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Archaeometallurgical residues from field D1, Brownie Cross, Shaugh Prior, Devon (Avon SWW Pipeline)

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Abstract

Slags from the Brownie Cross medieval tin smelting site proved to be unusually rich in tungsten. This unusual composition means that many of the slags have unusual and novel textures and mineral phases, including the dominant mineral of many of the samples which appears to be an undescribed iron-, magnesium- and manganese-tungstate.

The slags are divided into three compositional and textural groups, which probably reflect different source materials – with varying degrees of tungsten minerals (probably wolframite) having co-occurred with the cassiterite. In the slags with lower tungsten contents some showed elevated titanium contents and thus more closely resembled slags derived from alluvial tin in other parts of the orefield. The dominant tungsten-rich varieties probably reflect the site's proximity to the Hemerdon Bal tungsten mineralisation, but whether the greisen was worked directly, or whether the minerals were won from a derived alluvial source is not clear.

Only the slags with the lowest tungsten contents show the stretched glass rod morphology typical of the slags from Crift Farm. Most of the Brownie Cross slags are in the form of slag sheets which have been scraped or pulled from the surface of the tapped metal when they were either solid or plastic. The faces interpreted as being the lower surfaces of these thin sheets often show signs of interaction with the underlying tin, and may contain a variety of 'exotic' materials – including tin, hardhead, tungsten metal and coarse-grained tungstate minerals. One interesting form of inclusion closely resembled hammerscale and probably represents a thin oxide layer formed on the surface of iron-bearing tin.

The most tungsten-rich slags frequently show textures indicative of the presence of an emulsion in the melt, which although variable typically showed droplets of tungsten-rich melt dispersed through a less tungsten-rich matrix. As expected from a high viscosity liquid, the tungsten-rich components showed a particularly poor slag-metal separation and droplets of tin were common.

The slag system as a whole showed very high tin content, particularly in the most tungsten-rich examples. The tin was present not only as metal droplets, but as a major component of the glass phase. Tin varied inversely with silica in these glasses, with the most extreme composition being around 55% SnO and 21%SiO_2. This provides an excellent illustration of the property that gave that gave rise to the word 'wolfram', the old name for tungsten, derived from 'wolf rahm' – wolf foam in German, describing the tungsten-rich slag's voracious appetite for tin. The high viscosity of the slag produced by the elevated tungsten content of the ores smelted at Brownie Cross must have given rise to various problems in smelting, not just a poor yield of tin. The continuation of the operation despite these issues reflects the value of tin in the medieval period, when SW Dartmoor became a more significant producer, culminating in the elevation of Plympton to a Stannary Town in 1328.

The unusual composition of the ores worked at Brownie Cross means that it is difficult to employ the Brownie Cross site as evidence for the evolution of tin smelting technology in general. However, the textures of the slags, in particular the inclusions, would support the interpretation that a float was being used to assist with slag-metal separation and possibly with iron removal too. Despite the tungsten problem, the quality of tin produced may have been very good, with the analysed droplets being of high purity.

Contents

Methods

Materials from this site were assessed together with those from site D5 (Young & Kearns 2011). The assessment recommended further investigation because the technology of medieval tin smelting is very poorly understood and this site had the potential to yield valuable information.

From the materials examined for the evaluation, a variety of samples were selected as being possibly suitable for analysis and twenty samples (Table 1) were taken forward for detailed analysis.

The selected samples were drawn from just two contexts (1146) and (1349B), each with a large slag assemblage, to permit some degree of determination of variety within the assemblages, without being restricted to just a single context. Both contexts were slag deposits lying over the area of pit [1398] in the southwestern part of the structure.

Electron microscopy was undertaken on the Cambridge Instruments (LEO) S360 analytical electron microscope in the School of Earth and Ocean Sciences, Cardiff University. Microanalysis was undertaken using the system's Oxford Instruments INCA ENERGY energy-dispersive x-ray analysis system (EDX). All petrographic images presented in this report are backscattered electron photomicrographs. The polished blocks for investigation on the SEM were prepared in the Earth Science Department, The Open University.

Locations of analyses are presented as sample-area-analysis (e.g. AVN4 SOI2 #3), where the samples were labelled AVN1 to AVN20, the area of the sample is referred to as SOIn (SOI = *Site Of Interest* in the terminology of the INCA microanalysis software) and individual analyses (points or areas) are labelled #m.

In order to make the microanalytical results simply comparable across materials (and also sites), no attempt has been made to adjust for the oxidation state of elements with variable valency. The figures employed in the report have therefore been constructed with elements expressed as oxides in weight% calculated stoichiometrically, except for mineral structure calculations, where the measured oxygen has been used. Iron is reported in the report expressed as FeO, manganese as MnO, tin as SnO and tungsten as WO_3.

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

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

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Results

Mineralogy

Slags

Investigation of the prepared samples quickly demonstrated that the materials involved were extremely unusual. Three distinct sets of microstructures were present in the silicate slags of the assemblage (Figure 1; Plate 1; Table 2) and these sets correspond to the chemical compositional groupings:

Group 1 slags - with bulk tungsten contents below detection; the sample was a simple glass (at least at the limits of the resolution of the SEM).
(sample AVN6)

Group 2 slags - with 5-15% WO_3 and FeO/WO_3 of > 1 (approximately); the microstructure comprises spinels +/- ilmenite in glass. Locally there are other mineral phases such as olivine and Fe-cordierite. Group 2 slags also typically show a slightly higher alumina to silica ratio than the group 3 slags (although the fields overlap): the average alumina:silica ratio for Group 2 is 0.42, whereas for Group 3 it is 0.37. The Group 2 slags are also distinguished by elevated titanium (average of 4.1 wt% TiO_2, compared with an average of 3.5% in Group 1 and 1.3% in Group3).
(samples AVN1, 2, 5).

Group 3 slags - in slags with >15% WO_3 and FeO/WO_3 < 1 the principle crystalline phase is the tungstate mineral 'A'
(samples AVN 4, 6,8, 9, 10, 12, 13, 15, 16, 17, 18, 19 and 20; sample AVN7 is transitional to Group 2).

Spinels: three groups of spinels were identified – a close to end-member magnetite, a phase with a composition corresponding to a heavily Ti- and Al-substituted magnetite and a hercynite with major magnesium substitution (Figure 2).

The 'Ti- and Al- substituted magnetite' shows approximately 0.5 atoms of titanium, 0.7 atoms of aluminium, 0.07 atoms of magnesium, 0.1 atoms of magnesium and 1.6 atoms of iron per formula unit (calculated with 4 oxygens). This does not appear to be a true mineral composition and is likely to be a mixture of titanium-rich and aluminium-rich phases. In AVN2 SOI2 this material lies at the core of zone spinels, the outer parts of which are of Mg-hercynite (see below) and may thus be a mixture of a titanium-rich mineral and Mg-hercynite.

The hercynite shows minor substitution of manganese and major substitution of magnesium for iron, corresponding to a range of 18-51% of the spinel (*sensu stricto*) end member. In AVN2 SOI2 this material forms the outer part of zoned euhedral spinel grains with Ti-rich cores. In this context the degree of Mg replacement rises slightly from inner to marginal parts of the grain. In AVN2 SOI7 poorly delimited Mg-hercynite appears to locally overgrow the ilmenite

Ilmenite: Ilmenite was present in AVN2 as narrow (2-4 µm wide), elongate, segmented to dendritic crystals. It formed later than the spinels, the cordierite and the possible rhönite.

Ti-bearing alumno-silicate(?): AVN2 contained a finely dendritic mineral of low-electron density, which was closely associated with the ilmenite in the sample. Identification of this material was not possible because of its fine grain size and rather diffuse appearance even at high magnification. The best analyses of the phase suggest a composition close to the of a rhönite-aenigmatite group mineral, but the identification is not certain and the morphology does not resemble the usual morphology of rhönite in slags (both rhönite and aenigmatite were however reported in tin slags by Chirikure *et al.* 2010). The analyses show appreciable levels of both sodium and potassium.

Cordierite: this phase was only identified in a limited area of AVN2 (SOI7) in which it appears as hexagonal-sectioned euhedral grains 5-10µm across.

Tungstate 'A': The major crystalline component of the tungsten-rich slags is a phase for which there appears to be no equivalent in the published literature. EDS data from tungstates are particularly prone to error in the measurement of the oxygen present. Small errors in the estimation of the weight of oxygen present generate much larger errors in the calculation of the atom% of oxygen, because of the large disparity in the atomic weights of oxygen and tungsten. It is this phenomenon that is probably responsible for the spread of data in the plot of (Mn+Mg+Fe+Ti) vs W (Figure 3, lower right).

The natural tungstate minerals containing iron and manganese lie in the wolframite group, between ferberite ($FeWO_4$) and hübnerite ($MnWO_4$). There is a a degree of solid solution between the wolframite and scheelite ($CaWO_4$) groups at high temperature (Grubb 1967) leading to exsolution on cooling. Neither the scheelite not wolframite groups are known to allow magnesium to substitute for iron – in the case of Chang's (1967) study of scheelite, solid solution of magnesium was limited to below 2%.

The tungstate mineral in this study appears to exist in two different, but related, compositional ranges (Figure 3):

type 1. an iron-manganese tungstate with a wide range of the manganese end-member from 12% to 81%

type 2. an iron-manganese-magnesium tungstate with a narrow range of substitution, with 6% to 19% (average 12%) of the magnesium end-member and 2% to 25% (average 15%) of the manganese end-member.

In both cases the W:O ratio has been determined as close to 3:10. If the formula unit is calculated on the basis of 10 oxygens, then:

type 1 (n = 6) has averages of W = 3.05 and (Fe+Mg+Mn+Ti) = 3.02.

type 2 (n = 36) has averages of W = 3.00 and (Fe+Mg+Mn+Ti) = 3.00.

For a wolframite or scheelite group mineral the equivalent values for W and (Fe+Mg+Mn+Ti) would be 2.5 per formula.

So, to accept these materials as wolframite group minerals it would be necessary to have had a systematic underestimate of oxygen in the analysis by 17%, to relegate the integer ratios in the calculated formula to chance and to accept the substitution of magnesium into the wolframite structure which has neither been observed in nature nor been able to be synthesised in the laboratory.

The possibility of a systematic error in the estimation of oxygen in the EDS analyses is quite possible, given the issues described above. The discovery of a new range of solid solution in a well-studied mineral group is far less likely.

The alternative is that this material represents an entirely 'new' phase. If the analytical data are taken at face value, then the mineral has the general formula $(R^{II})_3 W_3 O_{10}$. Paratungstates incorporating a W_3O_{10} unit are known, but these have a valency of one (Huang *et al.* 2006). Clearly a structure involving tri-tungsten oxide clusters is possible here – but would be a very novel material.

Solving this enigma is clearly highly desirable, but is well beyond the scope of the current project. For the time being the term ***tungstate mineral 'A'*** is used in this project.

Scheelite: this phase was identified only in AVN2 SOI6 where it occurs as stubby, angular, dendrites. The analyses show low levels of iron and tin, with a slight deficiency of calcium compared to tungsten. It is likely that some of these impurities are present as phase inclusions rather than as impurities in the scheelite itself.

Olivine: olivine group minerals were recorded from samples AVN5, AVN7 and AVN17. In AVN5 the olivines were growing off the 'scale'-like oxide sheet, whereas in AVN7 and AVN17 they were close to coarse-grained tungstate mineral 'A'.

The olivines present were compositionally different in the three examples, but were consistent within each example. In AVN5 the olivines were Fa70-72Fo30-28 with 2% manganese substitution. In AVN7 they were Fa85-87Fo15-13 with 7-8% manganese substation. Those in AVN7 were more magnesian at Fa56-57Fo44-43 with 6-7% manganese substitution.

Tin: blebs (prills) of tin occur widely in the slags. They are mainly very small (mainly less than 10 µm, almost all less than 50 µm, but rare examples seen of up to 500 µm). Wherever analysed, the tin appeared to be of high purity. Iron was occasionally recorded at close to the limit of detection. Aluminium was more widely recorded in the EDS analyses, but this is believed to be as a result of the tin, or tin oxide, trapping alumina particles from the polishing process. The available evidence therefore suggests the production of good quality of tin, although the small prills are not necessarily representative of the bulk metal produced.

Glass: the glass phase (or what has been assumed to be glass – it may be microcrystalline in some cases) is only moderately siliceous in the Group 1 slag, at 43-48 wt% silica (Table 2), around 17% alumina, with moderate levels of iron (11% as FeO) and titania (3.6%), but with a fairly high tin content (average 16%). For Groups 2 and 3 there is a rather variable composition with much less silica (range 18-49%, mean 28%) because of the highly elevated levels of tin (average 35% SnO_2) and tungsten (average 8% WO_3). Interestingly, the limits of the variation in the glass composition of these two groups of slags is approximately the same, but the actual variation in the Group 3 slags is less – reflecting the simplicity of the associated crystalline material, which is limited to tungstate 'A', in comparison to the Group 2 slags which have crystallised a variety of minerals.

High-tin glasses have been discussed by Chrikure *et al*. (2010, p. 1663-4). They observed an inverse correlation between tin oxide and silica in the glasses of slags from Rooiberg, indicating that under reducing conditions SnO becomes a network-former in the glass. Both SnO and WO_3 will act to increase the viscosity of the glass, whereas FeO will tend to reduce it. The ratio of FeO:(SnO+WO3) will thus be an indicator of viscosity: a high ratio will give a low viscosity, a tendency for crystallisation and easier slag-metal separation; the converse will true for examples with a low ratio – leading to increased tin losses in smelting.

Metals and metal-oxide zones

Within the slag samples there were rare inclusions and zones that appeared to be rather distinct from the associated silicate slag.

These materials included *metallic tungsten* (AVN1, AVN10, AVN17, AVN19, AVN20), examples of the iron-tin intermetallics FeSn and $FeSn_2$ known as *hardhead* (AVN10, AVN20) and a variety of rather poorly characterised *tin oxides* (including examples from AVN7, AVN10, AVN15, AVN17, AVN19, AVN20). These materials are interpreted as inclusions carried by the slag, or associated with the slag, but representing material of quite distinct origin. Many of these inclusions rest near or on the margins of the slag, suggesting that they may have been acquired from the slag-metal or slag-dross interface.

Tin oxides are a major component of these materials but have proved difficult to analyse satisfactorily and they remain of uncertain precise nature. For many of the EDS analyses the oxygen content is in excess of what would be required for the minerals in the normal oxidation regime for tin: romarchite, hydroromarchite and cassiterite (Dunkle *et al.* 2003). These oxide phases often provide a matrix within which hardhead and tungsten occur (e.g. Plate 3e, f) – and so it would be very useful to be certain whether these materials represent a high temperature oxidation of tin or a low temperature alteration, but that is not possible on the current evidence.

Somewhat related to these materials are the laminar structures present in AVN5, which strongly resemble flake hammerscale, but are formed of a double oxide layer – the outer (?) of which is close to end-member magnetite, but the inner (?) is a mixed iron-tin oxide of uncertain precise nature (Plate 3a).

Metallic tungsten occurs in several samples (AVN1, AVN10, AVN17, AVN19, AVN20) and is in the form of small rounded blebs (often rather irregular where they are overgrown by tungstate minerals). In AVN1 (Plate 3c, d) the blebs are typically up to about 5 µm and overgrown with a thin oxide skin forming an aggregate particle, also associated with, or trapping, similarly sized tin prills. In AVN10(Plate 3f) and AVN20 (Plate 3e) the tungsten blebs are much smaller, are contained within a matrix of tin oxide and are spatially associated with hardhead. Slightly larger tungsten particles occur in AVN17 (Plate 3b) and these are overgrown by tungstate 'A' in euhedral grains.

One interesting component of the inclusions in AVN19 and AVN20 (Plate A20f; Plate A21a,b; Plate A22e, f; Plate 23a) is the presence of very large crystals (rather equant shapes of up to 300 µm)of tungstate 'A' with rounded outlines and carious textures indicative of resorption. The disparity in grain size with the tungstate mineral in the adjacent slag matrix suggests that these may be crystals that have been inherited from an earlier slower phase of crystallisation, perhaps within the furnace.

Detailed notes on the samples

AVN1: *(1349B), large fraction, <29>*
(Plate A1)
A section of elliptical cross-section glass 'rod', 20mm x 8mm with strongly fibrous structure. 40mm long (16g).

The body of the specimen is a banded glass (Plate A1e) bearing blebs of tin and small dendritic growths of up to 50 µm of a spinel (a Mn-, Ti- and Mg- bearing aluminous magnetite or a mixed phase?) cored on 5µm euhedral hercynite grains (Plate A1b).

One margin shows an included grain of metallic tungsten encased in a tungsten-iron oxide and with grains of oxidised tin (Plate A1a,c,d).

AVN2: *(1349B), large fraction, <29>*
(Plate A2, A3)
A complex contorted dark glass with elongate striations, 25mm x 15mm and 55mm long (22g).

The specimen is dominantly glass, but with rare large (up to 30µm) Mg-bearing euhedral hercynite grains (Plate A2 a,b). These are followed by elongate, sweeping dark dendritic crystals (up to 400µm; so far unidentified but appear to contain Na, Al, Si with Si:Al close to 2), which in some areas are associated with crystals of a Mn-, Ti- and Mg- bearing aluminous magnetite or mixture(?). The degree of crystallisation is patchy – with well crystallised areas in 'domains' interspersed with areas of simple glass (Plate A2a-f).

Other areas (Plate A3a) show a poorly defined, possibly relict, hercynite with the iron up to 50% substituted by magnesium, euhedral Mg-rich cordierite (10 µm), oxidised tin granules and abundant ilmenite.

One area shows the development of scheelite in stubby dendrites (and possibly rims) near partially filled vesicles. Associated minerals include segmented elongate crystals of ilmenite and droplets of oxidised tin (Plate A2f).

AVN3: *(1349B), large fraction, <29>*
35mm x 20mm and 20mm thick, piece of coarse-grained, dense 'metallic' tap slag with maroon surface and rather porous base (36g)

In reflected light this sample shows well-developed needle-like crystals, but was too thick to mount on the SEM.

AVN4: *(1349B), large fraction, <29>*
(Plate A4)
A slab like piece with vesicular core, a dense layer on one side and a thin layer on the other. Both surfaces have maroon colour, thinner layer has roughly planar surface, other is concave with raised lip on one side (42g).

This sample shows a striking, well-developed structure of coarse tungstate mineral 'A' in glass. The tungtstate shows complex cellular equant microstructure near margins (individual cells 50 – 100 µm, forming complexes of c. 1mm; Plate A4c), but internally is elongate (up to 2.5mm in length of more; Plate A4b). It locally has inclusions of oxidised tin (Plate A4a).

AVN5: (1349B), small fraction, <29>
(Plate A5, A6)
rod like fibrous dark glass, c. 6mm in diameter and 25mm long (4g).

This is mainly a simple glass with a rough devitrified surface like that of AVN1. Internally it shows a foliated structure, picked out by variations in glass composition and also by density of dendrites (Plate A6a).

The dendrites are formed of an Al- and Ti- substituted magnetite (or a mixture of phases with that composition), cored on small grains of Fe-, Ti-hercynite.

Within the structure was a distinct slab 20-25µm thick and almost 2mm long of 'scale'-like material (Plate A5 e,f). On one side this had a rather porous structure with blebs of tin interspersed with a mixed tin/iron oxide. This was overlain by a denser layer of similar mixed oxide forming part of a sheet with an apparent columnar structure, the outer part of which was formed by magnetite (5 µm thick). Both sides of the scale were overgrown by an olivine (Fa70-72Fo30-28 with 2% Mn substitution; 10 µm long) and by blades probably of tungstate mineral 'A' (10 µm long).

In some areas the hercynite crystals lie on apparently convoluted laminae within the slag (Plate A6a).

AVN6: *(1349B), small fraction, <29>*
(Plate A7)
An irregular lobe or flap of dark glass bearing partially melted grains, 15mm x 15mm and up to 6mm thick (2g).

The sample was a simple banded glass with abundant tin droplets.

AVN7: *(1349B), small fraction, <29>*
(Plate 6; Plate A8, A9)
An irregular sheet with porous planar base and irregular maroon smooth top, somewhat resinous lustre. 25mm x 25mm and 8mm thick (10g).

The sample has a planar vesicular (basal) surface, overlain by black crystalline layer and topped with brown glass.

The lower face is highly vesicular, with patches of tin oxides and rather fine grained slag in a thin layer. This 1mm thick layer has a very tin-rich glass, patches of tin oxide(?) and probably hollow tungstate mineral 'A' prisms (Plate A8a,b).

This is abruptly overlain by a layer with minor euhedral grains of hercynite (close to end member) overgrown by Al, Ti substituted magnetite (or a mixture of phases of similar composition) and abundant coarse tungstate mineral 'A' (Plate 8c). The tungstate is overlain by fringes of small olivine with a composition of Fa85Fo15 with 8%Mn substitution and similar small olivine crystals lie scattered in the matrix around the spinel clump.

The matrix (glass) bears tiny crystals of uncertain composition, but possibly including Fe-Ti oxides and or W oxides. Higher in the structure the coarse tungstate is replaced by finer dendrites possibly also tungstate 'A' in part (they are too fine for confident EDS analysis), but also show high levels of titanium and possibly therefore also containing Fe-Ti oxides. The glassy matrix to these dendrites shows small dark areas that may be hercynite (Plate A8f; Plate A9a).

AVN8: *(1349B), small fraction, <29>*
(Plate A9)
curved sheet with porous convex surface, elongate crystals. 12mm x 18mm and 7mm thick (6g).

Has an marginal equant blocky but cellular structure of tungstate mineral 'A' (Plate A10a,b), which changes to prismatic internally (Plate A10c).

AVN9: *(1146), large fraction, <24>*
(Plate A11)
60x35mm and 25mm thick, bulbous flowed lobe with smooth maroon top and 'frayed' base. Internally has dense upper section and vesicular lower part (70g).

This shows a complicated basal zone with vesicles and fine texture, overlain by simple textured upper zone with upward decreasing tungstate mineral 'A' in glass. Tungstate occasionally has oxidised tin inclusions (Plate A11c).

AVN10: *(1146), large fraction, <24>*
(Plate A12, Plate A13)
biconvex flowed material up to 16mm thick, both surfaces maroon and smooth, way-up not determinable. 65x50mm (62g)

This piece shows a curved external surface that may be a deformed basal surface (if slag deformed when very hot), or it may genuinely be a biconvex margin of a slag lobe.

The outer convex margin shows roots of inward growing crystals of tungstate mineral 'A' (Plate A12b). This zone contains vesicles, but only on one side of the curve. The tungstate grain size decreases inwards into complex forms (Plate 12f).

There are some rare tungsten rich blebs (Plate A12a) within the fabric and a few tin droplets (Plate A13a). On one short length of the external face there is a small patch of oxide crust (Plate A13b,c,d), with fine grained altered tin oxides, some very fine-grained tungsten (<1µm) and some elongate crystals of hardhead (iron distannide FeSn2) of at least 80µm in length and 10µm width.

AVN11: *(1146), large fraction, <24>*
90x40x20mm, 12mm thick curved slag sheet, convex surface maroon-brown, close above is rough contact, opposing concave side is matt (108g).

Reflected light shows crystalline layers developing from the from opposing faces, probably tungstate mineral 'A', but the sample was too thick to mount on the SEM.

AVN12: *(1146), large fraction, <24>*
(Plate A14)
A curiously folded slag sheet, one surface brown/maroon passes around 'U' bend onto rough, vesicular material via a fractured edge. Tightly concave side also rather brownish has wrinkles to glassy surface. Could this have come from a lowering metal tapping channel interface? (in this interpretation the rough surfaces face the tapping channel/mould, the smooth side the metal and the wrinkled side the air). Alternatively the sample has been deformed hot, the smooth surface is the free surface and the vesicular surface the metal contact. 75x35x35mm (58g).

