		0.23	23.49	<	1.94	4.35				<						
2A	13	10	contact zone	7.14		<	1.76	<	<	2.44		<	0.27	<		<	0.98	<	86.52	0.89				<						
2A	13	11	contact zone	58.83		0.48	14.44	7.91	<	<		0.07	16.43	0.06		<	1.46	<	0.21	<				0.12						
2A	13	12	contact zone	58.92		0.19	35.01	0.96	<	0.12		<	1.92	<		<	0.84	<	1.67	0.36				<						
2A	13	13	contact zone	11.37		0.80	7.20	1.62	<	<		<	3.15	<		<	49.46	0.75	<	25.64				<						
2A	13	14	contact zone	58.67		0.35	14.31	8.37	<	<		0.07	16.48	0.05		<	1.47	<	<	0.11				<			0.13			
2A	13	15	contact zone	58.64		1.62	11.36	9.65	<	<		<	16.68	<		<	1.96	<	<	0.09				<						
2A	13	16	main slag	58.42		3.04	3.46	14.43	<	<		0.11	16.56	<		<	1.58	<	<	2.29				0.11						
2A	13	17	main slag	59.19		2.00	2.14	15.96	0.10	<		0.18	15.22	<		<	2.01	<	<	3.09				0.10						
2A	13	18	main slag	59.69		2.01	2.29	15.92	<	<		0.23	14.81	<		<	1.93	<	<	2.99				0.13						
2A	13	19	main slag	59.79		1.97	2.82	15.41	<	<		0.17	15.08	<		<	1.77	<	<	2.87				0.11						
2A	13	20	main slag	58.11		4.43	2.13	14.36	0.19	0.09		0.68	3.66	0.15		0.14	13.76	<	<	2.30				<						
2A	13	21	main slag	58.22		3.88	1.96	14.82	0.13	<		0.79	4.83	0.12		0.17	12.54	<	<	2.43				0.12						
2A	13	22	main slag	58.02		3.50	0.42	14.09	<	0.06		0.22	9.26	<		0.18	11.98	<	<	2.27				<						
2A	13	23	main slag	57.21		5.43	22.53	1.22	0.09	<		0.12	0.51	0.11		0.11	8.88	0.12	<	3.67				<						
2A	13	24	contact zone	54.99		7.61	8.13	<	<	<		<	0.29	0.21		0.37	24.58	<	0.65	3.17				<						
2A	13	25	contact zone	56.46		13.43	13.57	0.23	<	<		<	0.29	0.15		0.56	14.82	<	0.29	0.18				<						
2A	13	26	contact zone	58.79		2.69	1.36	15.98	<	<		0.12	15.47	<		<	2.00	<	0.54	2.92				0.13						
2A	13	27	contact zone	57.04		5.24	11.46	6.42	<	<		0.11	1.34	0.25		0.11	13.20	<	0.11	4.73				<						
2A	13	28	contact zone	58.51		3.15	2.74	15.05	<	<		0.07	16.31	<		<	1.68	<	0.07	2.32				0.10						
2A	13	29	main slag	56.91		2.13	14.21	0.81	<	<		<	0.28	1.81		0.08	18.50	<	<	5.29				<						
2A	13	30	main slag	56.70		1.99	16.53	1.07	<	<		<	0.45	1.16		<	15.32	<	<	6.79				<						
2A	13	31	main slag	57.04		1.94	16.66	0.48	<	<		<	0.32	1.47		<	15.31	<	<	6.77				<						
			<b>inner margin of ceramic lump</b>																											
2A	17	1	main slag	56.09		2.72	27.81	0.25	0.07	<		<	0.12	0.12		<	<	5.72	<	<	7.10	<		<	<					
2A	17	2	main slag	59.35		2.32	1.98	16.02	0.07	<		0.18	15.25	<		<	1.80	<	<	2.92	<		0.10	<	<					
2A	17	3	main slag	57.62		4.18	1.05	14.45	0.09	<		0.46	7.29	0.10		<	0.16	12.61	<	<	2.00	<		<	<					
2A	17	4	spinel cluster	55.91		15.01	22.17	0.10	<	<		<	<	0.14		<	0.20	6.27	<	0.12	0.09	<		<	<					
2A	17	5	spinel cluster	56.41		14.54	23.37	0.18	<	<		<	<	0.09		<	0.14	5.01	<	0.10	0.16	<		<	<					
2A	17	6	spinel cluster	55.95		8.97	20.83	1.29	0.06	<		<	0.53	0.06		0.06	0.12	7.96	<	0.22	3.95	<		<	<					
2A	17	7	spinel cluster	52.09		4.85	0.82	<	<	<		<	0.13	0.19		<	0.24	36.63	<	<	5.06	<		<	<					
2A	17	8	spinel cluster	53.30		8.38	15.18	0.15	<	<		<	0.44	0.14		<	0.30	10.61	<	5.02	6.47	<		<	<					
2A	17	9	spinel cluster	54.83		10.17	17.83	<	<	<		<	0.17	0.13		<	0.22	9.38	<	0.73	6.53	<		<	<					
2A	17	10	spheroidal material	48.82		45.05	1.11	0.09	<	<		<	0.10	0.06		<	0.20	3.54	0.06	0.97	<	<	<	<	<					
2A	17	11	spheroidal material	56.40		7.09	0.19	13.94	<	<		0.08	21.83	0.05		<	<	0.24	<	0.07	<	<	<	<	<		0.10			
2A	17	12	spheroidal material	57.91		7.15	<	13.62	<	<		0.06	20.98	<		<	<	0.16	<	<	<	<	<	<	<		0.11			

S	A	#	Texture/location	atom%																												
				O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	As	Br	Ag	Sn	W	Sb	Pb	Ba	Bi		
2A	17	13	droplet in main slag	68.66	<	0.79	6.50	<	0.45	<	<	<	<	<	<	1.41	0.55	7.53	1.40	1.18				10.11		1.43						
2A	17	14	spinel cluster	53.37		2.39	0.64	0.16	<	<	<	<	0.12	0.19	<	0.10	38.63	<	0.22	4.18	<		<	<	<	<	<	<	<			
2A	17	15	main slag	55.58		3.99	19.40	<	<	<	<	<	0.14	0.14	<	0.07	13.17	<	0.43	7.09	<		<	<	<	<	<	<	<			
2A	17	16	main slag	55.23		6.45	20.46	<	<	<	<	<	0.21	0.10	0.17	0.11	13.65	0.09	0.95	2.58	<		<	<	<	<	<	<	<			
2A	17	17	spinel cluster	54.25		6.15	0.64	11.11	0.08	0.34		0.10	18.27	0.28	<	0.14	5.51	<	0.58	2.43	<		0.12	<	<	<	<	<	<			
2A	17	18	area of altered ceramic	57.29		15.36	7.59	5.32	<	0.10		<	7.09	0.15	<	0.13	4.63	<	0.95	1.40	<		<	<	<	<	<	<	<			
2A	17	19	area of slag	59.15		2.25	6.11	12.73	0.12	0.15		0.75	7.69	0.20	<	<	7.38	<	0.26	3.20	<		<	<	<	<	<	<	<			
2A	17	20	spinel cluster	55.87		3.86	9.46	<	<	<		<	0.18	0.86	<	0.15	24.83	<	<	4.79	<		<	<	<	<	<	<	<			
2A	17	21	spinel cluster	51.75		4.75	0.64	0.21	<	<		<	0.11	0.18	<	0.28	37.16	<	<	4.92	<		<	<	<	<	<	<	<			
2A	17	22	spinel cluster	60.31		1.40	0.28	12.61	0.07	<		0.16	23.89	0.09	<	<	0.38	<	0.48	0.20	<		0.15	<	<	<	<	<	<			
<b>inner slag</b>																																
2A	19	1	gehlenite dominated slag	58.95	<	1.24	11.36	9.39	<	<		<	16.81	<		<	1.11		0.08			0.96		0.09	<		<	<	<			
2A	19	2	gehlenite dominated slag	58.99	<	1.12	11.88	9.28	<	<		<	16.65	<		<	1.16		<			0.84		0.09	<		<	<	<	<		
2A	19	3	woolastonite/periclase slag	56.67	<	0.23	<	13.49	<	0.06		0.07	28.91	<		<	0.17		0.24			<		0.14	<		<	<	<	<		
2A	19	4	woolastonite/periclase slag	56.64	<	0.17	<	13.70	<	<		0.09	28.60	<		<	0.24		0.43			<		0.13	<		<	<	<	<		
2A	19	5	gehlenite dominated slag	56.96	0.26	3.30	<	13.86	<	<		0.18	24.32	<		<	0.23		<			0.45		0.15	<		<	<	<	0.29		
2A	19	6	gehlenite dominated slag	57.76	0.26	3.41	<	13.46	0.08	<		0.20	24.14	0.08		<	0.17		<			<		0.12	<		<	<	0.32			
2A	19	7	gehlenite dominated slag	62.72	<	4.83	<	17.41	0.26	<		<	13.54	0.12		<	0.45		0.13			0.46		0.08	<		<	<	<	<		
2A	19	8	woolastonite/periclase slag	71.17	<	<	4.32	0.40	<	4.84		<	18.93	<		<	0.25		<			<		0.10	<		<	<	<	<		
2A	19	9	gehlenite dominated slag	37.04	<	0.88	2.91	0.66	<	<		<	1.32	<		<	2.98		54.21			<		<	<		<	<	<	<	<	
2A	19	10	gehlenite dominated slag	39.27	<	1.95	<	<	<	<		<	0.93	<		0.22	7.54		50.08			<		<	<		<	<	<	<	<	
2A	19	11	woolastonite/periclase slag	34.70	<	0.70	3.23	0.78	<	0.16		0.14	10.45	0.54		0.12	7.28		41.91			<		<	<		<	<	<	<	<	
2A	19	12	woolastonite/periclase slag	50.80	<	46.20	<	<	<	<		<	0.11	<		0.17	1.87		0.75			<		<	0.05	<	<	<	<	<	<	
2A	19	13	woolastonite/periclase slag	48.57	<	46.01	0.74	<	<	<		<	0.14	<		0.16	1.93		2.45			<		<	<	<	<	<	<	<	<	
2A	19	14	woolastonite/periclase slag	58.14	<	14.11	17.15	<	<	<		<	0.23	0.10		0.49	8.24		0.30			1.25		<	<	<	<	<	<	<	<	
2A	19	15	area of slag	62.21	<	5.38	4.96	8.71	<	<		0.09	14.46	0.11		0.11	2.78		1.03			<		0.07	<		<	<	<	0.08	<	
<b>highly oxidised grains</b>																																
2B	1	1	area analysis of lower grain	37.35		<	0.65	<	<	0.49		<	<	0.77	<		0.18	<	51.12	0.33	<			3.66		0.20	5.26					
2B	1	2	area analysis of upper grain	38.45		<	2.83	0.34	<	1.96	0.90	<	<	<	<		<	<	52.24	<	<			0.85		0.33	2.10					
2B	1	3	area analysis of bright exterior of lower grain	61.96		<	1.56	1.11	<	<	<	<	<	<	<		1.13	<	10.80	4.72	<			6.00		<	12.73					
2B	1	4	Cu phase in lower grain	28.95		<	0.36	0.24	<	18.17	<	<	<	<	<		3.76	1.22	36.72	3.05	<			3.27		<	4.26					
2B	1	5	lead oxide in lower grain	56.77		<	<	0.47	<	<	1.45	<	<	<	<		<	<	0.82	<	<			<	<	<	40.49					
2B	1	6	Cu phase in lower grain	11.84		<	1.65	<	<	<	<	<	<	<	<		<	0.25	84.59	<	<			1.67		<	<	<	<	<	<	
2B	1	7	point within outer bright of lower grain	46.46		<	0.54	<	<	<	<	<	<	<	<		1.60	<	41.37	1.21	<			2.65		<	6.16					
2B	1	8	Cu phase in upper grain	45.16		<	0.25	0.67	<	1.07	0.50	<	<	<	<		<	<	43.55	<	<			2.27		0.85	5.69					
2B	1	9	point within outer bright of upper grain	64.17		<	<	0.30	<	<	<	<	<	<	<		1.12	<	4.22	<	<			14.95		<	15.23					
2B	1	10	lead within botryoidal area	72.42		<	<	<	<	<	<	<	<	3.37	<		0.39	<	0.47	0.71	<			<	<	<	22.65					
2B	1	11	area of slag	60.03		1.38	5.36	12.83	0.19	0.28	<	0.89	5.20	0.22			7.50	<	0.26	5.55	<			0.17		<	0.17					
<b>droplet in glassy slag</b>																																
2B	2	1	area of inner droplet	9.17		<	1.85	<	<	0.57		<	<	<			0.43	0.29	83.24	1.82	<			1.32		<	1.31					
2B	2	2	area of slag	61.81		1.43	4.94	16.15	0.16	0.11		1.18	5.14	0.24			5.72	<	0.08	3.03	<			<		<	<	<	<	<	<	
2B	2	3	area of outer drop layer	6.74		<	0.28	<	<	33.77		<	<	<			4.04	<	54.38	<	<			<		<	0.79					
2B	2	4	inclusion with Pb in droplet	4.46		<	<	<	<	36.89		<	<	<			2.25	<	35.99	19.89	<			<		<	0.52					
2B	2	5	point in Cu phase in droplet	6.51		<	0.95	<	<	0.26		<	<	<			0.27	0.41	88.35	2.01	<			1.24		<	<	<	<	<	<	<
2B	2	6	lead inclusion in drop	63.51		<	6.46	0.72	<	<		<	<	<			<	<	4.51	<	<			<		<	24.80					
2B	2	7	lead inclusion in drop	47.46		<	3.77	1.04	<	<		<	<	<			<	<	15.98	<	<			<		<	31.74					
2B	2	8	point in slag	61.62		1.42	4.33	15.67	0.16	0.12		0.87	5.76	0.24			6.53	<	0.08	3.21	<			<		<	<	<	<	<	<	
2B	2	9	droplet in slag	35.80		1.67	2.88	6.47	<	0.58		0.23	1.61	<			2.59	0.63	43.10	1.13	<			2.55		<	0.76					
2B	2	10	point in sulphide layer	3.85		<	<	<	<	33.42		<	0.16	<			1.37	<	60.87	<	<			<		<	0.32					
2B	2	11	inclusion with Pb in droplet	6.50		<	<	<	<	36.30		<	<	<			5.88	<	47.73	2.91	<			<		<	0.69					
<b>glassy slag</b>																																
2B	3	1	bright bleb	51.28			0.26		0.39								1.22	0.86	44.33					1.65								
2B	3	2	bright bleb	63.07			0.54	0.88																								



S	A	#	Texture/location	atom% O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	As	Br	Ag	Sn	W	Sb	Pb	Ba	Bi
4	2	2	point in main grain	2.66			<	<					<					0.66		88.44	4.56	1.08			2.60		<		<	
4	2	3	point in main grain	3.51			<	<					<					0.75		88.47	5.09	<			2.18		<		<	
4	2	4	area of interior of main grain	5.33			<	<					<					0.50		86.58	4.18	<			3.41		<		<	
4	2	5	weathered crust on main grain	72.03			0.15	5.03					<					0.49		11.05	0.72	<			9.45		1.08		<	
4	2	6	weathered crust on main grain	73.24			<	6.25					<					0.30		9.33	0.82	<			8.81		1.24		<	
4	2	7	point on small bleb	68.39			<	0.51					<					0.48		1.53	2.44	<			<		26.19		0.45	
4	2	8	point on small bleb	33.53			<	<					<					0.16		66.32	<	<			<		<		<	
4	2	9	bright grain in crust	57.13			4.92	1.35					1.75					2.39		6.00	2.99	<			<		22.47		1.00	
4	2	10	bright grain in crust	62.30			<	0.47					<					0.84		22.50	2.47	<			<		8.47		2.95	
4	2	11	point in main grain	4.38			<	<					<					0.60		87.60	4.42	<			2.85		0.13		<	
<b>large irregular grain</b>																														
4	3	1	area of interior of main grain	14.71			0.48	0.58		1.55	<		<					1.18	<	68.83	8.62	<			3.33		0.71			
4	3	2	area of interior of main grain	21.35			0.31	0.98		0.96	<		<					0.94	<	65.03	6.48	<			3.31		0.64			
4	3	3	area of interior of main grain	20.05			0.45	0.72		1.36	<		<					0.95	<	65.02	7.03	<			3.32		1.11			
4	3	4	material on grain boundaries and around Pb	35.11			<	<		1.12	0.53		<					0.17	<	60.99	0.63	<			<		1.44			
4	3	5	altered lead inclusion	61.38			0.24	0.29		17.43	<		<					<	<	2.29	<	<			<		18.38			
4	3	6	spot in middle of grain	2.99			0.37	<		0.20	<		<					1.48	0.30	82.40	10.33	<			1.93		<			
4	3	7	material on grain boundaries and around Pb	50.97			0.30	2.44		0.16	0.49		<					0.17	<	39.86	0.53	<			4.77		0.31			
4	3	8	material on grain boundaries and around Pb	33.58			<	<		<	<		<					0.29	<	65.91	<	<			0.22		<			
4	3	9	oxides external to grain	67.55			0.23	0.78		0.11	<		0.90					0.37	0.16	6.55	23.07	<			<		0.29			
4	3	10	bulk area - grain and surround	40.43			1.23	5.77		0.89	<		1.02					2.00	<	38.87	7.32	<			1.90		0.57			
4	3	11	oxides external to grain	67.06			<	0.59		<	<		0.29					0.37	<	8.31	22.87	<			<		0.51			
4	3	12	oxides external to grain	66.12			0.48	1.29		0.19	<		0.26					1.29	0.12	5.88	24.12	<			<		0.25			
4	3	13	oxides external to grain	63.24			1.82	2.68		<	<		0.29					2.60	0.11	5.42	23.56	<			<		0.27			
<b>broader view of SOI3</b>																														
4	4	1	error	58.36		0.32	6.11	18.84	0.14	0.29	0.34	0.82	1.35	0.15				1.78		7.67	3.66	<			<		0.18			
4	4	2	internal altered surface	68.40		<	0.66	5.46	<	0.49	<	<	0.22	<				20.77		1.38	1.97	<			<		0.64			
4	4	3	oxides external to grain	66.80		0.29	<	1.29	0.12	<	<	<	0.20	<				0.24		6.79	24.10	<			<		0.16			
<b>complex blebs in slag (UL)</b>																														
5	7	1	spherulitic growth	68.00		<	<	<	<	0.12	<		<	<				0.12		31.25	0.29				<		0.23			
5	7	2	hexagonal crystal dark core	57.68		1.11	16.60	5.28	<	<	<		0.26	0.18				2.71		<	16.08				0.10		<			
5	7	3	hexagonal crystal outer	56.96		1.51	2.78	13.16	<	<	<		0.10	<				2.18		0.13	23.18				<		<			
5	7	4	glass	60.12		0.46	3.94	16.24	0.13	0.49	0.73		7.70	0.42				3.48		0.17	5.70				0.24		0.18			
5	7	5	bright bleb in glass	7.91		<	0.94	0.86	<	34.74	<		0.45	<				1.26		38.27	3.36				0.43		11.79			
5	7	6	grain in main bleb	4.11		<	<	<	<	39.59	<		<	<				5.45		50.53	<				<		0.31			
5	7	7	dark ?glass in main bleb	1.67		<	<	<	<	48.58	0.18		<	<				1.33		1.13	46.73				<		0.39			
5	7	8	bright area in grain	62.80		<	<	1.90	<	4.57	<		0.63	<				0.62		9.43	1.27				1.56		17.23			
5	7	9	mixed brightish area in grain cracks	19.82		<	<	0.28	<	37.93	<		<	<				0.90		34.99	0.65				0.45		4.96			
5	7	10	glass	59.31		0.67	3.35	16.27	0.17	0.42	0.83		6.34	0.31				3.13		0.33	8.41				0.24		0.20			
5	7	11	mixed brightish area in grain cracks	39.33		<	0.23	0.82	<	24.40	<		<	<				1.70		23.44	0.92				1.32		7.84			
5	7	12	dark ?glass in main bleb	3.42		<	<	<	<	47.06	<		<	<				1.48		7.26	40.36				<		0.43			
5	7	13	striated grain in main bleb	3.50		<	<	<	<	39.45	<		<	<				5.32		50.75	0.59				<		0.39			
<b>complex blebs in slag (UR)</b>																														
5	8	1	central bright bleb	72.13		<	<	0.30	<	<	<	<	<	<				<		0.30	0.39				<	<	26.88			
5	8	2	bright grain on margin of complex	70.51		<	<	0.33	<	<	<	<	<	<				<		2.18	<				<	<	26.99			
5	8	3	spherulitic growth	69.64		<	0.18	<	<	<	<	<	0.11	<				0.11		27.08	2.53				<	<	0.35			
5	8	4	dark in main grain	2.07		<	<	<	<	48.26	<	<	<	<				1.23		1.29	46.79				<	<	0.35			
5	8	5	striated grain in main bleb	2.43		<	<	<	<	39.66	<	<	<	<				1.18		56.42	<				<	<	0.31			
5	8	6	dark in main grain	2.60		<	<	<	<	48.00	<	0.18	<	<				1.31		0.80	46.73				<	<	0.37			
5	8	7	dark aluminosilicate lath	61.32		0.47	13.47	15.19	<	<	<	0.52	5.51	0.17				2.15		<	0.91				0.10	0.11	0.06			
5	8	8	dark aluminosilicate lath	61.50		0.50	13.99	14.66	<	<	<	0.26	5.88	0.09				2.00		<	0.99				0.08	<	0.05			
5	8	9	interstitial ?glass	63.27		0.92	4.64	18.19	0.18	<	<	0.83	2.98	0.35				4.37		0.18	2.77				0.35	<	0.96			
5	8	10	interstitial ?glass	61.58		0.48	3.83	18.38	0.18	<	<	0.71	3.33	0.33				4.05		<	5.80				0.32	<	1.00			