This sample shows some similarities with other slag sheets like AVN7. There is a gradation from a coarse basal texture, rich in tungstate minerals, through a delicately dendritic zone of tungstate mineral 'A' into laminated 'glass' – much of which is probably actually microcrystalline. In this view, the 'up' direction is to the left in the images in Plate A14.

The large tungstate minerals in the basal zone are the variant of tungstate mineral 'A' in which magnesium is below detection (Plate A14b). These large crystals are overlain by finer grained tungstate mineral 'A' of a more usual composition.

The basal layer is rich in vesicles and contains some large tin blebs (Plate A14e)

AVN13: *(1146), large fraction, <24>*
(Plate A15)
A part of a slag sheet, planar surface, slightly brown with pin head dimples, has tubular vesicles off this connecting into vesicular layer (of fracture of opposing face). 40x40mm and 10mm thick (34g)

These sheet shows two distinct layers, with a large central cavity. The original orientation of the piece (compared for instance with AVN7 in Plate 6) is probably the opposite of the orientation of the images in Plate 15.

The basal layer was probably the convoluted, vesicle-rich, zone in the upper part of Plate1A5e. This was overlain by a zone of coarse tungstate mineral 'A', truncated by the large void (lower part of Plate A15e). Above the void, with its 'frayed' margins, the coarse tungstate zone continues (Plate A15c,d), but the grain size fines rapidly (Plate A15a,b) and the uppermost part of the slag sheet is formed of finely crystalline tungstate mineral 'A' in glass forming a relict emulsion texture (Plate A15a,b,f).

AVN14: (*1146), large fraction, <24>*
A 35x40mm and 12mm thick sheet. One almost planar surface, opposing surface irregular, vertical margin to sheet, internally has large rounded vesicles (32g).

Sample too thick to mount in SEM.

AVN15: *(1146), large fraction, <24>*
(Plate A16)
10mm thick rounded lobe of slag with one rough surface on convex side with part fractured inner face, wrinkled surface with brownish colour curves away from this fracture. The opposing face also matt but less sediment rich - again a complex metal/mould air contact? 60x40mm (48g).

This sample has similar orientation issues to samples AVN12 and 16. The convex surface of the lobe is strongly vesicular on one side (the' upper' margin as seen in Plate A16), where it also has small lumps of adhering coarse-grained slag (Plate A16a).

Further around the curve of the surface the texture is porous, with elongate crystals of tungstate mineral 'A' defining the vesicles (Plate A16f).

Finally, on the surface where it opposes the zone with the coarse texture slag, there are oxide crusts, tin blebs and occasional coarse tungstate crystals (Plate 16d).

The interior of the piece has finely dendritic tungstate mineral 'A with tin blebs (Plate 16b,c).

AVN16: (1146), large fraction, <24>
(Plate A17)
This is a twisted 4-15mm thick sheet, 35mm x 40mm, grey colour, dark glassy slag internally (44g)

This is another specimen (like AVN12 and 15) with a strongly convex chilled margin surrounding a rounded slag lump. For most of the sample there is an outer zone of coarse tungstate mineral 'A' (Plate A17e) which grades in rather abruptly to an inner zone (Plate A17e) in which very fine-grained tungstate mineral 'A' picks out compositional laminae within a more glassy material. This suggests that the basal surface is the external one, with the chilled upper part of the material now in the core of lump.

On one small section of the exterior surface there is a small attached zone with a very strong relict emulsion texture (Plate 17 a-d).

AVN17: *(1146), large fraction, <24>*
(Plate 18)
5mm thick sheet, one end curved, outer face matt, inner face maroon-brown with large surficial crystals, planar end has rough porous face instead of maroon face. 50x30mm (32g).

This sample represents a section through a slag sheet with much in common with sample AVN7 (Plate 6). The orientation of the images in Plate 18 is probably the opposite of the original orientation.

What is probably the base of the sheet (top of Plate A18a; top of Plate A18d) shows a discontinuous coarse-grained slag layer around 200µm thick.

In detail (Plate A18b,c) this layer contains coarse crystals of tungstate mineral 'A' which are locally euhedral and cored on metallic tungsten. This grains show overgrowths of both olivines and spinels. The same areas show sheet-like tin oxides with angular oxide crystals growing from the sheet in both directions.

The top of the coarse grained layer (where present) forms the point of origin for the dendritic growths of tungstate mineral 'A' which occupy much of the thickness of the sheet, becoming finer upwards.

AVN18: *(1146), large fraction, <24>*
(Plate A19)
A curved slag sheet, 5mm thick, concave face seems matt, convex face has smooth end, but becomes rough and porous around bend. Sheet 40mm long curved and 25mm wide (24g).

This sheet is dominated by finely dendritic tungstate mineral 'A' (similar to the structures in the main body of the sheet in AVN17). These domains of dendrites include many tin blebs, and also preserve locally tin-tungsten rich glass patches, suggestive of relict emulsion.

AVN19: *(1146), large fraction, <24>*
(Plate A20, Plate A21)
60x35mm and 6mm thick. Curved sheet, both faces maroon-brown and wrinkly, thickness shows slight vescularity near convex margin (40g).

The upper surface of the sample in Plate A20b, c, d, e is interpreted as the original base. It shows an adhering layer of tin oxides. Growing from this margin are sheaves of tungstate mineral 'A' (Plate A20e), with some indications of relict emulsion textures, but which fine up rapidly into a fine-grained, relatively homogeneous interior (Plate 20a).

Along this margin are several somewhat diffuse patches with both emulsion textures and a rather coarser grained variety of the tungstate (Plate A20b,d).

On the lower right of the sample (as oriented in Plates A20, A21) there is a large and complex inclusion (Plate A20f; Plate A21a,b). This is apparently within the sheet, rather than on a margin of the sheet folded around (and as such this resembles the complex inclusion in AVN20, see below).

The inclusion is dominated by large crystals of tungstate mineral 'A', at least 200-300 µm across. These crystals contain many tiny inclusions of tungsten metal, as well as a few larger ones and some much larger (50 µm) blebs of tin and tin oxide. Some of the margins of the large tungstate crystals (e.g. above centre of Plate A21a), show curved margins and there are many internal curved cavities. These features are suggestive of resorption and somewhat resemble features of the tungstate within the clast in AVN20 (Plate 5; Plate A22f; Plate A23a).

AVN20: *(1146), large fraction, <24>*
(Plate A22, Plate A23, Plate 5)
4mm thick slag sheet, one face smooth maroon-brown with micro-wrinkles near margin, vesicular internally, opposing face rough, vesicular (28g).

This is a fragment of a complex slag sheet. The whole sample is illustrated in Plate 5.

The fragment has a slightly convex basal surface, probably fractured ends and a planar upper surface (probably the original free air surface).

The basal surface is partially fractured, but shows a number of tin prills and areas rich in tin oxides. Fine tungstate 'A' prisms and dendrites grow upwards from this surface (Plate A22c).

The tungstate rich zone is interrupted by the occurrence of a layer of partially reacted coarse quartz grains, of up to 2.5mm across. Towards the left of the sample some silica rich glass patches (Plate A23 c,d) mark similar grains, no almost entirely destroyed and the glass adjacent ot these grains is rich in extremely tin- and tungsten-rich droplets, probably of an unmixed metlal-rich slag, rather than of metal itself.

The tungstate dendrite zone passes up into a very fine-grained material, partly glass, but probably largely microcrystalline.

The left had side of the specimen (as seen in Figure 5) is marked by brittle fracture cutting through a complex inclusion. Most of the matrix of the inclusion is formed by complexly textured tin oxides of uncertain precise nature (Plate A22d,e,f; Plate A23a,b). This matrix contains voids filled by (secondary?) iron-rich material (darker areas in Plate A22e), crystals of hard head (with inner FeSn and outer $FeSn_2$; Plate A22d,f), probably partially-resorbed coarse tungstate crystals (Plate A22f; Plate A23a) and irregular, sometimes polygonal, trains of metallic tungsten (plate A22d,e,f; Plate A23a).

Interpretation

The slag samples described above show several sets of features which allow some extraction of general properties:

(a) a rod-like form
Samples AVN1, AVN2 and AVN5 are all dark glasses with a fibrous structure. AVN6 is a flap – possibly related.

(b) A sheet-form:
Samples AVN7, AVN13, AVN17, AVN19, AVN20

(c) A rounded form but displaying similar progression of textures to those in the sheets (b)
Samples AVN10, AVN12, AVN15, AVN16

(d) Inclusions with tin oxides, +/- coarse tungstate, +/- tungsten, +/- hardhead
- in a basal marginal zone
  Samples AVN7, AVN10, AVN15, AVN17

- Inclusions with the body of the slag
  Samples AVN1, AVN19, AVN20

(e) laminar inclusions (cf hammerscale)
Samples AVN5, AVN17?

(f) remnant emulsion textures
Slight: samples AVN10, AVN18
Strong: strong AVN13, AVN16, AVN19

These features provide a series of close textural links between the majority of the tungsten-rich slags, whether from (1146) or (1349B). The most easily identified set of characteristics is provided by the slag sheets – which are well represented by five specimens (AVN7, AVN13, AVN17, AVN19, AVN20).

These sheets are typically about 5mm thick. They commonly show a discrete basal layer, which may be vesicular, rich in tin, rich in particularly coarse crystals of tungstate mineral 'A' and may have tin-oxide dominated area, occurrences of tungsten metal and crystals of hardhead. The basal facies of slag may also include minor amounts of very small crystals of olivine and spinel in some instances.

The basal layer is abruptly overlain by a layer dominated by sub-vertical prismatic crystals of tungstate mineral 'A' in glass, which become finer upwards, trending towards dendritic growths in discrete domains. In some instances this zone preserves relict high-tungsten belbs, preserved in part by localised thickening of the tungstate prisms.

The uppermost development in the sheets is a fine-grained material, often appearing like glass in hand specimen, but on the SEM often seen to be microcrystalline (with crystallites probably of tungstate mineral 'A'). These finely crystalline zones may preserve a laminar texture, sometimes convoluted and sometimes an emulsion texture.

In some instances, these sheets may contain coarse inclusions of derived materials including tungstate, tungsten, tin, and tin oxides. These clasts share many of the features of the more common inclusions or zone on the basal surface.

Four of the specimens (AVN10, AVN12, AVN15, AVN16) show similar textures to the sheet specimens, but in a rounded, lobe like form. Although an origin as a slag lobe is not impossible, it is considered more likely that these samples represent slag sheets deformed when still largely molten and plastic.

The rod-like, striated, fibrous rods are all from slag Groups 1 and 2. They resemble the most common slag morphology from Crift Farm. Although it might be possible to suggest that these derive from a different phase or process to the sheets, the relationship with the composition suggests that these silica rich (rather than tin-rich) glasses have been stretched during clearance because they are more highly plastic (slightly less viscous) than the tin/tungsten rich slags at the same temperature.

In general then it can be suggested that slag was removed from the surface of the tin in a float. For the high silica glasses this resulted in stringy, fibrous slag rods, but for the high tungsten slags the high liquidus and solidus temperatures, as well as the high viscosity, meant that the slags tended to deform less – forming twisted sheet fragments or still planar sheet fragments on removal.

The big question with the inclusions is whether they were tapped with the slag from the furnace or whether they have segregated from the underlying tin in the float.

For some of the larger inclusions within the body of the slag, unless the system had been stirred vigorously, it is hard to imagine the inclusions becoming incorporated in the float – and so these are interpreted as having been derived inside the furnace.

On the other hand, the persistent occurrence of 'exotic' materials in the basal layer of the slag may well imply that these materials have segregated out of the metal within the float.

Discussion

Historical Background

The conventional model for the evolution of tin smelting is that fairly early in the medieval period manually-blown smelting facilities were superseded by the water-powered 'blowing house', the earliest documented example of which in Britain was at Lostwithiel, where in 1332 a 'Blouynghous' was serving Blackmore stannary (Hatcher 1970; Greeves 1991). Documents, particularly leases, of the 15th and 16th century show that use of the term 'blowing house' had spread widely across the SW in this period.

Blowing houses are much better known in the post-medieval period, with the earliest comprehensive written descriptions dating to the late 17th century (Earl 1985 cites descriptions from 1664 by Cotton and an anonymous description from 1671). Earl (p. 155) also quotes a sixteenth century account of some details of the furnace, but this provides little of the broader technological context of the detail. One of the earliest descriptions of tin smelting in Europe is given by Agricola (1556) and the techniques appear to have been fairly standardised across Europe by this time. A full, if late, description of the SW British blowing house was given by Pryce (1778).

The question of what was employed before the blowing house has not been fully resolved. The site of Crift Farm (Cornwall) provides a model for smelting in the earlier medieval period. This site appears to be a longhouse that was converted for metallurgical use with construction of both an internal smithy and an external extension apparently housing tin smelting. The site lies at moderate altitude, away from a watercourse, and is assumed to have employed a furnace blown manually. In many of these respects it parallels the Brownie Cross site. Initial studies of slag from Crift Farm were conducted by Tylecote (Tylecote *et al.* 1989) and Adriaens (1996). A later, more extensive study of the Crift Farm slag was conducted by Malham *et al.* (2002) and reworked by Malham (2010).

Despite the large quantity of slag at Crift Farm (estimated at 5 tonnes), the excavators found no trace of a furnace, which they surmised was likely to have been a hand-blown elevated furnace built of granite blocks. Crift Farm has not been described as a blowing house. It lacks water power and was not apparently a purpose built structure.

At first sight, the 13th-14th centuries should represent a transition from manual- to water-powered blowing and the evolution of the blowing house. The analyses of Malham *et al.* (2002; discussed further below) would appear to suggest that although the technology varied in terms of power, the metallurgical process remained rather unchanged. It seems likely however that the issues are not quite that simple.

Examination of the historical evidence paints a rather different picture and Greeves (1991) states:

In the 12th century all tin was smelted twice. After the first smelting, which presumably took place near the tinwork itself, a tax of 30d per thousandweight (1200 lb) had to be paid; it was then taken to a market town for a second refining smelt after which it could be sold ... From 1198 an additional tax of one mark per thousandweight had to be paid on tin of the second smelt ....

By 1303 both these taxes had been abolished and replaced by one on the finished metal of 1s 6¾d per hundredweight (120 lb). This suggests that at some time during the 13th century there had been an improvement in smelting technique which obviated the need for two smelts, and it may well be that the blowing house, or tin blast furnace, which survived in its basic form until the 19th century, was evolved at this time.

In other words, Greeves implies that an early two-stage process was replaced by the later blowing house, which then survived in use for many centuries; either the metallurgical process was changed by the change of power, or that parallel changes in technology and power took place in this period. Greeves (1981 p. 30) argued that this indicates that there was an improvement in the initial smelting process during the 13th century.

There are, however, other interpretations that can be placed on this account and Malham (2010, p. 485-6) has dismissed the fiscal change as a simple streamlining of tax-collecting procedure. Indeed Malham goes farther and suggests that the introduction of the water-powered blowing house may have actually reduced tin quality (by increasing the reduction of iron and hence the production of hardhead).

If the dual taxation of the 12th century was based on real metallurgical requirements, then it is likely that the second stage was a remelt to allow better separation of an impurity – presumably hardhead. One technique in modern tin extraction is to refine tin containing hardhead by gentle oxidation at a temperature just above its melting point (232°C), at which temperature the solubility of iron in tin is at its minimum (Chirikure *et al.* 2010). It is likely that this was one of the purposes of the use of a float or forehearth in early smelting (besides allowing for gravity separation of metal from slag and/or hardhead). Thus it is possible that improvements in the use of the float during the 13th century removed the need for a separate remelting.

The Role of Tungsten

The residues from Brownie Cross are very unusual, but are significant, not only for understanding the medieval smelting of tin, but also for understanding the origin of the term 'wolfram' – an early name for tungsten and its ore (modern wolframite). It is clear that the tin source(s) exploited by the smelters at Brownie Cross were also rich in wolframite, the main ore of tungsten.

This reflects the proximity of Brownie Cross to the major tungsten deposit of Hemerdon Bal (3km SE of Brownie Cross; soon to be reopened as one of the world's largest tungsten prospects) and adjacent areas. The mineralisation has been described by Dines (1956), Bray & Spooner (1983) and Alderton (1990).

Tin and tungsten are commonly associated in orefields (see Alderton 1996 for a discussion of Sn-W mineralisation in SW England). Both cassiterite (the main tin ore) and wolframite (the main tungsten ore) are dense (cassiterite ~7, wolframite 7-7.5), so would be difficult to separate through the normal process of vanning.

The name wolfram is derived from the German "wolf rahm", the name given to tungsten by Johan Gottschalk Wallerius in 1747. This appears to share a common origin with the term "Lupi spuma", the name Georg Agricola used for the mineral in 1546 and it is likely that Agricola was himself translating a contemporary expression from German. The precise translation of these terms is lost, but broadly corresponds to wolf's froth, soot, spittle, spray or cream. The meaning ascribed to this is that the froth (slag) voraciously consumed the tin being smelted.

The isolation of tungsten metal is technically difficult and was not formally achieved until 1783. Carl Wilhelm Scheele discovered in 1781 that a new acid, tungstic acid, could be made from scheelite (at the time named tungsten). Scheele and Torbern Bergman suggested that it might be possible to obtain a new metal by reducing this acid. In 1783, José and Fausto Elhuyar found an acid made from wolframite that was identical to tungstic acid. Later in 1783, in Spain, the Elhuyar brothers succeeded in isolating tungsten by reduction of this acid with charcoal, and they are credited with the discovery of the element (Wikipedia).

The occurrence of metallic tungsten in the Brownie Cross slags therefore potentially predates the discovery of metallic tungsten by 500 years. There are several previous records of early metallic tungsten from SW England. The most extraordinary of these is the Trehiddle bloom (Rehren 2005). This object resembles an iron bloom, but comprises metallic tin, containing inclusions of hardhead, intermixed with subspherical particles of tungsten embedded in a matrix of an iron-tungsten alloy. The tungsten particles are approximately 10 µm in diameter, rather larger than the subspherical components of the aggregate in AVN1 (typically up to about 5 µm) and much larger than the more isolated rounded particles in AVN10 and AVN20, but of broadly similar size to the tungsten particles overgrown by tungstate 'A' in AVN17. The origin if the bloom itself is uncertain – it is undated and it remains unclear if it is from an early experiment with tungsten or if it is simply a fortuitous by-product from a smelt intended to produce either tin or iron. A small quantity of metallic tungsten has also been described recently by Malham (2010) in her unpublished thesis. She illustrated tungsten in a tin prill from High Down (Figure A13.5) and describes (p. 307) prills of tungsten in reverberatory furnace slags from Carvedras. Further examples of tungsten in reverberatory furnace slags have been described, also in an unpublished thesis, by Farthing (2002).

Of the five occurrences of tungsten metal in the Brownie Cross samples (AVN1, 10, 17, 19 and 20), four (possibly all five) are associated with tin (or oxidised tin), two with hardhead, and four with an overgrowth of tungstate mineral 'A'. In three of the five cases the samples also contain unusually coarse grained tungstate mineral 'A' (either directly or indirectly associated with the tungsten). These features suggest that there is a link between the occurrences, with all reflecting incorporation of particulate materials from high-temperature growth, within the slags.

The examples of this association of materials are drawn from samples with a wide variety of tungsten contents from AVN1 with an average of 23.7wt% SnO_2 and 6.6wt% WO_3 to AVN10 with 20.8 wt% SnO_2 and 33.5wt% WO_3.

Interestingly, of the examples showing this association of tungsten-hardhead-tin-coarse tungstate 'A', four of the five come from the ten samples from context 1146 and only one from amongst the seven samples from context 1349B.

The samples from context 1146 also include all five of the examples of evidence for the mixing of two liquids (AVN10, 13, 16, 18 and 19). These five samples show good evidence (Plate 4) for the incorporation of droplets of high tungsten content with a liquid of generally somewhat lower (although still high) tungsten content (Figure 7).

The samples from context 1349B include all the examples of slags in compositional Group 1 and Group 2.

Sources of variation

As described above, some significant differences exist not only between the compositional groups but also between the materials sampled from contexts 1349B and 1146.

There are three main potential causes for such variability:

1. the slags may be showing differences because the slags from the two contexts are from, or are biased towards, different stages of the production process.

2. the slags may be showing differences because of a change to, or evolution of, the technology involved in the time period between the deposition of the two contexts.

3. the slags may be showing variation produced by differences in the raw materials

Of these three, the first point is intimately associated with the development of a smelting technique. As described above, there has been much discussion about the significance of multiple stages to the smelting process and to what extent, if any, medieval smelters recycled slag to improve yield.

The textural evidence from this site would not support the proposition that the slags have been crushed to extract tin prills or to aid resmelting. The fragmentation of the slag may simply be a product of the technique of slag extraction – probably by ladling or scraping from the top of the float, possibly followed by quenching in water.

The curved and twisted forms recorded for many of the slag pieces (including most of those in compositional Groups 1 and 2 in this study) suggest that they at least some were still plastic when removed. Although the rod-like form of some of the glassy slags has been ascribed to a 'tapping' texture (e.g. Malham *et al.* 2002 p.86 and Figure 4) this seems an unlikely interpretation; development of the striated textures by stretching during ladling or drawing from the surface of the float seems more likely. There is no evidence for separate slag tapping in medieval or blowing-house tin smelting technology. The different physical form of these pieces might be used to argue that they derive from a different process from the other slags, but it may also be that the different physical properties of this group lead to different behaviour when the float was cleared of slag. The high solidus and liquidus temperatures of the tungsten-rich slags would have meant they were more likely to have been completely solid soon after leaving the furnace.

Thus at present there is no evidence for the slags at Brownie Cross representing more than one process. Their composition and textures show a continuum, with many shared features between samples, with the variation between them linked to compositional changes that are unlikely to be indicative of a staged process (e.g. They are all most likely to represent a simple, single-stage smelting process

The second option is perhaps also unlikely. There is no evidence for a protracted history of tin working on the site with accompanying significant changes in structures. The most likely interpretation of the site is that its features present evidence of a single, albeit poorly understood, technology.

The third option, that of variation in the process chemistry because of variation in the raw materials, is a far more likely scenario.

Figure 8 shows an almost complete lack of overlap in the TiO2:FeO ratio between the Brownie Cross Group 3 slags on one hand and the Group 2 slags, together with the Crift Farm and blowing house slags reported by Malham *et al*. (2002) on the other. It is also noteworthy (Figure 9) that the Group 3 slags are very tightly clustered on the basis of their FeO:SnO ratio compared with the Group 2 slags and those recorded by Malham *et al.* (2002).

The most likely reason for these variations between the Group 2 and Group 3 slags is that the ores of Group 2 were lower in tungsten and higher in titanium than those of Group 3. Titanium is common in several accessory minerals in the Dartmoor granite and these occur widely in the derived alluvial sediments. The high tungsten ores would have had a higher component of wolframite, which the major tungsten mineral in the Hemerdon Bal tin-tungsten deposit. It would be likely that even if the tin-bearing veins of the Hemerdon deposit were not being worked directly (which is a possibility) then even small changes in the location of stream-tin sources might affect the balance of these contributing sources. The sources being worked when the deposits of (1349B) were deposited were, on average, slightly less tungsten-rich and slightly more titanium-rich than those being worked when the slags of (1146) were generated.

Summary

At both Crift Farm (Malham *et al*. 2002; dated on the basis of an associated iron-working hearth to a period between the 9^{th} and 13^{th} centuries, cal. AD 896-1210 (OxA-2400)) and Brownie Cross the evidence appears to suggest a manually-blown version of the later blowing house. The Brownie Cross site contains reasonable evidence for the location of features associated with the furnace, but these are very difficult to interpret. It is quite plausible that, as interpreted at Crift Farm, the furnace itself was an above-ground stone construction, subsequently lost. At both sites there was a large accumulation of slag, with little indication of that slag having been crushed to reprocess. The very small size of the observed tin prills in the slag would mean extraction of metal would be very difficult without remelting, and given the high viscosity of the slags, it is likely that a remelting would not be a profitable exercise.

It has been argued above that the thin slag sheets which characterise much of the Brownie Cross material were formed on top of the molten tin in the float. The precise technique of clearing these slags may have required a different method from that on low-tungsten sites, but shares them same underlying approach to slag-metal separation.

The chemical differences between the slags examined here may be explained through the exploitation of slightly different ores. In general the materials are very rich in tungsten – which must be a product of the influence of the wolframite of the Hemerdon depost (and associated veins).

Unlike the slags so far described from Crift Farm, the Brownie Cross slags contained abundant inclusions of oxidised tin, tungsten metal and hardhead. Some of the inclusions were probably swept out of the furnace with the slag flow, but others may have segregated from the tin in the float. There is no evidence that this indicates a problem with tin quality; all analysed tin prills were of high purity.

The presence of sheets of oxide, in one instance iron-rich and resembling hammerscale and in the other purely tin oxides, may be the product of surficial oxidation of the hot metal. Whether the iron-rich example represents a deliberate attempt to oxidise the iron from the tin in the float is not known, but such an approach to lower the iron content of the tin is possible and is known in later periods.

The project leaves some important analytical questions unanswered – the most important of which is the mineralogical nature of the tungstate mineral 'A'. The investigation of this phase requires additional approaches to fully characterise it, and these were beyond the scope of the present archaeometallurgical project. It is to be hoped that such work can, however, eventually be pursued.

The chemical trends with the tungsten-rich slags have demonstrated the significance of the term 'wolf's foam' for a tungsten-rich tin smelting slag devouring tin. The tungsten-rich slag was viscous, leading to trapping of tin prills – and particularly so once the network of crystals of the tungstate mineral 'A' had formed. However, this is only part of the story, for the glass phase also has a very enhanced content of tin – as an actual network-forming element. The combined effect of these features would have lead to significant tin-loss. The identification of emulsions within the molten slag is interesting – and raises the question of whether this effect would have been visible and contributed towards the choice of the old German expression.

The high viscosity of the slag produced by the elevated tungsten content of the ores smelted at Brownie Cross must have given rise to various problems in smelting, not just a poor yield of tin. The continuation of the operation despite these issues reflects the value of tin in the medieval period, when SW Dartmoor became a more significant producer, culminating in the elevation of Plympton to a Stannary Town in 1328.

Glossary

Aenigmatite: a sodium, iron, titanium silicate mineral - $Na_2Fe^{2+}{}_5TiSi_6O_{20}$

Cassiterite: a tin (IV) oxide, the main tin ore mineral, SnO_2.

Bleb: a small rounded particle or textural component, often a droplet or prill

Bloomery: a furnace for smelting iron from ore in which iron is produced as a solid material. The bloomery process was employed mainly prior to the introduction of the later blast furnace from the late 15th century.

Blowing house: usually defined as a tin smelting works with a shaft furnace, blown by bellows operated by a waterwheel.

Cordierite: a magnesium iron silicate - $(Fe,Mg)_2Al_3(Si_5AlO_{18})$

Dendrite: a branched crystal form, often associated with rapid growth.

Dross: a mass of solid impurities floating on a molten metal

End member: the limiting composition in a solid solution. Often a mineral in which the possible substitution is represented by a single element – e.g. the olivine minerals fayalite Fe_2SiO_4 and forsterite Mg_2SiO_4 are end members of a solid solution.

Euhedral: a crystal shape in which the crystal has developed its faces, indicating its growth was unobstructed by previously formed phases.

Fayalite: the iron-rich end member of the olivine group - Fe_2SiO4.

Ferberite: the iron tungstate end-member of the wolframite series - $FeWO_4$

Float/Floatstone: a trough in front of the tin furnace, often of granite, where the molten tin could stand (to allow the separation of slag andother impuritites) before beiig ladled into the mouldstone.

Forehearth: a pit in front of, and linked to, the furnace into which the tin would flow during smelting. This is functionally equivalent to a float, but is the normal continental practice.

Forsterite: the magnesium-rich end member of the olivine group - Mg_2SiO4.

Greisen: highly altered granite formed by the action of gas- and water-rich fluids concentrated during the late stages of cooling of the granite.

Hardhead: the iron-tin intermetallics FeSn and $FeSn_2$

Hercynite: an iron-aluminium member of the spinel group of minerals - $FeAl_2O_4$

Hübnerite: the manganese tungstate end-member of the wolframite series - $MnWO_4$

Hydroromarchite: a hydrated tin (II) oxide, which forms as a weathering product of tin - $Sn_3O_2(OH)_2$

Interstitial space or interstice: the space between the main generation of crystals in a material. On cooling the main phase of crystals will solidify whilst the interstitial spaces are still occupied by molten material, which will solidify at a lower temperature.

Ilmenite: an iron-titanium oxide - $FeTiO_3$

Kaolinite: a hydrous alumina-silicate clay mineral, the major component of china clay - $Al_2Si_2O_5(OH)_4$

Liquidus: the temperature at which the first component of a melt solidifies

Magnetite: an iron oxide member of the spinel group - Fe_3O_4.

Olivine: a group of silicate minerals of the form $(M^{2+})_2SiO_4$ where M can commonly be iron, magnesium, calcium (up to half the M^{2+} ions) or manganese

Prill: a small aggregate of a material, either a spheroidal droplet or a runnel, formed from a melted liquid and either occurring as a discrete particle or as an inclusion within another material.

Quench: to cool rapidly from high temperature.

Reverberatory furnace: a furnace in which the charge is heated by heat bounced from the roof, rather than through direct contact with the fuel. This allowed the use of coal in many metallurgical processes. It became the dominant form of tin smelting furnace from the 18th century.

Rhönite: a calcium, iron titanium silicate related to aeanigmatite - $Ca_2(Mg,Fe^{++},Fe^{+++},Ti)_6(Si,Al)_6O_20$

Romarchite: a tin (II) oxide, which forms a weathering product of tin, SnO.

Spinel: a mineral group with the general formula $X^{2+}Y^{3+}{}_2O_4$, which includes, amongst many others, the minerals hercynite and magnetite.

Scheelite: A calcium tungstate, often with considerable molybdenum -. $CaWO_4$

Shaft furnace: a furnace in which the charge descends under gravity as the fuel burns and the reducing gasses rise. The blast furnace, the bloomery and the early tin smelting furnaces are all shaft furnaces.

Solid solution: a material with a variable composition between two or more end members

Solidus: the temperature at which the last component of a melt solidifies (alternatively the temperature at which the first component of a solid becomes liquid)

Stoichiometry: the determination of a formula or equation by consideration of the numerical balance required.

Tungstate mineral 'A': the provisional name given to a mineral in the Brownie Cross slags with a composition apparently of $(Mg,Mn,Fe)_3W_3O_{10}$

Subhedral: a form of crystal growth which is impeded by some pre-existing phases to permit only some of a crystals faces to be developed.

Valency: a measure of the number of bonds formed by an atom of a given element

Vanning: a type of ore dressing by which ores are washed on a shovel

Vesicle: a void, usually rounded and formed as a preserved gas bubble in a solidified melt.

Wolframite: a group of tungstate minerals, forming a solid solution between ferberite and hübnerite. This forms the main mineral ore of tungsten.

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Figure Captions

Figure 1
Plot of SnO v WO_3 for EDS analyses of representative areas of samples from Brownie Cross. The samples are grouped into three groups on textural, mineralogical and compositional criteria. The extreme tungsten contents of the Group 3 slags are outside the range of slag compositions record previously in SW England.

Figure 2
Chemical composition from EDS microanalysis of selected spinels and ilmenite.

Spinel compositions calculated to 4 oxygens per formula unit and ilmenite calculated to 6 oxygens.

Selected analyses:

Magnetite: AVN15 SOI6 (#1, #13)

Ilmenite: AVN2 SOI6 (#4, #5);, SOI7 (#1, #2, #8, #14)

'Ti-Al magnetite': AVN2 SOI2 (#1, #2); AVN7 SOI3 (#5)

Hercynite: AVN1 SOI2 (#1); AVN2 SOI2 (#3, #5); AVN7 SOI3 (#3, #4)

The material broadly corresponding in composition to a Ti, Al-substitute magnetite is probably a mixture of phases.

Figure 3
Tungstate 'A' composition.
The binary plots show the modelled composition based on a formula unit with 10 oxygens. The data are EDS point analyses. The data scatter, particularly prominent in the lower right diagram which incorporates data from all elements in the mineral, is probably due to a poor resolution of the oxygen in the analyses (see text for further discussion).

Figure 4
Bulk chemical variation in slags of the different groups from Brownie Cross. Data are area EDS analyses of representative zones of samples.

Figure 5
Chemical variation in the glass phase of slags of the different groups from Brownie Cross. Data are both area and point EDS analyses of representative zones of samples.

Figure 6
Bivariate diagram showing relationship between SnO:SiO2 ratio and the WO_3 content for slags from Brownie Cross. Analyses of slags from Crift Farm and from selected blowing houses are shown for comparison (data from Malham *et al.* 2002). The analyses are area analyses by EDS, so may include both tin present in the glass and any incorporated tin droplets.

Figure 7
Diagram as Figure 6, but showing the Brownie cross analyses referred to individual specimens and their groups. The coloured areas show the fields of compositions of the W-poor (blue) and W-rich (orange) components of the relict emulsions present in the high–W slags.

Figure 8.
Bivariate plot on logarithmic axes for the TiO_2:FeO ratio against the SnO:WO_3 ratio. The low TiO_2:FeO ratio of the Group 2 Brownie Cross slags reflects both a low content of TiO_2 in the ore and the elevated FeO that probably was contained in the wolframite in the ore. Many of the Group 2 slags show a higher TiO_2:FeO ratio and this may reflect an alluvial 'placer'-type source more strongly influenced by the granite. Analyses of slags from Crift Farm and from selected blowing houses are shown for comparison (data from Malham *et al.* 2002).

Figure 9.
Bivariate plot on logarithmic axes for the FeO:SnO ratio against the SnO:WO_3 ratio. Group 3 slags are tightly clustered on both measures, but Group 2 slags have a more diverse range of FeO:SnO ratios – similar to those seen in the Crift Farm slag. Analyses of slags from Crift Farm and from selected blowing houses are shown for comparison (data from Malham *et al.* 2002).

Plate Captions

Plate 1
Backscattered electron micrographs of representative slags:

a. Group 1 slag: AVN6 soi1 – *a glass of variable composition with abundant prills of tin*
b. Group 2 slag: AVN2 soi3 – *a slag with marginal crystallisation of dendrites of ilmenite and spinels. The interior of the slag is glassy or microcrystalline*.
c. Group 3 slag: AVN8 soi3 - *a slag with prismatic crystals of tungstate mineral 'A' in glass.*

All scale bars 500 µm

Plate 2
Backscattered electron micrographs of characteristic minerals/phases

a. Dendritic growth of an Fe, Ti-rich mineral, growing upon a euhedral hercynite crystal. AVN1 SOI 2; scale bar 30µm.
b. Zoned spinels, with Ti-rich material in the core of a Mg-rich hercynite, overgrown by a Ti-rich mineral. AVN2 SOI 2; scale bar 60µm.
c. Tungstate mineral 'A' forming a quenched cellular structure. This is commonly seen in the outer parts of slag lobes. AVN4. SOI 3; scale bar 600µm.
d. Tungstate mineral 'A' forming a prismatic crystals. This is commonly seen in the mid to outer parts of slag lobes. AVN9 SOI 3; scale bar 300µm.
e. Droplet of tin, lying between complex crystals of tungstate mineral 'A'. AVN10 SOI 7; scale bar 40µm.
f. Tungstate mineral 'A' forming mossy dendritic growths, its common habit in the inner parts of slag lobes. AVN9 SOI 5; scale bar 300µm.

Plate 3
Backscattered electron micrographs of examples of slags bearing particulate impurities derived from the tin:

a. Hammerscale-like particle of iron and tin oxides, supporting olivine and spinel minerals in the slag. The probably originally inner face of the scale is the lower face, which shows numerous tin blebs associated with the oxide. The lower part of the scale is tin-rich, the upper part close to end-member magnetite. This is interpreted as an oxide scale formed on the surface of liquid iron-bearing tin and subsequently incorporated into a slag. AVN5 SOI4 scale bar 50µm.
b. Coarse grained area on the margin of a normal tungsten-rich slag. The marginal zone includes blebs of tungsten overgrown (and replaced?) by tungstate. Close to the tungsten this seems close to a simple tungsten oxide, but the outer parts of the euhedral crystals show the normal Mn-, Mg- and Fe- substitution of tungstate 'A'. These tungstate grains have formed the substrate for the growth of some minor olivine. The upper part of the view shows plate-like growths of a tin oxide – possibly another type of 'scale'. AVN17. SOI 3; scale bar 30µm.
c. Inclusion rich in metallic tungsten on the margin of a glassy slag. The devitrified margin contains abundant tin blebs, so is probably the original tin-contact. AVN1 SOI 6; scale bar 600 µm.
d. Detail of the particle shown in (c). The metallic tungsten (bright) is coated in the thin layer of tungstate and traps a few prills of tin (most now oxidised). AVN1 SOI 4; scale bar 30 µm.
e. Detail with the complex oxide zone in sample AVN20 (left hand side of specimen in Plate 5). Euhedral hardhead (FeSn inside $FeSn_2$) is associated with strings of tungsten inclusions demarking the polygonal outlines of prior grains. The matrix is a tin oxide. SAVN19 SOI 11; scale bar 60µm.
f. Elongate hardhead crystals and minor isolated blebs of tungsten within a tin oxide matrix. AVN10 SOI 8; scale bar 90µm.

Plate 4
Backscattered electron micrographs of examples of slags with relict emulsion structures.

a. this slag piece shows emulsion structures towards the lower face (original orientation uncertain), shown in detail in (b). AVN13 SOI 1; scale bar 4mm.
b. a detail of (a) showing complex emulsion relationships, including a major boundary just above the centre with irregularities that resemble density driven boundary deformation. AVN13 SOI 2; scale bar 2mm.
c. Typical preservation of a tungsten rich emulsion droplet – the tungstate 'A' crystals cut across the bleb, but thicken markedly in the tungsten rich zone. AVN18 SOI 5; scale bar 400µm.
d. Detail of the bleb shown in (c) showing the tin droplets trapped in the tungstate crystals. AVN18 SOI 6; scale bar 100µm.
e. Margin of a slag piece showing (as seen in (a) and (b) above too) the emulsion growing finer towards the margin – which is probably the tin-contact. AVN16 SOI 2; scale bar 200µm.
f. Detail of a series of blebs with a more complex texture. The tungstate 'A' crystals are here restricted ti individual blebs. They also show ghosted outlines probably representing belbs of low-tungsten melt with the high-tungsten blebs. AVN16 SOI 4; scale bar 60µm.

Plate 5
Backscattered electron micrograph montage of sample AVN20. This sample has a particularly complex texture. The upper surface was planar and smooth, although slightly wrinkled near the edge. This surface overlies a glassy slag, so is interpreted as a free-air margin. The main body of the slag shows tungstate 'A' crystals growing from the lower rough margin. The slag contains partially reacted gains of quartz ranging up to almost 3mm across. Towards the right side this zone shows a large prill of tin. On the left side small diffuse dark patches represent sites of melted grains – and here the melt contains prills of a composition compatible with being a mixture of tungstate 'A' and tin (so possibly an extreme preserved example of droplets of the kind seen in Plate 3). The left hand side of the piece shows signs of brittle fracture and includes a complex mix of oxidised tin, tungsten, hardhead and partially resorbed coarse grained tungstate, all associated with secondary minerals.

Plate 6
Backscattered electron micrograph montage of a section through sample AVN7. The section shows the basal contact layer, with vesicles and abundant tin blebs and oxides, which has a rather abrupt contact with the overlying poorly-vesicular slag. Elongate large prisms of tungstate mineral 'A' grow off the boundary between the zones. The tungstate decreases in grain-size upwards into 'mossy' dendritic clumps, before passing into convoluted laminated glass.

Table 1. Material sampled from D1

code	context	sample	part	weight	notes
AVN1	1349B	29	large	16g	section of elliptical cross-section glass 'rod', 20mm x 8mm with strongly fibrous structure. 40mm long
AVN2	1349B	29	large	22g	complex contorted dark glass with elongate striations, 25mm x 15mm and 55mm long
AVN3	1349B	29	large	36g	35mm x 20mm and 20mm thick, piece of coarse-grained, dense tap-slag like piece with metallic lustre, maroon surface and rather porous base
AVN4	1349B	29	large	42g	Slab-like piece with vesicular core, a dense layer on one side and a thinner slag layer on the other. Both surfaces have maroon colour, thinner layer has roughly planar surface, other is concave with raised lip on one side.
AVN5	1349B	29	small	4g	rod like fibrous dark glass, c. 6mm in diameter and 25mm long
AVN6	1349B	29	small	2g	irregular lobe or flap of dark glass bearing partially melted rains, 15mm x 15mm and up to 6mm thick
AVN7	1349B	29	small	10g	irregular sheet with porous planar base and irregular maroon smooth top, somewhat resinous lustre. 25mm x 25mm and 8mm thick
AVN8	1349B	29	small	6g	curved sheet with porous convex surface, elongate crystals. 12mm x 18mm and 7mm thick.
AVN9	1146	24	large	70g	60x35mm ad 325mm thick, bulbous flowed lobe with smooth maroon top and 'frayed' base. Internally, has dense upper section and vesicular lower part
AVN10	1146	24	large	62g	biconvex flowed material up to 16mm thick, both surfaces maroon and smooth, way-up not determinable. 65x50mm
AVN11	1146	24	large	108g	90x40x20mm, 12mm thick curved slag sheet, convex surface maroon-brown, close above is rough contact, opposing concave side is matt.
AVN12	1146	24	large	58g	folded slag sheet, one surface brown/maroon passes around ‘U’ bend onto rough, vesicular material via a fractured edge. Tightly concave side also rather brownish has wrinkles to glassy surface. Could this have come from a lowering metal tapping channel interface? (in this interpretation the rough surfaces face the tapping channel/mould, the smooth side the metal and the wrinkled side the air). 75x35x35mm
AVN13	1146	24	large	34g	part of a slag sheet, planar surface, slightly brown with pin head dimples, has tubular vesicles off this surface connecting into vesicular layer (of fracture of opposing face). 40x40mm and 10mm thick
AVN14	1146	24	large	32g	35x40mm and 12mm thick sheet. One almost planar surface, opposing surface irregular, vertical margin to sheet, internally has large rounded vesicles
AVN15	1146	24	large	48g	10mm thick rounded lobe of slag with one rough surface on convex side with part fractured inner face, wrinkled surface with brownish colour curves away from this fracture, opposing face also matt but less sediment rich - again a complex metal/mould air contact? 60x40mm
AVN16	1146	24	large	44g	twisted 4-15mm thick sheet, 35mm x 40mm, grey colour, dark glassy slag internally
AVN17	1146	24	large	32g	5mm thick sheet, one end curved, outer face matt, inner face maroon-brown with large surficial crystals, planar end has rough porous face instead of maroon face. 50x30mm
AVN18	1146	24	large	24g	curved slag sheet, 5mm thick, concave face seems matt, convex face has smooth end, but becomes rough and porous around bend, sheet 40mm long curved and 25mm wide.
AVN19	1146	24	large	40g	60x35mm and 6mm thick. Curved sheet, both faces maroon-brown and wrinkly, thickness shows slight vesicularity near convex margin
AVN20	1146	24	large	28g	4mm thick slag sheet, one face smooth maroon-brown with micro-wrinkles near margin, vesicular internally, opposing face rough, vesicular.

Table 2. Average bulk composition of each sample. Microanalysis by EDS, expressed in normalised wt% calculated stoichiometrically.

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	S	K_2O	CaO	TiO_2	V_2O_5	CrO_3	MnO	FeO	ZrO_2	SnO	WO_3
Group 1																
AVN6	1.47	3.69	17.27	46.41	0.66	0.00	0.77	1.15	3.59	0.00	0.00	0.81	11.35	0.00	12.83	0.00
Group 2																
AVN1	0.95	2.49	13.19	31.63	0.54	0.00	1.11	0.69	2.85	0.00	0.00	0.69	17.29	0.00	21.77	6.79
AVN2	0.76	1.43	11.44	24.93	0.11	0.00	1.09	1.46	6.88	0.05	0.00	1.45	13.32	1.27	25.25	10.56
AVN5	0.89	2.32	11.01	28.63	0.54	0.00	1.00	0.55	2.94	0.00	0.00	0.71	17.62	0.00	25.65	8.15
Group 3																
AVN7	0.69	1.42	9.31	23.40	0.38	0.00	0.89	0.81	1.92	0.00	0.00	1.68	17.89	0.14	21.59	19.87
AVN4	0.26	0.46	4.17	10.88	0.36	0.00	0.38	0.00	0.62	0.00	0.00	3.05	14.33	0.00	24.72	40.78
AVN8	0.00	0.74	5.21	16.20	0.55	0.00	0.13	0.67	0.73	0.00	0.00	2.59	15.90	0.00	24.56	32.73
AVN13	0.47	1.13	6.47	17.97	0.33	0.00	0.47	0.47	1.11	0.00	0.00	2.30	14.13	0.19	21.52	33.34
AVN10	0.50	1.12	6.61	18.34	0.46	0.00	0.63	0.56	1.14	0.00	0.00	2.40	14.91	0.09	18.99	34.24
AVN15	0.47	1.26	7.58	18.70	0.28	0.00	0.30	0.64	1.30	0.00	0.00	2.36	15.38	0.19	18.67	32.87
AVN17	0.37	1.29	6.77	18.32	0.17	0.00	0.45	0.57	1.42	0.00	0.00	2.44	14.50	0.26	20.78	32.67
AVN19	0.55	1.27	6.78	18.91	0.36	0.00	0.48	0.49	1.27	0.00	0.00	2.37	15.22	0.34	19.37	32.61
AVN16	0.42	1.29	6.86	19.28	0.15	0.00	0.48	0.58	1.15	0.00	0.00	2.40	14.78	0.29	19.74	32.57
AVN18	0.46	1.46	7.34	20.29	0.45	0.00	0.28	0.50	1.42	0.00	0.00	2.33	15.14	0.00	18.16	32.18
AVN9	0.58	1.36	7.54	21.31	0.49	0.00	0.20	0.57	1.40	0.00	0.00	2.18	14.51	0.00	20.28	29.59
AVN20	0.40	1.56	8.23	21.55	0.39	0.36	0.00	0.52	1.62	0.00	0.00	2.32	14.76	0.00	17.51	30.78
AVN12	0.62	1.58	8.31	21.92	0.30	0.00	0.58	0.63	1.79	0.00	0.00	2.25	14.89	0.32	18.66	28.16

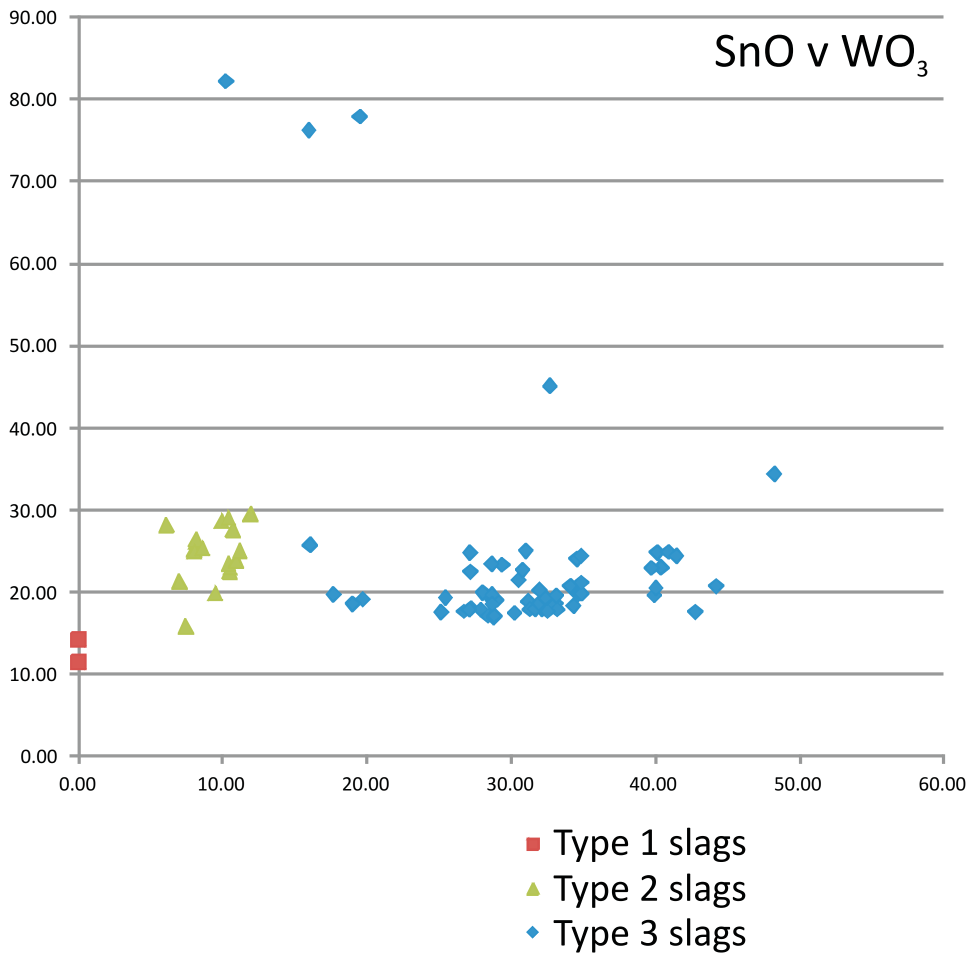
Table 3. Average EDS analyses of representative areas, normalised against SiO_2 to demonstrate background variation in slag components.