S	A	#	Texture/location	atom%																											
				O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	As	Br	Ag	Sn	W	Sb	Pb	Ba	Bi	
5	8	11	dark skeletal phase cf. 5.7.2	60.43		1.45	11.33	12.41	0.12	<	<	1.20	2.99	0.30			3.66		<	5.75					0.17	<		0.18			
5	8	12	dark in main grain	2.58		<	<	<	<	47.65	<	<	<	<			1.27		1.59	46.47				<	<			0.44			
5	8	13	striated grain in main bleb	3.71		<	<	<	<	40.80	<	<	<	<			5.13		49.97	<				<	<			0.39			
5	8	14	dark margin to grain	67.47		<	<	<	<	<	<	<	0.19	<			0.12		27.69	4.25				<	<			0.28			
5	8	15	dark adjacent to central lead oxide	58.32		0.72	3.68	13.94	0.13	0.36	0.13	0.63	4.73	0.53			7.04		1.81	5.98				1.03	0.13			0.84			
5	8	16	hole	60.82		<	23.80	0.89	<	1.57	0.59	0.32	0.41	<			1.55		2.49	4.49				<	<			3.09			
<b>second multiple bleb</b>																															
5	9	1	area of interior of right grain	74.57		<	1.21	4.83	<	0.26		<	0.33	<			1.69	<	4.69	1.09	<				6.54	0.19		4.61			
5	9	2	area of interior of left grain	74.83		<	2.10	5.22	<	0.43		<	0.38	<			2.80	<	3.16	1.10	<				6.45	0.22		3.30			
5	9	3	elongate crystal in glass	55.79		1.69	<	14.79	<	<		<	<	<			0.46	<	<	27.27	<				<	<		<			
5	9	4	elongate crystal in glass	57.68		0.42	21.70	4.65	<	<		0.35	1.41	0.18			1.65	<	<	11.79	<				0.07	<		0.10			
5	9	5	dull area in LH grain	71.05		<	1.72	7.35	<	0.37		<	0.38	<			3.96	<	4.43	1.34	<				7.93	<		1.48			
5	9	6	bright area in LH grain	72.48		<	<	0.45	<	<		<	<	<			<	<	0.69	<	<				<	<		26.39			
5	9	7	bright bleb in rh grain - no - dull?	72.89		<	1.38	6.97	<	0.21		<	0.31	<			2.33	<	4.99	1.39	<				7.88	0.25		1.40			
5	9	8	bright area in LH grain	73.46		<	0.26	0.31	<	<		<	<	<			<	<	<	<	<				<	<		25.97			
5	9	9	bright belb in glass	29.52		<	9.94	0.96	<	1.06		<	0.48	<			0.98	0.62	42.65	2.38	<				3.76	1.66		5.98			
5	9	10	glass	58.01		2.11	18.53	7.98	0.13	<		0.52	1.18	0.28			3.54	<	0.29	7.36	<				<	<		0.07			
5	9	11	glass	62.15		1.35	6.83	18.99	0.10	0.10		2.24	3.48	0.34			2.31	<	<	2.11	<				<	<		<			
5	9	12	bright area in LH grain	73.09		<	0.27	0.43	<	<		<	<	<			0.36	<	0.49	<	<				<	<		25.37			
5	9	13	bright crystal in central hole	71.75		<	<	0.45	<	<		<	<	<			<	<	0.67	<	<				<	<		27.13			
5	9	14	dull crystal in central hole	61.76		<	<	<	<	6.96		<	<	<			0.10	<	31.03	<	<				<	<		0.15			
5	9	15	elongate crystal in glass	55.71		1.95	0.58	14.38	<	<		<	<	<			2.44	<	<	24.94	<				<	<		<			
5	9	16	dull area in rh grain	72.65		<	1.19	3.27	<	<		<	<	<			1.43	<	2.61	1.21	<				7.70	<		9.95			
5	9	17	bright bleb in rh grain	72.69		<	<	0.30	<	<		<	<	<			<	<	0.49	<	<				<	<		26.53			
5	9	18	dull area in lh grain	71.31		<	1.85	7.19	<	0.30		<	0.27	<			3.97	<	4.80	1.22	<				7.70	<		1.39			
<b>anorthite-rich slag</b>																															
5	10	1	patch of blebs	74.99	<	<	0.19	<	<			<	<	<			<	0.40	<	0.32	<				24.10			<			
5	10	2	fibrous interstitial	69.81	<	<	0.27	<	<			<	0.09	<			<	0.54	<	28.40	0.67				<	<		0.21			
5	10	3	dark lath	61.81	0.37	0.40	13.03	15.53	<	<		0.28	6.80	0.10			<	0.86	<	0.55	0.08				0.11	<		0.07			
5	10	4	dark lath	62.78	0.51	0.48	12.33	15.19	0.06	<		0.49	6.59	0.16			<	1.09	<	0.15	<				0.12	<		0.04			
5	10	5	rhombic	56.54	0.73	5.06	8.89	1.77	<	<		<	0.72	0.25			0.10	21.46	0.17	1.72	2.24				0.35	<		<			
5	10	6	interstitial plates/glass	60.01	<	2.17	4.43	16.71	0.23	<		1.05	4.12	0.43			0.09	3.64	<	5.54	0.54				0.35	<		0.72			
5	10	7	rhombic	57.45	0.49	5.45	8.46	0.34	<	<		<	0.26	0.25			0.12	22.00	0.12	1.90	2.68				0.48	<		<			
5	10	8	rhombic	57.99	0.60	5.81	7.59	1.13	<	<		0.10	0.20	0.37			0.11	21.15	<	1.86	2.54				0.55	<		<			
5	11	1	dark in glass	61.32	1.56	0.08	7.74	23.16	<	<		4.98	0.63	<			<	<	0.21	0.13	0.19					<		<			
5	11	2	bright glass	58.88	2.60	1.00	5.24	17.53	0.16	0.11		1.25	5.28	0.27			<	<	2.40	<	5.05					<		0.23			
5	11	3	dark grain in glass	65.05	0.20	0.09	2.08	31.62	<	<		0.78	0.07	<			<	<	0.10	<	<					<		<			
5	11	4	bright glass	56.60	0.41	8.62	24.74	0.90	<	<		<	0.60	0.10		0.08	0.14	6.27	0.09	1.45						<		<			
5	11	5	large dark phase near contact	58.74	0.45	2.71	8.98	11.81	<	<		0.07	16.35	<			<	<	0.89	<	<					<		<			
5	11	6	large dark phase near contact	58.54	0.64	2.62	8.95	11.98	<	<		0.08	16.23	<			<	<	0.95	<	<					<		<			
5	11	7	large dark phase near contact	59.15	0.44	3.35	7.27	12.48	<	<		0.08	16.17	<			<	<	1.06	<	<					<		<			
5	11	8	large dark phase near contact	58.81	<	4.46	4.83	13.51	<	<		0.19	16.15	0.08			<	0.05	1.91	<	<					<		<			
5	11	9	dark bodies in altered ceramic?	73.52	0.41	0.22	0.45	0.42	<	0.14		<	22.49	<			<	<	0.18	0.40	1.55					<		0.21			
5	11	10	dark bodies in altered ceramic?	70.62	<	8.35	2.42	0.56	<	0.66		<	15.43	<			<	0.09	0.48	0.51	0.75					<		0.13			
5	11	11	dark bodies in altered ceramic?	71.32	0.53	6.69	2.65	1.02	<	0.35		<	11.54	<			<	0.08	0.54	1.14	4.00					<		0.15			
<b>vein of spheroidal material in slag</b>																															
5	12	1	spheroids	43.24		3.76	2.03	10.70		0.53	<		1.12	0.10			0.87	20.67	6.18	10.26	<				<	<		0.54			
5	12	2	matrix	72.08		0.64	0.53	0.18		0.73	<		24.94	<			<	0.32	0.13	0.25	<				0.10	<		0.11			
5	12	3	matrix	74.55		1.05	0.49	0.23		0.11	<		20.98	<			0.07	0.16	0.53	1.53	<				0.08	<		0.22			
5	12	4	spheroids	45.87		2.39	2.33	9.15		0.37	<		1.16	0.12			0.78	21.61	5.81	9.61	<				<	<		0.79			
5	12	5	spheroids	50.75		0.81	3.12	8.76		0.35	<		1.31	<			0.19	20.25	5.34	8.44	<				<	<		0.69			
5	12	6	matrix	63.95		13.56	5.50	2.68		1.02	0.08		0.46	<			0.24	6.95	1.97	3.43	<				<	<		0.17			
5	12	7	spheroids	62.08		3.33	1.26	6.48		0.36	0.13		1.22	0.11			0.78	15.00	3.16	5.42	<				<	<		0.69			
5	12	8	spheroids	57.34		8.39	0.																								

S	A	#	Texture/location	atom%																													
				O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	As	Br	Ag	Sn	W	Sb	Pb	Ba	Bi			
5	12	9	spheroids	57.45		1.74	1.60	5.74		0.36	<		1.14	0.13		0.66	21.15		3.47	5.87	<			<									0.71
5	12	10	spheroids	58.84		1.97	2.00	6.97		0.34	<		0.92	<		0.78	18.15		3.50	5.74	<			<								0.78	
5	12	11	matrix	67.55		9.60	3.96	6.34		0.45	0.06		0.81	0.34		0.16	4.59		1.70	4.24	<			<								0.22	
5	12	12	matrix	68.97		15.73	6.44	2.20		1.11	0.07		1.16	<		0.05	0.48		1.63	2.11	<			<								0.06	

Table 5: EDS analyses of points and areas in the crucible samples PWL2-5.

				Atomic %																				
				Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Br	Ba	Pb	O	
<b>Grain 17</b>																								
7	8	1	Area of inner wustite grains	0.00		0.86	0.53	0.00	0.00		0.08	0.00					48.06							50.46
7	8	2	Area of outer wustite dendrites	0.29		1.68	2.47	0.00	0.27		0.10	0.09					43.28							51.83
7	8	3	point in oxidised crust	0.00		1.27	0.00	0.00	0.00		0.00	0.00					48.42							50.32
7	8	4	point in outer dendrite	0.00		0.70	0.00	0.00	0.00		0.00	0.00					49.13							50.17
7	8	5	point in inner grain	0.00		0.53	0.00	0.00	0.00		0.00	0.00					49.33							50.13
7	8	6	interstitial to dendrites	0.44		3.42	12.57	0.12	1.83		0.56	0.46					21.79							58.81
7	8	7	interstitial to dendrites	0.41		2.94	11.57	0.12	1.36		0.75	0.37					24.80							57.68
7	9	1	area of tight polygonal grains			0.43	0.21		0.00			0.00					49.15							50.21
7	9	2	area of tight polygonal grains with voids			2.69	0.64		0.00			0.10					45.57							50.99
7	9	3	area of polygonal grains with slag films			1.09	1.70		0.31			0.15					45.33							51.43
7	9	4	point on oxidised surface layer			0.00	0.00		0.00			0.00					50.00							50.00
7	9	5	point on tight polygonal grains with voids			0.66	0.00		0.00			0.00					49.18							50.16
7	9	6	point on tight polygonal grains			0.59	0.00		0.00			0.00					49.26							50.15
7	9	7	point on polygonal grain next to vesicle			1.12	0.00		0.00			0.00					48.60							50.28
<b>Grain 1</b>																								
8	21	1	area of typical texture gn1			3.72	3.11	0.23	0.55		0.14	1.45					37.62							53.18
8	22	1	magnetite core			4.10	0.00		0.00		0.00	0.07					44.80							51.03
8	22	2	magnetite margin			7.15	0.48		0.00		0.00	0.19					40.14							52.03
8	22	3	magnetite core			5.92	0.25		0.00		0.00	0.00					42.22							51.61
8	22	4	magnetite margin			3.74	0.49		0.00		0.00	0.13					44.48							51.18
8	22	5	marginal (intergrowth?)			1.90	2.12		0.00		0.15	0.87					43.47							51.50
8	22	6	rounded wustite grain (dendrite)			1.31	0.16		0.00		0.00	0.00					48.13							50.41
8	22	7	angular wustite grain			1.33	0.00		0.00		0.00	0.10					48.24							50.33
<b>Grain 2</b>																								
8	23	1	area error	0.41	0.80	5.12	8.67		2.16		0.54	3.62	0.00				20.78				0.36			57.54
8	23	2	area on outer part of gn2	0.30	0.89	6.63	7.71		1.80		0.50	3.31	0.00				21.43				0.31			57.11
8	23	3	area of inner part of gn2	0.56	1.07	9.32	11.62		0.72		0.93	4.51	0.15				12.04				0.52			58.56
<b>glassy core</b>																								
8	24	1	Fe2S, bleb in glass	0.00	0.00	0.00	0.18		13.29		0.05	0.11	0.00	0.00	0.00		22.61	0.12	0.16	0.00	0.00	0.11		63.37
8	24	2	Fe2S, bleb in glass	0.00	0.00	0.00	0.28		11.53		0.00	0.18	0.07	0.00	0.00		25.94	0.00	0.18	0.00	0.00	0.12		61.71
8	24	3	glass	0.90	1.23	10.36	14.80		0.18		1.20	5.24	0.22	0.00	0.00		5.08	0.00	0.00	0.88	0.59	0.00		59.32
8	24	4	glass	0.65	1.14	9.58	13.33		0.26		1.36	5.40	0.19	0.00	0.00		8.58	0.00	0.00	0.00	0.60	0.00		58.92
8	24	5	bright spinel	0.27	1.72	16.39	1.35		0.16		0.05	0.59	0.30	0.00	0.00		24.10	0.00	0.00	0.00	0.08	0.00		55.00
8	24	6	bright spinel	0.25	1.61	14.67	1.39		0.37		0.10	0.82	0.29	0.00	0.00		24.88	0.00	0.00	1.46	0.10	0.00		54.06
8	24	7	inner dark spinel	0.21	4.83	25.82	0.15		0.00		0.00	0.07	0.00	0.09	0.00		11.52	0.00	0.00	1.46	0.05	0.00		55.81
8	24	8	outer dark spinel	0.26	5.07	25.76	0.29		0.00		0.00	0.16	0.00	0.09	0.09		10.90	0.00	0.00	1.56	0.00	0.00		55.83
8	24	9	bright spinel core	0.47	1.27	8.58	9.01		0.84		0.87	3.71	0.00	0.00	0.00		17.20	0.00	0.00	0.94	0.43	0.00		56.69
8	24	10	outer dark spinel	0.00	2.98	25.32	0.17		0.00		0.00	0.08	0.08	0.00	0.12		14.08	0.00	0.00	1.33	0.00	0.00		55.82
8	24	11	bright oxide dendrite	0.00	0.64	2.10	4.89		3.70		0.45	2.33	0.11	0.00	0.00		28.93	0.00	0.00	0.00	0.23	0.00		56.61
8	24	12	Fe2S, bleb	0.00	0.00	0.00	0.18		12.96		0.00	0.16	0.00	0.00	0.00		23.45	0.00	0.09	0.00	0.00	0.12		63.05
8	24	13	mixed	0.48	0.67	4.14	12.93		1.36		0.78	5.37	0.00	0.00	0.00		14.86	0.00	0.00	0.71	0.52	0.00		58.19
8	24	14	Fe2S, bleb	0.00	0.00	0.00	0.17		12.57		0.00	0.13	0.00	0.00	0.00		24.09	0.00	0.14	0.31	0.00	0.08		62.51
<b>marginal area</b>																								
8	25	1	point in large oxide grain	0.00	0.21	0.40	0.20	0.00	0.00	0.00	0.00	0.08	0.18	0.00	0.00		48.15				0.00	0.00		50.29
8	25	2	glass	0.46	0.36	3.23	9.25	3.11	0.66	0.08	0.08	0.86	5.49	0.15	0.00	0.00		18.15			0.08	0.00		58.13
8	25	3	dark spinel core	0.00	1.67	25.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.09		16.06				0.00	0.00		56.47
8	25	4	bright spinel outer	0.45	0.76	14.84	6.84	0.11	0.18	0.00	0.59	1.50	0.20	0.00	0.00		17.31				0.00	0.00		57.23
8	25	5	dark spinel core	0.00	1.61	23.53	0.41	0.00	0.00	0.00	0.05	0.10	0.08	0.07	0.09		17.71				0.00	0.00		56.19
8	25	6	bright spinel outer	0.32	1.05	15.09	6.84	0.13	0.38	0.00	0.65	2.18	0.12	0.00	0.00		15.65				0.09	0.00		57.49
8	25	7	intermediate tiny ?spinel	0.00	2.03	18.23	0.82	0.00	0.00	0.00	0.08	0.32	0.09	0.00	0.07		23.17				0.00	0.00		55.01

Atomic %				Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Br	Ba	Pb	O	
8	25	8	intermediate tiny ?spinel	0.00	1.11	9.40	1.80	0.00	0.27	0.00	0.12	0.71	0.16	0.00	0.00		32.47				0.08	0.00	53.57	
8	25	9	intermediate tiny ?spinel	0.00	1.15	11.46	0.54	0.00	0.09	0.00	0.00	0.27	0.11	0.00	0.00		32.71				0.09	0.00	53.28	
8	25	10	bright bleb	0.00	0.17	0.94	2.92	0.00	11.03	0.00	0.26	1.14	0.00	0.00	0.00		20.59				0.10	0.09	62.66	
8	25	11	bright bleb	0.00	0.68	1.82	3.60	0.00	0.53	0.00	0.21	1.35	0.00	0.00	0.00		38.61				0.14	0.00	52.73	
8	25	12	glass	0.57	0.68	3.58	13.63	0.10	1.54	0.00	0.86	5.87	0.00	0.00	0.00		13.53				0.52	0.00	58.97	
8	25	13	glass	0.78	0.58	4.28	13.27	0.13	0.96	0.00	1.06	5.59	0.00	0.00	0.00		14.50				0.40	0.00	58.31	
8	25	14	bright dendrite	0.00	0.84	3.55	3.71	0.00	0.59	0.00	0.32	1.66	0.11	0.00	0.00		35.43				0.15	0.00	53.31	
8	25	15	bright belb	0.00	0.00	0.57	3.77	0.00	12.81	0.00	0.23	1.09	0.26	0.00	0.00		4.36				10.25	0.19	64.91	
8	25	16	cavity?	0.34	0.29	1.17	14.38	0.38	0.36	0.14	0.24	1.84	0.00	0.00	0.00		22.66				0.15	0.00	57.91	
8	25	17	cavity?	0.00	0.00	1.18	9.70	0.38	1.86	0.13	0.21	1.96	0.00	0.00	0.00		25.44				1.54	0.00	57.17	
8	25	18	bright outer crust	0.00	0.34	2.33	3.49	0.38	0.09	0.00	0.32	1.96	0.00	0.00	0.00		38.15				0.00	0.00	52.63	
8	25	19	glass	0.63	0.35	4.15	13.78	0.29	1.12	0.00	1.23	5.28	0.10	0.00	0.00		14.12				0.09	0.00	58.85	
<b>Grain 3</b>																								
8	26	1	point in outer wustite			0.72	3.38	1.74	0.19			0.99					39.63						53.36	
8	26	2	outer oxidised crust			0.58	0.14	0.00	0.00			0.00					49.07						50.21	
8	26	3	inner wustite			0.45	0.22	0.00	0.00			0.00					49.11						50.22	
8	26	4	typical area of grain			1.98	0.94	0.38	0.23			0.21					44.79						51.48	
<b>Grain 4</b>																								
8	27	1	overall area of grain	0.48		5.38	4.92		0.00	0.30	0.34	0.65					34.47						53.45	
8	27	2	area of mixed oxides	0.32		3.87	4.73		0.00	0.00	0.27	0.51					37.10						53.19	
8	27	3	area of inner dendritic oxide	0.36		4.54	4.84		0.00	0.09	0.35	0.53					35.95						53.33	
8	27	4	area near margin	0.42		3.62	5.27		0.35	0.00	0.35	0.55					35.73						53.70	
<b>detail near area 2 above</b>																								
8	28	1	glass	0.50	0.33	3.56	13.62		0.66		0.77	1.62	0.06				20.50						58.23	
8	28	2	glass	0.50	0.22	3.42	13.27		0.69		0.67	1.69	0.00				21.66						57.88	
8	28	3	spinel	0.00	0.31	10.25	0.19		0.00		0.00	0.00	0.14				36.38						52.73	
8	28	4	spinel	0.00	0.36	7.73	0.23		0.00		0.06	0.00	0.00				39.59						52.03	
8	28	5	bright core to spinel	0.00	0.24	2.61	0.72		0.00		0.00	0.11	0.00				45.31						51.01	
8	28	6	spinel	0.00	0.20	10.07	0.22		0.00		0.00	0.00	0.07				36.77						52.66	
8	28	7	spinel	0.00	0.28	9.90	1.84		0.00		0.31	0.24	0.11				33.95						53.37	
8	28	8	wustite grain	0.00	0.00	1.26	0.18		0.00		0.00	0.00	0.00				48.15						50.40	
8	28	9	wustite grain	0.00	0.00	1.12	0.14		0.00		0.00	0.00	0.00				48.40						50.35	
8	28	10	wustite crust	0.00	0.00	1.02	0.00		0.00		0.00	0.00	0.00				48.72						50.26	
8	28	11	wustite crust	0.00	0.30	1.06	0.00		0.00		0.00	0.00	0.00				48.37						50.27	
8	28	12	wustite crust	0.00	0.30	0.82	0.00		0.00		0.00	0.00	0.00				48.68						50.20	
8	28	13	wustite crust	0.00	0.00	0.76	0.00		0.00		0.00	0.00	0.00				49.05						50.19	
8	28	14	oxidised section of crust	0.00	0.25	7.13	1.78		0.16		0.16	0.21	0.09				37.38						52.84	
8	28	15	area	0.29	0.00	4.66	4.59		0.17		0.31	0.48	0.00				36.02						53.48	
<b>Grain 5</b>																								
8	29	1	typical area			2.06	1.53	0.32	0.19			0.38					43.81						51.71	
<b>detail</b>																								
8	30	1	outer oxidised crust			0.00	0.22	0.00									49.67						50.11	
8	30	2	outer oxidised crust			0.00	0.21	0.19									49.35						50.25	
8	30	3	dense wustite layer			0.16	0.14	0.00									49.59						50.11	
8	30	4	dense wustite layer			0.48	0.00	0.00									49.39						50.12	
8	30	5	inner wustite pseudodendrite			0.66	0.00	0.00									49.18						50.16	
8	30	6	inner wustite pseudodendrite			0.76	0.00	0.00									49.06						50.19	

Atomic %				Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Br	Ba	Pb	O
<b>Grain 6</b>																							
8	31	1	area excluding crust but otherwise typical			2.05	3.02	0.10	0.61	0.00	0.17	0.59					40.80						52.66
8	31	2	area just below crust			2.51	2.78	0.17	0.40	0.14	0.19	0.58					40.81						52.43
8	31	3	dense crust			1.29	1.24	0.23	0.00	0.19	0.12	0.31					45.63						50.99
<b>detail of margin</b>																							
8	32	1	outer oxidised crust	0.00		0.00	0.48	0.00	0.00		0.00	0.00					49.27						50.24
8	32	2	outer oxidised crust	0.00		0.17	0.00	0.00	0.00		0.00	0.00					49.79						50.04
8	32	3	bright crust	0.00		0.23	0.16	0.00	0.00		0.00	0.00					49.48						50.14
8	32	4	inner dull crust	0.00		4.54	0.69	0.12	0.00		0.07	0.13					42.91						51.55
8	32	5	magnetite grain	0.00		2.86	1.60	0.14	0.18		0.08	0.35					43.02						51.78
8	32	6	magnetite grain	0.00		5.46	0.40	0.00	0.00		0.00	0.00					42.58						51.56
8	32	7	magnetite grain	0.00		2.39	0.54	0.00	0.12		0.00	0.09					45.87						50.99
8	32	8	rounded wustite bleb	0.00		1.07	0.16	0.00	0.00		0.00	0.00					48.42						50.35
8	32	9	wustite granular lump	0.00		0.58	0.00	0.00	0.00		0.00	0.00					49.28						50.14
8	32	10	wustite granular lump	0.00		0.75	1.03	0.00	0.00		0.00	0.25					47.26						50.70
8	32	11	rounded wustite bleb	0.00		1.02	0.19	0.00	0.00		0.00	0.00					48.45						50.35
8	32	12	wustite dendrite	0.00		1.01	0.16	0.00	0.00		0.00	0.00					48.51						50.33
8	32	13	glass	0.50		3.46	12.00	0.29	1.74		0.72	2.28					20.49						58.52
8	32	14	glass	0.43		3.79	12.89	0.31	1.25		0.87	2.49					19.41						58.55
8	32	15	glass	0.52		4.03	13.92	0.34	1.26		0.87	3.03					16.90						59.13
<b>Grain 7</b>																							
8	33	1	error			0.00	0.00	0.00	0.00	73.76	0.00	0.00					13.12						13.12
8	33	2	small area			2.92	3.58	0.19	0.51	0.00	0.19	0.75					38.73						53.13
8	33	3	large area			2.81	3.36	0.31	0.55	0.00	0.17	0.80					38.87						53.13
<b>detail of margin</b>																							
8	34	1	outer crust	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.19	0.00				49.27						50.18
8	34	2	inner crust	0.00	0.00	0.00	0.18	0.16	0.00	0.00	0.00	0.00	0.00				49.44						50.21
8	34	3	fine mass on inside of crust	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00				49.73						50.09
8	34	4	magnetite	0.00	0.00	3.91	1.81	0.20	0.00	0.00	0.00	0.36	0.08				41.57						52.07
8	34	5	magnetite	0.00	0.00	5.59	0.40	0.00	0.00	0.00	0.00	0.08	0.11				42.16						51.66
8	34	6	magnetite	0.00	0.00	5.94	0.58	0.36	0.00	0.00	0.00	0.22	0.11				40.68						52.10
8	34	7	magnetite	0.00	0.00	7.24	0.34	0.00	0.00	0.00	0.00	0.00	0.12				40.26						52.04
8	34	8	magnetite	0.30	0.23	4.89	2.96	0.91	0.21	0.00	0.19	0.71	0.10				35.97						53.53
8	34	9	wustite pseudodendrite	0.00	0.00	0.86	0.77	0.00	0.11	0.00	0.10	0.21	0.00				47.27						50.68
8	34	10	wustite pseudodendrite	0.00	0.00	1.00	0.86	0.00	0.12	0.00	0.00	0.20	0.00				47.01						50.80
8	34	11	wustite pseudodendrite	0.00	0.00	1.34	0.16	0.00	0.00	0.00	0.00	0.00	0.00				48.08						50.42
8	34	12	internal crust	0.00	0.00	0.73	0.15	0.24	0.00	0.00	0.00	0.52	0.00				47.94						50.43
8	34	13	glass	0.51	0.25	1.99	12.65	3.71	0.16	0.00	0.71	3.81	0.00				16.75						59.46
8	34	14	glass	0.45	0.21	1.85	12.96	2.75	0.53	0.00	0.63	3.03	0.00				18.34						59.27
8	34	15	glass	0.44	0.15	2.61	13.18	3.75	0.18	0.10	0.91	3.69	0.00				15.16						59.84
8	34	16	glass (inside magnetite)	0.32	0.00	3.25	7.86	1.27	0.13	0.06	0.42	1.14	0.07				29.83						55.64
<b>Grain 8</b>																							
9	5	1	area of dense core	0.00		1.90	0.65	0.13	0.00		0.00	0.09					46.32						50.90
9	5	2	dark "vein"	0.15		1.61	24.07	0.23	0.00		0.11	0.10					11.15						62.52
9	5	3	minor darker "vein"	0.00		0.77	13.46	1.18	0.00		0.00	0.07					26.71						57.81
9	5	4	bulk area	0.00		1.58	4.57	0.24	0.00		0.09	0.00					40.67						52.84
9	5	5	point in dense wustite	0.00		1.00	0.00	0.00	0.00		0.00	0.00					48.75						50.25
9	5	6	point in dull wustite	0.50		2.55	5.33	0.68	0.00		0.00	0.24					37.01						53.69
9	5	7	point in dull wustite	0.00		6.61	0.00	0.15	0.00		0.00	0.11					41.37						51.76
9	5	8	quartz grain	0.00		0.00	33.25	0.00	0.00		0.00	0.00					0.06						66.60

			Atomic %	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Br	Ba	Pb	O
9	5	9	point in dark vein	0.00		0.96	19.82	0.15	0.13		0.00	0.12					18.42						60.40
<b>detail around quartz</b>																							
9	6	1	bright wustite	0.00	0.00	0.32	0.00	0.00	0.15		0.00	0.00	0.00				49.30						50.23
9	6	2	margin	0.00	0.00	8.57	10.29	0.00	0.00		0.11	0.00	0.25				23.40						57.39
9	6	3	margin	0.00	0.00	2.98	14.93	0.08	0.00		0.07	0.08	0.00				23.60						58.25
9	6	4	margin	0.00	0.00	1.97	0.21	0.00	0.00		0.00	0.00	0.21				46.90						50.70
9	6	5	quartz	0.00	0.00	0.08	33.16	0.00	0.00		0.00	0.00	0.00				0.11						66.58
9	6	6	dull wusite	0.00	0.00	0.95	0.00	0.00	0.00		0.00	0.00	0.00				48.81						50.24
9	6	7	margin	0.86	0.21	1.41	13.74	0.58	0.28		0.61	0.30	0.12				24.26						57.63
9	6	8	margin	0.00	0.00	0.80	4.53	0.19	0.20		0.17	0.11	0.00				41.25						52.76
<b>detail darker area</b>																							
9	7	1	slightly variegated grain		0.00	0.65	17.11	0.10	0.00		0.05	0.82	0.00			0.00	22.47						58.78
9	7	2	dense white grain		0.00	0.48	0.16	0.00	0.00		0.00	0.13	0.00			0.00	49.04						50.20
9	7	3	fine matrix		0.20	1.96	16.75	0.10	0.12		0.34	0.06	0.06			0.15	21.25						59.01
9	7	4	fine matrix		0.00	1.43	17.15	0.18	0.09		0.00	0.00	0.00			0.15	21.82						59.17
9	7	5	fine matrix		0.00	1.91	18.69	0.42	0.00		0.00	0.00	0.00			0.18	18.66						60.14
9	7	6	bright rounded bleb		0.00	3.17	0.53	0.00	0.00		0.00	0.00	1.35			0.00	43.21						51.73
9	7	7	quartz		0.00	0.10	33.04	0.00	0.00		0.00	0.00	0.00			0.00	0.31						66.55
9	7	8	quartz		0.00	0.15	32.97	0.00	0.00		0.00	0.00	0.00			0.00	0.36						66.52
9	7	9	cavernous quartz		0.00	0.10	33.00	0.00	0.00		0.00	0.00	0.00			0.00	0.37						66.53
9	7	10	bright bleb in cavernous quartz		0.20	0.00	16.26	0.09	0.00		0.00	0.00	0.00			0.28	24.98						58.20
9	7	11	quartz		0.00	0.35	31.10	0.21	0.08		0.00	0.14	0.00			0.00	2.24						65.88
<b>Grain 9</b>																							
9	8	1	?			1.26	0.96	0.00	0.00								46.99						50.79
9	8	2	area on dense margin of concentric structure			0.48	0.00	0.00	0.14								48.69						50.26
9	8	3	area in core of concentric structure			2.77	0.34	0.24	0.00								45.22						51.04
9	8	4	bulk area analysis			2.32	0.63	0.19	0.19								45.15						51.23
<b>Grain 10</b>																							
9	9	1	typical area			1.96	0.75	0.29	0.21	0.11		0.21					45.24						51.23
9	9	2	dull grain			1.99	23.71	0.20	0.00	0.10		0.30					11.24						62.45
9	9	3	wustite			0.00	0.46	0.00	0.00	0.00		0.00					49.30						50.23
9	9	4	wustite			0.00	0.00	0.00	0.20	0.00		0.00					49.60						50.20
<b>Grain 11</b>																							
10	17	1	point in medium bright crystals	0.46	0.79	4.40	13.33	0.47	1.96		0.73	5.67					12.41						59.78
10	17	2	typical area	0.33	2.18	8.50	10.57	0.30	1.27		0.57	3.68	0.17				13.66						58.77
10	17	3	area of simple medium bright texture		0.59	5.27	9.67	0.38	1.98		0.41	3.67	0.15				19.48						58.39
10	17	4	quartz				33.28										0.07						66.64
10	17	5	dark area	0.30	0.19	24.82	10.92	0.11		0.09	0.98	0.28	0.17				0.67						61.47
10	17	6	point in bright crystals			2.39	1.15	0.15	0.25			0.43					44.08						51.54
10	17	7	point in bright crystals				0.94		10.35								27.89						60.82
10	17	8	point in bright crystals		0.21	0.78	2.12		7.71			0.14	0.09				29.95						59.01
10	17	9	point in bright crystals				0.61		12.65			0.13					23.67						62.95
<b>detail near edge</b>																							
10	18	1	bright grain			0.36	0.84		13.43			0.33					20.95				0.13		63.94
10	18	2	glass	0.37	0.49	4.49	13.84	0.62	0.88		0.70	5.51					13.98						59.12
10	18	3	bright grain				0.46		12.61			0.11					23.99						62.84
10	18	4	medium grains		0.36	4.83	2.57		1.53			1.06	0.32				35.15						54.19
10	18	5	medium grains		0.45	3.30	2.14		2.89			0.86	0.12				35.40						54.84
10	18	6	medium grains		0.42	5.43	0.70		0.13			0.26	0.34				40.71						52.01

Atomic %				Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Br	Ba	Pb	O
10	18	7	medium grains		0.60	9.81	5.71	0.31	1.21		0.26	2.08	0.19				23.04						56.78
10	18	8	medium grains		0.78	13.30	1.26		0.39			0.59	0.30				28.89						54.49
10	18	9	bright grain				0.19		14.76			0.12					20.08						64.85
10	18	10	medium "wisp"		0.55	5.89	5.91	0.21	0.62		0.22	1.75	0.25				29.33						55.27
<b>detail in dark core</b>																							
10	19	1	dark glass	0.39	5.85	3.76	14.49	0.18			0.25	15.48					1.28						58.21
10	19	2	medium glass		5.85	5.24	13.49	0.42	0.11		0.45	9.79	0.21			0.10	5.85						58.48
10	19	3	fine medium grain (hercynite)		3.12	16.77	1.82				0.08	0.89	0.28				21.83						55.22
10	19	4	core of central crystals		40.51	0.75						0.10				0.24	8.10						50.25
10	19	5	margin central crystals		35.52	2.71						0.15				0.26	10.68						50.68
10	19	6	dark glass		14.20	1.27	13.21	0.20				13.08				0.11	0.85						57.07
10	19	7	hole?			35.84	0.81		0.52	3.16		0.52					0.84						58.31
10	19	8	core of central crystals		15.22	7.41	1.79					0.69	0.26			0.14	21.64						52.87
10	19	9	glass outside core	0.38	2.18	4.88	13.78	0.46	0.69		0.53	6.97	0.19				10.94						59.01
10	19	10	glass outside core		1.30	8.45	9.31	0.27	0.63		0.27	3.99	0.47				17.54						57.77
10	19	11	medium bright crystals		0.78	9.16	0.37					0.26	0.10				36.59	0.21					52.53
10	19	12	medium bright crystals			3.62											45.48						50.90
10	19	13	medium bright crystals		0.59	3.85	4.29	0.23	5.25		0.13	1.56	0.21				25.27						58.61
10	19	14	bright grain			0.13	0.47		13.14			0.07					22.65				0.12		63.41
10	19	15	medium dull crystal		0.64	16.17	0.31					0.19	0.24				28.14						54.31
10	19	16	core of central crystals		33.39	2.27						0.18				0.30	13.30						50.57
10	19	17	margin central crystals		13.12	12.33	0.70					0.74	0.21			0.20	19.18						53.53
<b>detail</b>																							
10	20	1	dark lath	0.77		20.56	13.71	0.15			1.71	1.39					0.22						61.49
10	20	2	core spinel		2.34	12.75	4.69	0.18	0.35		0.20	1.83	0.18				21.44						56.05
10	20	3	margin spinel		1.56	13.55	4.11	0.13	0.15		0.14	1.47	0.31				22.77						55.81
10	20	4	hole?		0.38	22.43	5.85	0.25	0.27	0.10	0.27	2.94	0.17				8.36						58.97
10	20	5	dark glass/hole?			33.30	3.67		0.13	0.30	0.86	0.53	0.08				1.16						59.96
10	20	6	light glass around dendrites	0.60	1.11	7.28	13.96	0.37	0.53		1.12	4.75	0.33				10.60						59.35
10	20	7	dark glass	0.54	0.13	7.76	24.22				2.81	0.17	0.51				0.39						63.46
10	20	8	late dendrite	0.44	1.21	7.46	12.37	0.35	0.50		0.71	4.81	0.33				13.13						58.69
10	20	9	glass around anorthite	0.51	1.99	8.18	14.39	0.66			0.63	7.64	0.38				5.98						59.64
10	20	10	bright grain Fe2S			0.53	1.58	0.08	12.92			0.92					20.06						63.91
10	20	11	dark lath (anorthite)	0.21	0.16	14.96	15.25				0.07	7.68					0.38						61.29
10	20	12	hole?			37.73	0.49	0.15	0.16	0.26	0.13	0.39					0.80						59.79
10	20	13	spinel		0.48	10.09	1.24		0.77			0.87	0.21				32.14						54.02
<b>Grain 12</b>																							
10	21	2	bulk area	0.60	0.41	16.65	16.65			0.88	1.42	0.70	0.26				0.74						61.67
<b>detail of margin</b>																							
10	22	1	typical area	0.87	1.66	11.16	18.25	0.43			1.16	2.43	0.33				1.82						61.89
10	22	2	fine oxide dendrites	1.09	1.02	7.89	10.84	0.22			1.33	0.45	1.05				18.62						57.48
10	22	3	fine oxide dendrites	0.50	1.10	8.37	11.96	0.17			1.21	0.49	1.14				16.72						58.34
10	22	4	glass	1.27	0.50	10.81	19.81	0.21			1.31	2.57	0.34				0.89						62.29
10	22	5	dark crystal	1.36	0.50	12.38	17.60	0.27			0.49	4.71	0.14				0.86						61.70
10	22	6	?dark crystal	0.71	2.23	10.74	18.61	0.47			1.32	1.89	0.28				1.78						61.97
10	22	7	bright fleck	0.75	2.54	10.51	16.85	0.35			1.50	0.99	0.32				5.29						60.91
10	22	8	medium fleck	0.78	2.61	8.83	18.18	0.60			1.51	1.39	0.45				4.26						61.40
<b>detail</b>																							
10	23	1	typical area	0.54	0.34	17.66	16.49	0.12		0.53	1.15		0.31				0.39						62.33
10	23	2	bright grain		0.66	9.07	10.93				0.41		13.72	0.15			0.44						64.61
10	23	3	dark area		0.12	15.06	19.66	0.10			0.70		0.39				0.24						63.67

				Atomic %																			
				Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Br	Ba	Pb	O
10	23	4	dark area	0.34		13.40	21.03				1.01	0.24				0.18							63.73
10	23	5	medium area	0.54	0.62	12.48	20.78				1.62	0.43				0.35							63.18
<b>detail</b>																							
10	24	1	dark crystal (anorthite)	0.57		14.81	15.88				0.13	6.93				0.21							61.47
10	24	2	bright grain		5.26	7.11	0.93				0.09	0.15	0.75		0.10	0.19	32.80						52.62
10	24	3	glass	1.45	0.81	7.25	20.36	0.85			1.31	3.38	0.56				1.65						62.29
10	24	4	dark crystal (anorthite)	0.98	0.18	13.02	16.80	0.15			0.29	6.17	0.10				0.81						61.50
<b>Grain 13</b>																							
10	25	1	dense wustite		0.35	5.87										42.31							51.47
10	25	2	dense wustite		0.35	4.85	0.20									43.29							51.31
10	25	3	dense wustite			1.65						0.11				47.83							50.41
10	25	4	glass	0.24	0.21	8.34	14.50	0.62			0.09	10.04	0.19			5.96							59.82
10	25	5	wusite			3.96	2.67	0.17				1.93				38.81							52.46
10	25	6	wusite		0.79	3.49	0.81					1.01				42.63							51.28
10	25	7	glass		0.29	8.06	12.87	0.58			0.09	12.19	0.20			6.75							58.96
10	25	8	magnetite		1.71	4.78						0.29				42.02							51.19
10	25	9	magnetite		2.41	7.44	0.63					0.48				36.87							52.17
10	25	10	magnetite		2.35	6.24						0.27				39.58							51.56
10	25	11	glass		0.40	10.03	13.29	0.62				11.13	0.16			4.68							59.69
10	25	12	glass		1.78	8.99	4.88					7.25				22.42							54.69
10	25	13	dark lath		1.53	8.81	5.80					7.86				20.89							55.10
10	25	14	magnetite		3.51	2.96						0.59			0.40	41.80							50.74
10	25	15	dark lath		1.83	8.60	4.42					7.40				23.39							54.36
10	25	16	glass		0.41	7.94	12.27	0.54			0.12	12.86	0.19			7.08							58.59
10	25	17	glass	0.35		7.94	14.72	0.58			0.11	10.42	0.17			5.96							59.75
10	25	18	wusite		0.41	3.99						0.27				44.34							51.00
<b>detail</b>																							
10	26	1	dark lath		1.52	10.82	4.84					7.26				20.43							55.13
10	26	2	dark lath		1.65	10.60	4.47					7.09				21.29							54.89
10	26	3	glass	0.37	0.39	7.28	12.96	0.69			0.10	12.68	0.26			6.43							58.83
10	26	4	glass	0.43	0.41	8.36	12.79	0.67			0.07	12.36	0.19			5.77							58.95
10	26	5	magnetite		2.47	3.93						0.38				42.24							50.98
10	26	6	magnetite		2.47	3.97						0.41				42.15							50.99
<b>bulk area</b>																							
10	27	1	main area		1.06	8.93	8.02	0.35				6.39	0.09			18.62							56.55
<b>Grain 14</b>																							
10	28	1	bulk area		1.35	12.89	8.54	1.11	0.94	0.07	0.22	12.74	0.23		0.11	2.52							59.29
10	28	2	rounded grain		0.52	0.32	0.60	0.44	0.97			45.25											51.75
10	28	3	rounded grain		0.72	0.44	0.55	1.36	0.90			43.23				0.27							52.38
10	28	4	medium lath		0.45	12.19	6.82	1.26	2.48		0.12	11.47				5.35							59.85
10	28	5	medium lath		0.43	16.79	7.75					16.76				0.09							58.11
10	28	6	medium fine grain		2.80	4.13	0.29		0.36			0.24			3.09	36.34	0.86		0.35				51.54
10	28	7	bright crust		0.58	14.61	7.50		1.45			15.57				1.45							58.85
<b>detail</b>																							
10	29	1	rounded grain		1.34	1.17	0.78	1.39	1.22			40.91				0.26							52.94
10	29	2	lath		0.53	16.10	8.30					16.79				0.11							58.17
10	29	3	lath with intergrowth		0.73	15.97	8.23					16.78				0.18							58.11
10	29	4	bright grain Fe2S			0.10	0.15	0.07	16.47			0.22			0.42	15.50	0.45						66.62
10	29	5	medium grian		0.37	0.46	0.59	0.27	1.73			43.97				0.26							52.34
10	29	6	lath with intergrowth		1.14	14.47	9.60				0.21	15.86				0.23							58.41

				Atomic %																				
				Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Br	Ba	Pb	O	
10	29	7	leucite lineation?		0.48	7.61	12.52	1.17	0.24		0.41	5.72	0.33			9.66	1.36	0.45				0.20	59.35	
<b>detail</b>																								
10	30	1	lath		0.53	16.16	8.16					16.91					0.12						58.12	
10	30	2	lath		0.50	16.35	8.16					16.83											58.17	
10	30	3	pore fill		0.30			0.43	1.34			46.10											51.72	
10	30	4	lath with intergrwoth		0.59	13.82	12.91	1.92	0.14		0.61	8.37					0.30						61.33	
10	30	5	intergrowth		0.33	12.15	7.87	1.47	0.12		0.26	19.02					0.66						58.13	
10	30	6	medium grain		2.48	7.03		0.42	1.16			35.50					0.18						53.23	
10	30	7	bright crust			0.88						0.16				0.75	47.29	0.70					50.22	
<b>Grain 15</b>																								
10	31	1	bulk area	0.88	0.63	10.46	13.66	0.13			0.86	7.79	0.25				6.08						59.24	
10	31	2	central grain - fspar?	1.93		6.71	18.03	0.13			2.37	6.36	0.33				4.24						59.89	
<b>detail</b>																								
10	32	1	wustite		0.57	1.86	0.26					0.18	0.26				46.14						50.72	
10	32	2	wustite		1.32	2.16						0.14					45.77						50.61	
10	32	3	dark lath (anorthite)	0.28		14.48	15.13				0.12	7.77	0.06				1.04						61.12	
10	32	4	dark lath (anorthite)			15.10	15.07					7.78					0.74						61.31	
10	32	5	bright wisp	0.62	2.85	7.60	11.24	0.16			0.56	8.07	0.36				11.01						57.52	
10	32	6	late dendrite in glass	0.77	1.70	8.87	13.59	0.20			1.26	9.53	0.27				5.03						58.79	
10	32	7	glass	1.62	1.26	9.15	13.89	0.18			1.59	9.73	0.27				3.62						58.70	
<b>Grain 16</b>																								
11	4	1	bright		5.61	2.56	0.65					1.36	0.11			0.83	37.40	0.16					51.02	
11	4	2	bright		3.74	4.90	5.64					5.10	0.17			0.36	25.95						54.13	
11	4	3	medium core		1.73	5.95	12.23					10.56	0.26				11.54						57.73	
11	4	4	medium margin		2.12	6.35	12.48					10.31	0.26				10.53						57.96	
11	4	5	medium core		2.52	6.63	13.06					10.24	0.35				8.84						58.36	
11	4	6	medium margin		2.72	6.06	12.91	0.18				10.47	0.36				9.01						58.29	
11	4	7	medium margin		3.05	6.09	13.23	0.14				10.34	0.37				8.35						58.43	
11	4	8	glass	0.80	0.28	7.61	18.84	0.59	0.08		3.58	5.71	0.30				1.32						60.89	
11	4	9	glass	0.47		14.19	15.66				0.16	7.17					1.14						61.22	
11	4	10	glass	0.47		14.44	15.56				0.13	7.13					1.03						61.24	
11	4	11	bright		4.91	2.01						0.23	0.17			0.70	41.00	0.39					50.59	
11	4	12	bright		4.71	2.08	0.28					0.27	0.15			0.71	40.64	0.31					50.73	
11	4	13	bright			1.87	0.57					0.67	0.49				45.40						51.00	
11	4	14	bright		6.36	2.56	0.31					0.62				0.93	38.17						50.80	
11	4	15	glass	0.63	0.27	6.76	18.03	0.84	0.21		2.49	7.85	0.32				1.66						60.93	
11	4	16	glass	0.49	0.38	7.16	17.79	0.50			1.90	8.36	0.40				2.35						60.66	
11	4	17	glass	0.51	0.33	7.57	18.14	0.44	0.07		2.23	7.54	0.33				2.00						60.84	
11	4	18	medium lath	0.22	3.47	5.57	13.32	0.27				10.32	0.46				7.92						58.44	
11	4	19	bright		4.69	1.81						0.24	0.12			0.79	41.55	0.29					50.51	
11	4	20	bright		3.91	2.95	3.29				0.21	1.10	0.16			0.67	35.03	0.28					52.41	
11	4	21	medium		2.92	6.14	12.89	0.31			0.08	10.24	0.43				8.58						58.41	
11	4	22	glass	0.63	0.33	6.95	17.86	0.48			2.25	8.40	0.47				2.10						60.54	
11	4	23	medium		3.05	5.82	13.09	0.37				10.17	0.45				8.54						58.50	
11	4	24	medium (small)	0.31	0.29	4.19	17.87	0.80			0.98	12.19	0.54			0.08	2.21						60.53	
<b>overview</b>																								
11	5	1	error		3.52	4.25	16.86				1.06	3.45	0.47				10.92						59.47	
11	5	2	bulk area	0.48	1.30	9.23	13.93	0.24			0.91	5.74	0.24				8.71						59.22	
<b>detail</b>																								
11	6	1	anorthite	0.28		15.40	15.26				0.09	7.45					0.13						61.39	

Atomic %			Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Br	Ba	Pb	O
11	6	2	anorthite	0.46		15.11	15.58			0.16	7.15					0.14						61.41
11	6	3	medium		5.62	3.69	16.87	0.16			8.53	0.30			0.17	5.04						59.63
11	6	4	medium		6.07	3.16	17.04	0.16			8.59	0.25			0.15	5.03						59.55
11	6	5	spinel core		8.35	27.62							0.08	0.13	0.12	6.71						57.00
11	6	6	spinel margin		2.48	8.21	0.46				0.18	1.31			0.19	34.24						52.94
11	6	7	spinel margin		1.55	5.48	0.25			0.10	0.13	1.85			0.20	38.03						52.40
11	6	8	medium		5.86	4.06	16.56	0.20			8.66	0.22			0.15	4.76						59.55
11	6	9	medium		5.57	4.21	16.72	0.24			8.66	0.15			0.11	4.66						59.67
11	6	10	medium		5.77	3.42	16.92	0.23			8.87	0.14			0.12	4.97						59.56
11	6	11	dull rounded grain		8.69	27.67		0.12			0.14		0.08	0.09		6.12						57.09
11	6	12	spinel core		11.67	27.67	0.16				0.06				0.16	3.28						57.00
11	6	13	spinel core		6.29	23.09	2.81			0.15	0.88	0.09			0.14	9.25	0.10					57.18
11	6	14	spinel margin		1.55	9.01	3.00			0.26	0.23	0.85				30.97						54.12
11	6	15	glass	0.34	0.34	8.99	19.20	0.22	0.47	0.91	3.93	0.07			0.08	3.23						62.21
<b>overview</b>																						
11	7	1	area of contorted foliation		0.45	16.26	17.93		0.16	1.25	0.18	0.27				0.43						62.92
11	7	2	area of contorted foliation	0.19	0.48	16.71	17.43		0.11	1.63	0.16	0.31				0.44						62.54
11	7	3	detail slag area	0.29	0.51	14.39	15.21			0.42	6.42	0.10				1.57						61.08
11	7	4	detail slag area	0.36	1.50	13.69	13.50	0.13		0.42	5.34	0.19			0.08	4.62						60.17
11	7	5	bulk slag area	0.41	1.72	11.85	13.64	0.14	0.13	0.50	4.87	0.19				6.86						59.69

Table 6. EDS analyses of points and areas in microresidues

Grain	sample	area	analysis	Atomic %															
				Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	Ba	O		
Grain 17	7	8	1	Area of inner wustite grains	0.00		0.86	0.53	0.00	0.00		0.08	0.00			48.06		50.46	
Grain 17	7	8	2	Area of outer wustite dendrites	0.29		1.68	2.47	0.00	0.27		0.10	0.09			43.28		51.83	
Grain 17	7	9	1	area of tight polygonal grains			0.43	0.21		0.00			0.00			49.15		50.21	
Grain 17	7	9	2	area of tight polygonal grains with voids			2.69	0.64		0.00			0.10			45.57		50.99	
Grain 17	7	9	3	area of polygonal grains with slag films			1.09	1.70		0.31			0.15			45.33		51.43	
Grain 1	8	21	1	area of typical texture gn1			3.72	3.11	0.23	0.55		0.14	1.45			37.62		53.18	
Grain 2	8	23	2	area on outer part of gn2	0.30	0.89	6.63	7.71		1.80		0.50	3.31	0.00		21.43	0.31	57.11	
Grain 2	8	23	3	area of inner part of gn2	0.56	1.07	9.32	11.62		0.72		0.93	4.51	0.15		12.04	0.52	58.56	
Grain 3	8	26	4	typical area of grain			1.98	0.94	0.38	0.23			0.21			44.79		51.48	
Grain 4	8	27	1	overall area of grain	0.48		5.38	4.92		0.00	0.30	0.34	0.65			34.47		53.45	
Grain 5	8	29	1	typical area			2.06	1.53	0.32	0.19			0.38			43.81		51.71	
Grain 6	8	31	1	area excluding crust but otherwise typical			2.05	3.02	0.10	0.61	0.00	0.17	0.59			40.80		52.66	
Grain 7	8	33	3	large area			2.81	3.36	0.31	0.55	0.00	0.17	0.80			38.87		53.13	
Grain 8	9	5	4	bulk area	0.00		1.58	4.57	0.24	0.00		0.09	0.00			40.67		52.84	
Grain 9	9	8	4	bulk area analysis			2.32	0.63	0.19	0.19						45.15		51.23	
Grain 10	9	9	1	typical area			1.96	0.75	0.29	0.21	0.11		0.21			45.24		51.23	
Grain 11	10	17	2	typical area	0.33	2.18	8.50	10.57	0.30	1.27		0.57	3.68	0.17		13.66		58.77	
Grain 12	10	21	2	bulk area	0.60	0.41	16.65	16.65			0.88	1.42	0.70	0.26		0.74		61.67	
Grain 13	10	27	1	main area			1.06	8.93	8.02	0.35			6.39	0.09		18.62		56.55	
Grain 14	10	28	1	bulk area			1.35	12.89	8.54	1.11	0.94	0.07	0.22	12.74	0.23	0.11	2.52		59.29
Grain 15	10	31	1	bulk area	0.88	0.63	10.46	13.66	0.13			0.86	7.79	0.25		6.08		59.24	
Grain 16	11	5	2	bulk area	0.48	1.30	9.23	13.93	0.24			0.91	5.74	0.24		8.71		59.22	
Grain 16	11	7	5	bulk slag area	0.41	1.72	11.85	13.64	0.14		0.13	0.50	4.87	0.19		6.86		59.69	

Table 7. EDS analysis of areas of microresidue particles. Elements of these data are represented graphically in Figure 2.