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	S	K_2O	CaO	TiO_2	V_2O_5	CrO_3	MnO	FeO	ZrO_2	SnO	WO_3
Group 1																
AVN6	0.03	0.08	0.37	1.00	0.01	0.00	0.02	0.02	0.08	0.00	0.00	0.02	0.24	0.00	0.28	0.00
Group 2																
AVN1	0.03	0.08	0.42	1.00	0.02	0.00	0.04	0.02	0.09	0.00	0.00	0.02	0.55	0.00	0.69	0.21
AVN2	0.03	0.06	0.46	1.00	0.00	0.00	0.04	0.06	0.28	0.00	0.00	0.06	0.53	0.05	1.01	0.42
AVN5	0.03	0.08	0.38	1.00	0.02	0.00	0.03	0.02	0.10	0.00	0.00	0.02	0.62	0.00	0.90	0.28
Group 3																
AVN7	0.03	0.06	0.40	1.00	0.02	0.00	0.04	0.03	0.08	0.00	0.00	0.07	0.76	0.01	0.92	0.85
AVN4	0.02	0.04	0.38	1.00	0.03	0.00	0.04	0.00	0.06	0.00	0.00	0.28	1.32	0.00	2.27	3.75
AVN8	0.00	0.05	0.32	1.00	0.03	0.00	0.01	0.04	0.04	0.00	0.00	0.16	0.98	0.00	1.52	2.02
AVN13	0.03	0.06	0.36	1.00	0.02	0.00	0.03	0.03	0.06	0.00	0.00	0.13	0.79	0.01	1.20	1.85
AVN10	0.03	0.06	0.36	1.00	0.03	0.00	0.03	0.03	0.06	0.00	0.00	0.13	0.81	0.01	1.04	1.87
AVN15	0.03	0.07	0.41	1.00	0.02	0.00	0.02	0.03	0.07	0.00	0.00	0.13	0.82	0.01	1.00	1.76
AVN17	0.02	0.07	0.37	1.00	0.01	0.00	0.02	0.03	0.08	0.00	0.00	0.13	0.79	0.01	1.13	1.78
AVN19	0.03	0.07	0.36	1.00	0.02	0.00	0.03	0.03	0.07	0.00	0.00	0.13	0.81	0.02	1.02	1.72
AVN16	0.02	0.07	0.36	1.00	0.01	0.00	0.02	0.03	0.06	0.00	0.00	0.12	0.77	0.01	1.02	1.69
AVN18	0.02	0.07	0.36	1.00	0.02	0.00	0.01	0.02	0.07	0.00	0.00	0.11	0.75	0.00	0.90	1.59
AVN9	0.03	0.06	0.35	1.00	0.02	0.00	0.01	0.03	0.07	0.00	0.00	0.10	0.68	0.00	0.95	1.39
AVN20	0.02	0.07	0.38	1.00	0.02	0.02	0.00	0.02	0.08	0.00	0.00	0.11	0.68	0.00	0.81	1.43
AVN12	0.03	0.07	0.38	1.00	0.01	0.00	0.03	0.03	0.08	0.00	0.00	0.10	0.68	0.01	0.85	1.28

Table 4. Average composition of glass in each sample. Microanalysis by EDS, expressed in normalised wt% calculated stoichiometrically.

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	S	K_2O	CaO	TiO_2	V_2O_5	CrO_3	MnO	FeO	ZrO_2	SnO	WO_3
Group 1																
AVN6	1.31	3.61	16.8	45.2	0.58	b.d.	0.69	1.03	3.66	b.d.	b.d.	0.76	11.5	b.d.	14.8	b.d.
Group 2																
AVN1	0.93	1.96	10.9	31.6	0.53	b.d.	0.79	0.60	1.37	b.d.	b.d.	0.54	15.0	b.d.	30.2	5.68
AVN2	0.75	1.33	10.7	25.6	0.09	b.d.	1.12	1.38	5.08	0.05	b.d.	1.44	12.3	1.37	26.9	11.80
AVN5	0.86	2.37	10.7	29.8	0.50	b.d.	1.02	0.56	2.43	b.d.	b.d.	0.71	16.5	b.d.	26.2	8.31
Group 3																
AVN7	0.98	0.32	9.34	31.7	0.59	b.d.	0.65	1.10	0.63	b.d.	b.d.	0.90	9.23	b.d.	39.2	5.37
AVN4	0.57	0.09	7.85	23.5	0.69	b.d.	0.39	0.10	1.18	b.d.	b.d.	1.40	13.0	b.d.	43.3	7.90
AVN8	0.57	0.48	7.98	27.4	0.63	b.d.	0.39	0.75	1.15	b.d.	b.d.	1.66	15.6	b.d.	36.7	6.68
AVN13	0.73	0.90	11.7	33.9	0.72	b.d.	0.66	0.51	1.84	b.d.	b.d.	1.69	13.5	b.d.	29.1	4.71
AVN10	0.78	0.81	10.1	30.2	0.61	b.d.	0.70	0.83	1.74	b.d.	b.d.	1.59	13.4	b.d.	31.5	7.82
AVN15	0.08	0.97	10.8	32.3	0.58	b.d.	0.60	0.91	1.42	b.d.	b.d.	1.66	15.5	b.d.	28.4	5.94
AVN17	0.36	0.67	7.44	23.7	0.26	b.d.	0.15	0.50	1.02	b.d.	b.d.	1.15	10.3	b.d.	47.1	7.37
AVN19	0.82	0.77	10.8	31.5	0.61	b.d.	0.90	0.66	1.79	b.d.	b.d.	1.60	12.6	b.d.	29.2	8.66
AVN16	0.69	0.71	9.50	28.3	0.56	b.d.	0.57	0.67	1.47	b.d.	b.d.	1.53	12.8	b.d.	35.2	7.96
AVN18	0.68	0.92	10.1	29.3	0.58	b.d.	0.71	0.73	1.72	b.d.	b.d.	1.42	13.2	b.d.	32.3	8.34
AVN9	0.75	0.94	10.8	31.8	0.56	b.d.	0.76	0.74	1.84	b.d.	b.d.	1.67	13.7	b.d.	28.1	8.33
AVN20	1.07	0.96	11.5	41.6	0.73	0.90	1.40	b.d.	1.02	b.d.	b.d.	1.34	10.0	b.d.	20.3	9.09
AVN12	0.72	1.22	10.2	29.3	0.56	b.d.	0.56	0.70	2.37	b.d.	b.d.	1.85	14.8	b.d.	27.3	10.4

Figure 1



SnO v WO3
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Type 1 slags
Type 2 slags
Type 3 slags

Figure 2

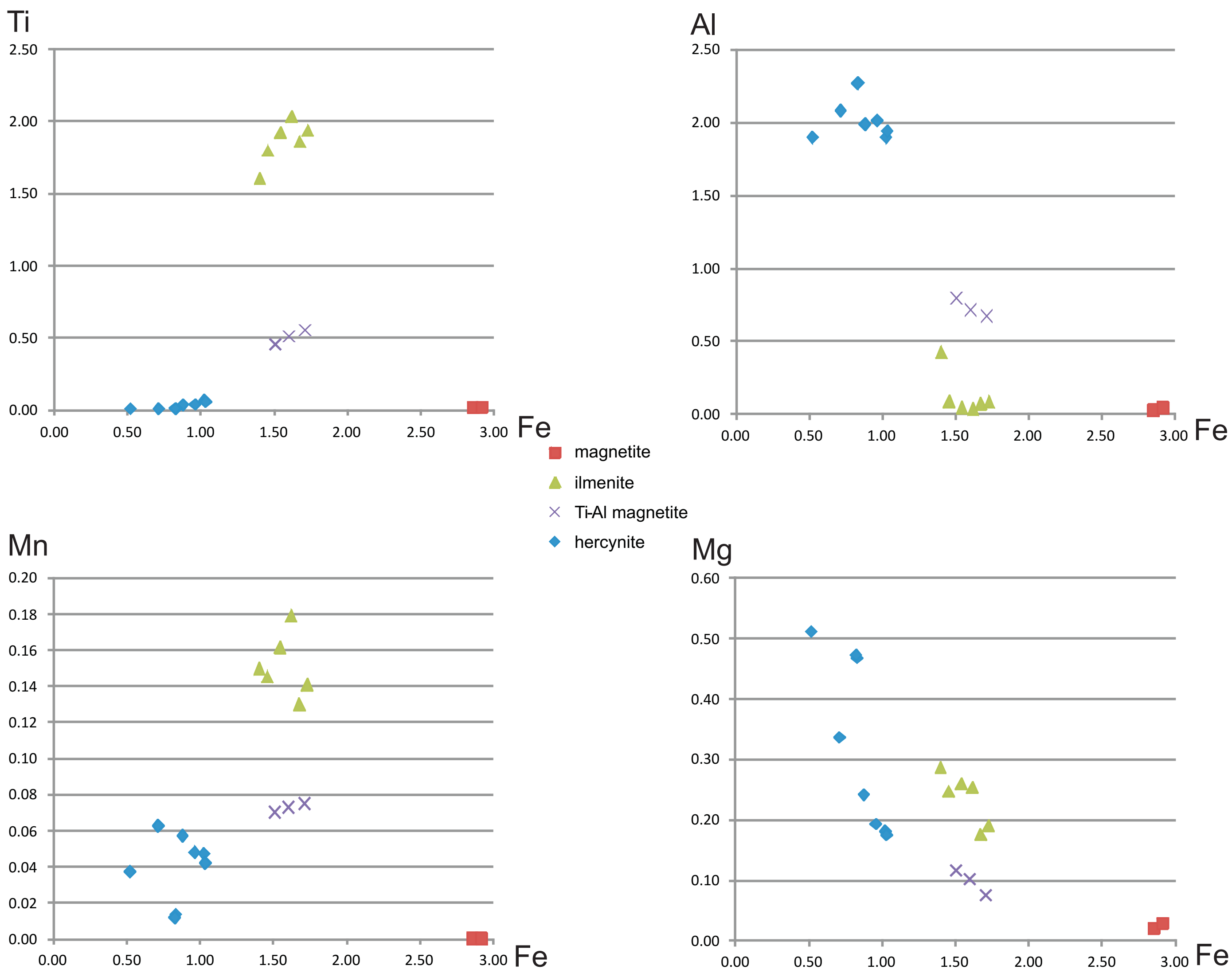
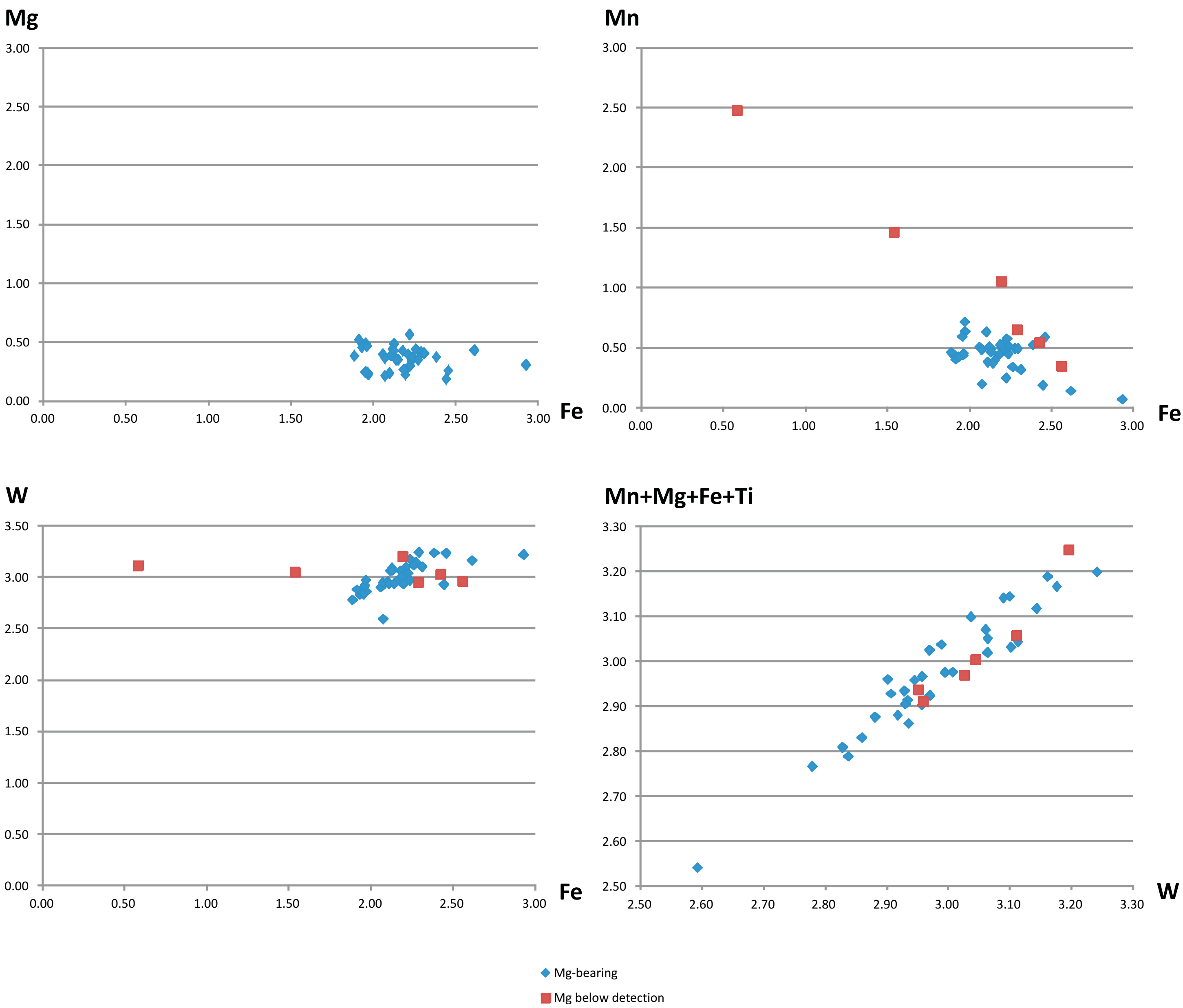
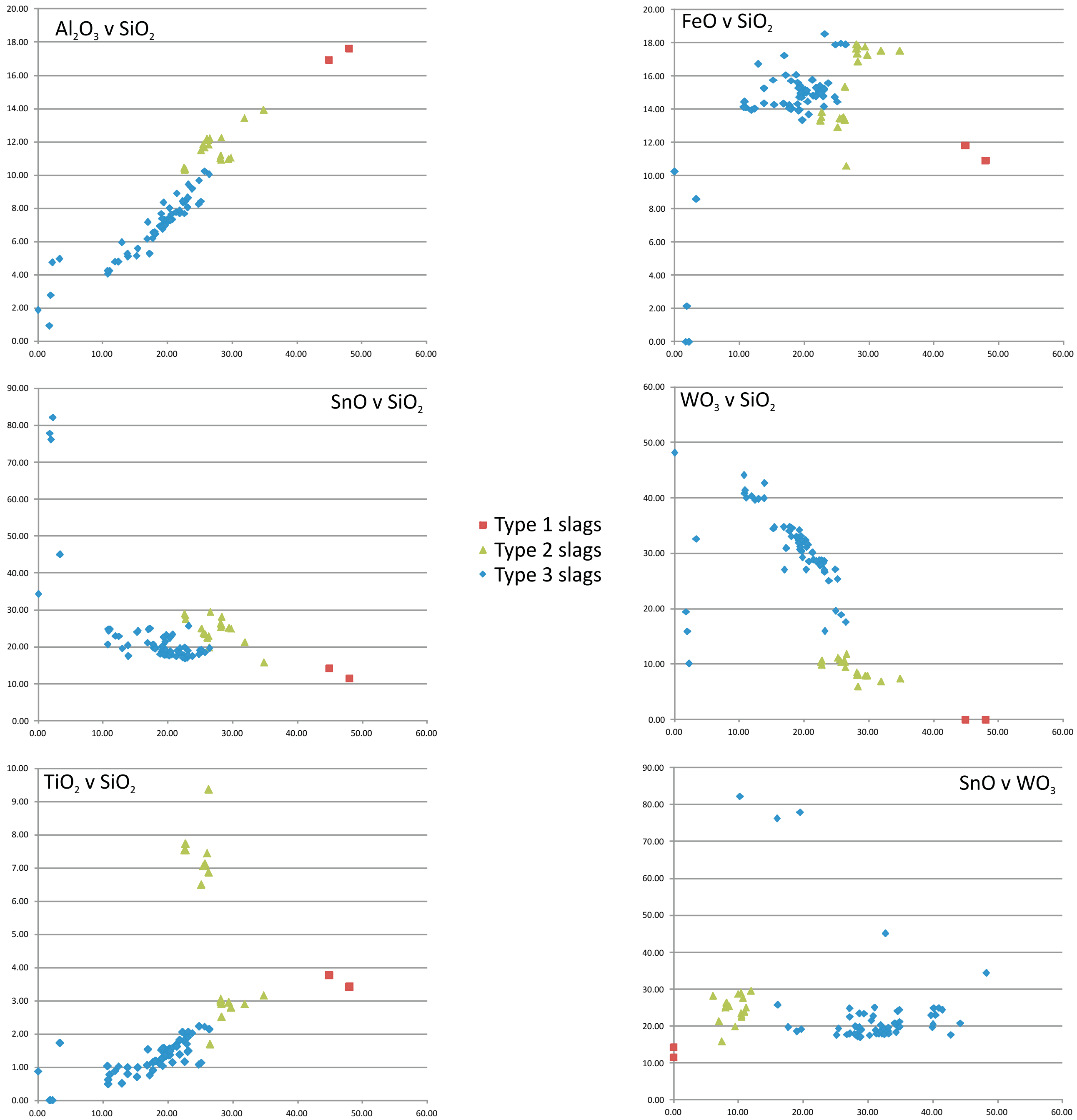

Ti
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Fe
Al
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Fe
magnetite
ilmenite
Ti-Al magnetite
hercynite
Mn
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Fe
Mg
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Fe

Figure 3



Mg
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Fe
Mn
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Fe
W
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Fe
Mn+Mg+Fe+Ti
3.30
3.20
3.10
3.00
2.90
2.80
2.70
2.60
2.50
2.50
2.60
2.70
2.80
2.90
3.00
3.10
3.20
3.30
W
Mg-bearing
Mg below detection

Figure 4



Al_2O_3 v SiO_2
FeO v SiO_2
SnO v SiO_2
WO_3 v SiO_2
Type 1 slags
Type 2 slags
Type 3 slags
TiO_2 v SiO_2
SnO v WO_3

Figure 5

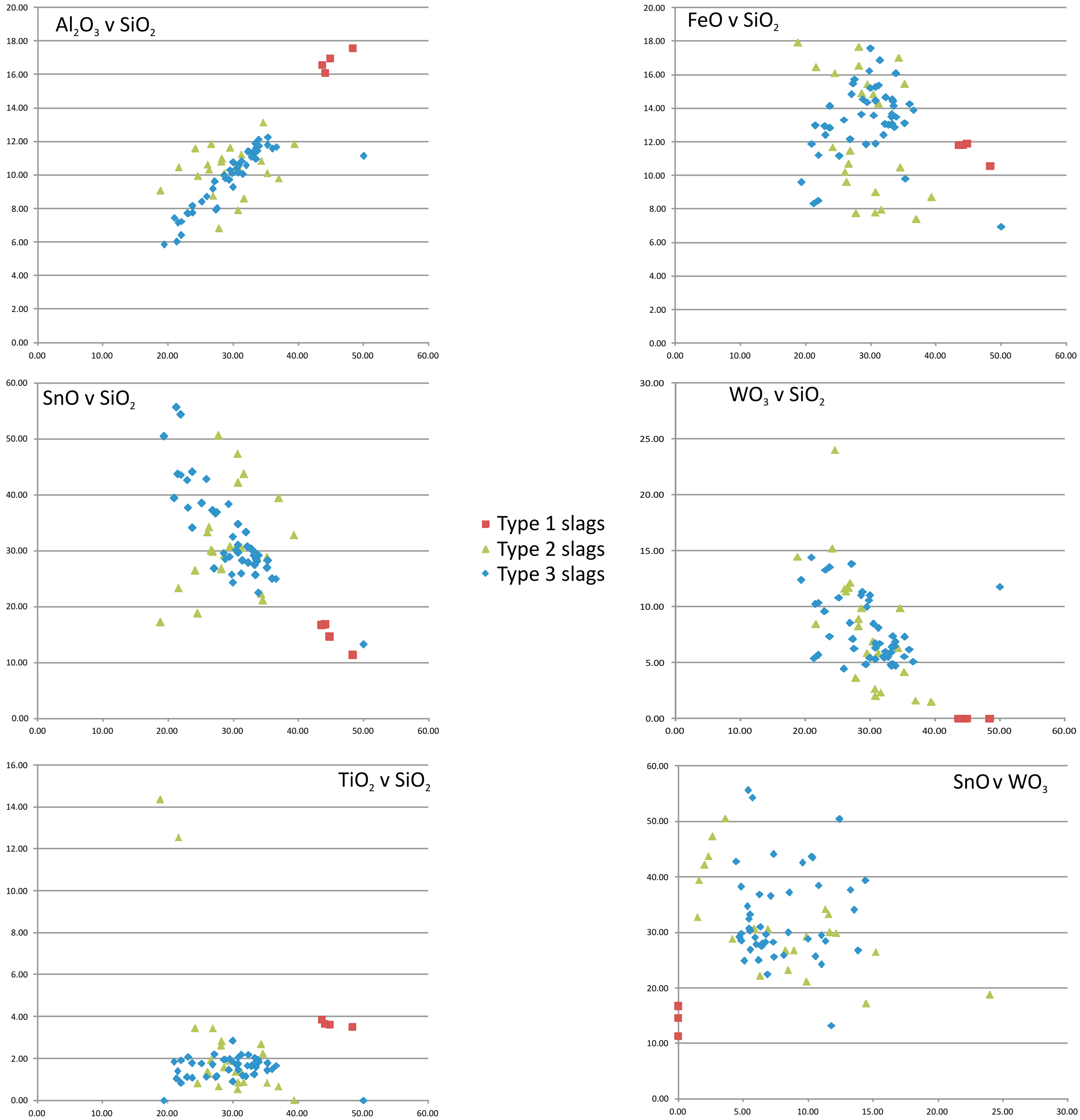
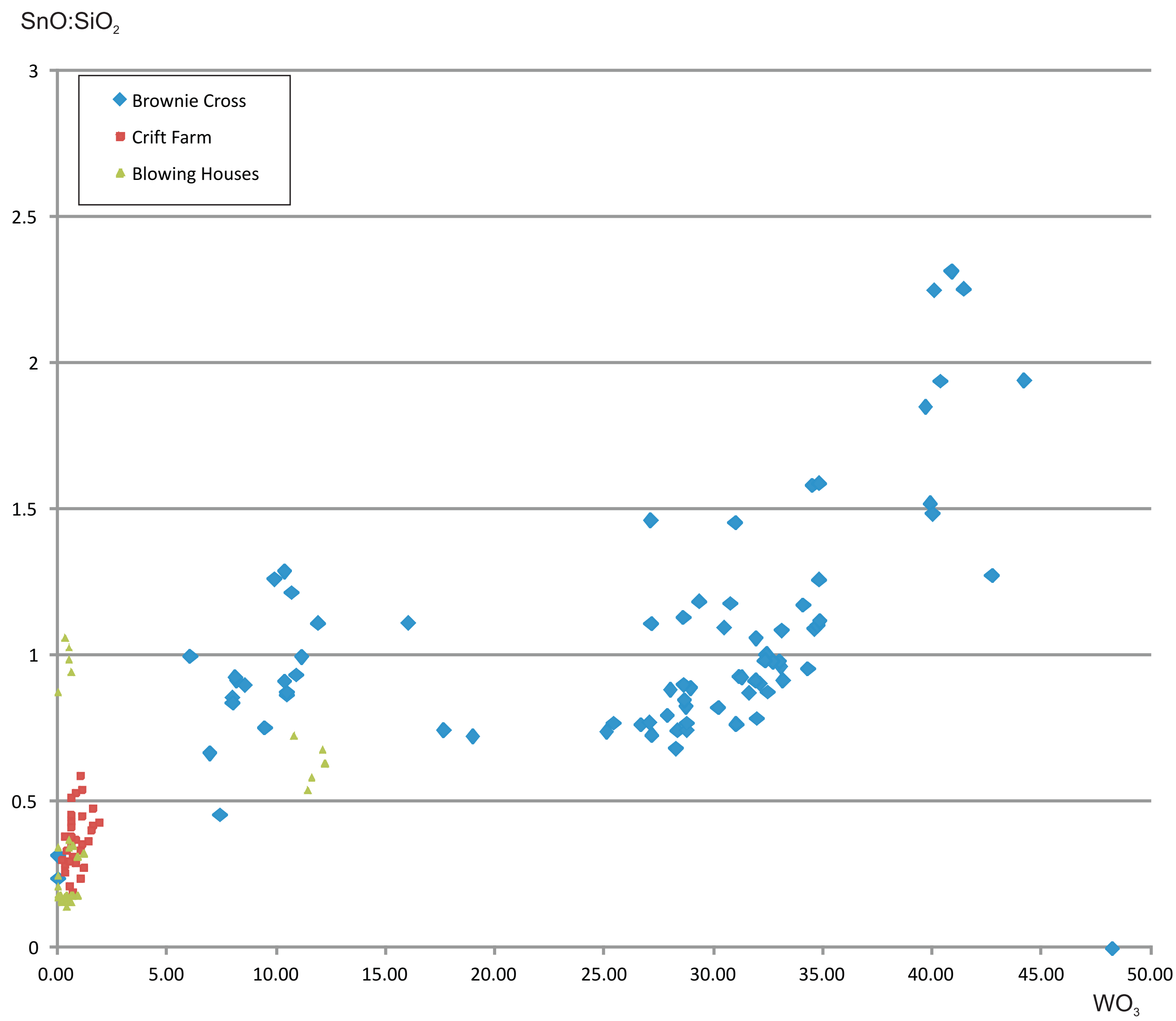

Al_2O_3 v SiO_2
FeO v SiO_2
SnO v SiO_2
WO_3 v SiO_2
TiO_2 v SiO_2
SnO v WO_3
Type 1 slags
Type 2 slags
Type 3 slags

Figure 6



SnO:SiO2
Brownie Cross
Crift Farm
Blowing Houses
3
2.5
2
1.5
1
0.5
0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
WO3

Figure 7

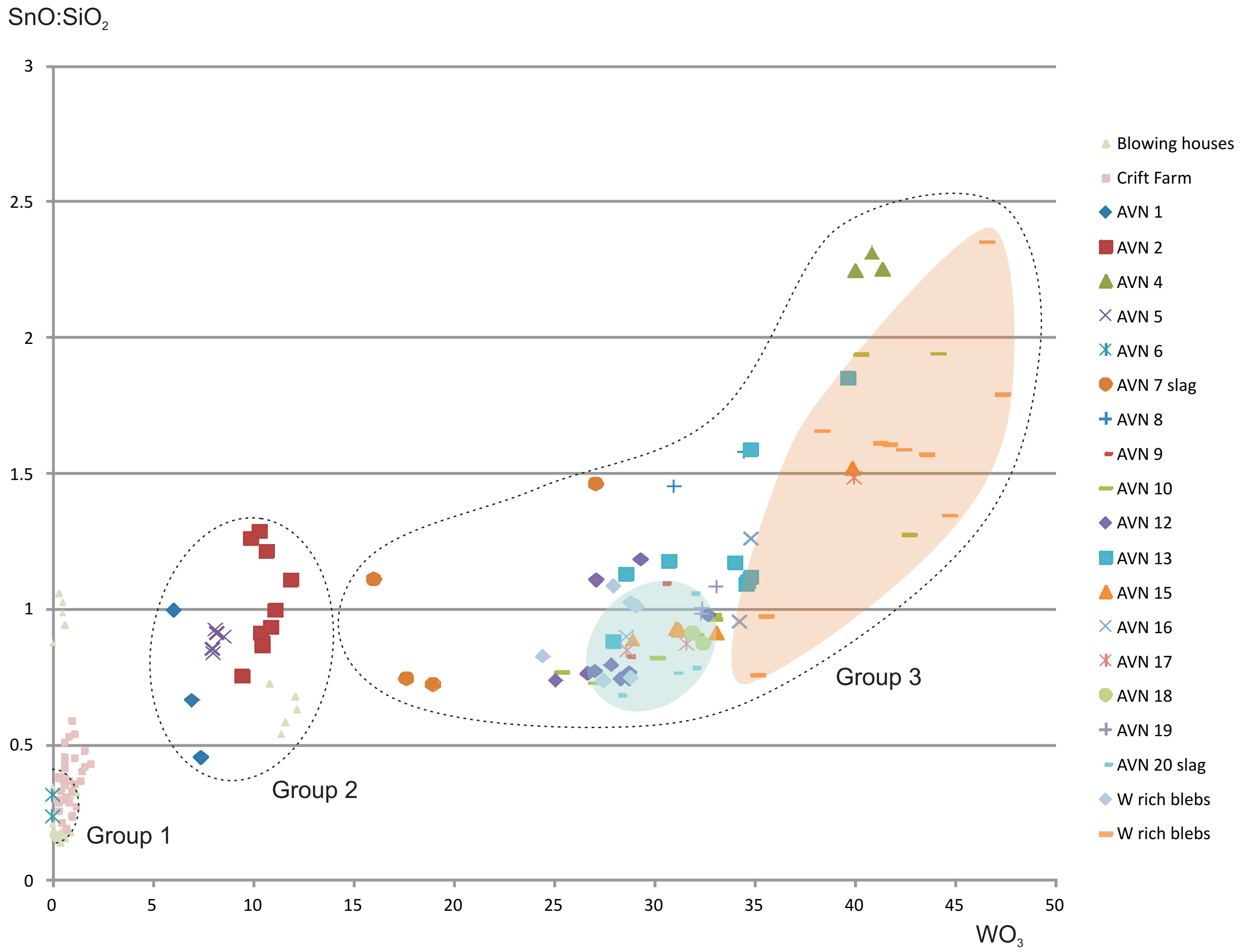
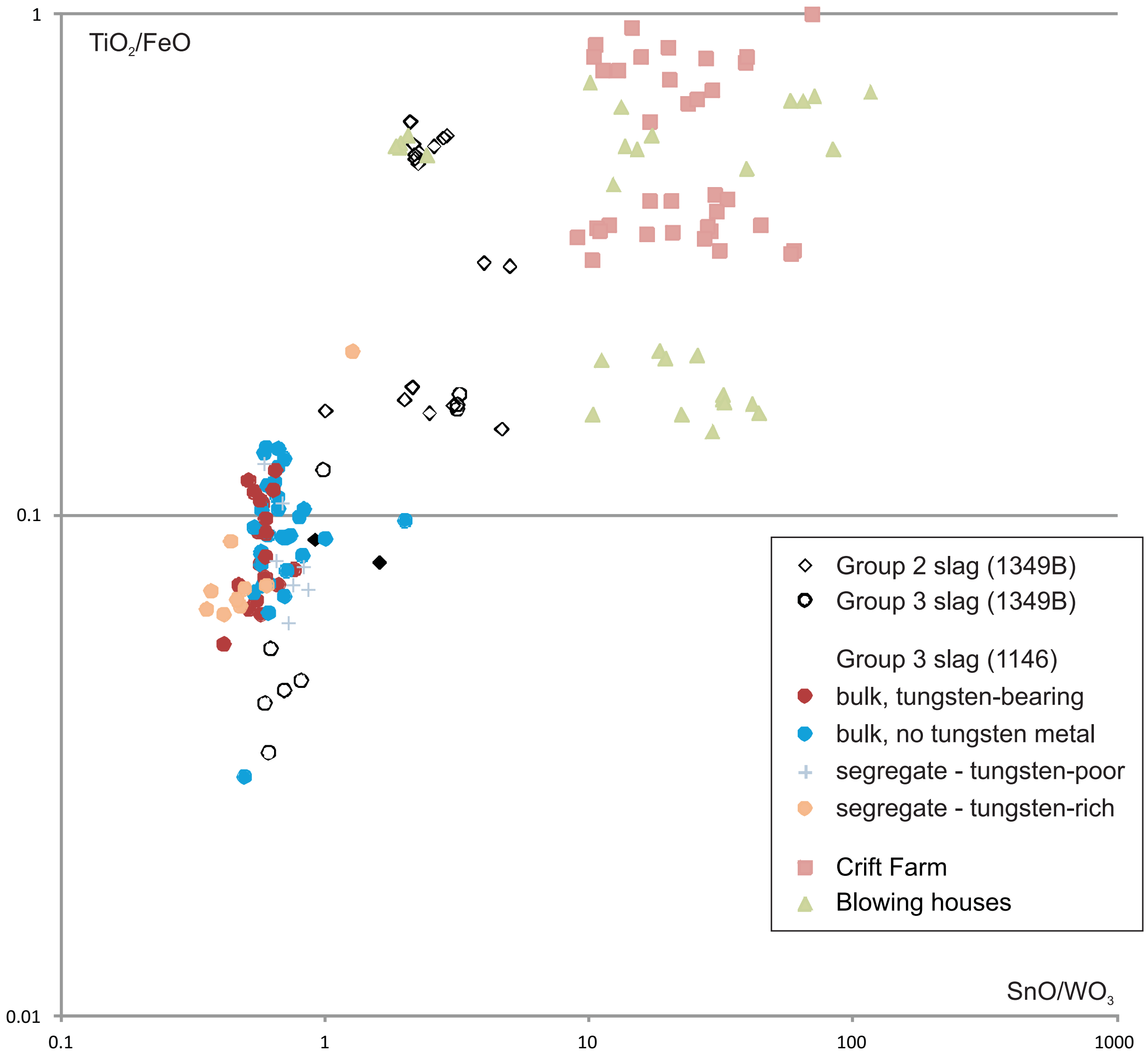
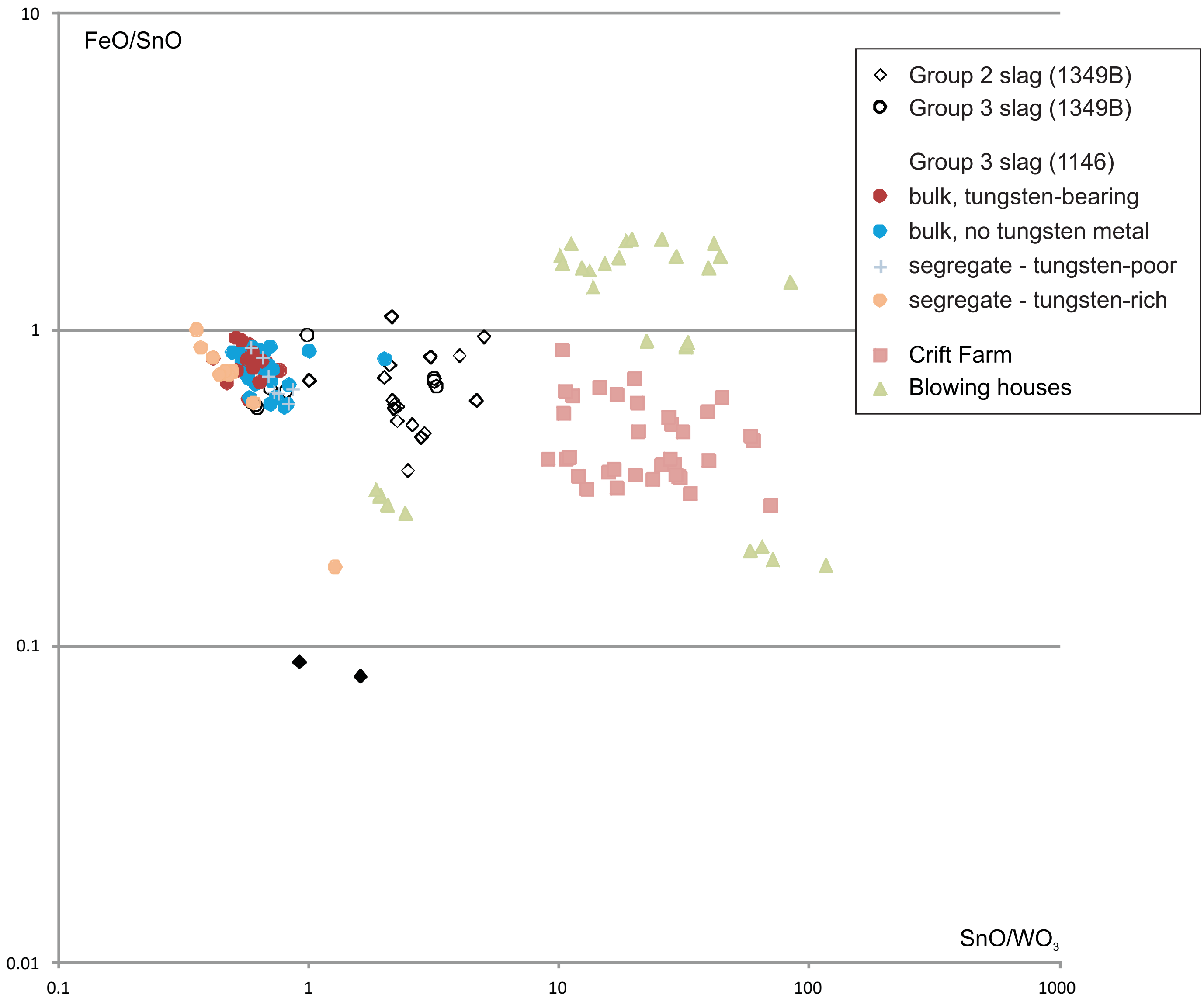

SnO:SiO2
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
45
50
WO3
Group 1
Group 2
Group 3
Blowing houses
Crift Farm
AVN 1
AVN 2
AVN 4
AVN 5
AVN 6
AVN 7 slag
AVN 8
AVN 9
AVN 10
AVN 12
AVN 13
AVN 15
AVN 16
AVN 17
AVN 18
AVN 19
AVN 20 slag
W rich blebs
W rich blebs

Figure 8



1
0.1
0.01
TiO2/FeO
0.1
1
10
100
1000
SnO/WO3
Group 2 slag (1349B)
Group 3 slag (1349B)
Group 3 slag (1146)
bulk, tungsten-bearing
bulk, no tungsten metal
segregate - tungsten-poor
segregate - tungsten-rich
Crift Farm
Blowing houses

Figure 9



10
1
0.1
0.01
FeO/SnO
SnO/WO3
0.1
1
10
100
1000
Group 2 slag (1349B)
Group 3 slag (1349B)
Group 3 slag (1146)
bulk, tungsten-bearing
bulk, no tungsten metal
segregate - tungsten-poor
segregate - tungsten-rich
Crift Farm
Blowing houses