Figure 1

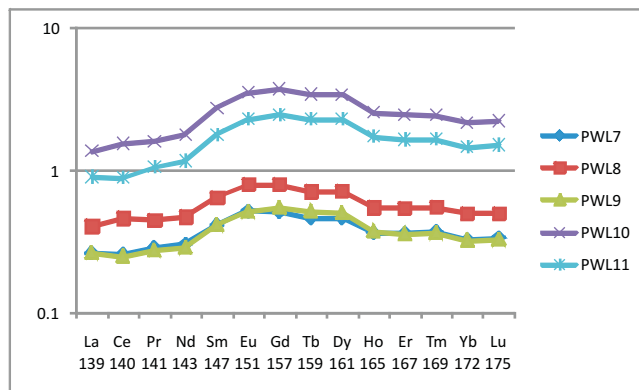
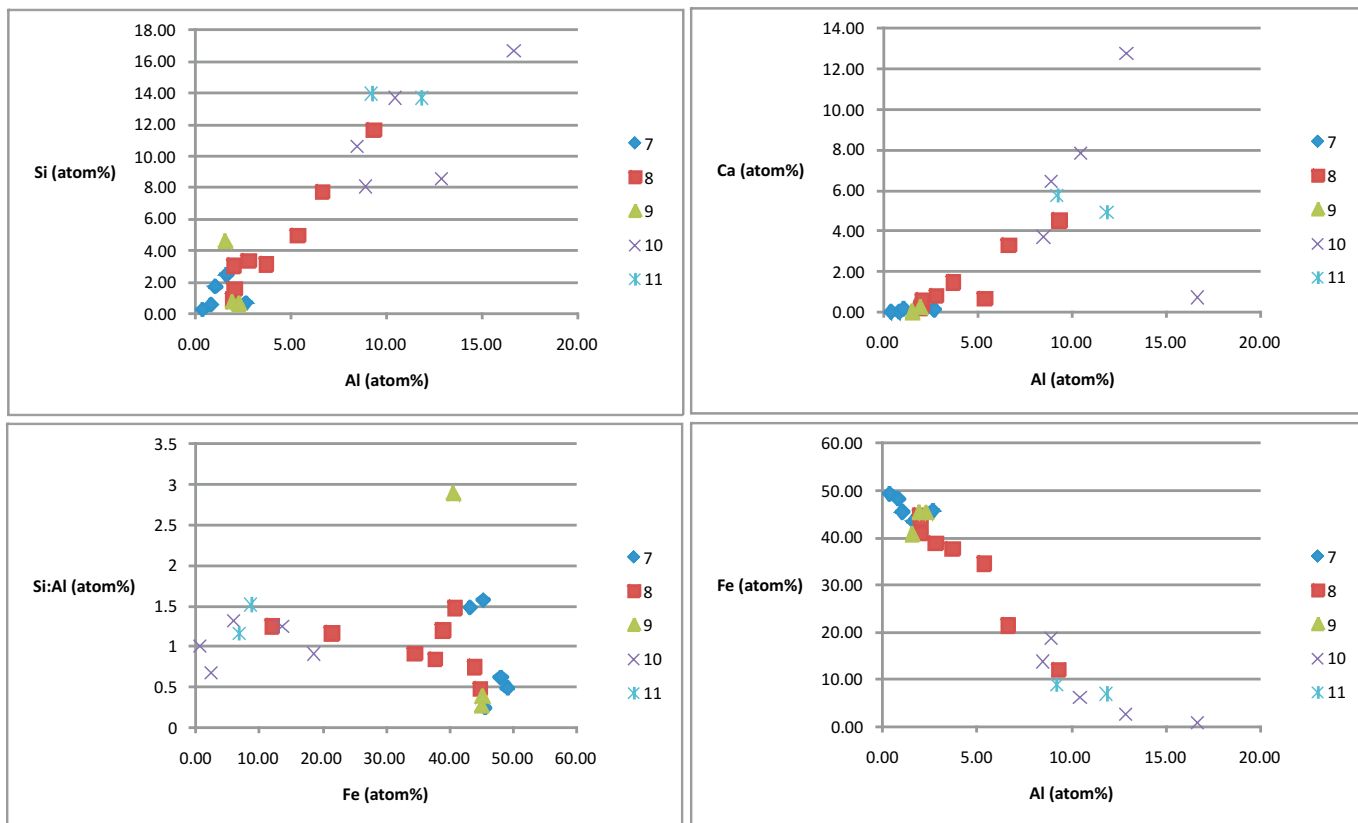
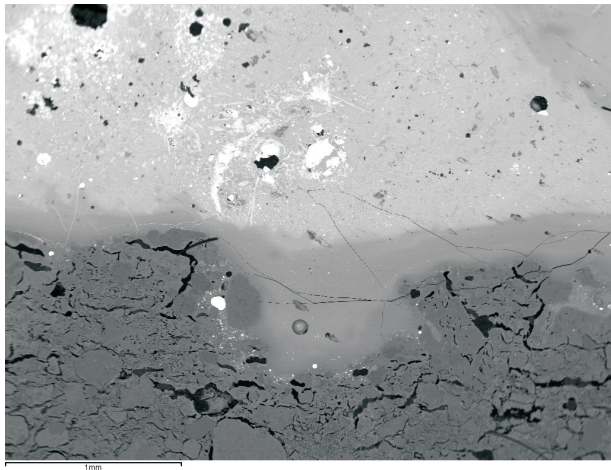


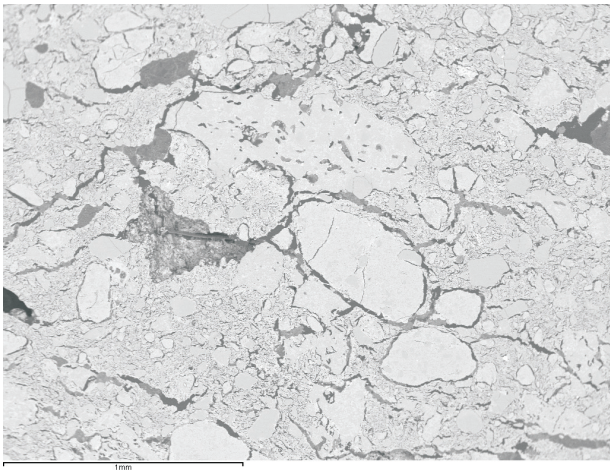
Figure 2



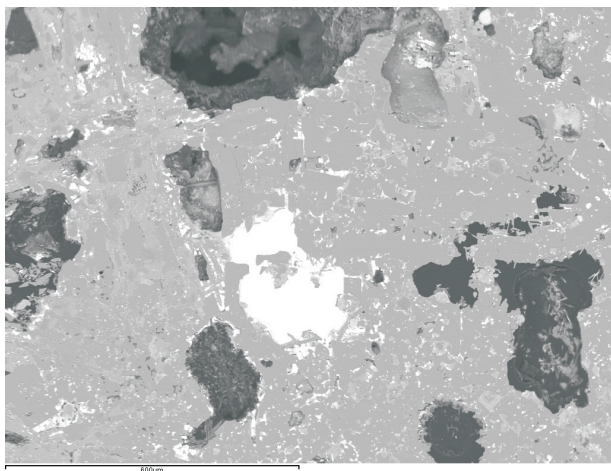
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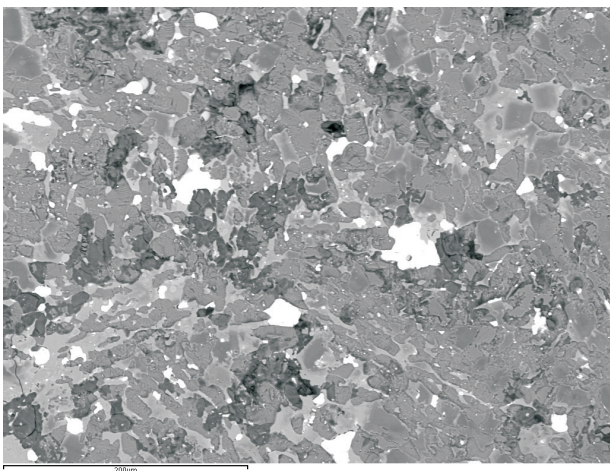
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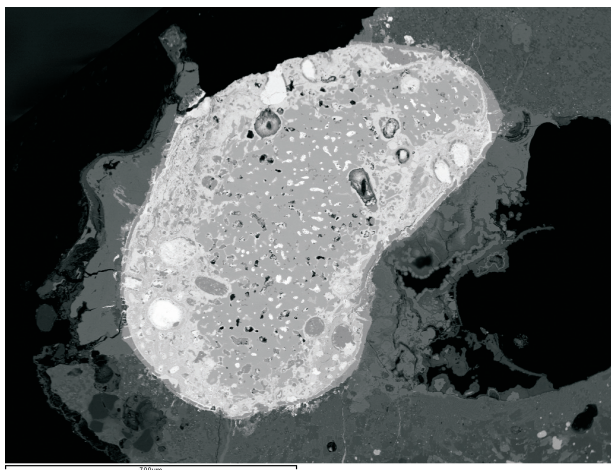
c



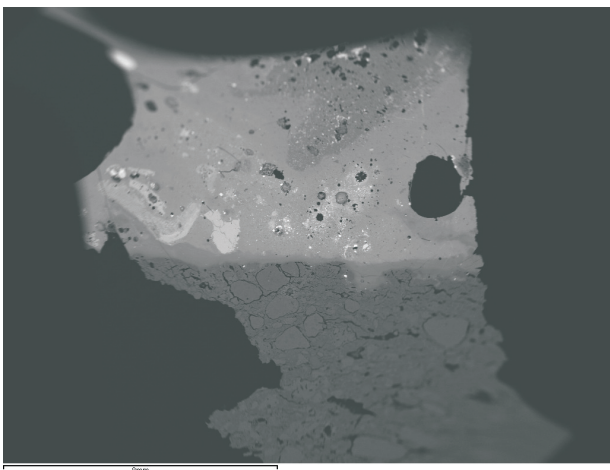
d



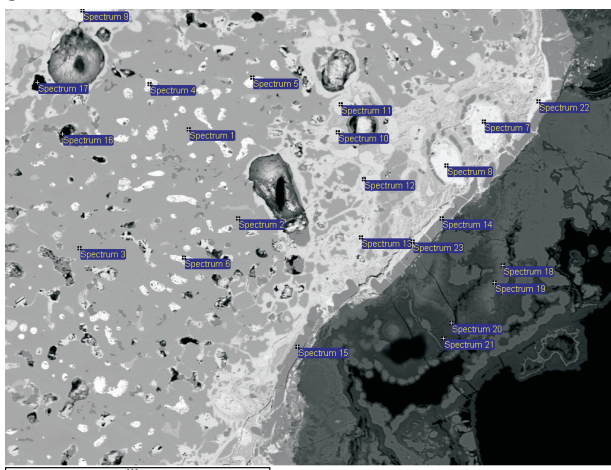
e



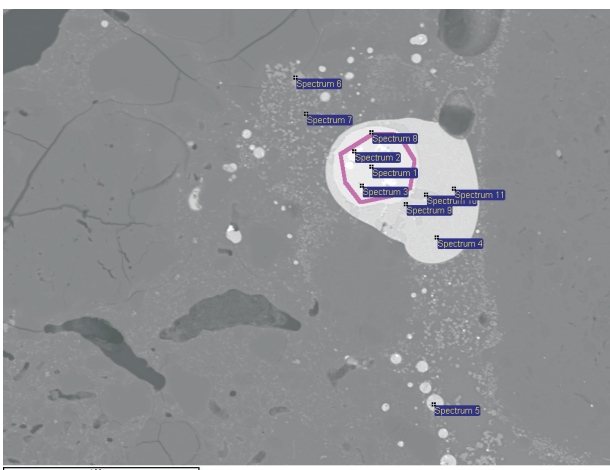
f



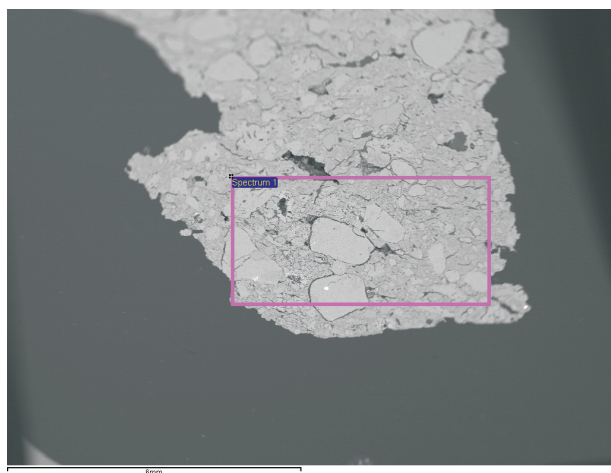
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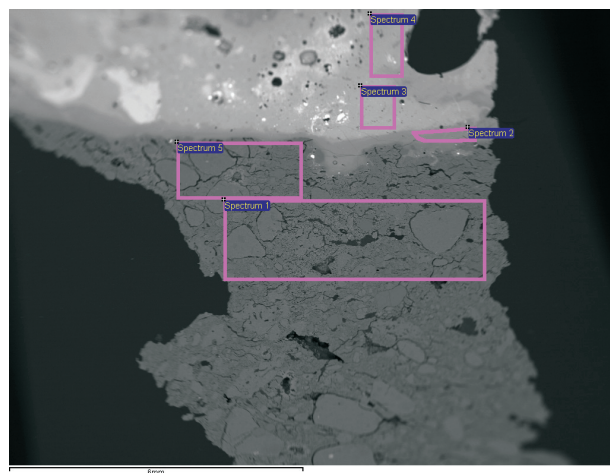
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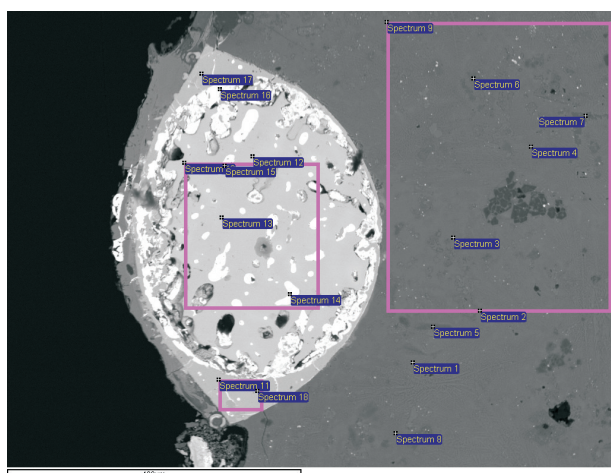
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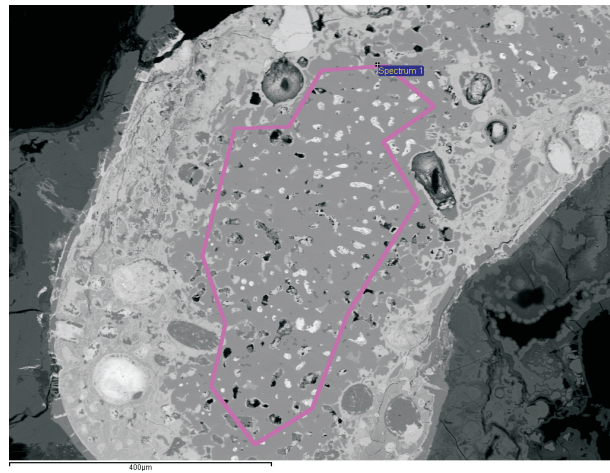
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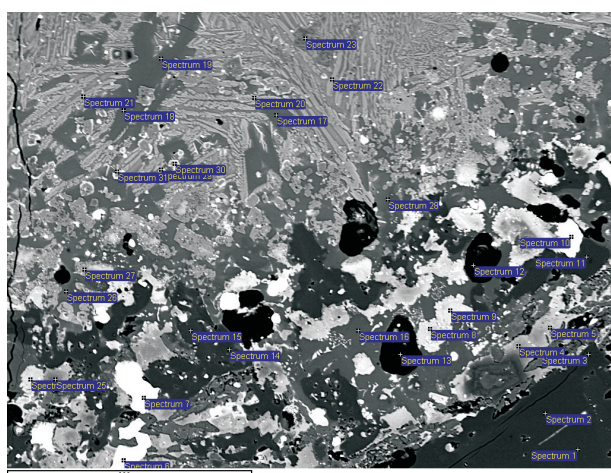
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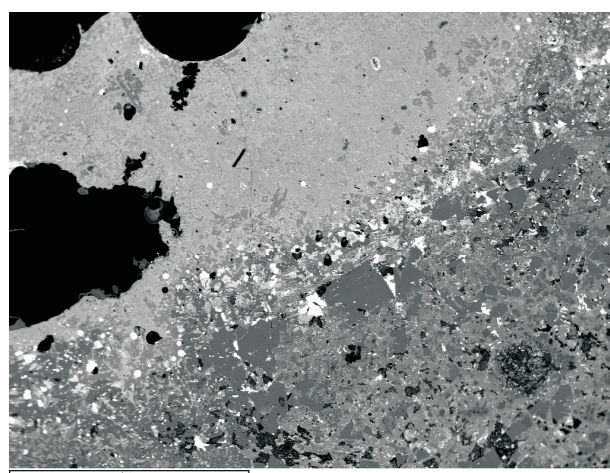
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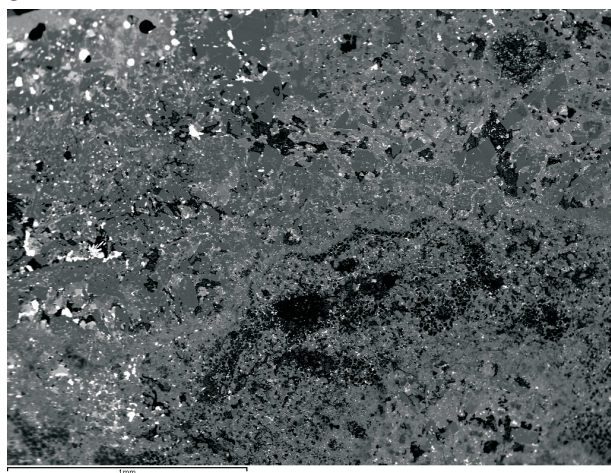
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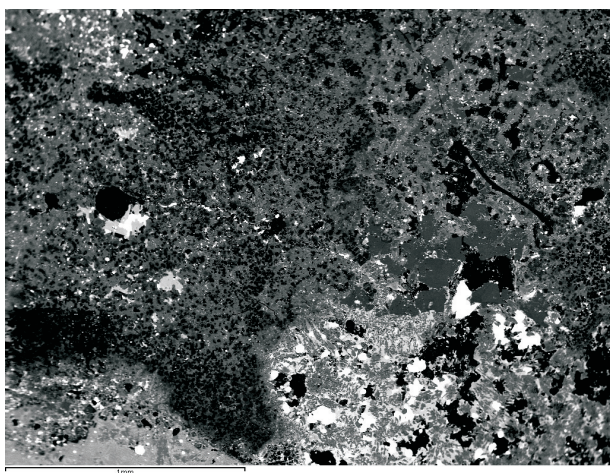
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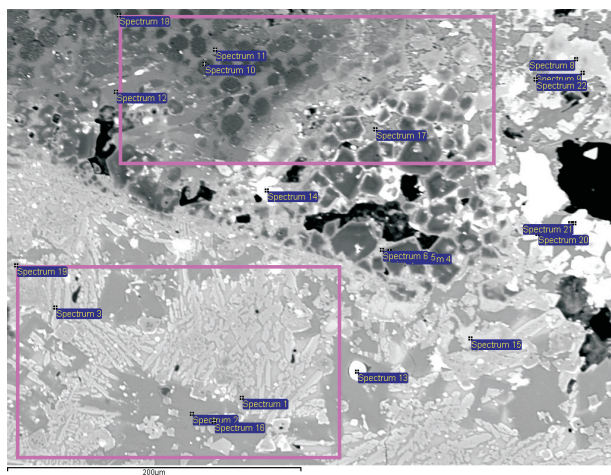
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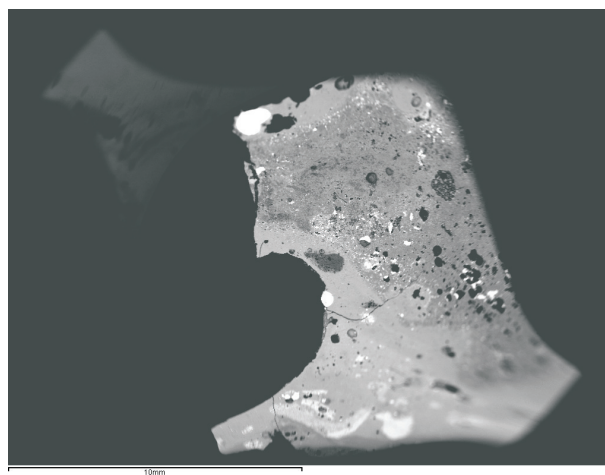
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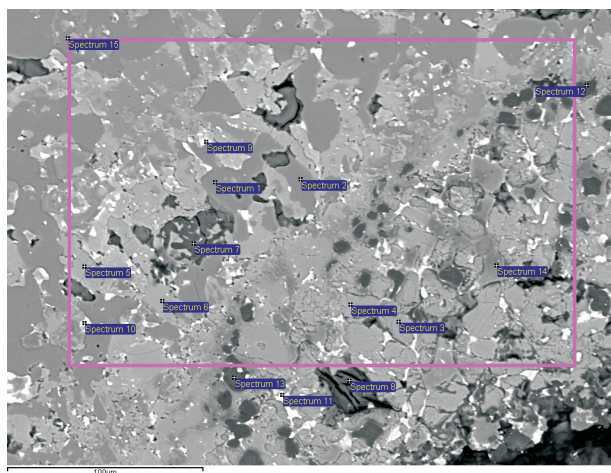
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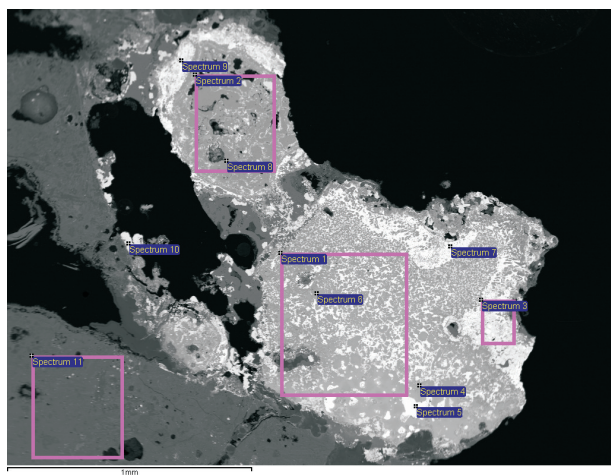
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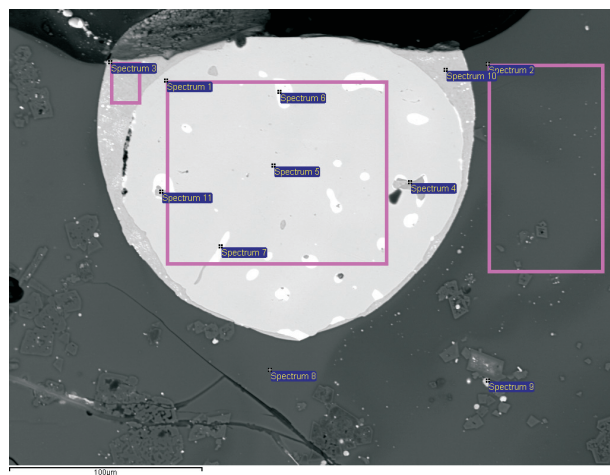
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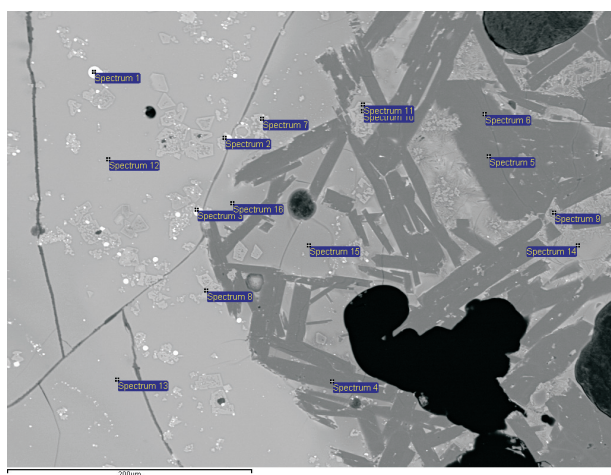
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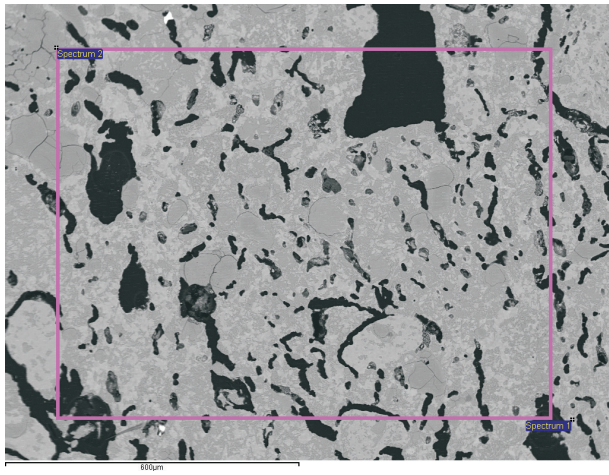
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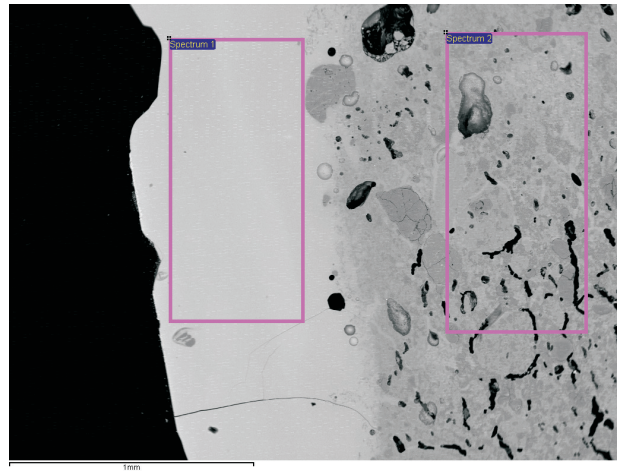


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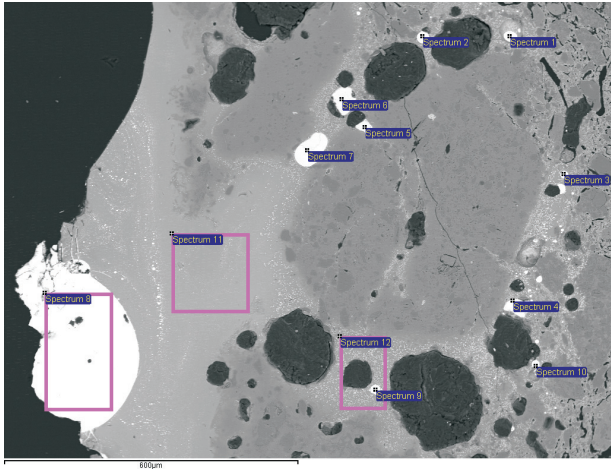