Plate 1

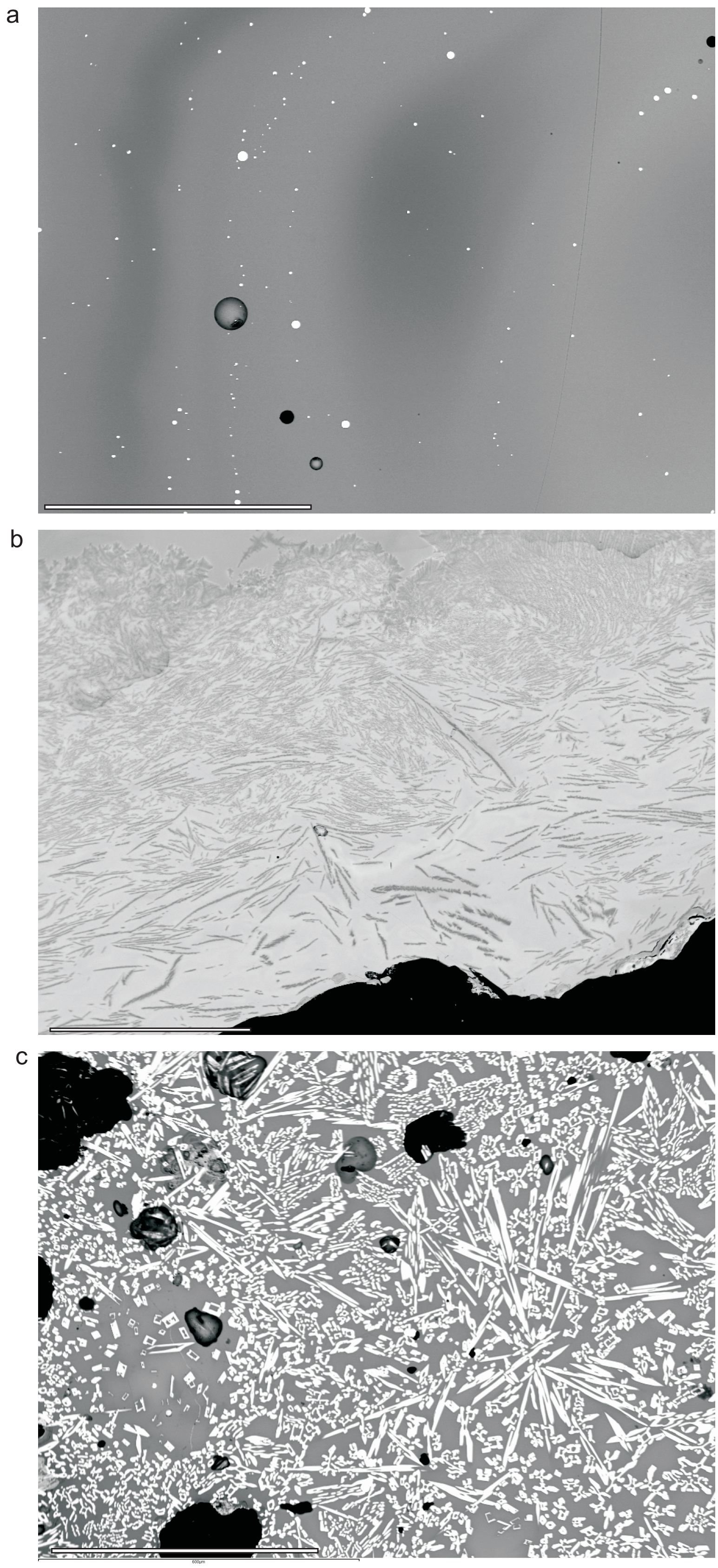


Plate 2

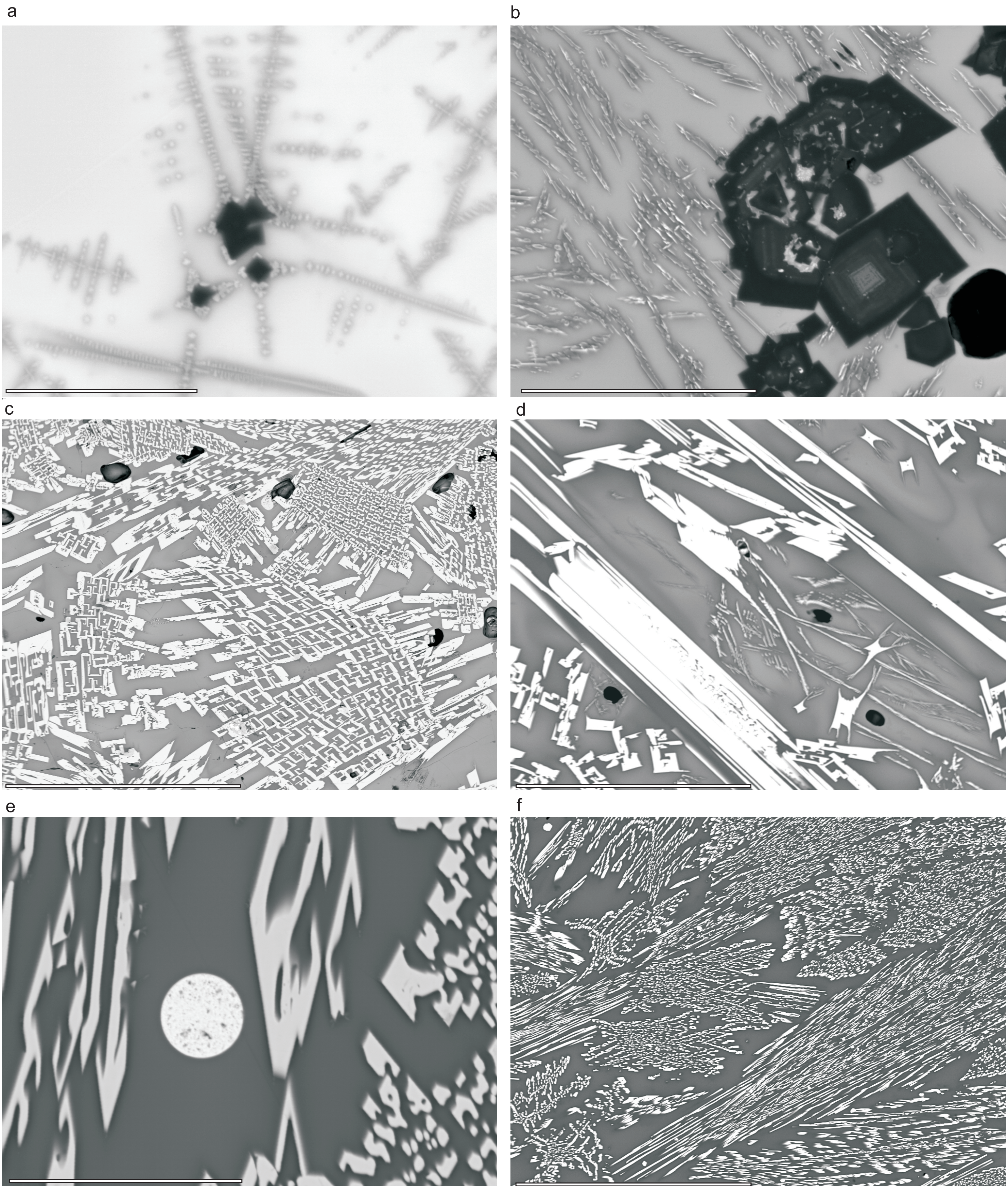


Plate 3

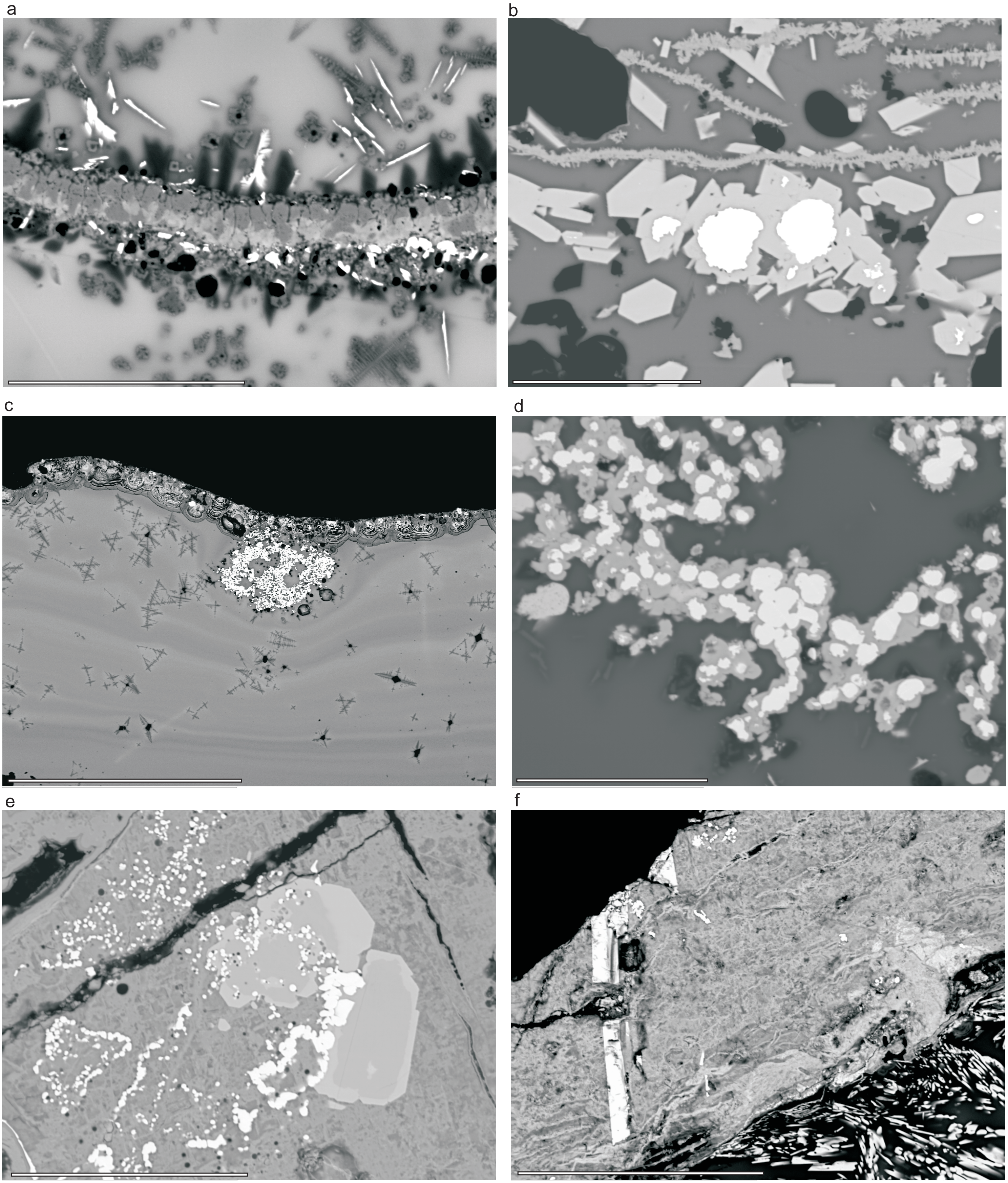
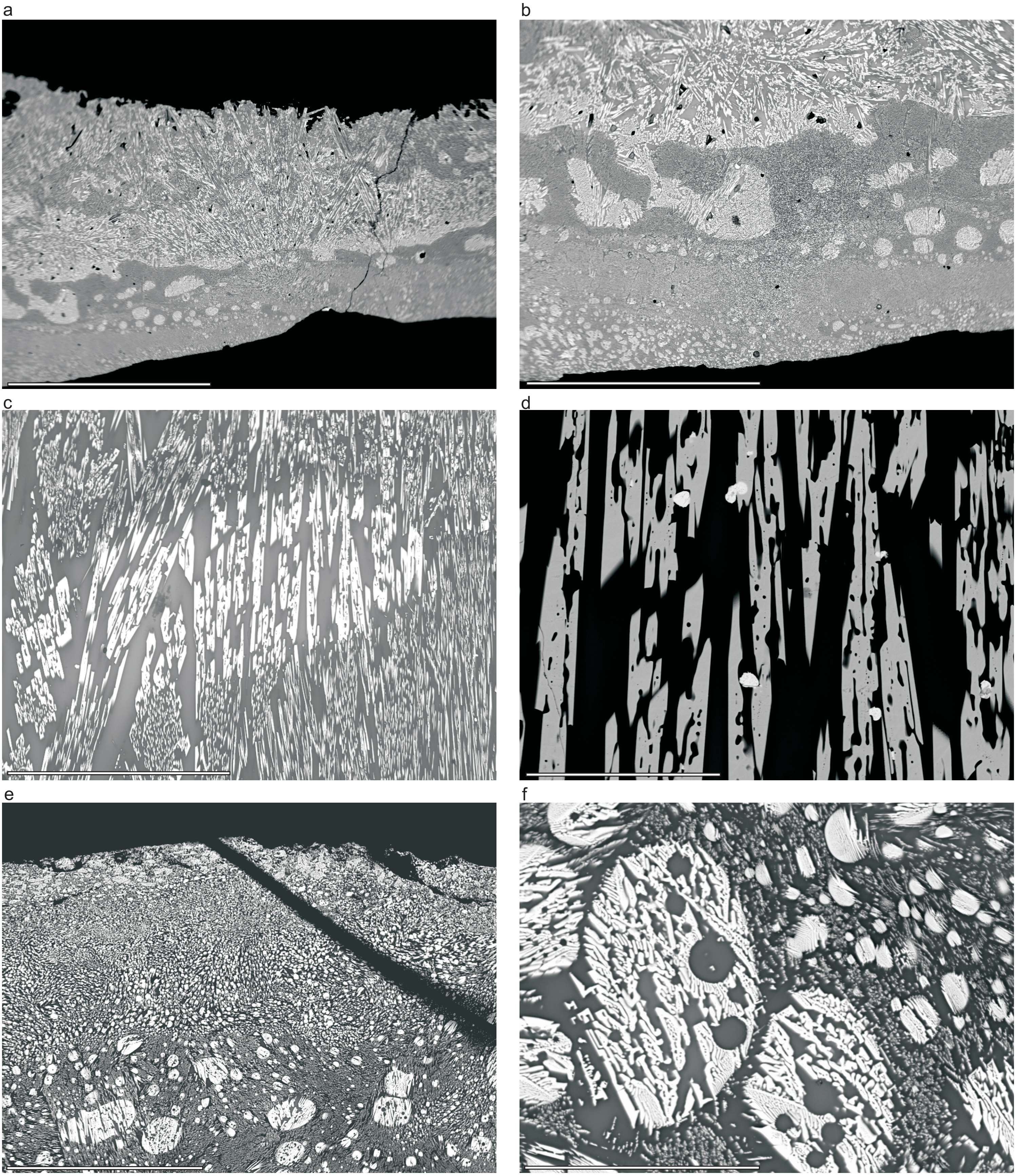


Plate 4



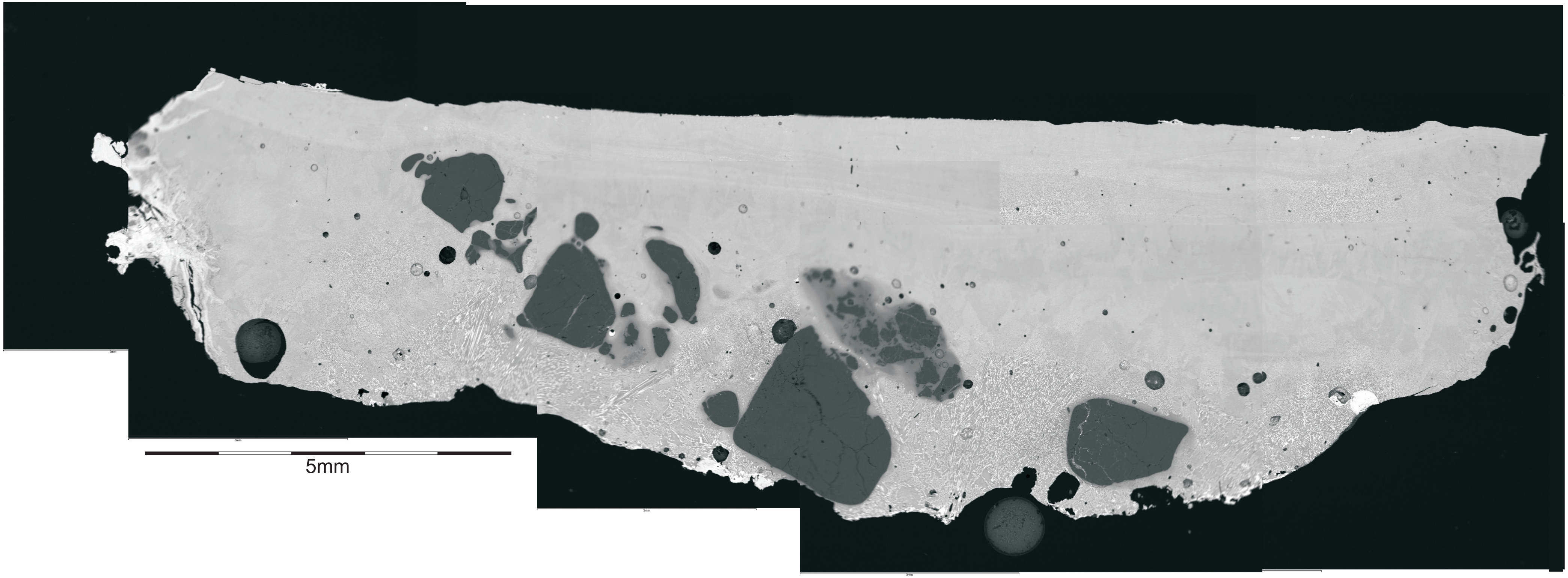
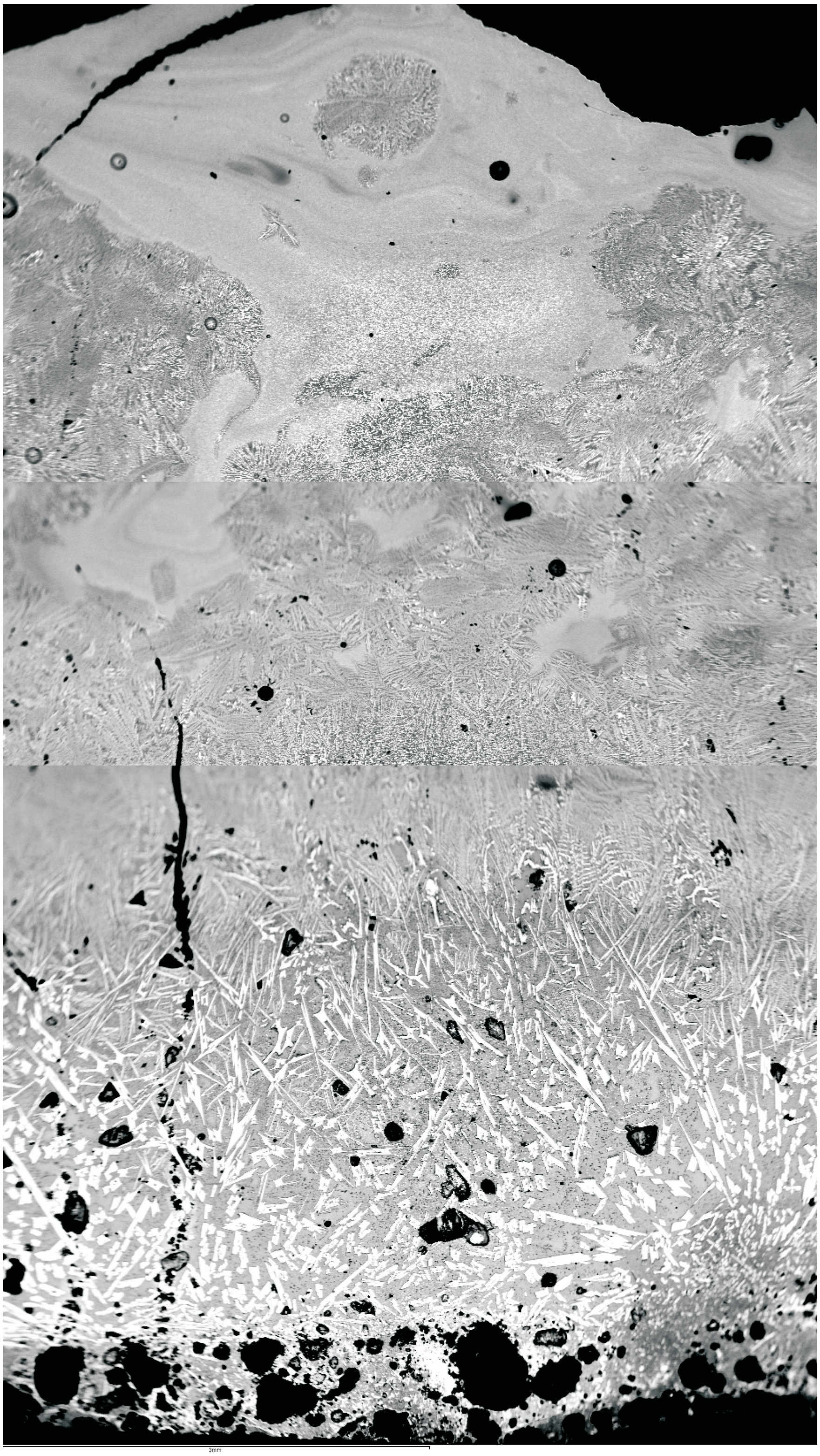

5mm

Plate 6



5mm

Appendix : Data Archive

Archive Plate Captions

Plate A1
Sample AVN1, backscattered electron micrographs.

a. SOI 1; scale bar 600µm
b. SOI 2; scale bar 30µm.
c. SOI 3; scale bar 30 µm.
d. SOI 4; scale bar 30 µm.
e. SOI 6; scale bar 600 µm.
f. SOI 7; scale bar 30µm.

Plate A2
Sample AVN2, backscattered electron micrographs.

a. SOI 1; scale bar 400µm.
b. SOI 2; scale bar 60µm.
c. SOI 3; scale bar 8800µm.
d. SOI 4; scale bar 800µm.
e. SOI 5; scale bar 60µm.
f. SOI 6; scale bar 70µm.

Plate A3
Sample AVN2, backscattered electron micrographs.

a. SOI 7; scale bar 70µm.

Plate A4
Sample AVN4, backscattered electron micrographs.

a. SOI 1; scale bar 70µm.
b. SOI 2; scale bar 3mm.
c. SOI 3; scale bar 600µm.

Plate A5
Sample AVN5, backscattered electron micrographs.

a. SOI 1; scale bar 300µm.
b. SOI 2; scale bar 600µm.
c. SOI 3; scale bar 80µm.
d. SOI 4; scale bar 50µm.
e. SOI 5; scale bar 900µm.
f. SOI 6; scale bar 50µm.

Plate A6
Sample AVN5, backscattered electron micrographs.

a. SOI 7; scale bar 600µm.

Plate A7
Sample AVN6, backscattered electron micrographs.

a. SOI 1; scale bar 600µm.
b. SOI 2; scale bar 200µm.

Plate A8
Sample AVN7, backscattered electron micrographs.

a. SOI 1; scale bar 3mm.
b. SOI 2; scale bar 800µm.
c. SOI 3; scale bar 70µm.
d. SOI 4; scale bar 3mm.
e. SOI 5; scale bar 3mm.
f. SOI 6; scale bar 600µm.

Plate A9
Sample AVN7, backscattered electron micrographs.

a. SOI 7; scale bar 30µm.
b. SOI 8; scale bar 300µm.

Plate A10
Sample AVN8, backscattered electron micrographs.

a. SOI 1; scale bar 2mm.
b. SOI 2; scale bar 200µm.
c. SOI 3; scale bar 600µm.

Plate A11
Sample AVN9, backscattered electron micrographs.

a. SOI 2; scale bar 3mm.
b. SOI 3; scale bar 300µm.
c. SOI 4; scale bar 300µm.
d. SOI 5; scale bar 300µm.

Plate A12
Sample AVN10, backscattered electron micrographs.

a. SOI 1; scale bar 3mm.
b. SOI 2; scale bar 600µm.
c. SOI 3; scale bar 70µm.
d. SOI 4; scale bar 600µm.
e. SOI 5; scale bar 100µm.
f. SOI 6; scale bar 400µm.

Plate A13
Sample AVN10, backscattered electron micrographs.

a. SOI 7; scale bar 40µm.
b. SOI 8; scale bar 90µm.
c. SOI 9; scale bar 50µm.
d. SOI 10; scale bar 30µm.

Plate A14
Sample AVN12, backscattered electron micrographs.

a. SOI 1; scale bar 300µm.
b. SOI 2; scale bar 100µm.
c. SOI 3; scale bar 1mm.
d. SOI 4; scale bar 100µm.
e. SOI 5; scale bar 100µm.

Plate A15
Sample AVN13, backscattered electron micrographs.

a. SOI 1; scale bar 4mm.
b. SOI 2; scale bar 2mm.
c. SOI 3; scale bar 600µm.
d. SOI 4; scale bar 50µm.
e. SOI 5; scale bar 1mm.
f. SOI 6; scale bar 50µm.

Plate A16
Sample AVN15, backscattered electron micrographs.

a. SOI 1; scale bar 400µm.
b. SOI 2; scale bar 60µm.
c. SOI 3; scale bar 60µm.
d. SOI 4; scale bar 200µm.
e. SOI 5; scale bar 50µm.
f. SOI 6; scale bar 1mm.

Plate A17
Sample AVN16, backscattered electron micrographs.

a. SOI 1; scale bar 200µm.
b. SOI 2; scale bar 200µm.
c. SOI 3; scale bar 200µm.
d. SOI 4; scale bar 60µm.
e. SOI 5; scale bar 200µm.
f. SOI 6; scale bar 600µm.

Plate A18
Sample AVN17, backscattered electron micrographs.

a. SOI 1; scale bar 100µm.
b. SOI 2; scale bar 60µm.
c. SOI 3; scale bar 30µm.
d. SOI 4; scale bar 300µm.
e. SOI 5; scale bar 300µm.

Plate A19
Sample AVN18, backscattered electron micrographs.

a. SOI 1; scale bar 100µm.
b. SOI 2; scale bar 100µm.
c. SOI 3; scale bar 100µm.
d. SOI 4; scale bar 30µm.
e. SOI 5; scale bar 400µm.
f. SOI 6; scale bar 100µm.

Plate A20
Sample AVN19, backscattered electron micrographs.

a. SOI 1; scale bar 200µm.
b. SOI 2; scale bar 600µm.
c. SOI 3; scale bar 70µm.
d. SOI 4; scale bar 100µm.
e. SOI 5; scale bar 200µm.
f. SOI 6; scale bar 600µm.

Plate A21
Sample AVN19, backscattered electron micrographs.

a. SOI 7; scale bar 90µm.
b. SOI 8; scale bar 60µm.

Plate A22
Sample AVN20, backscattered electron micrographs.

a. SOI 1; scale bar 800µm.
b. SOI 2; scale bar 800µm.
c. SOI 3; scale bar 3mm.
d. SOI 11; scale bar 60µm.
e. SOI 12; scale bar 300µm.
f. SOI 13; scale bar 100µm.

Plate A23
Sample AVN20, backscattered electron micrographs.

a. SOI 14; scale bar 50µm.
b. SOI 15; scale bar 900µm.
c. SOI 16; scale bar 100µm.
d. SOI 17; scale bar 20µm.
e. SOI 18; scale bar 200µm.

Table A1: Raw EDS microanalysis data in elemental weight%. For locations of the analyses see plates A1-A24.

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN1	1	# 1	area	38.11	0.58	1.45	6.57	13.41	0.22			0.80	0.48	1.52			0.49	13.30						25.21	4.85	107.00
AVN1	2	# 1	point	30.22		5.37	28.91	0.15						0.35	0.76	0.87	0.35	21.90								88.88
AVN1	2	# 2	point	30.60		5.50	29.25	0.18						0.36	0.73	0.83	0.30	22.01								89.77
AVN1	2	# 3	point	38.84	0.58	1.69	8.03	10.86	0.15			0.89	0.22	4.61			0.44	22.29						16.62	2.94	108.15
AVN1	2	# 4	point	29.84		2.87	13.28	2.83						7.84	0.71		0.45	35.15						3.16	0.70	96.83
AVN1	2	# 5	point	30.02		2.48	10.62	3.55				0.25	0.13	7.54	0.40		0.49	33.01						6.69		95.17
AVN1	2	# 6	point	36.59	0.43	1.70	7.68	10.98	0.14			0.81	0.34	3.87			0.43	20.34						17.23	3.15	103.70
AVN1	2	# 7	point	35.32	0.69	1.14	5.62	13.80	0.20			0.56	0.55	0.78			0.36	10.50						25.49	4.37	99.38
AVN1	2	# 8	point	35.31	0.53	1.15	5.84	13.07	0.14			0.50	0.45	1.08			0.46	11.37						25.65	4.38	99.92
AVN1	2	# 9	point	32.67	0.30	2.17	9.33	6.33				0.52		7.70	0.36		0.45	31.67						9.62	1.34	102.44
AVN1	3	# 1	point															0.77							98.33	99.10
AVN1	3	# 2	point	0.67														0.57							98.45	99.69
AVN1	3	# 3	point	0.72														0.98							96.77	98.47
AVN1	3	# 4	point	5.02			0.33											0.75						98.58	2.23	106.91
AVN1	3	# 5	point	3.15			0.41	0.13										0.42						100.50	0.00	104.62
AVN1	3	# 6	point	15.83														14.98							64.21	95.01
AVN1	3	# 7	point	16.75														17.32							59.43	93.50
AVN1	3	# 8	point	16.00		0.75											0.39	16.36						0.69	59.18	93.37
AVN1	4	# 1	point	37.43	0.68	0.95	4.94	15.19	0.28			0.72	0.42	0.46			0.37	11.08						23.40	3.04	98.96
AVN1	4	# 2	point	36.23	0.70	1.21	5.25	13.42	0.25			0.69	0.24	0.77			0.39	10.89						25.47	5.16	100.68
AVN1	4	# 3	point	29.92		3.24	18.13	1.51						6.26	0.92	0.22	0.40	29.92						1.85	1.26	93.63
AVN1	4	# 4	point	28.88		3.58	22.41	0.58						3.72	0.93		0.30	27.27						0.64	0.79	89.11
AVN1	4	# 5	point	5.50			0.28											0.85						97.62	3.31	107.56
AVN1	4	# 6	point	0.69														0.55							97.69	98.94
AVN1	4	# 7	point	0.75														0.75							98.46	99.96
AVN1	4	# 8	point	17.22														16.81							60.25	94.28
AVN1	4	# 9	point	21.01			0.69	1.42						0.33				16.47						3.86	54.41	104.26
AVN1	4	# 10	point	35.68	0.38	1.45	2.76	6.90				0.40	0.16	16.46			0.52	22.81						12.99	3.21	103.73
AVN1	4	# 11	point	34.73	0.43	1.46	2.87	6.64				0.47	0.00	17.37			0.60	24.13						10.05	4.48	103.22
AVN1	6	# 1	area	36.95	0.71	1.36	6.38	14.08	0.24			1.04	0.44	1.64			0.60	11.79						12.10	5.08	92.41
AVN1	6	# 2	area	39.70	0.69	1.45	6.83	14.33	0.21			0.75	0.50	1.67			0.42	13.09						18.02	5.30	102.95
AVN1	6	# 3	area	6.19			0.70	4.96																91.95		103.80

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN1	7	# 1	point	2.90			0.32	48.33																23.52		75.07
AVN1	7	# 2	point	7.10			0.52	37.69																38.72		84.03
AVN1	7	# 3	point	1.05				42.83																56.67		100.56
AVN1	7	# 4	point	1.79			0.19	45.24																23.61		70.83
AVN1	7	# 5	area	5.27			0.75	5.69																98.15		109.86
AVN1	7	# 6	point	2.80			0.22												0.40					101.22		104.64
AVN1	7	# 7	point	6.47			0.94																	101.24		108.65
AVN1	7	# 8	point	4.24			0.55												0.64					101.76		107.19
AVN1	7	# 9	point	3.91			0.42																	101.15		105.47
AVN2	1	# 1	area	36.95	0.58	0.74	5.37	10.42				0.80	0.94	4.44			1.09	10.55					1.10	23.89	8.31	105.18
AVN2	2	# 1	point	29.76		1.15	8.93							11.50	0.24		1.86	41.57						3.39		98.39
AVN2	2	# 2	point	30.95		1.37	10.36							10.62	0.36		1.87	40.60						3.44		99.57
AVN2	2	# 3	point	33.83		2.34	27.04							1.83	0.18		1.37	30.19						0.43		97.20
AVN2	2	# 4	point	34.83		3.20	29.19							1.09	0.29		1.70	26.66								96.96
AVN2	2	# 5	point	35.68		4.57	31.31							0.35	0.66		1.92	22.10								96.58
AVN2	2	# 6	point	40.45		4.27	28.07	2.42				0.18	0.14	0.68	0.66		1.29	21.09						4.58	1.74	105.60
AVN2	2	# 7	point	33.62	0.43	0.98	3.71	7.11				0.77	0.74	6.85			1.64	12.91					2.01	14.08	21.28	106.12
AVN2	2	# 8	point	36.35	0.57	0.57	4.61	12.50				1.17	0.99	2.05			1.00	8.86					1.25	26.15	9.58	105.65
AVN2	2	# 9	point	37.00	0.63	0.92	4.30	7.85				0.79	0.50	11.74			1.59	16.67					1.87	13.55	12.59	110.01
AVN2	2	# 10	point	38.18	0.50	0.65	5.54	12.00				0.85	1.06	0.81			0.86	7.81					1.12	28.88	9.05	107.31
AVN2	2	# 11	point	39.07	0.61	0.60	5.44	12.23				0.85	1.15	0.76			0.86	7.43					1.15	29.97	8.94	109.03
AVN2	3	# 1	point	27.18	0.39	0.66	3.23	5.73				0.48	0.49	8.93			1.13	12.31					0.92	10.60	6.04	78.08
AVN2	3	# 2	area	36.54	0.46	0.71	5.31	10.31				0.80	0.97	4.50			1.15	10.21					1.08	24.53	7.63	104.22
AVN2	3	# 3	area	37.53	0.45	0.77	5.54	10.57				0.87	0.96	4.53			1.08	10.38					0.85	25.68	8.24	107.45
AVN2	4	# 1	area	32.69	0.53	0.80	5.41	10.22				0.72	0.95	3.74			0.95	8.81					0.84	16.66	6.95	89.26
AVN2	4	# 2	area	37.32	0.60	0.90	6.16	11.85				0.91	1.22	3.97			1.09	10.00					0.91	19.52	8.01	102.45
AVN2	4	# 3	area	37.38	0.49	0.93	6.10	11.92				0.95	1.15	4.23	0.26		1.09	10.35					0.98	20.52	8.14	104.49
AVN2	5	# 1	point	38.57	0.65	0.93	6.21	11.85				1.28	0.93	5.36			1.22	12.29					1.05	15.81	8.13	104.29
AVN2	5	# 2	point	37.46	0.63	1.07	6.29	12.11				1.15	0.95	6.93			0.99	9.83					1.09	15.99	6.57	101.06
AVN2	5	# 3	point	38.50	0.68	1.06	6.36	12.43				1.26	0.93	6.07			1.02	10.00					1.03	17.82	6.68	103.84
AVN2	5	# 4	point	37.54	0.61	1.00	6.18	12.05	0.22			1.15	0.93	6.65			0.90	9.72					0.66	16.97	6.67	101.27
AVN2	5	# 5	point	37.64	0.60	0.96	6.08	12.10				1.07	0.97	5.20			1.15	11.71					0.86	16.93	6.94	102.20
AVN2	5	# 6	point	36.98	0.45	0.87	5.94	10.94				0.68	1.05	2.00			1.02	8.78					1.23	22.57	11.68	104.20
AVN2	5	# 7	point	35.86	0.48	0.94	5.17	9.83				0.67	0.96	4.06			1.22	10.72					1.50	18.54	14.73	104.68

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN2	5	# 8	point	37.29	0.46	1.09	4.84	8.84				0.72	0.78	8.68	0.23		1.46	14.02					1.18	15.24	11.54	106.35
AVN2	5	# 9	point	34.83	0.37	1.02	4.42	8.25				0.61	0.84	7.48			1.50	13.71					1.31	16.85	13.53	104.73
AVN2	5	# 10	point	37.12	0.56	0.94	6.18	12.13				1.10	1.14	6.67			0.90	9.65					0.86	17.12	6.81	101.18
AVN2	5	# 11	area	37.95	0.54	0.85	6.11	11.59				0.87	1.10	4.12			1.04	10.17					0.93	20.43	8.41	104.10
AVN2	5	# 12	area	37.50	0.56	0.79	6.27	12.04	0.27			0.88	1.12	0.98			0.93	7.99					0.74	25.22	9.15	104.44
AVN2	5	# 13	area	37.61	0.62	0.94	6.06	11.91				1.12	0.91	5.44			1.22	11.56					0.80	16.93	7.26	102.39
AVN2	5	# 14	area	38.12	0.59	0.88	5.93	11.45	0.19			0.82	0.98	3.79			1.16	9.77					0.80	21.51	8.61	104.59
AVN2	6	# 1	point	8.08			0.87											0.29						103.93		113.17
AVN2	6	# 2	point	22.28				0.00					12.24					0.92						1.67	62.63	99.75
AVN2	6	# 3	point	7.10			0.56											0.34						105.80		113.80
AVN2	6	# 4	point	31.52		1.41	0.63	0.38						29.30	0.62		2.34	30.66					0.38	1.54	1.04	99.83
AVN2	6	# 5	point	30.43		1.47	0.70	0.40						29.43	0.48		2.45	30.58						1.29	1.02	98.25
AVN2	6	# 6	point	38.22	0.56	0.62	6.11	12.12				1.03	1.02	1.13			0.97	8.11					1.03	25.83	9.02	105.76
AVN2	6	# 7	point	36.08	0.41	1.11	3.73	6.44				0.55	0.48	15.31	0.31		1.72	19.98					0.86	13.09	7.49	107.55
AVN2	6	# 8	point	37.74	0.46	0.76	5.40	9.84				0.78	0.79	7.33			1.34	12.46					1.05	19.94	6.52	104.40
AVN2	6	# 9	point	19.50									12.51					0.69						1.06	64.07	97.83
AVN2	6	# 10	point	24.54			0.83	0.66					12.02	0.26				1.36						2.90	61.31	103.87
AVN2	6	# 11	point	46.63			13.04	1.32			0.16							0.97						91.72		156.49
AVN2	7	# 1	point	32.54		2.15	0.41	0.36						31.26	0.42		3.01	29.19						0.72		100.06
AVN2	7	# 2	point	33.11		2.08	0.78	1.24				0.13		29.77	0.43		2.75	28.03						1.79	0.85	100.95
AVN2	7	# 3	point	41.49	0.79	1.17	6.73	15.64	0.32			1.23	1.09	1.31			1.25	7.88						18.01	7.57	104.47
AVN2	7	# 4	point	11.92			1.51															0.49		106.80		120.73
AVN2	7	# 5	point	7.91			0.17	0.19		0.07	0.54			2.60			0.15	1.87		0.32				1.13		14.94
AVN2	7	# 6	point	46.64		5.15	17.59	22.45				0.79		0.20			0.80	5.84								99.44
AVN2	7	# 7	point	43.89		4.99	16.42	21.57				0.42		0.18			0.80	5.39								93.69
AVN2	7	# 8	point	30.61		1.97	0.29							31.12	0.46		3.13	28.81						0.95	0.59	97.93
AVN2	7	# 9	point	8.49			1.00																	105.49		114.98
AVN2	7	# 10	point	41.59	0.84	1.47	5.70	12.31				0.87	0.89	1.91			1.63	9.24					0.84	12.80	21.76	111.83
AVN2	7	# 11	point	1.19			0.16	0.33				0.05	0.05	0.23			0.10	0.92						0.78	0.19	4.02
AVN2	7	# 12	point															0.58						108.87		109.45
AVN2	7	# 13	point	11.03		0.23	1.11	2.22										1.47						90.18	3.84	110.08
AVN2	7	# 14	point	34.18		2.49	4.04	0.35						27.43	0.40		2.93	27.85						0.60		100.26
AVN2	7	# 15	point	35.77		5.12	27.07	1.57				0.19	0.10	1.44	0.26		1.35	18.36						1.67	0.66	93.57
AVN2	7	# 16	point	37.78		7.35	30.19	0.29						0.42	0.47	3.39	1.20	17.08								98.19
AVN2	7	# 17	point	36.14		5.82	30.38	0.71						0.56	0.36	0.46	1.25	18.57						1.03		95.29
AVN2	7	# 18	point	21.01		0.82	2.24	2.86	0.14		0.40		0.45	8.99			0.92	8.60		0.36				2.58	1.46	50.82
AVN2	7	# 19	point	27.91		1.69	0.86	0.77				0.22	0.21	27.16	0.41		2.61	26.47						2.49	0.76	91.54

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN2	7	# 20	area	11.52			1.33															0.47		104.68		118.01
AVN4	1	# 1	area	5.67			0.63	0.14																101.15		107.59
AVN4	1	# 2	area	35.09	0.42	0.22	3.96	10.37	0.28					0.65			1.15	9.74						36.31	7.35	105.54
AVN4	1	# 3	point	3.81			0.38	0.00										0.31						100.57	0.00	105.07
AVN4	1	# 4	point	18.71		0.64											4.09	12.87							61.48	97.79
AVN4	1	# 5	point	18.05		0.66	0.13										4.45	12.40							61.62	97.31
AVN4	1	# 6	point	17.91		0.63											3.90	13.13							60.85	96.41
AVN4	1	# 7	point	18.55		0.68											3.79	12.64						1.37	60.48	97.51
AVN4	1	# 8	point	35.50	0.26		3.72	9.86	0.33			0.40		0.83			1.03	9.89						37.74	7.96	107.51
AVN4	1	# 9	point	37.25	0.53		4.45	11.68	0.29			0.41	0.28	0.65			1.01	9.97						36.34	3.39	106.25
AVN4	1	# 10	point	35.77	0.40		3.95	10.65	0.28			0.45		0.62			1.01	9.58						37.34	5.59	105.64
AVN4	2	# 1	area	34.37	0.25	0.56	2.74	6.30	0.28			0.39		0.56			2.84	13.37						26.72	38.79	127.17
AVN4	2	# 2	area	21.68	0.29	0.29	1.65	3.88				0.26		0.22			1.78	8.64						16.92	24.97	80.58
AVN4	3	# 1	area	27.83			2.25	5.12	0.24			0.30		0.37			2.47	11.37						21.76	33.22	104.93
AVN5	1	# 1	area	37.88	0.58	1.41	5.66	12.96	0.24			0.87	0.39	1.71			0.57	13.60						22.36	6.36	104.58
AVN5	2	# 1	area	6.61	0.30		0.76	0.00																99.87		107.54
AVN5	2	# 2	area	34.49	0.56	1.28	5.35	11.93	0.19			0.77	0.44	1.64			0.51	12.19						20.84	5.81	96.01
AVN5	2	# 3	point	9.92			1.36	0.13																102.28		113.69
AVN5	3	# 1	point	6.80			0.19																	44.04		51.03
AVN5	3	# 2	point	11.15	0.51	0.23	1.14				0.22													98.97		112.22
AVN5	3	# 3	point	3.30																				100.82		104.11
AVN5	4	# 1	point	31.09	0.71	1.34	6.60	10.25	0.12			1.03	0.19	4.98	0.39		0.40	23.55						10.80	1.97	93.42
AVN5	4	# 2	point	33.67	0.33	1.63	7.20	8.02				0.82	0.17	5.29	0.27		0.64	27.48						10.74	2.42	98.66
AVN5	4	# 3	point	35.11	0.62	1.63	6.72	9.84				0.87	0.32	5.12	0.23		0.48	26.14						12.43	3.08	102.60
AVN5	4	# 4	point	35.51	0.61	1.30	5.03	12.54	0.20			0.53	0.40	0.89			0.57	10.84						24.15	7.33	99.89
AVN5	4	# 5	point	35.72	0.44	1.31	5.43	12.33	0.18			0.56	0.37	1.58			0.51	12.83						22.04	6.11	99.43
AVN5	4	# 6	point	36.20	0.77	1.43	5.97	12.40	0.20			1.14	0.34	2.82			0.54	17.92						16.78	4.39	100.90
AVN5	4	# 7	point	30.95	0.61	1.61	7.22	8.93				0.81	0.17	5.51	0.39		0.52	26.87						9.72	1.84	95.16
AVN5	4	# 8	point	36.63	0.80	1.31	5.48	15.29	0.19			1.45	0.36	1.53			0.41	12.61						18.65	4.75	99.47
AVN5	6	# 1	point	26.72		0.30	0.48	0.25						0.53				68.14						1.01		97.42
AVN5	6	# 2	point	29.77		0.42	2.16	0.33						1.32				53.86						13.76	0.47	102.08

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN5	6	# 3	point	29.08			0.66	1.30										4.83						62.64	6.32	104.84
AVN5	6	# 4	point	29.25	0.47	0.66	3.24	9.15				0.97	0.27	0.58			0.51	11.41						15.38	27.03	98.91
AVN5	6	# 5	point	32.61		6.91	0.25	14.31	0.38					0.24			1.32	40.33						0.69		97.04
AVN5	6	# 6	point	33.87		7.12	0.53	14.41	0.31					0.27			1.19	38.44						2.06		98.21
AVN5	6	# 7	point	33.71		0.25	28.26	3.21	0.15		0.26		0.64	0.53			0.21	5.13						5.79	0.97	79.12
AVN5	6	# 8	point	32.47		2.83	17.50	1.83				0.12		5.53	0.47	0.20	0.52	33.74						4.14	0.64	99.99
AVN5	6	# 9	point	36.85		1.32	8.05	5.72				0.38	0.16	8.01	0.41		0.62	35.71						9.89	1.82	108.93
AVN5	6	# 10	point	30.11		1.68	7.77	1.65						9.71	0.45		0.59	42.14						3.87		97.97
AVN5	6	# 11	point	31.93		1.81	8.23	3.03				0.27		8.38	0.43		0.50	35.75						7.00	1.09	98.42
AVN5	6	# 12	point	29.95			0.48							0.33			0.34	54.96						16.67	1.03	103.76
AVN5	6	# 13	point	27.11		0.22	0.25	0.24						0.46				67.74						1.37		97.36
AVN5	6	# 14	point	29.26		1.75	8.86	0.80						9.31	0.65		0.62	42.03						3.41		96.69
AVN5	6	# 15	point	30.43		1.40	5.31	2.91						4.42	0.24		0.60	44.49						8.68	2.02	100.51
AVN5	7	# 1	area	34.54	0.62	1.21	5.05	11.97	0.20			0.68	0.28	1.54			0.44	12.02						19.34	5.51	93.41
AVN5	7	# 2	area	35.87	0.61	1.25	5.36	12.09	0.19			0.70	0.35	1.63			0.50	12.60						21.44	5.92	98.49
AVN5	7	# 3	area	39.03	0.70	1.39	5.82	13.86	0.27			0.91	0.34	1.67			0.59	13.38						21.91	6.32	106.21
AVN5	7	# 4	area	39.06	0.67	1.43	5.92	13.34	0.26			0.80	0.51	1.85			0.50	14.13						22.65	6.87	107.99
AVN5	7	# 5	point	40.50	0.63	1.62	5.95	13.71	0.28			0.71	0.47	1.64			0.66	13.37						24.50	7.34	111.38
AVN5	7	# 6	point	42.30	0.86	1.41	5.46	17.09	0.29			1.45	0.29	0.38			0.48	10.41						23.81	7.30	111.53
AVN5	7	# 7	point	43.23	1.02	1.28	5.85	17.95	0.26			1.53	0.42	0.58			0.53	10.54						22.60	5.98	111.78
AVN5	7	# 8	point	37.36	0.75	1.75	6.97	12.74	0.20			1.09	0.36	3.89			0.48	19.61						14.98	4.60	104.78
AVN6	1	# 1	area	47.35	0.97	2.02	8.44	19.77	0.26			0.56	0.83	2.13			0.70	8.64						11.81		103.49
AVN6	1	# 2	area	44.25	1.04	2.07	8.37	20.15	0.27			0.62	0.72	1.84			0.47	7.62						9.07		96.47
AVN6	1	# 3	point	44.79	1.00	2.09	8.29	20.14	0.22			0.64	0.71	1.88			0.55	7.32						8.88		96.49
AVN6	1	# 4	point	46.82	0.92	2.05	8.46	19.74	0.25			0.51	0.78	2.05			0.58	8.71						12.11		102.98
AVN6	1	# 5	point	9.65			0.51	0.20			0.15													107.17		117.67
AVN6	1	# 6	point	16.49			2.69											0.37						100.04		119.59
AVN6	2	# 1	area	11.26			1.16	0.18																103.41		116.01
AVN6	2	# 2	point	6.48			0.62																	102.59		109.69
AVN6	2	# 3	point	6.17			0.49	0.00																102.53		109.19
AVN6	2	# 4	point	23.36			3.37	0.24			0.24							0.41						102.91		130.53
AVN6	2	# 5	point	12.38			1.40	0.18											0.52					96.67		111.14
AVN6	2	# 6	area	47.77	0.84	2.02	8.11	19.61	0.22			0.45	0.64	2.09			0.56	8.72						14.10		105.14
AVN6	2	# 7	area	43.52	0.79	1.81	7.70	17.90	0.22			0.49	0.61	2.02			0.46	8.06						12.90		96.50
AVN7	2	# 1	area	29.44	0.40	0.59	3.32	6.93	0.17			0.46	0.34	0.81			1.27	11.72						19.12	18.80	93.38

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN7	2	# 2	area	38.93	0.51	0.56	5.15	11.18	0.28			0.79	0.60	0.92			1.38	14.87						23.43	13.11	111.72
AVN7	2	# 3	area	28.91			1.69	0.58		0.00	0.18						0.66	7.72						41.46	26.69	107.88
AVN7	2	# 4	point	16.59		0.88				0.00							2.28	12.47							56.38	88.60
AVN7	2	# 5	point	32.69	0.45		3.03	10.90	0.23				0.48	0.34			0.50	5.06						37.42	2.41	93.48
AVN7	2	# 6	point	37.60	0.53		3.85	13.17	0.23				0.73	0.30			0.50	5.55						38.24	1.91	102.60
AVN7	2	# 7	point	43.55	0.88		5.11	17.02	0.29				1.11	0.39			0.63	5.66						34.17	1.24	110.04
AVN7	3	# 1	point	18.27		0.97											2.34	13.65							61.63	96.86
AVN7	3	# 2	point	18.15		1.06								0.16			2.39	13.35							61.10	96.21
AVN7	3	# 3	point	32.17		2.37	27.25	0.13						1.09	0.81	0.24	1.32	26.94								92.32
AVN7	3	# 4	point	31.89		2.13	26.06	0.13						1.48	0.51		1.15	28.65								92.00
AVN7	3	# 5	point	27.78		0.80	7.87	0.21						11.61	0.63		1.78	41.46						1.33		93.46
AVN7	3	# 6	point	30.18		3.13	3.04	11.91	0.30					0.45			3.52	40.07						0.61		93.22
AVN7	3	# 7	point	30.50		2.91	2.05	11.76	0.44					0.66			3.60	40.27						0.98		93.17
AVN7	3	# 8	point	23.60		0.52	1.37	1.61		0.00		0.00	0.28	1.03			2.26	14.10						7.19	48.04	99.99
AVN7	3	# 9	point	28.78	0.47		5.02	8.56				0.69	0.46	2.12			1.10	13.21						21.43	10.43	92.26
AVN7	3	# 10	point	37.89	0.84		4.21	13.67	0.23			0.88	0.83	0.48			0.59	5.70						35.63	1.69	102.65
AVN7	3	# 11	point	37.93	0.67	0.18	5.18	13.48	0.20			0.96	0.60	0.48			0.64	6.54						34.81	1.48	103.17
AVN7	3	# 12	point	30.16		3.11	0.92	13.07	0.41					0.34			3.73	41.02						1.26		94.01
AVN7	3	# 13	point	29.74		2.73	1.87	10.63	0.43					0.53			3.53	37.39						0.99	4.35	92.19
AVN7	3	# 14	point	32.59		2.39	9.72	9.41						0.29			2.97	36.89						1.83	1.27	97.35
AVN7	6	# 1	area	34.72	0.49	0.94	4.89	11.08				0.79	0.62	1.28			1.26	13.26					0.50	16.08	14.89	100.78
AVN7	6	# 2	area	33.79	0.50	0.89	4.72	10.95	0.15			0.70	0.65	1.13			1.01	12.34						15.40	12.41	94.63
AVN7	7	# 1	point	25.41		1.16	1.86	5.21	0.13			0.36	0.24	2.27			1.64	16.04						7.85	32.38	94.55
AVN7	7	# 2	point	27.24	0.27	0.74	1.99	5.52	0.18			0.47	0.32	1.30			1.47	11.93						10.14	35.46	97.01
AVN7	7	# 3	point	24.88		0.77	2.20	4.30	0.00			0.38	0.31	3.23			1.47	14.34					0.46	8.34	33.31	93.99
AVN7	7	# 4	point	38.75	0.78	0.25	5.44	15.97	0.26			0.94	0.90				0.55	5.87						25.01	1.01	95.74
AVN7	7	# 5	point	37.21	0.37	1.52	17.01	8.34	0.12			0.37	0.31	0.54			1.05	20.34						9.22	1.71	98.10
AVN7	7	# 6	point	37.56	0.32	1.24	15.83	9.51	0.16			0.57	0.56	0.61	0.17		0.76	16.87						13.88		98.04
AVN7	8	# 1	point	31.63	0.49	0.75	4.61	10.05	0.19			0.64	0.50	0.43			1.01	10.95						14.51	16.66	92.42
AVN7	8	# 2	area	32.83	0.49	0.96	4.83	10.70	0.17			0.70	0.56	1.18			1.11	12.45						14.62	13.41	94.02
AVN8	2	# 1	area	29.93		0.42	2.71	7.80	0.21			0.20	0.47	0.44			1.94	12.11						21.42	23.84	101.51
AVN8	2	# 2	area	37.10	0.45	0.30	4.08	12.40	0.27			0.33	0.46	0.66			1.22	11.69						31.32	5.48	105.76
AVN8	2	# 3	point	36.15	0.36	0.26	4.06	12.27	0.26			0.30	0.59	0.67			1.26	11.68						31.01	4.73	103.59
AVN8	2	# 4	point	17.49		0.80											3.51	13.73							58.78	94.31