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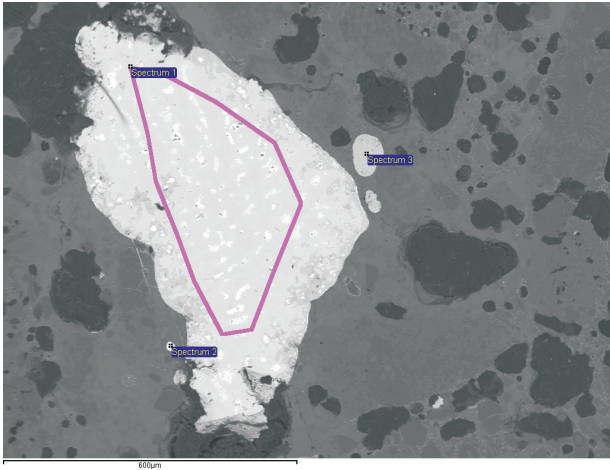
Plate 5



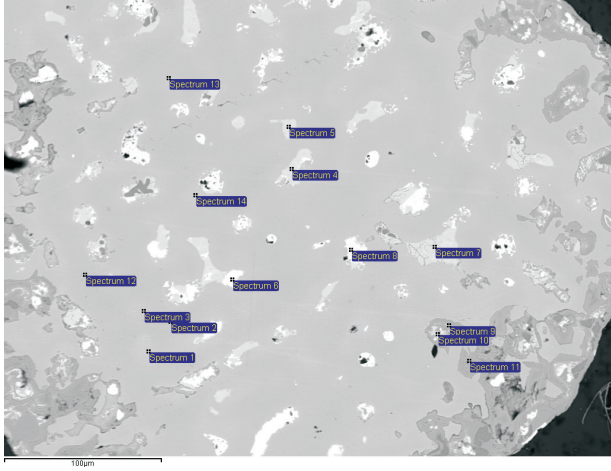
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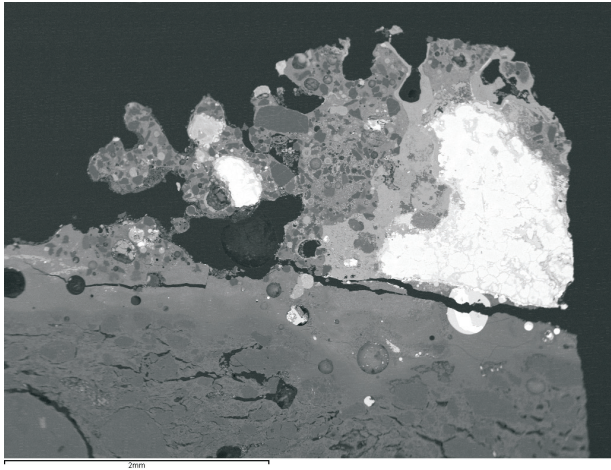
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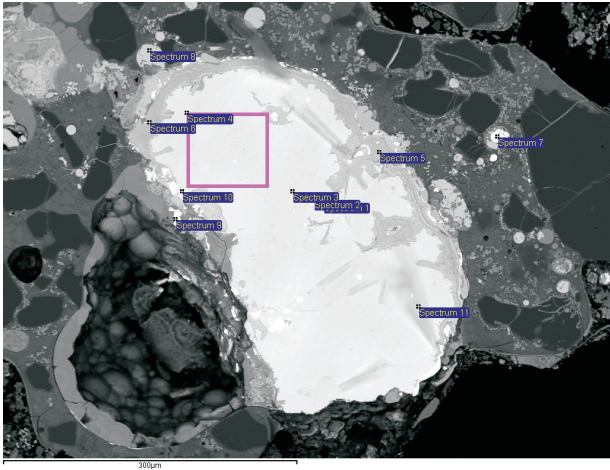
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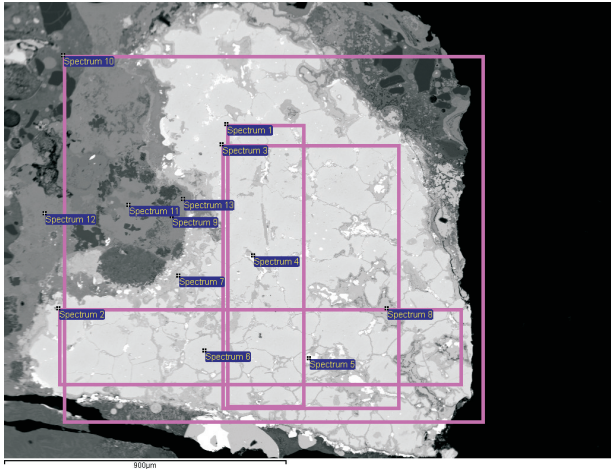
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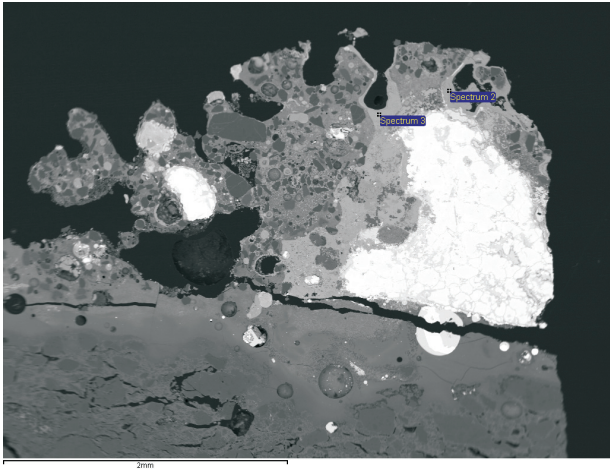
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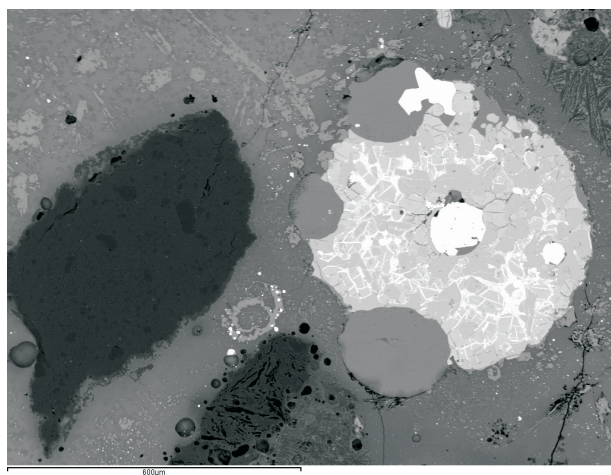
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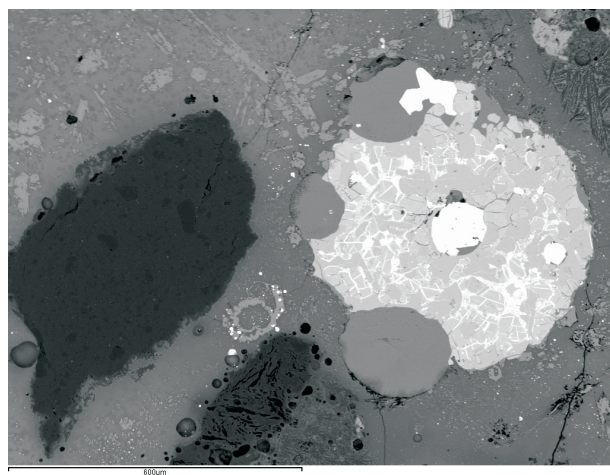
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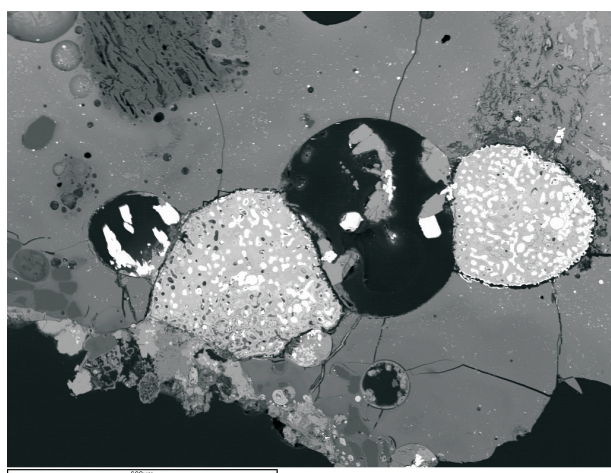
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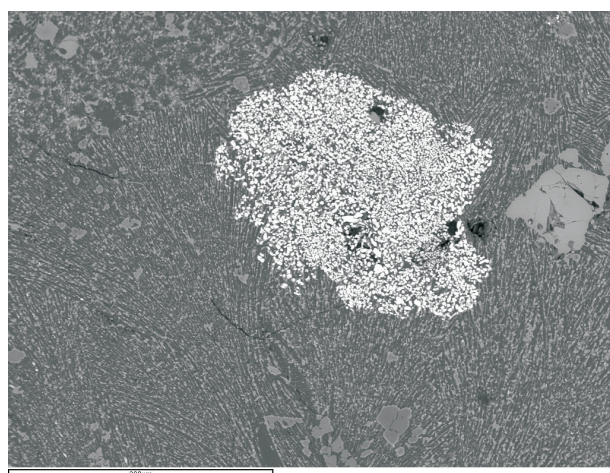
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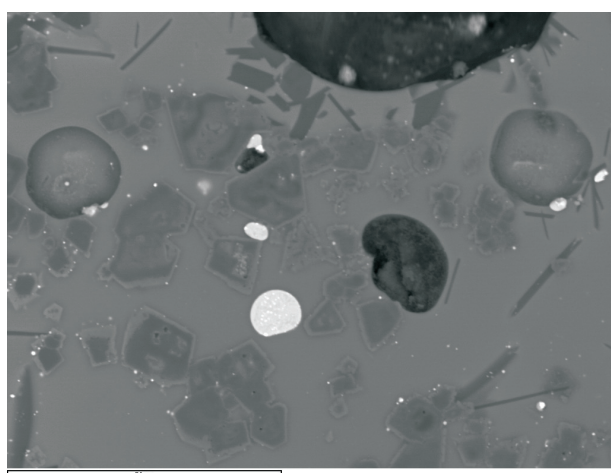
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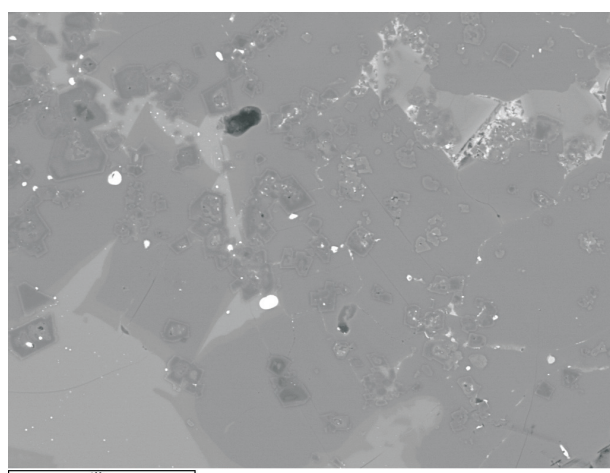
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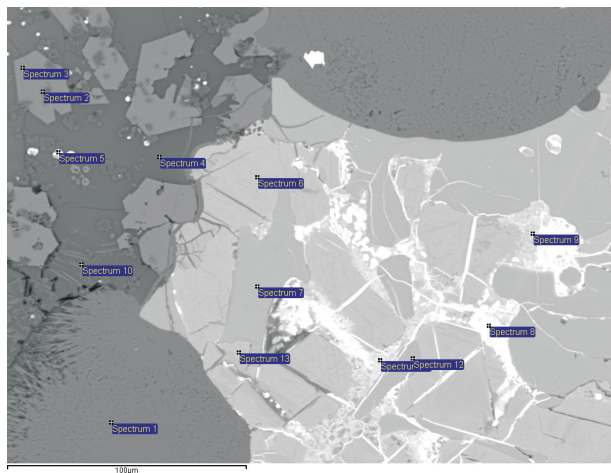
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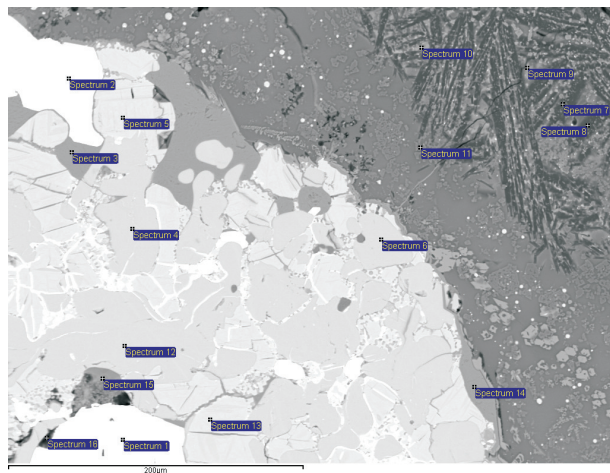
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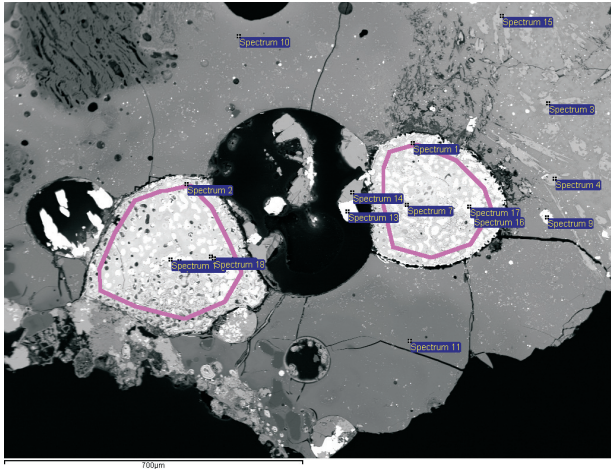
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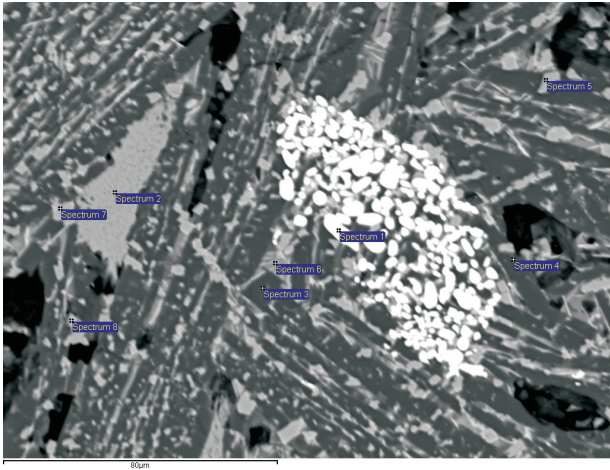
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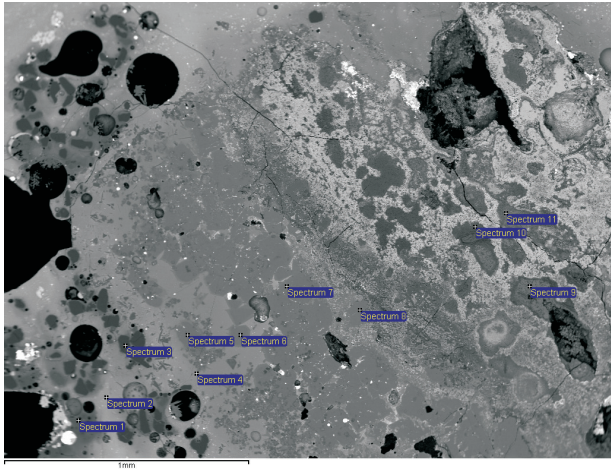
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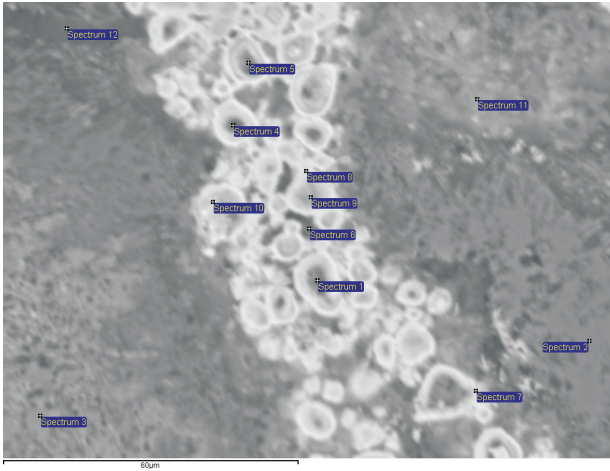
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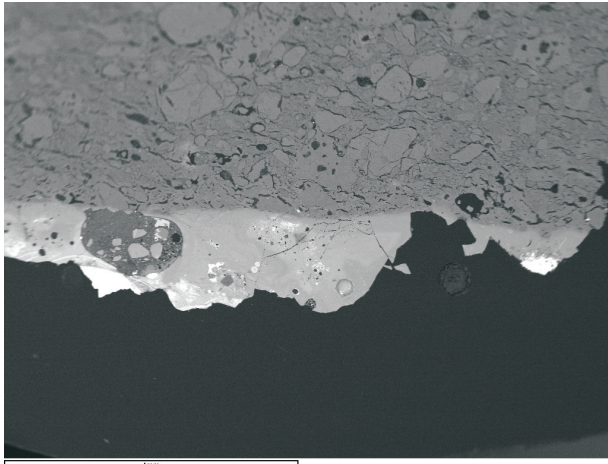
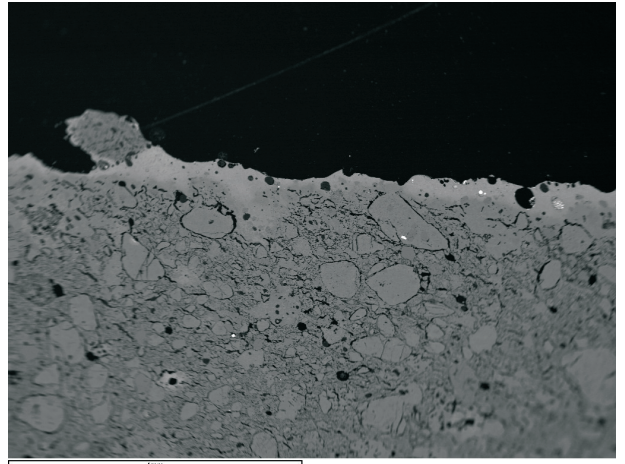
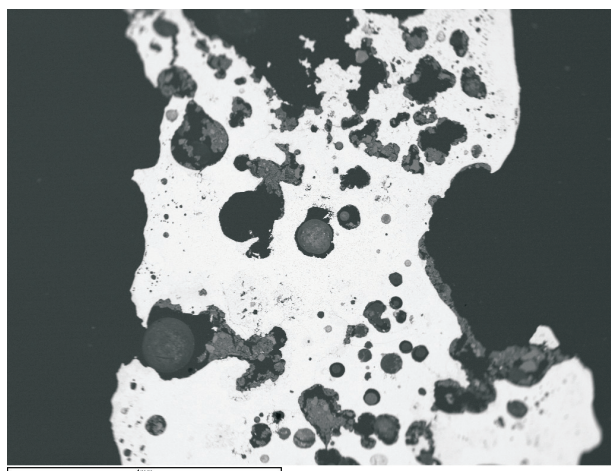


Plate 10

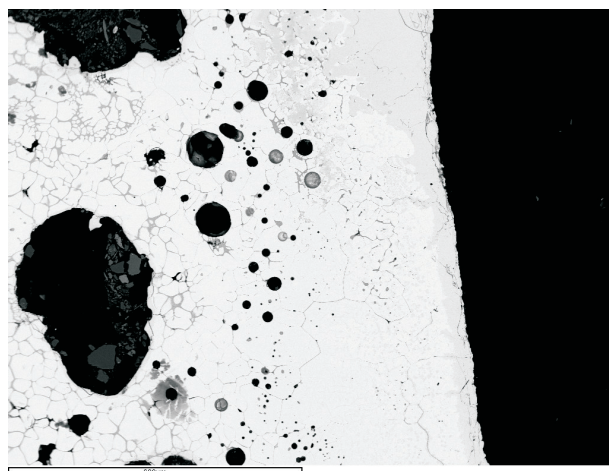
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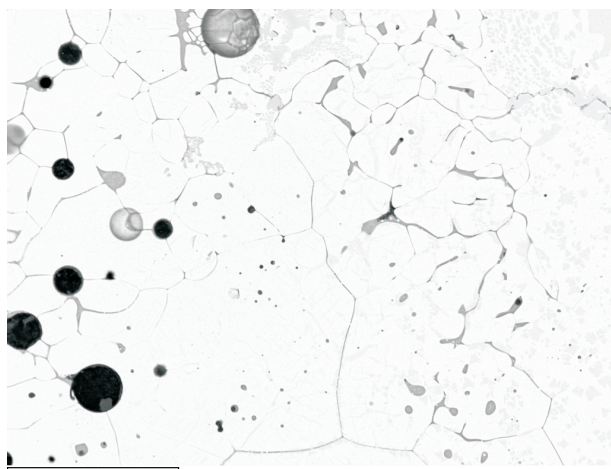
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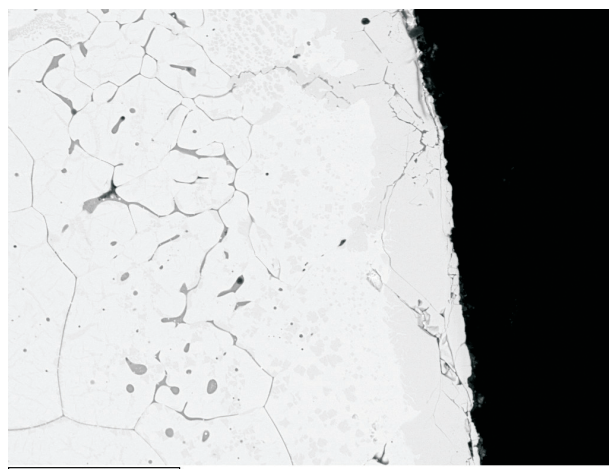
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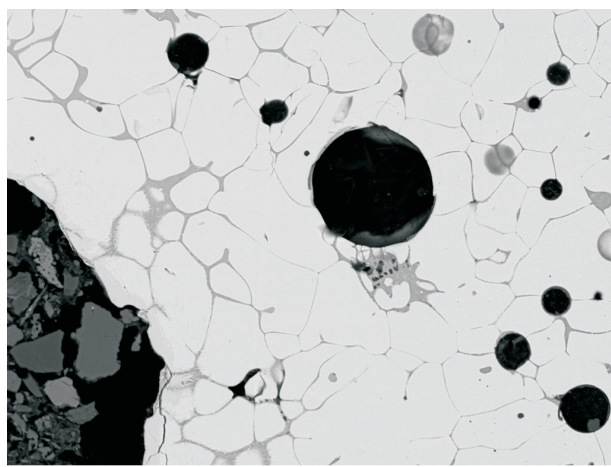
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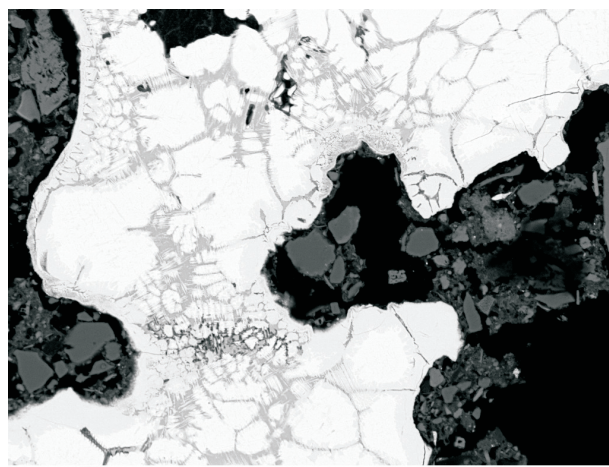
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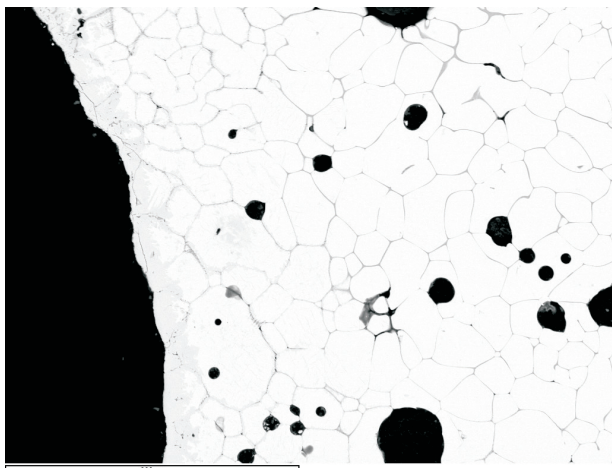
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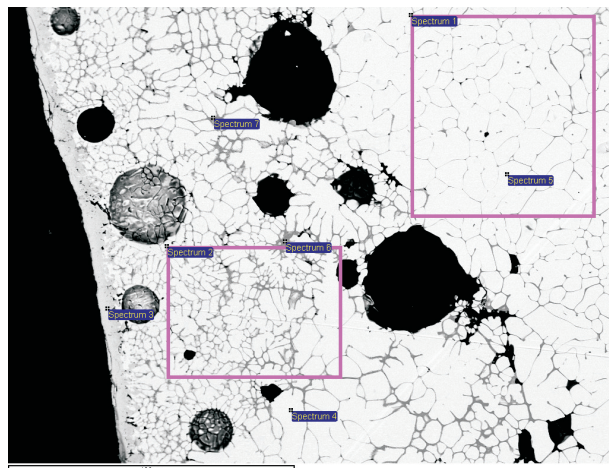
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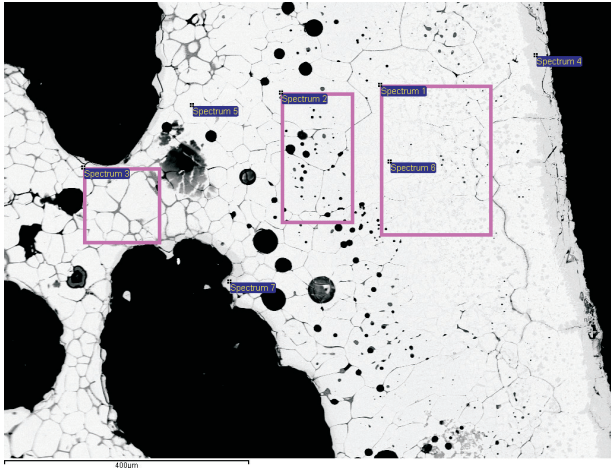
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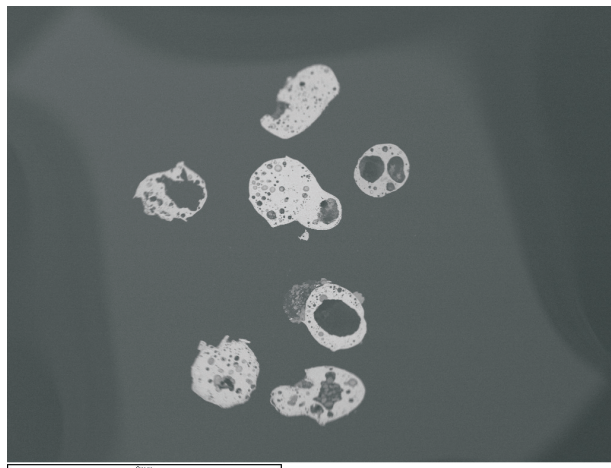
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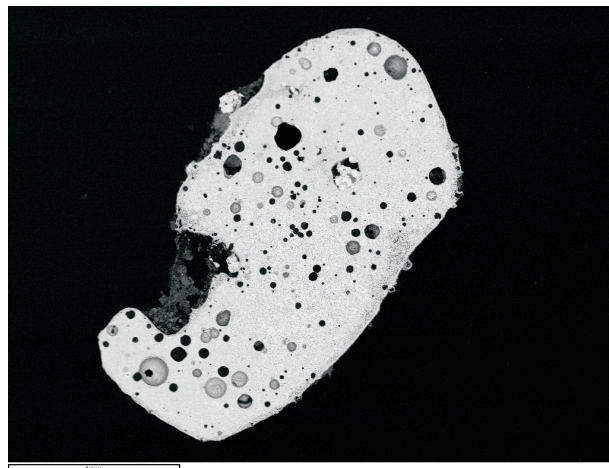
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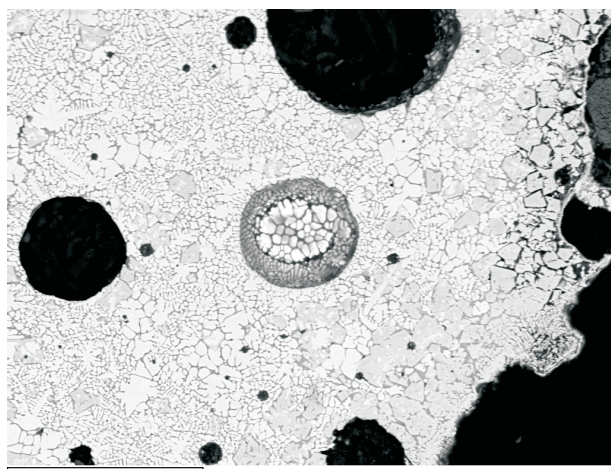
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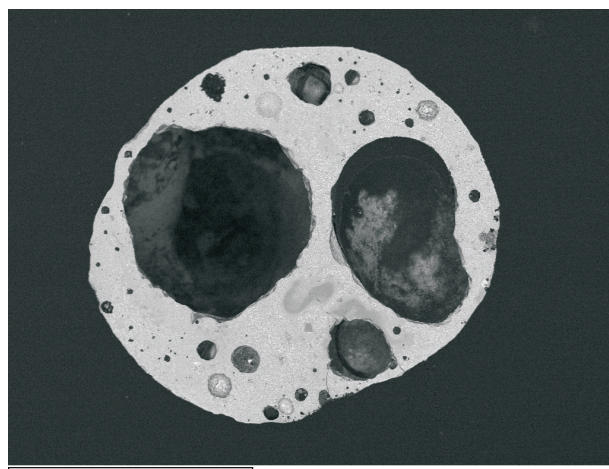
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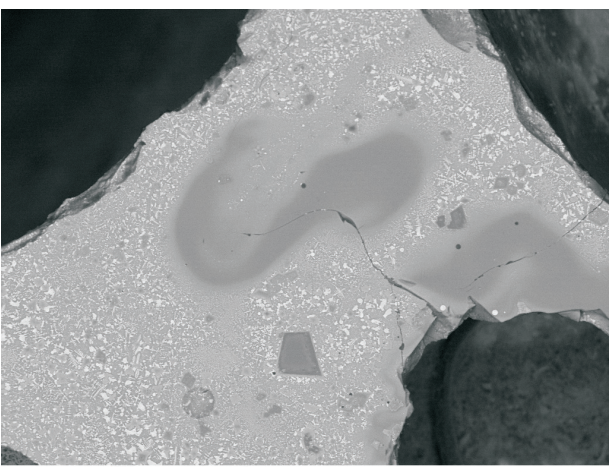
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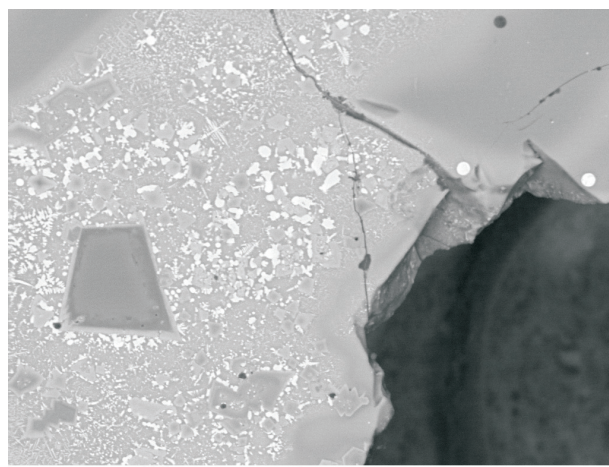
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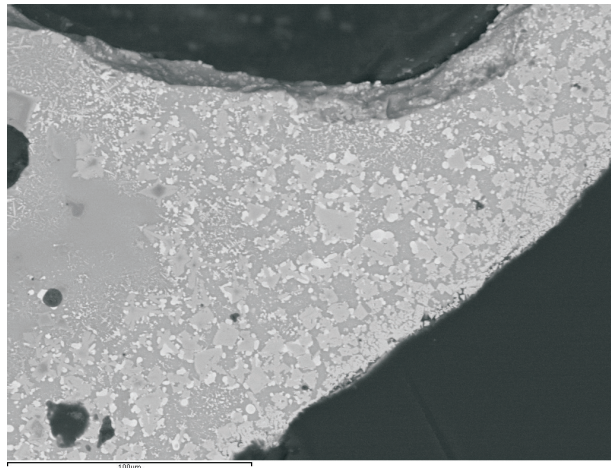
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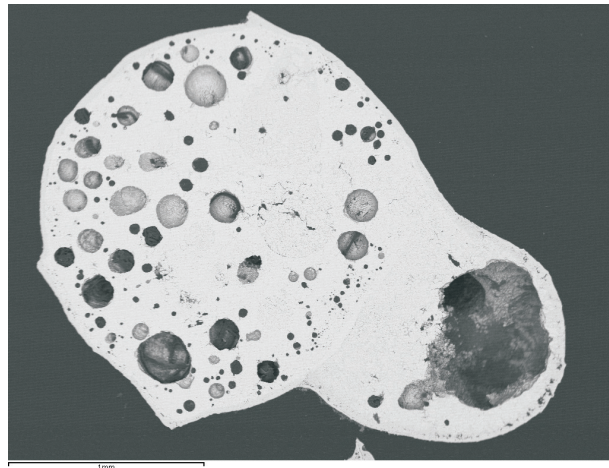
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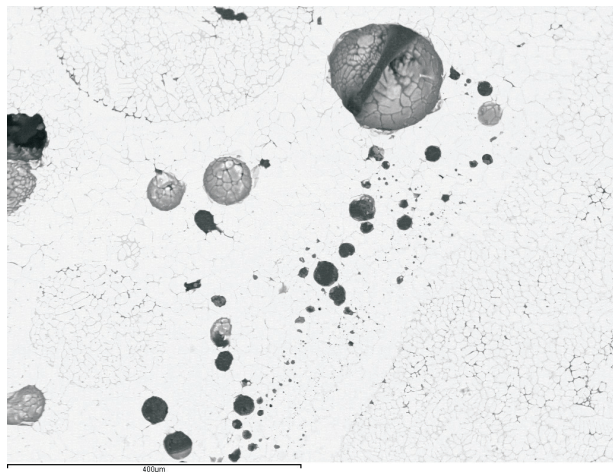
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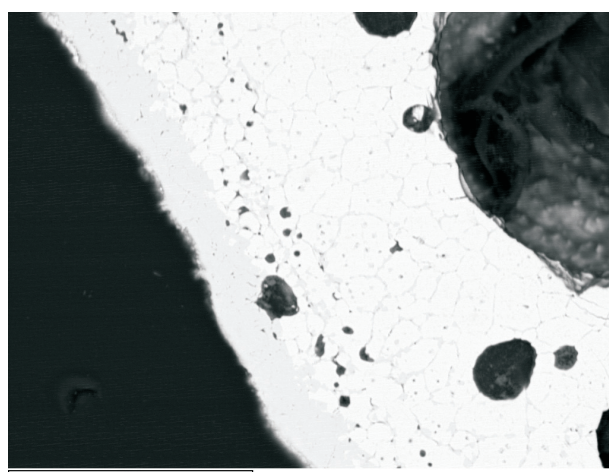
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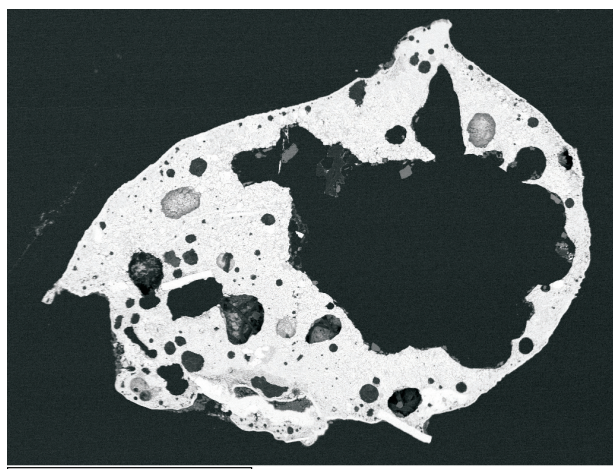
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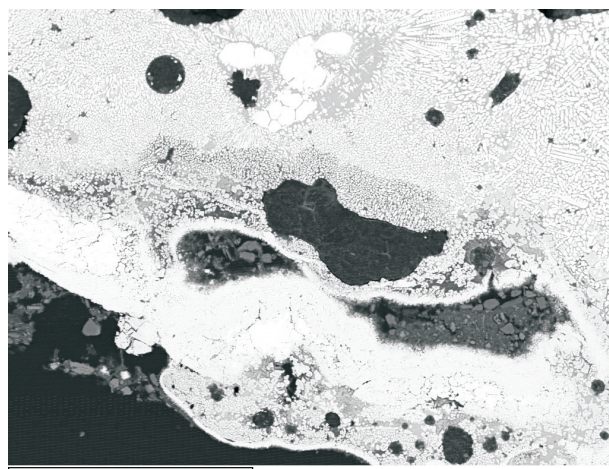
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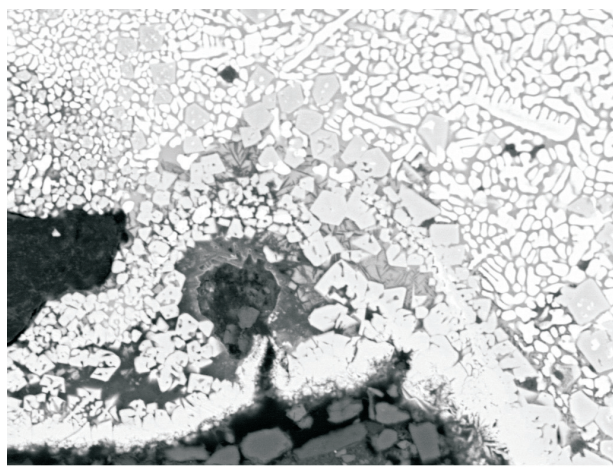
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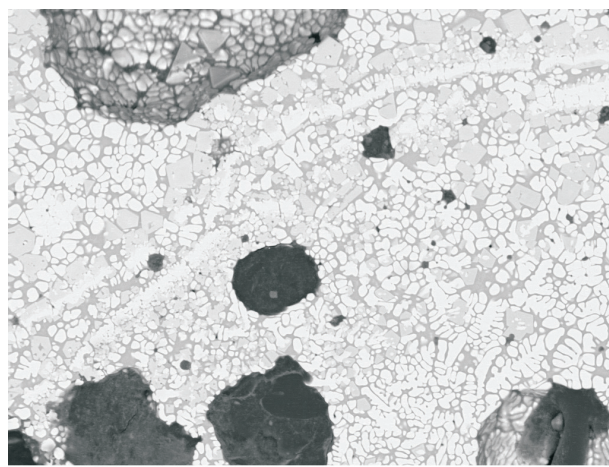
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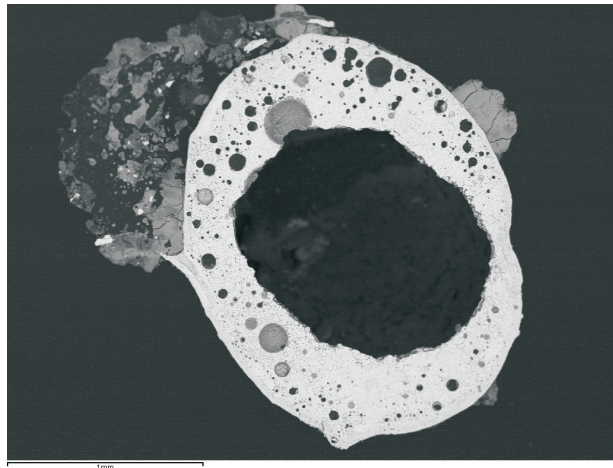
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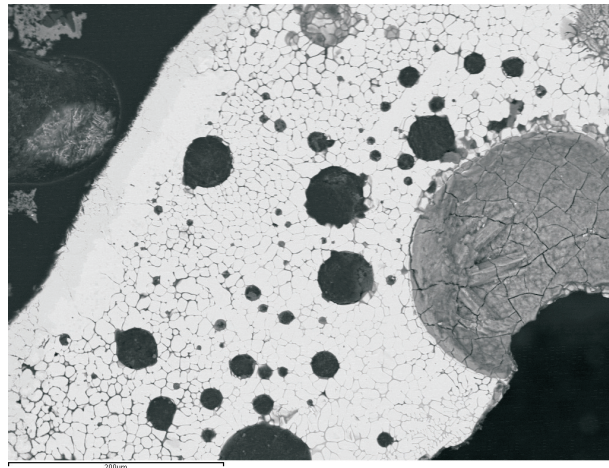
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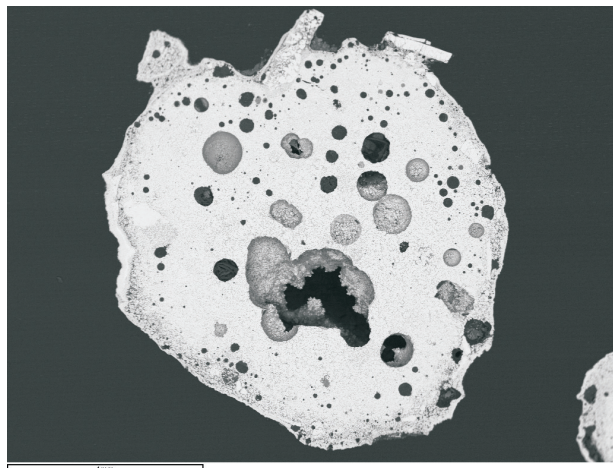
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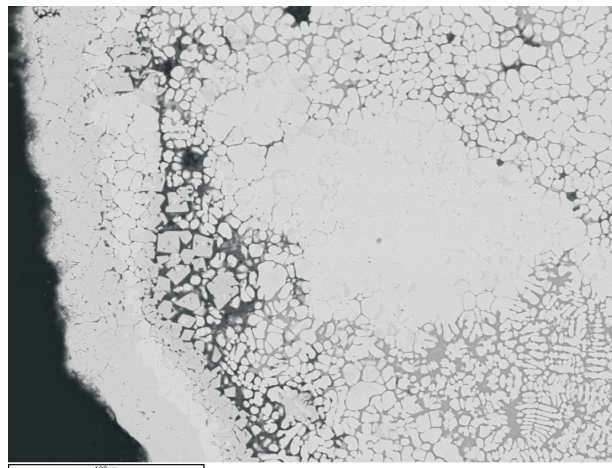
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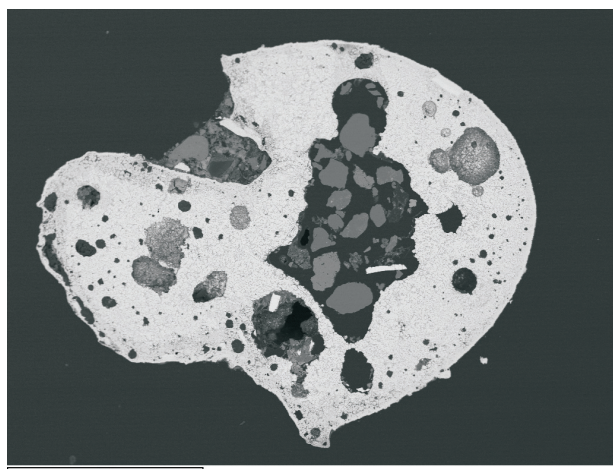
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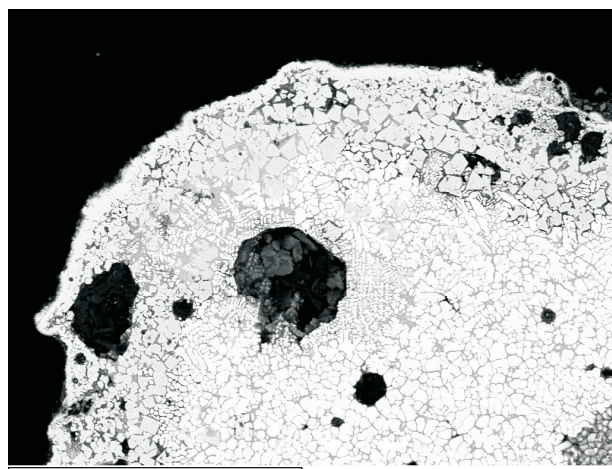
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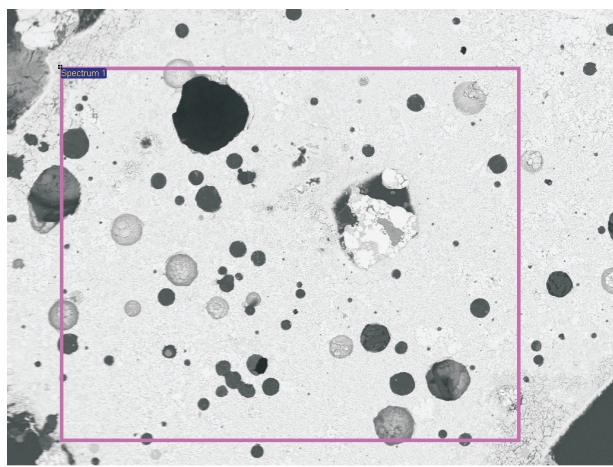
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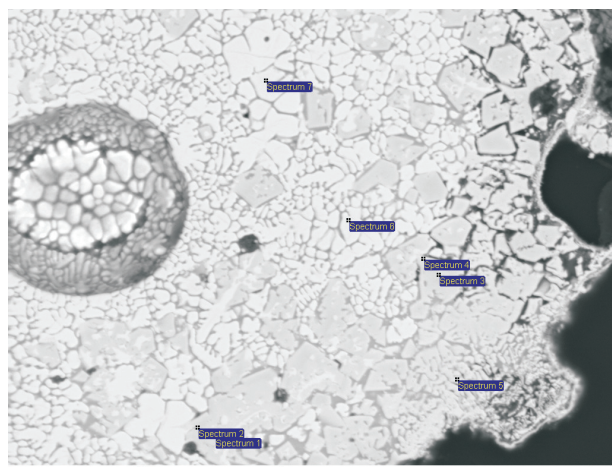
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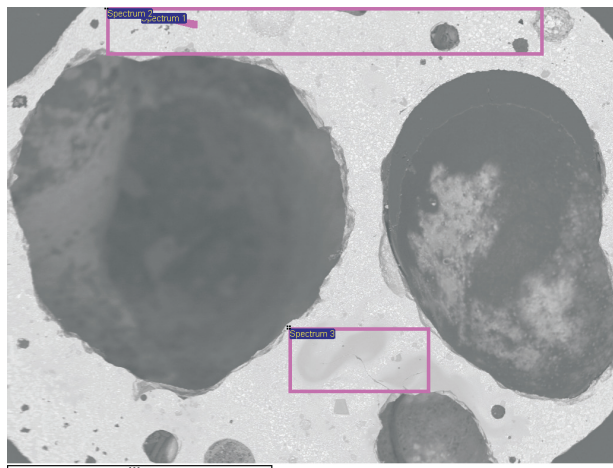
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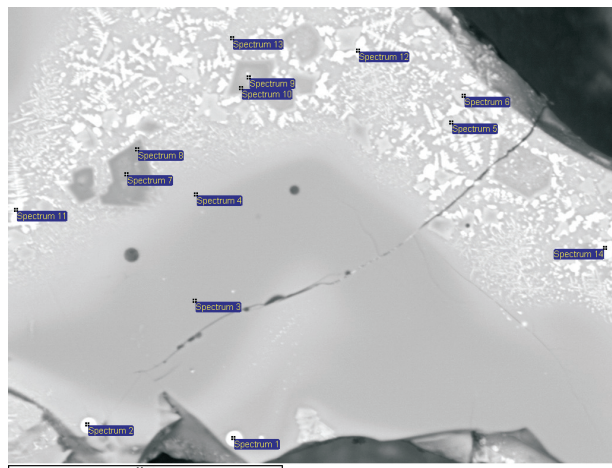
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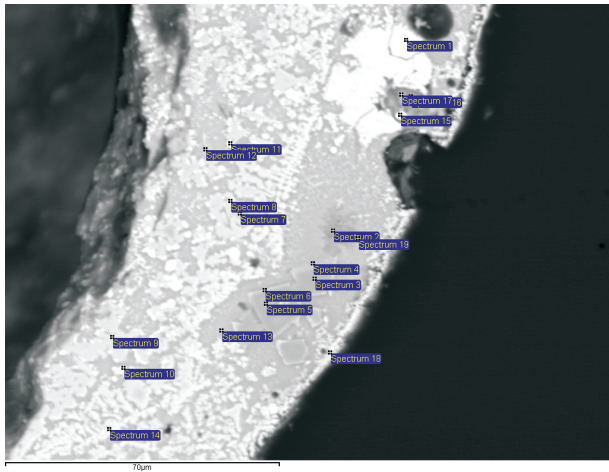
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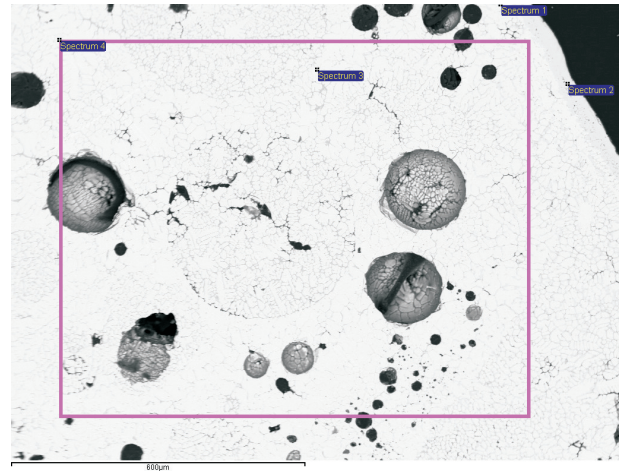
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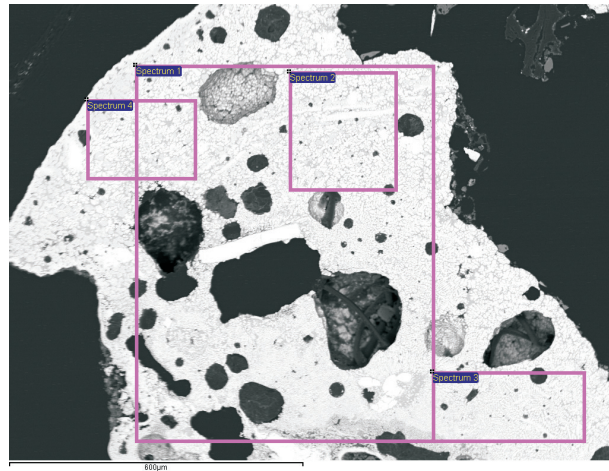
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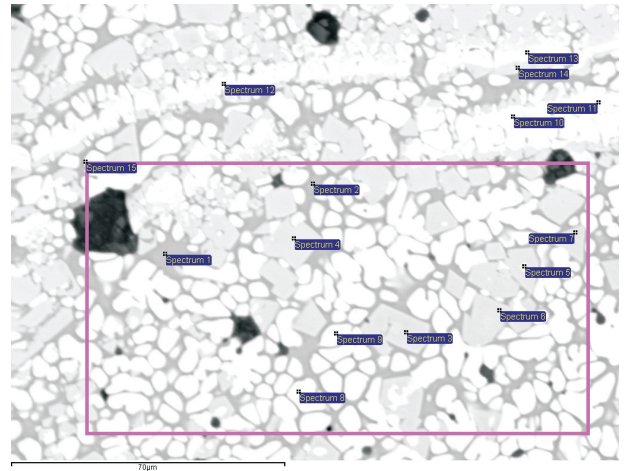
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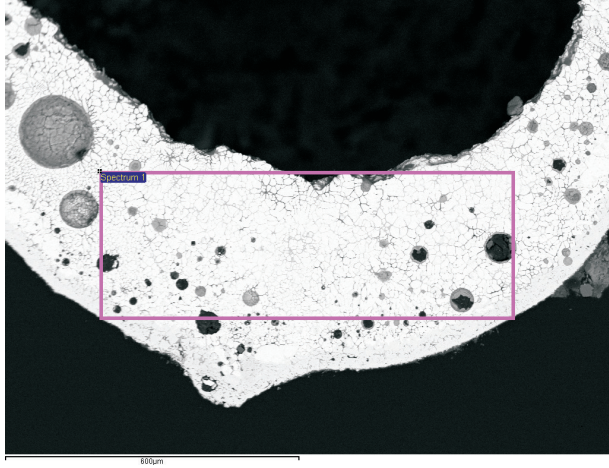
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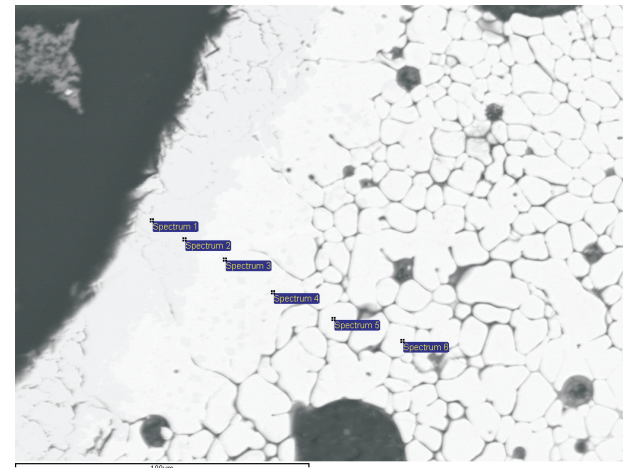
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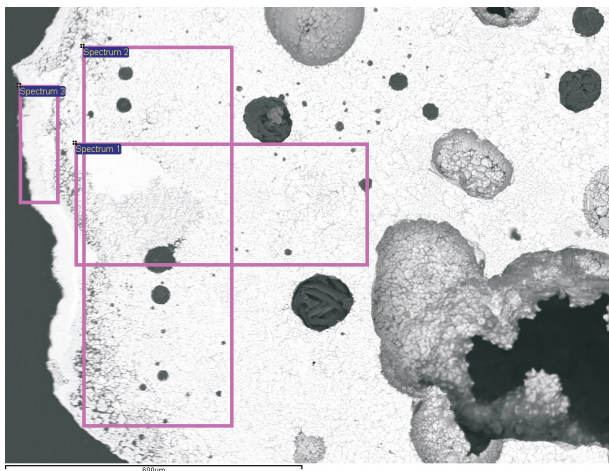
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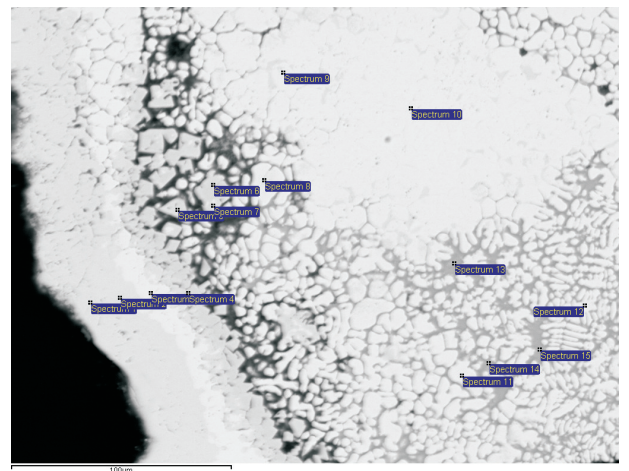
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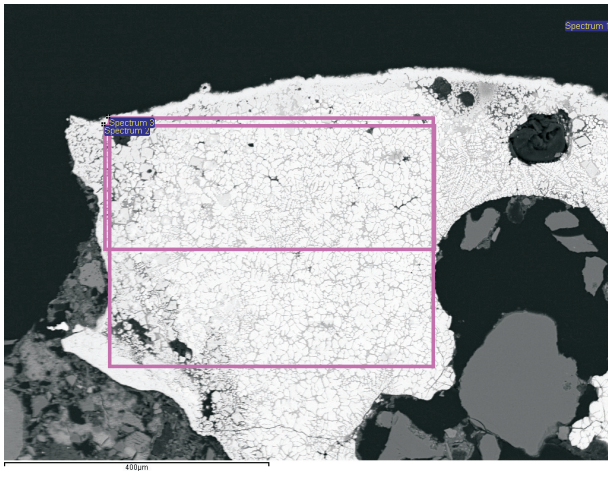
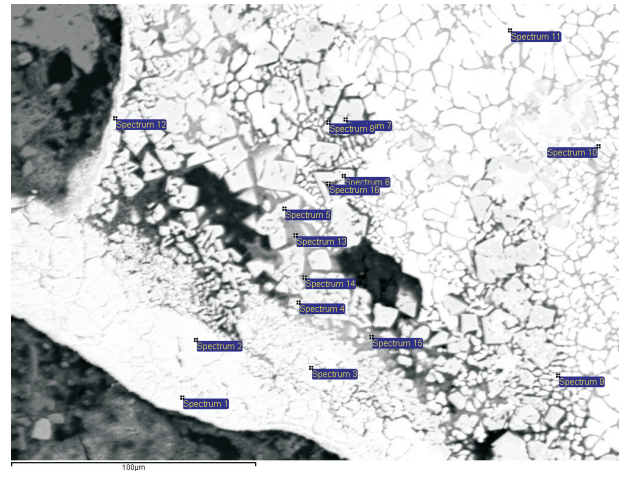
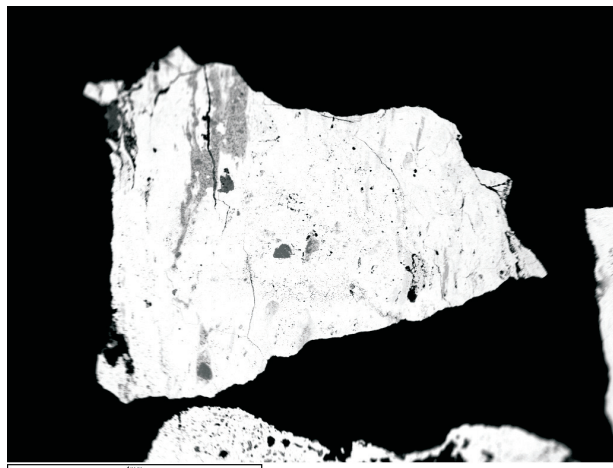


Plate 17

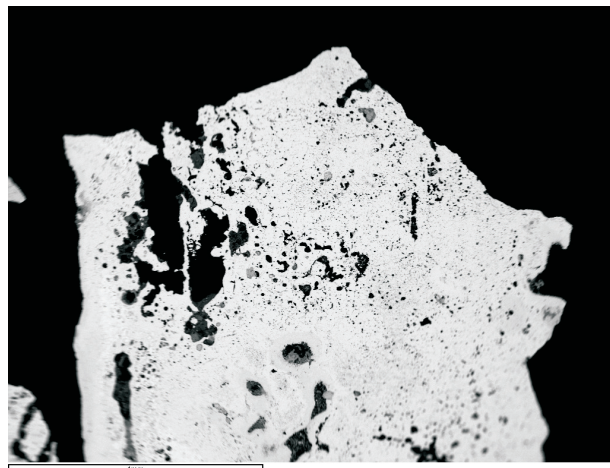
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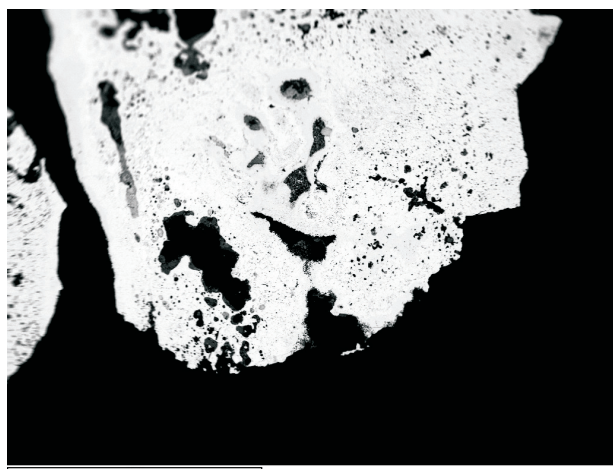
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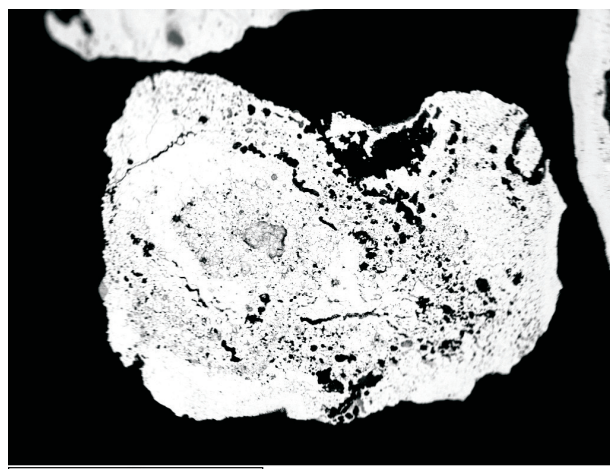
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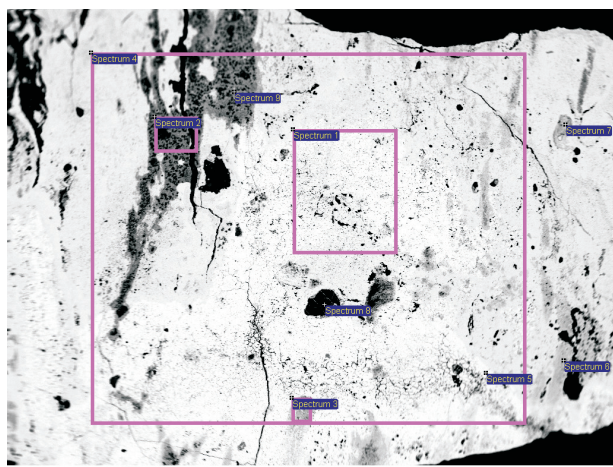
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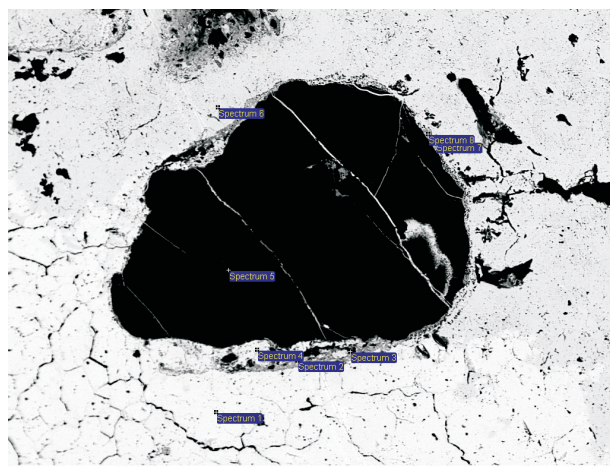
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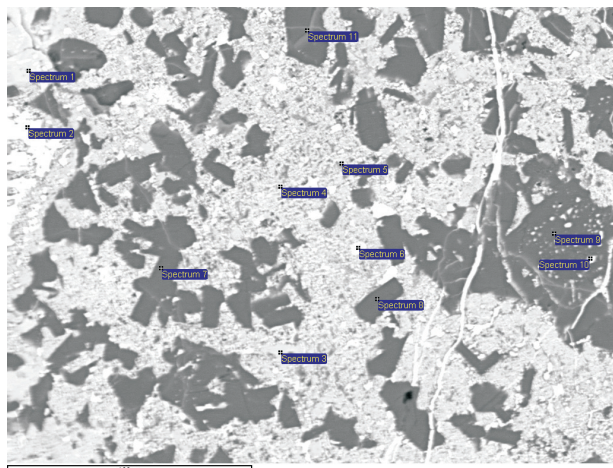
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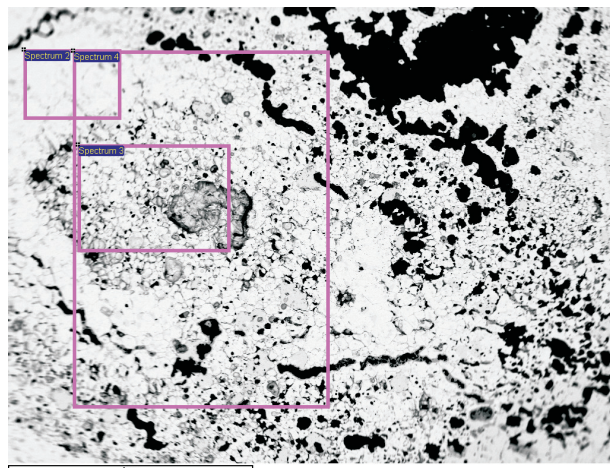
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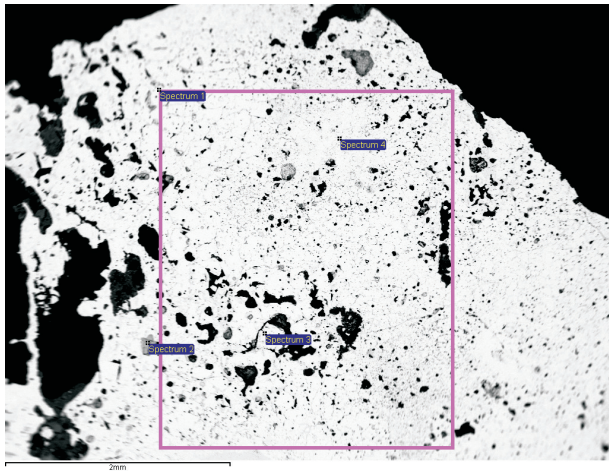
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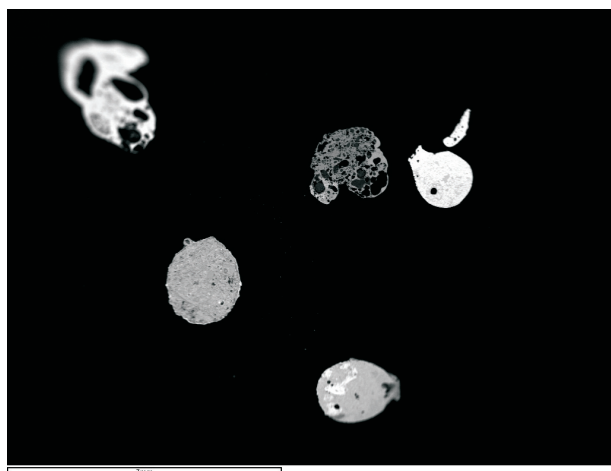
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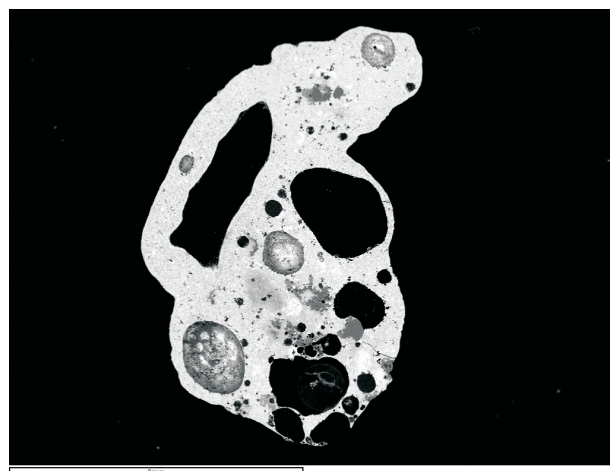
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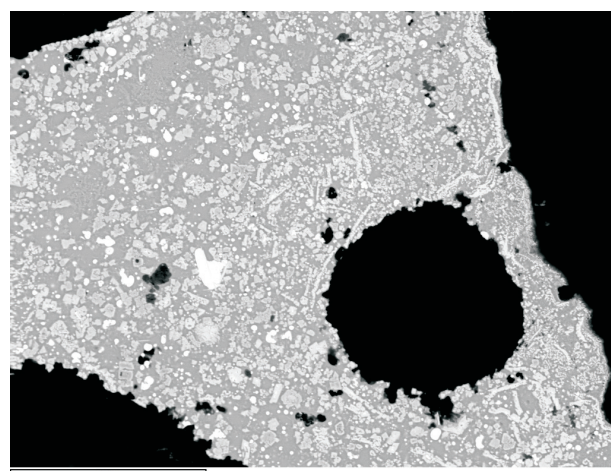
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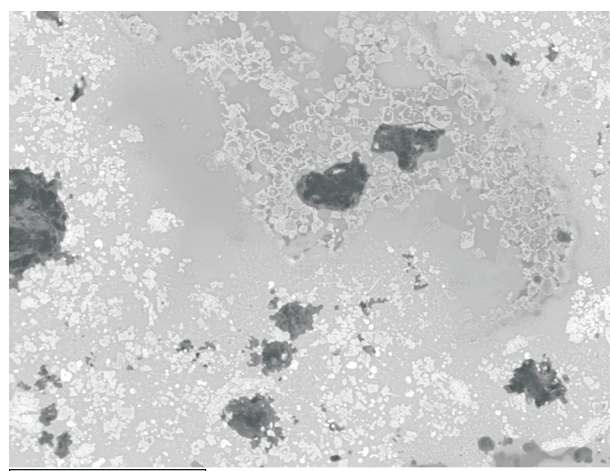
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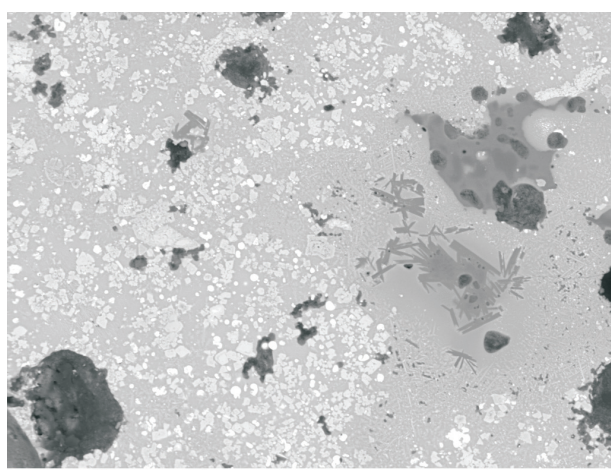
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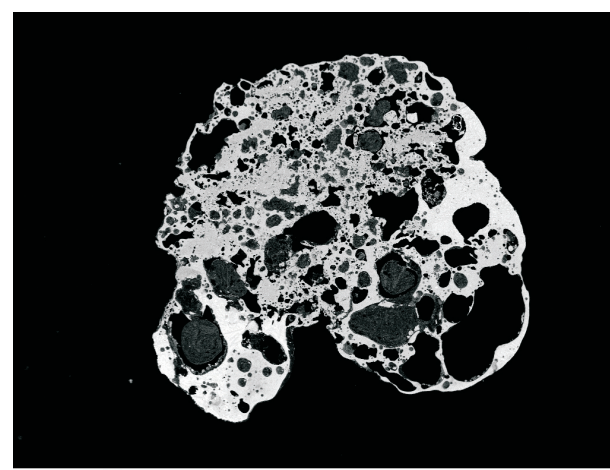
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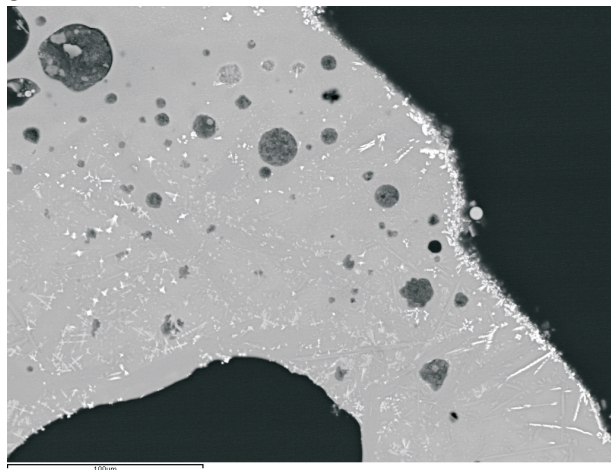
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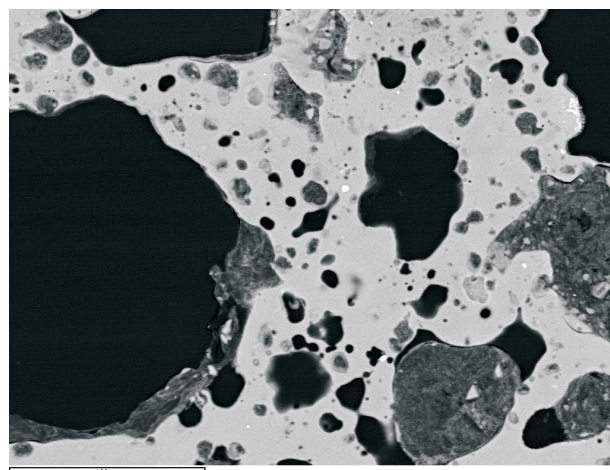
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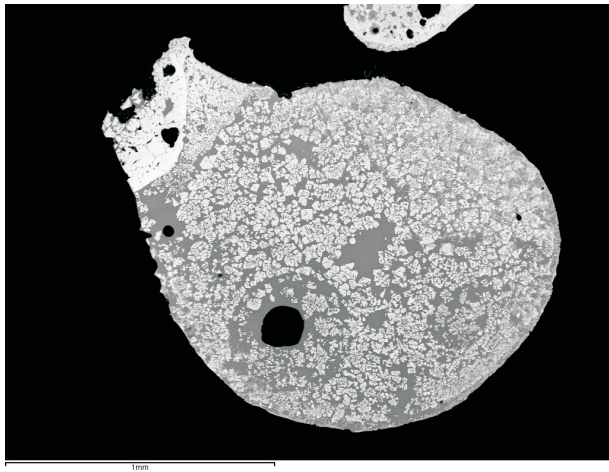
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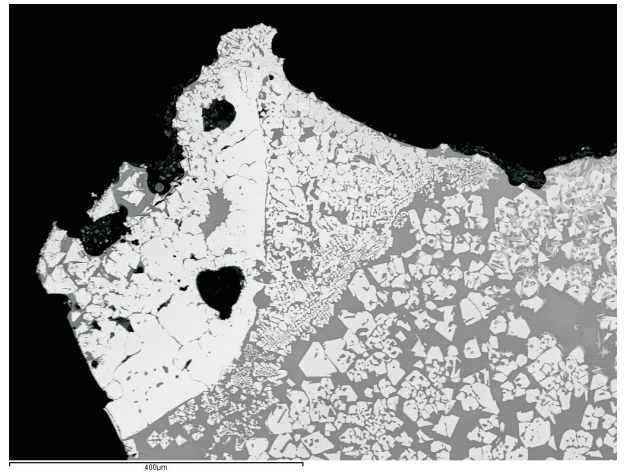
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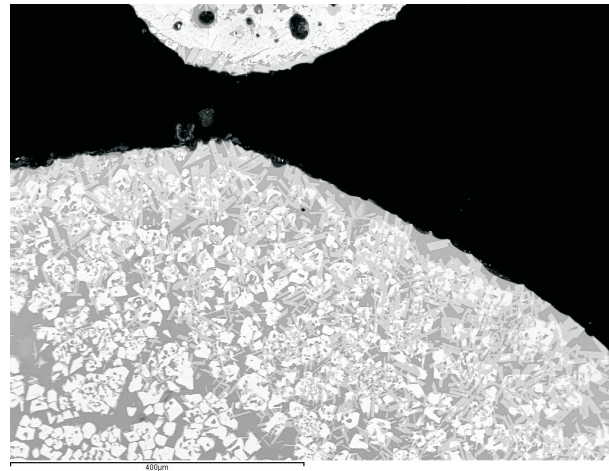
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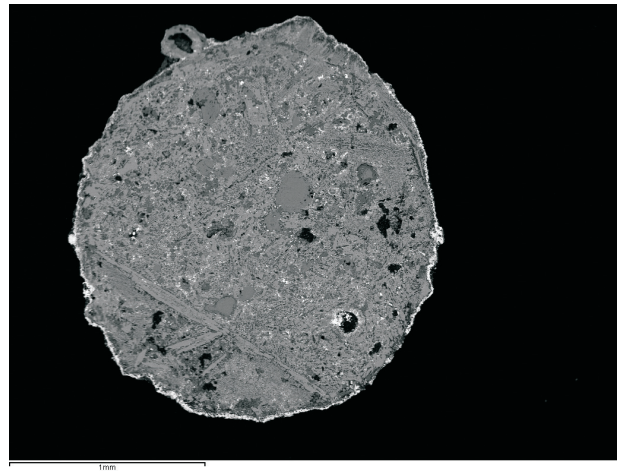
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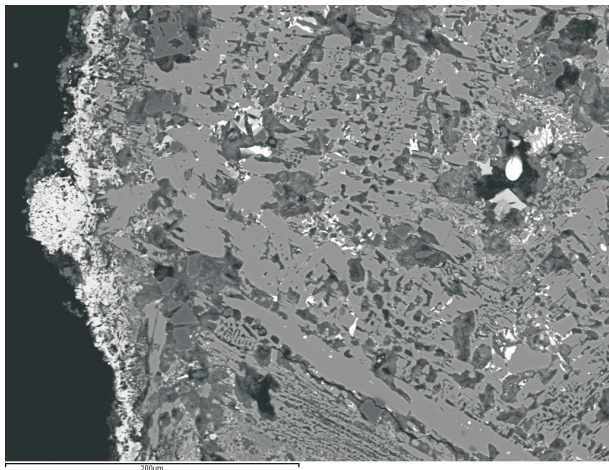
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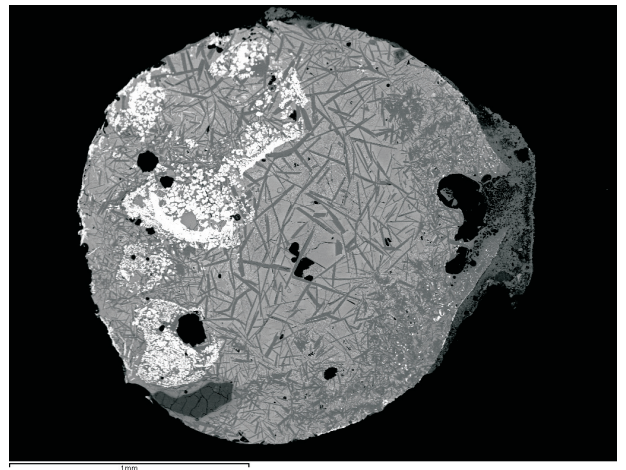
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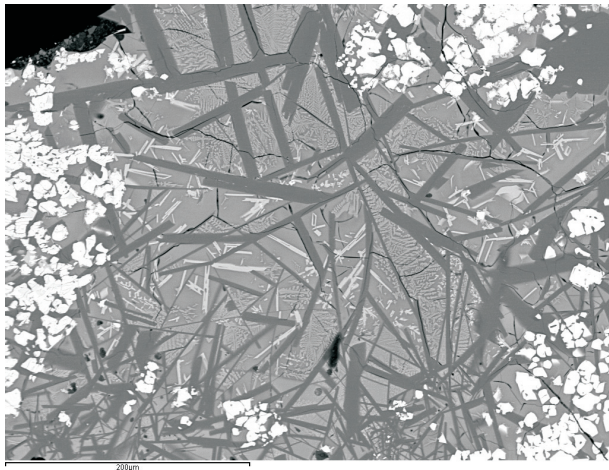
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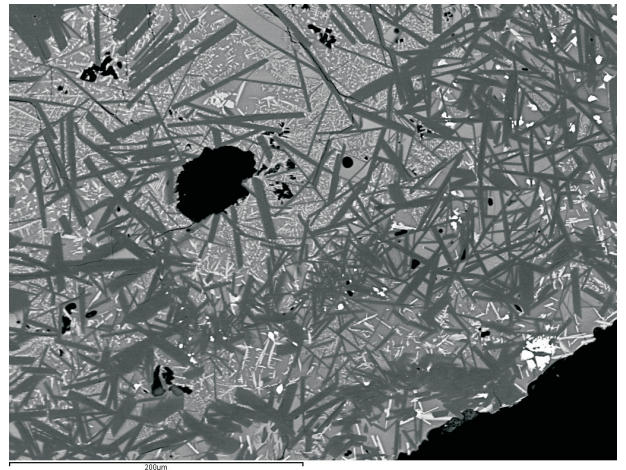
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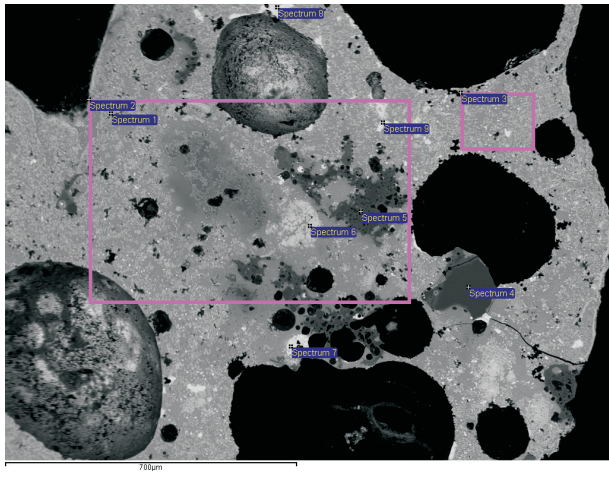
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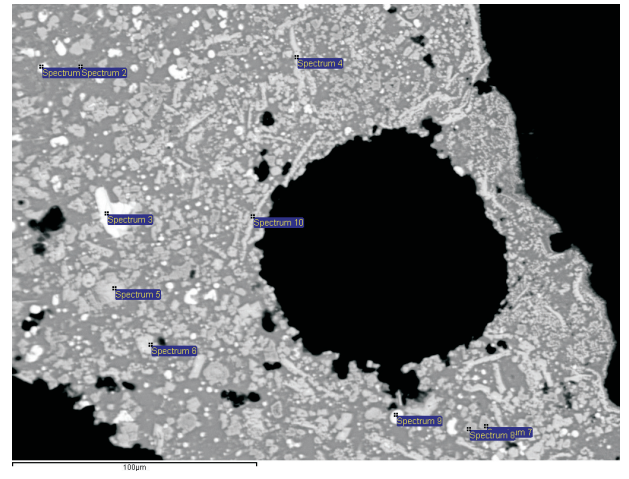
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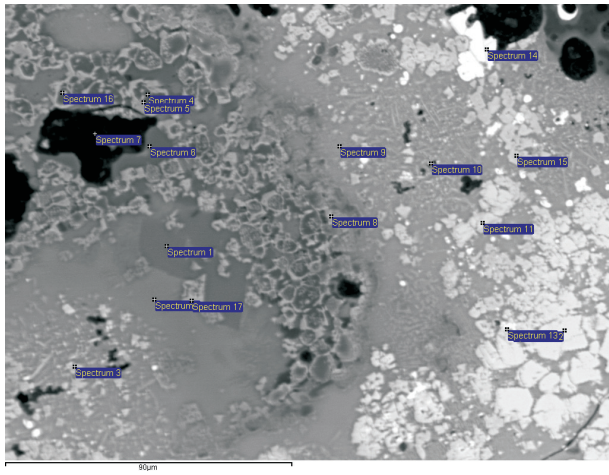
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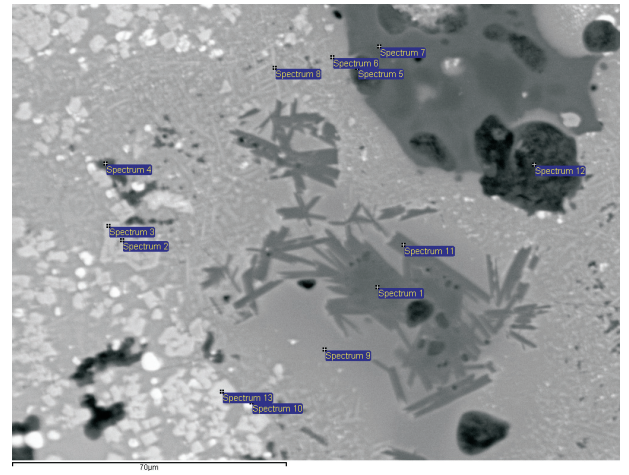
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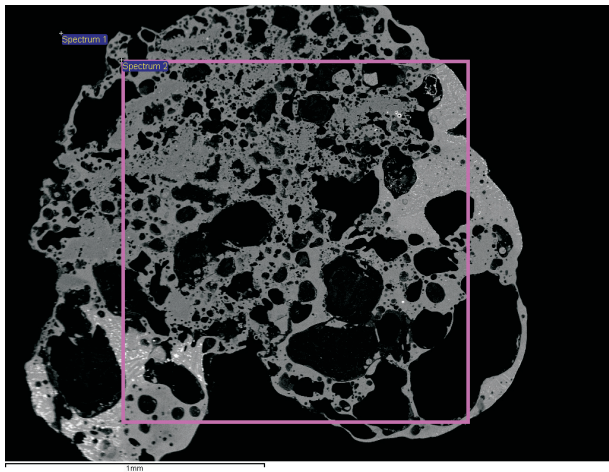
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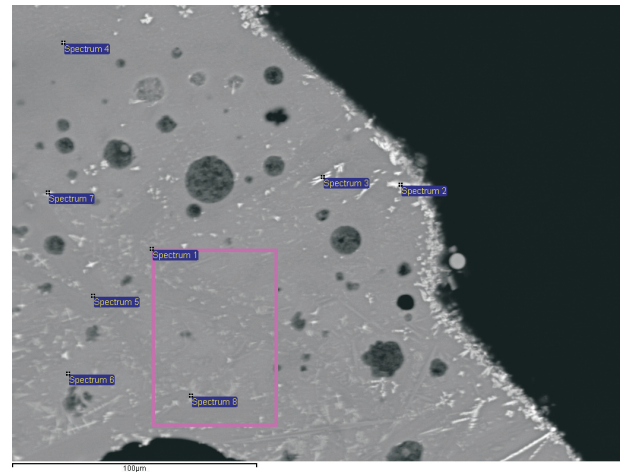
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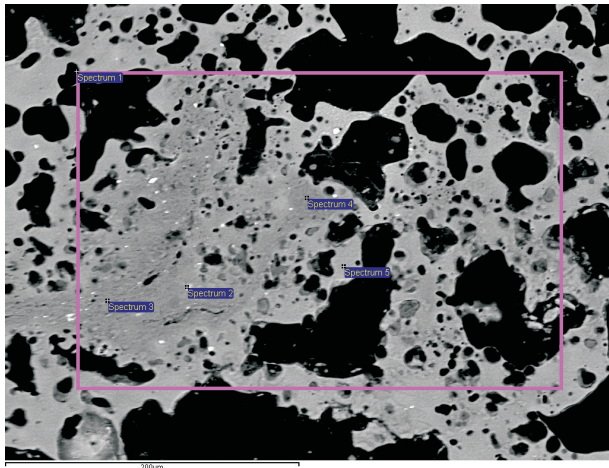
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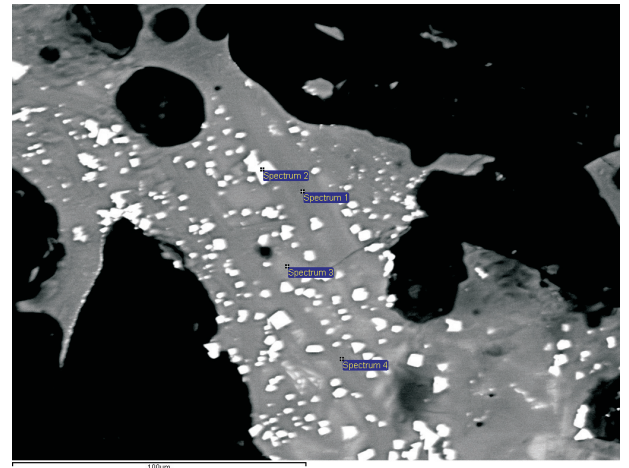
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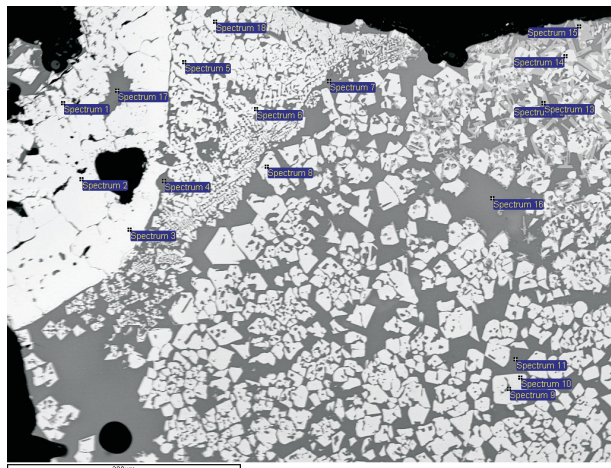
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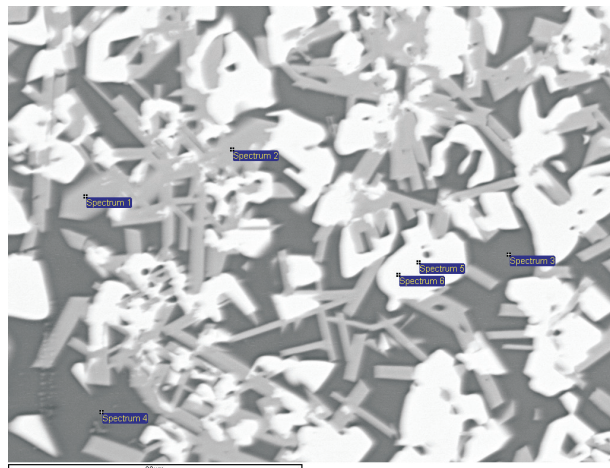
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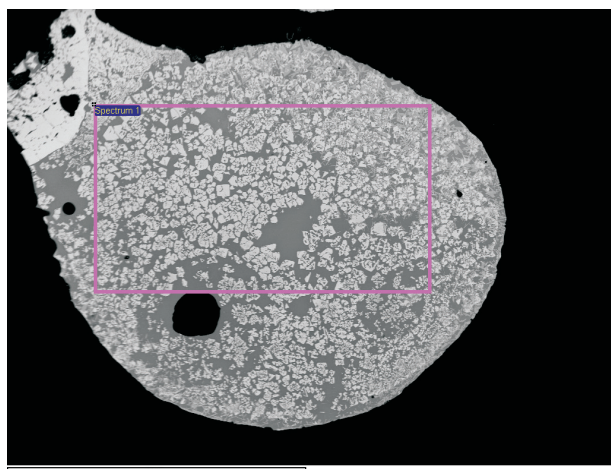
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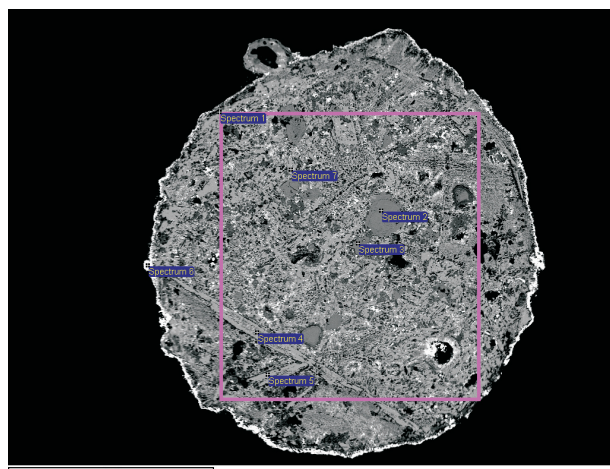
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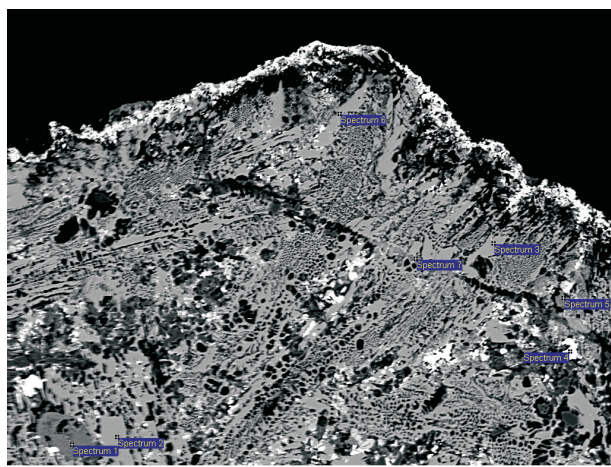
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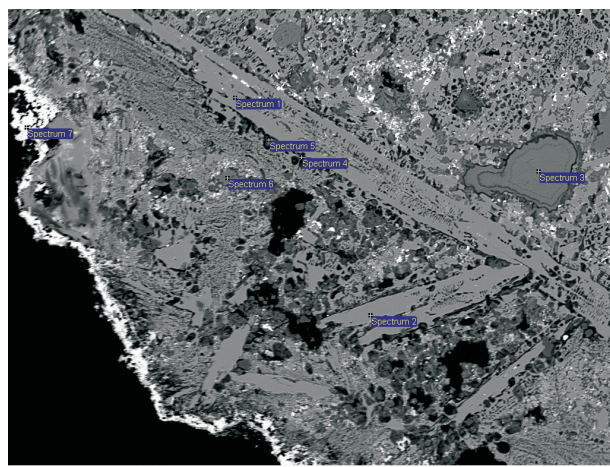
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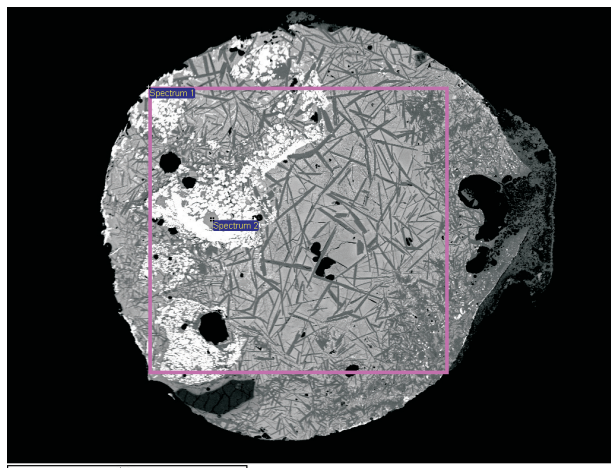
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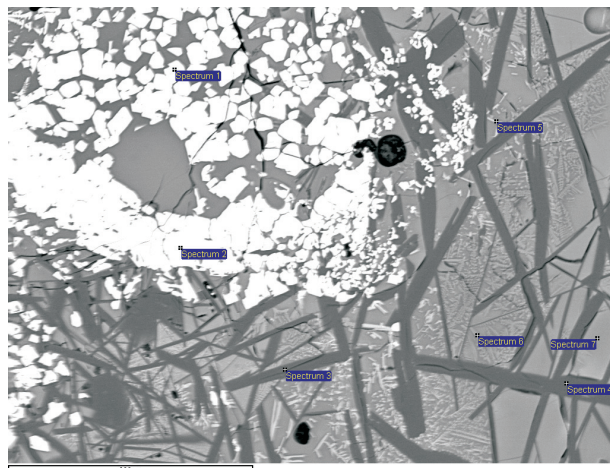
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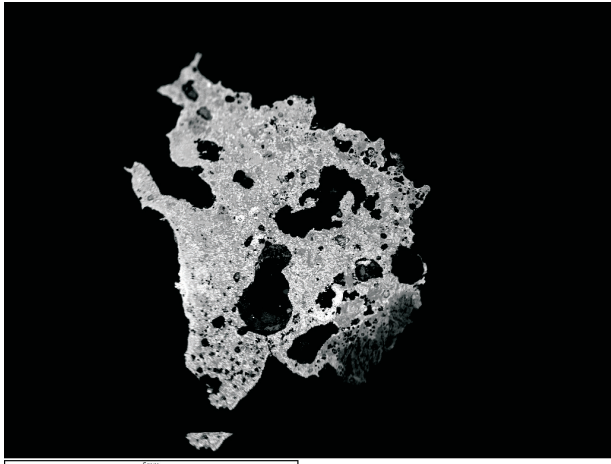
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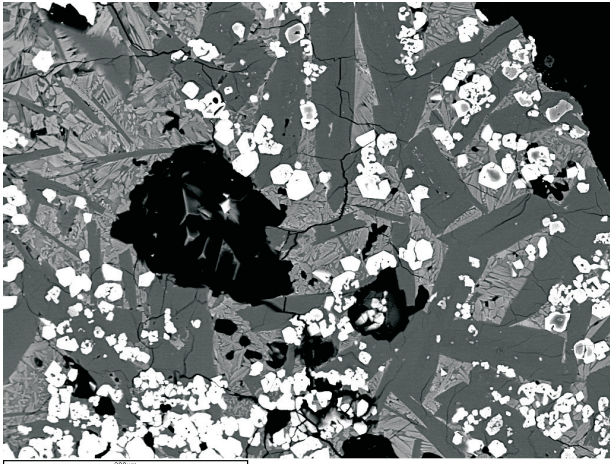
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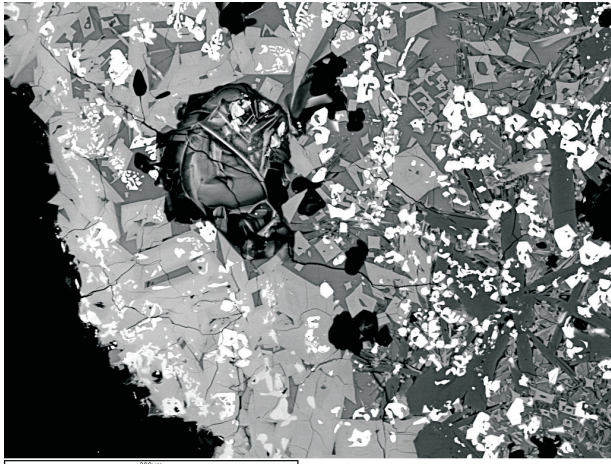
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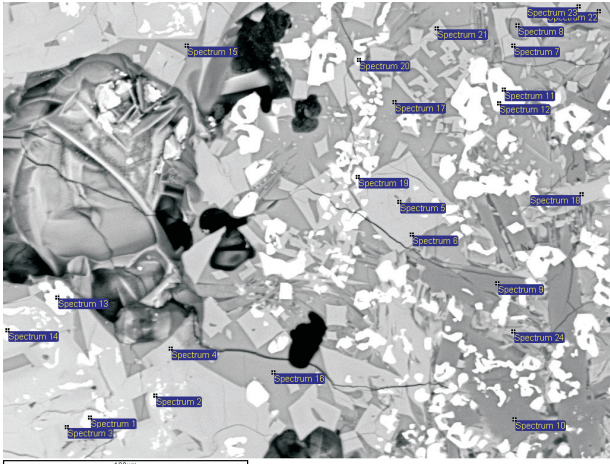
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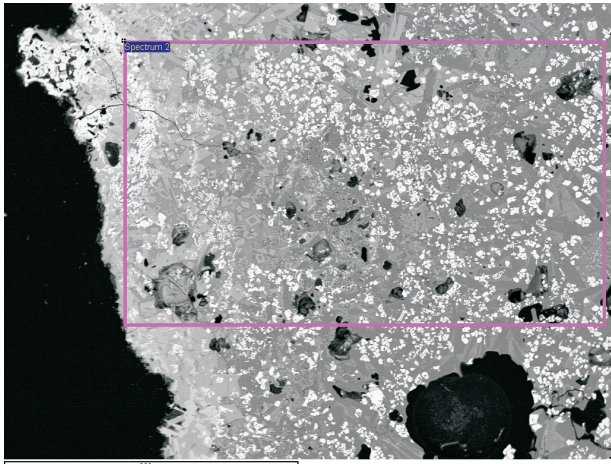
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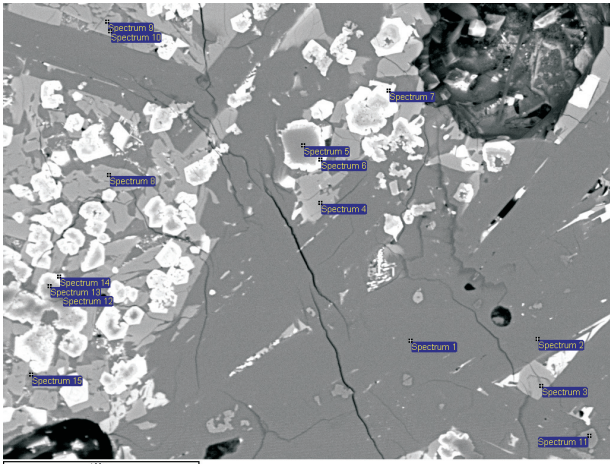
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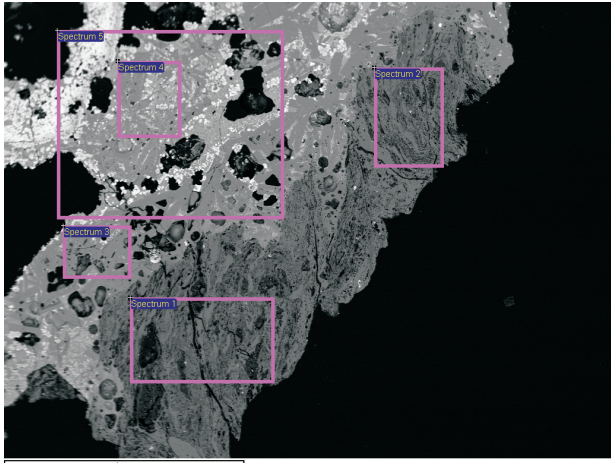
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# GeoArch



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