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN8	3	# 1	point	17.94		0.72				0.00			0.00				3.25	13.69							62.00	97.59
AVN8	3	# 2	area	29.00		0.45	2.71	7.10	0.26				0.49	0.42			2.01	12.21						21.19	27.30	103.15
AVN9	3	# 1	area	29.33	0.31	0.62	3.30	8.13	0.20			0.29	0.22	0.71			1.61	10.27						16.81	21.45	93.25
AVN9	3	# 2	area	31.81	0.37	0.44	4.10	10.64	0.21			0.35	0.47	0.93			1.03	8.94						19.81	7.10	86.20
AVN9	3	# 3	point	33.01	0.38	0.40	4.34	10.95	0.20			0.48	0.36	0.95			1.01	8.86						20.19	6.30	87.42
AVN9	3	# 4	point	9.64			1.29											0.61						87.71	0.91	100.16
AVN9	3	# 5	point	23.78		0.70	1.53	3.19				0.20		1.18			1.94	11.76						7.18	41.10	92.57
AVN9	3	# 6	point	17.75		1.03								0.19			2.82	11.69							56.69	90.18
AVN9	3	# 7	point	39.19	0.62	0.48	5.59	14.74	0.21			0.83	0.48	0.78			1.21	9.12						21.22	3.93	98.39
AVN9	3	Sum #	area	25.64	0.30	0.57	2.84	7.19					0.35	0.56			1.38	8.92					0.45	13.71	19.05	80.97
AVN9	5	# 1	area	29.85	0.45	0.84	3.83	9.68	0.18				0.52	0.78			1.40	9.89						15.10	20.46	93.00
AVN9	5	# 2	area	35.88	0.50	0.60	5.30	13.77	0.20			0.50	0.51	1.03			1.09	8.75						21.62	4.48	94.21
AVN9	5	# 3	point	17.65			3.29	0.23										0.37						92.88		114.43
AVN10	2	# 1	area	31.02	0.43	0.85	3.91	9.61				0.50	0.41	0.87			2.03	12.23					0.66	16.41	26.41	105.35
AVN10	2	# 2	area	26.14	0.28	0.62	3.22	7.71	0.21			0.43	0.49	0.57			1.73	10.97						14.01	23.04	89.42
AVN10	3	# 1	area	29.93	0.39	0.68	3.63	8.86	0.24			0.45	0.34	0.74			1.89	12.10						16.40	26.10	101.75
AVN10	3	# 2	point	17.07		0.90											2.91	13.55							61.66	96.09
AVN10	3	# 3	point	17.47		1.05								0.23			2.96	13.50							62.23	97.43
AVN10	3	# 4	point	18.01		0.99								0.20			3.02	13.03					0.83	1.52	60.96	98.56
AVN10	3	# 5	point	36.02	0.51	0.52	5.31	13.58	0.27				0.67	0.99			1.40	11.21						24.67	5.05	100.19
AVN10	4	# 1	area	34.50	0.55	0.66	4.67	12.40	0.24			0.82	0.37	0.69			1.98	12.25						17.04	23.05	109.20
AVN10	4	# 2	area	24.28	0.38	0.50	2.36	5.17	0.23			0.34	0.39	0.49			1.58	10.10						18.90	29.83	94.55
AVN10	5	# 1	point	16.90		0.95								0.23			3.04	14.06							62.81	97.99
AVN10	5	# 2	point	38.85	0.64	0.58	6.04	16.71	0.25			0.98	0.53	0.97			1.39	10.54						21.42	3.94	102.84
AVN10	5	# 3	point	37.27	0.69	0.59	5.80	15.62	0.31			1.00	0.55	1.02			1.48	11.21						22.51	5.83	103.89
AVN10	5	# 4	point	37.24	0.74	0.58	5.79	15.88	0.22				0.71	0.84			1.39	10.46						20.79	4.62	99.27
AVN10	5	# 5	point	36.04	0.60	0.47	5.26	13.64	0.21			0.76	0.39	0.99			1.25	10.10						25.32	6.43	101.45
AVN10	5	# 6	point	35.94	0.58	0.45	5.56	14.51	0.25			0.92	0.48	0.94			1.18	9.58						25.27	4.13	99.78
AVN10	5	# 7	point	35.78	0.56	0.37	5.21	13.45	0.27			0.83	0.54	0.83			0.97	8.65						28.61	3.94	100.00
AVN10	5	# 8	point	33.90	0.49	0.23	4.53	11.69	0.21			0.51	0.56	0.96			0.88	8.81						30.54	6.32	99.62
AVN10	5	# 9	point	32.28	0.36	0.32	3.78	9.38	0.28			0.34	0.62	1.07			0.78	8.85						33.28	10.94	102.30
AVN10	5	# 10	point	30.64	0.41	0.22	3.51	9.43	0.28			0.21	0.69	1.05			0.58	7.98						35.11	7.52	97.63

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN10	5	# 11	point	16.36		0.92								0.23			2.88	12.78							59.70	92.86
AVN10	5	# 12	area	31.77	0.62	0.63	4.33	11.43	0.20			0.81	0.42	0.66			1.63	10.92						16.57	19.60	99.59
AVN10	5	# 13	area	25.50	0.34	0.63	2.63	6.29	0.22			0.55	0.25	0.46			1.87	10.86						15.11	32.96	97.66
AVN10	5	# 14	area	24.97	0.00	0.56	2.16	4.80	0.23			0.30	0.47	0.59			1.81	10.55						17.56	33.66	97.67
AVN10	6	# 1	area	30.45	0.35	0.81	3.99	9.65	0.21			0.42	0.41	0.97			1.84	11.89						14.97	23.26	99.21
AVN10	7	# 1	point	16.89		1.23								0.23			2.84	12.54							59.96	93.68
AVN10	7	# 2	point	6.74			0.49	0.21										0.26						99.87		107.57
AVN10	7	# 3	point	36.44	0.50	0.76	5.46	13.89	0.24			0.57	0.59	1.25			1.59	11.36						21.70	6.12	100.47
AVN10	7	# 4	area	14.50			2.11	0.31										0.42						100.97	0.00	118.30
AVN10	8	# 1	point	3.46			0.16	0.00										18.40						84.70		106.72
AVN10	8	# 2	point	9.17			1.31											0.50						2.47	101.79	115.23
AVN10	8	# 3	point	40.24			0.49	0.70					0.79					0.61						71.62	2.29	116.73
AVN10	8	# 4	point	27.60			0.25	0.21										0.27						74.60	0.80	103.74
AVN10	8	# 5	point	20.66		0.14	0.12	0.33			0.13							0.27						77.94		99.58
AVN10	8	# 6	area	35.51			0.64	0.58				0.00	1.01					0.59						66.54	2.46	107.34
AVN10	8	# 7	area	31.22			0.34	0.32		0.12														75.20		107.19
AVN10	9	# 1	point	24.40			0.72	0.34	0.00		0.16	0.00						0.42						78.04		104.08
AVN10	9	# 2	point	8.52			1.57	0.75										0.52						1.09	74.09	86.54
AVN10	9	# 3	point	3.18																				2.13	86.61	91.92
AVN10	9	# 4	area	6.86			0.82											0.50						4.04	77.47	89.69
AVN10	9	# 5	point	12.27			1.09											0.78					0.90	11.88	86.71	115.96
AVN10	9	# 6	point	4.46					1.40									0.48						5.85	83.53	95.72
AVN10	9	# 7	point	9.20			0.63	0.11	16.81									0.32						70.55		97.61
AVN10	9	# 8	point	29.03			0.15	0.12	0.11			0.00												72.39		101.80
AVN10	9	# 9	point	30.83		0.19	0.43	1.52				0.00	1.29											60.86		95.11
AVN10	9	# 10	point	40.70		0.33	0.18	1.47					1.22											64.61		108.50
AVN10	9	# 11	point	30.19			0.18	0.77				0.00	0.80								1.82			65.00		98.76
AVN10	9	# 12	point	33.62			0.20	0.13	0.30			0.00												72.00		106.25
AVN10	9	# 13	point	18.73			0.19	0.17				0.00												74.51		93.60
AVN10	9	# 14	point	0.29			0.06											0.19						0.52	0.00	1.06
AVN10	10	# 1	point	2.99			0.00	0.00										18.23						82.74		103.96
AVN10	10	# 2	point	4.60														0.34						1.39	94.99	101.33
AVN10	10	# 3	point															17.63						79.30		96.93
AVN10	10	# 4	point	3.38			0.26	0.00										17.28						77.38		98.31

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN10	10	# 5	point	1.53														0.57						0.85	101.36	104.31
AVN10	10	# 6	point	10.24								0.00						1.08						5.29	104.69	121.29
AVN10	10	# 7	point	3.06								0.00												6.97	90.15	100.18
AVN10	10	# 8	point	46.59			0.53					0.00						0.71						73.73	0.88	122.45
AVN10	10	# 9	point	60.03			5.56	0.71				0.00	0.61					3.24						70.88	4.54	145.57
AVN10	10	# 10	point	40.87			0.59	0.49				0.00	1.04					1.22						67.38	5.43	117.01
AVN10	10	# 11	point	9.23														0.77						8.97	97.51	116.47
AVN12	1	# 1	area	28.48	0.40	0.86	3.89	9.24	0.17			0.40	0.46	0.95			1.63	10.55						13.87	19.47	90.38
AVN12	1	# 2	area	30.04	0.38	0.72	3.71	8.90				0.42	0.48	0.77			1.36	10.02					0.64	19.89	22.46	99.78
AVN12	1	# 3	area	30.89	0.42	0.84	4.06	8.87	0.18			0.46	0.29	0.91			2.22	11.12						16.41	25.90	102.56
AVN12	2	# 1	point	17.17													14.61	3.47						0.99	61.39	97.63
AVN12	2	# 2	point	16.76													6.08	12.82							61.57	97.23
AVN12	2	# 3	point	17.28													8.70	9.28					0.95	1.06	60.47	97.73
AVN12	2	# 4	point	35.28	0.47	0.71	4.95	12.31	0.23			0.45	0.52	1.29			1.46	11.21						22.92	10.66	102.47
AVN12	2	# 5	point	16.28		0.63											3.30	13.97							60.50	94.68
AVN12	2	# 6	point	17.80		1.15											2.74	13.54						1.19	62.67	99.09
AVN12	3	# 1	area	41.20	0.61	1.29	5.67	13.44				0.62	0.53	1.27			2.17	14.40					0.81	18.86	28.17	129.05
AVN12	3	# 2	area	36.80	0.53	1.18	4.99	11.89				0.52	0.50	1.34			1.85	13.04					0.58	16.70	25.60	115.54
AVN12	3	# 3	area	31.84	0.42	1.03	4.42	10.32	0.22			0.43	0.55	1.21			1.75	11.55						14.96	22.59	101.30
AVN12	3	# 4	area	27.24	0.41	0.83	3.64	8.61	0.21			0.47	0.40	0.98			1.41	9.40						12.41	16.85	82.85
AVN12	3	# 5	area	23.10	0.35	0.73	3.26	7.44				0.26	0.40	0.81			1.16	8.11					0.37	10.38	13.33	69.71
AVN12	3	# 6	area	38.98	0.54	1.21	5.29	12.46	0.22			0.62	0.61	1.33			1.98	13.62						17.63	26.94	121.45
AVN12	4	# 1	point	37.18	0.56	0.88	5.47	13.42	0.23			0.41	0.48	1.64			1.39	11.33						20.49	8.38	101.84
AVN12	4	# 2	point	22.24			3.97	0.21										0.53						107.21	0.00	134.16
AVN12	4	# 3	point	18.81		1.49								0.21			2.62	12.57							62.28	97.98
AVN12	4	# 4	area	31.99	0.54	1.04	4.31	10.09	0.17			0.44	0.33	1.12			1.70	11.25						13.75	23.33	100.06
AVN12	4	# 5	area	33.63	0.44	0.99	4.51	10.62	0.22			0.56	0.46	1.12			1.65	11.66						15.48	21.12	102.45
AVN12	5	# 1	point	6.28																		0.53		104.24	0.00	111.05
AVN12	5	# 2	point	3.73			0.38																	101.24	0.00	105.36
AVN12	5	# 3	point	6.89			0.94	0.14																99.86		107.82
AVN12	5	# 4	point	29.82		0.22		0.31				0.00												73.32	2.41	106.08
AVN12	5	# 5	point	16.75													3.13	14.17							58.22	92.28
AVN12	5	# 6	point	37.38	0.51	0.53	5.08	13.58	0.24			0.47	0.46	1.16			1.27	10.61						25.80	4.73	101.84
AVN12	5	# 7	area	32.76	0.42	0.69	4.14	9.25	0.23			0.48	0.29	0.91			1.57	11.47						19.35	20.98	102.53

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN12	5	# 8	point	17.47		0.91											2.70	13.62							59.62	94.32
AVN13	2	# 1	area	23.98	0.34	0.47	2.40	5.84				0.32	0.23	0.48			1.40	9.02						17.50	22.44	84.40
AVN13	2	# 2	area	26.51	0.33	0.59	3.31	8.58	0.16			0.48	0.20	0.56			1.56	9.45						14.30	18.05	84.06
AVN13	2	# 3	area	28.97	0.29	0.59	2.78	6.35				0.30	0.37	0.67			1.82	11.96					0.74	22.18	34.49	111.51
AVN13	2	# 4	area	35.68	0.35	0.92	4.07	10.09				0.46	0.44	0.85			2.26	13.01					0.67	20.78	32.72	122.31
AVN13	2	# 5	area	36.86	0.48	0.95	4.28	10.34	0.28			0.44	0.48	0.86			2.28	13.38						21.51	33.86	126.03
AVN13	2	# 6	area	39.35	0.46	0.97	4.54	10.86	0.29			0.49	0.52	0.89			2.54	14.50						22.91	36.20	134.51
AVN13	3	# 1	area	32.50	0.40	0.69	3.95	9.86	0.20			0.36	0.40	0.69			1.64	10.84						21.03	23.11	105.67
AVN13	4	# 1	point	38.84	0.52	0.53	6.01	15.31	0.30			0.53	0.36	1.07			1.26	10.11						24.77	3.61	103.22
AVN13	4	# 2	point	17.87		1.19											3.15	13.21							62.85	98.27
AVN13	5	# 1	area	31.56	0.28	0.68	3.86	9.31	0.24			0.37	0.37	0.79			1.67	11.22						20.70	25.21	106.28
AVN13	6	# 1	area	25.41	0.30	0.65	2.36	5.56	0.21			0.00	0.25	0.57			1.73	10.89	0.55					16.66	32.44	97.59
AVN13	6	# 2	area	31.31	0.55	0.74	3.86	10.07	0.23			0.57	0.22	0.60			1.65	10.77	0.57					19.51	23.18	103.85
AVN13	6	# 3	area	25.99	0.28	0.66	2.49	5.73	0.21			0.00	0.28	0.56			1.85	11.04	0.75					17.36	32.70	99.91
AVN13	6	# 4	area	26.07	0.40	0.74	2.58	5.49	0.28			0.00	0.37	0.57			2.06	11.75	0.84					16.25	35.46	102.85
AVN13	6	# 5	area	30.00	0.42	0.68	3.70	9.53	0.19			0.41	0.31	0.61			1.57	10.09	0.62					19.55	21.35	99.04
AVN13	6	# 6	area	32.64	0.59	0.74	4.19	10.44	0.22			0.50	0.40	0.52			1.82	11.21	0.94					19.92	24.54	108.66
AVN13	6	# 7	area	29.49	0.35	0.68	3.33	8.41	0.25			0.47	0.34	0.55			1.85	11.10	0.70					18.59	27.46	103.56
AVN15	1	# 1	area	30.70	0.31	0.46	3.23	6.20					0.62	0.31			1.91	13.34						17.77	32.46	107.30
AVN15	1	# 2	area	32.15	0.30	0.82	4.43	9.40	0.16				0.58	0.91			1.60	10.83						15.77	21.57	98.50
AVN15	1	# 3	point	12.95		0.61	0.19										3.12	12.71							52.91	82.49
AVN15	1	# 4	point	18.87													2.27	16.86							64.16	102.16
AVN15	1	# 5	point	2.51																				108.99		111.49
AVN15	1	# 6	point	2.64																				115.70		118.34
AVN15	1	# 7	point	19.53		0.65											3.34	14.97					0.95		65.84	105.28
AVN15	1	# 8	point	20.94		0.82											3.74	16.06							72.08	113.65
AVN15	1	# 9	point	2.80			0.27											0.31						116.84		120.21
AVN15	1	# 10	point	38.47	0.46	0.26	4.75	13.51	0.23			0.22	0.64	0.53			1.19	13.20						27.60	4.15	105.21
AVN15	1	# 11	point	44.98	0.62	0.49	5.87	16.19	0.31			0.60	0.92	0.79			1.29	14.44						27.42	5.85	119.78
AVN15	1	# 12	point	4.60			0.35	0.00				0.00						0.52						110.01	0.00	115.47
AVN15	2	# 1	area	32.18	0.34	0.88	3.90	9.18	0.23			0.44	0.35	0.86			1.85	11.72						15.85	26.47	104.25
AVN15	2	# 2	point	39.08	0.58	0.75	5.73	14.73	0.23			0.55	0.56	0.71			1.12	9.96						24.35	4.44	102.79

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN15	2	# 3	point	24.21		0.49	3.28	4.86	0.19			0.00					1.20	6.93						49.72	17.32	108.19
AVN15	3	# 1	point	12.49			1.48											0.31						102.38		116.65
AVN15	3	# 2	area	10.24			1.32	0.19																100.44	0.00	112.19
AVN15	3	# 3	point	41.08	0.51	0.61	5.83	15.11	0.24			0.46	0.52	1.04			1.30	10.33						25.54	3.73	106.28
AVN15	3	# 4	area	33.00	0.42	0.86	3.91	9.49	0.22			0.47	0.40	0.82			1.78	11.60						16.61	24.62	104.19
AVN15	3	# 5	point	21.87		1.15	1.20	2.02				0.18	0.17	0.34			2.23	12.13					0.74	5.10	51.85	98.98
AVN15	4	# 1	point	40.35	0.76	0.76	6.08	15.00	0.24			0.62	0.64	1.10			1.44	11.84						18.73	5.15	102.72
AVN15	4	# 2	point	18.63													4.16	14.87							63.19	100.85
AVN15	4	# 3	point	18.80		1.39								0.25			2.84	12.84							62.81	98.95
AVN15	4	# 4	point	18.13		1.24											2.65	12.22							58.90	93.14
AVN15	4	# 5	area	32.84	0.36	0.73	4.28	8.77				0.34	0.35	0.92			1.88	11.61					0.67	15.30	24.01	102.06
AVN15	5	# 1	point	24.26		1.34											2.47	13.24						0.94	67.97	110.22
AVN15	5	# 2	point	38.61			3.05	1.97	0.49				0.52	2.00				9.42						41.32	11.25	108.60
AVN15	5	# 3	point	19.03														18.12							62.05	99.20
AVN15	5	# 4	point	34.91			0.42											2.64						70.96	5.82	114.75
AVN15	5	# 5	point	47.81			2.68	2.24	0.38				0.56	1.00				8.64						52.24	7.43	122.97
AVN15	5	# 6	point	18.86					0.20									14.79						14.80	60.41	109.06
AVN15	5	# 7	point	18.20									0.38					15.19					0.91	14.82	60.58	110.08
AVN16	1	# 1	area	26.42	0.26	0.76	3.44	8.65	0.19			0.37	0.35	0.60			1.91	11.03						15.59	26.20	95.78
AVN16	1	# 2	area	28.70	0.45	0.76	4.24	10.78	0.23			0.57	0.27	0.68			1.78	10.83						14.99	20.69	94.96
AVN16	1	# 3	area	22.65		0.67	1.91	3.94	0.21			0.00	0.31	0.76			1.79	11.14						17.47	35.87	96.72
AVN16	4	# 1	point	35.24	0.36	0.35	4.96	13.21	0.28			0.36	0.69	0.84			1.00	8.89						32.51	3.69	102.38
AVN16	4	# 2	point	18.13		0.87		0.65						0.59			2.41	13.08						5.28	54.00	95.01
AVN16	4	# 3	point	19.24		0.86	0.82	0.84						0.33			2.49	13.03					0.80	5.43	54.47	98.32
AVN16	4	# 4	point	36.27	0.60	0.47	5.44	14.53	0.22			0.75	0.33	0.68			1.16	9.37						28.48	4.25	102.56
AVN16	4	# 5	area	29.27	0.44	0.59	4.33	11.51				0.76	0.39	0.56			1.64	10.27					0.48	17.97	18.76	96.99
AVN16	4	# 6	area	23.60		0.64	1.98	4.51				0.00	0.22	0.65			2.06	11.86					0.71	15.24	37.13	98.59
AVN16	5	# 1	area	27.80	0.27	0.74	3.24	7.81				0.31	0.38	0.62			1.73	11.07					0.63	18.56	27.41	100.57
AVN16	5	# 2	point	31.23	0.51	0.42	4.14	10.60	0.21			0.25	0.40	1.03			1.26	10.51						28.72	10.26	99.54
AVN16	5	# 3	point	16.32		1.02											2.77	13.05							60.77	93.93
AVN16	6	# 1	area	30.65	0.38	0.77	3.91	9.82				0.47	0.50	0.80			1.79	11.43						16.67	21.83	99.03

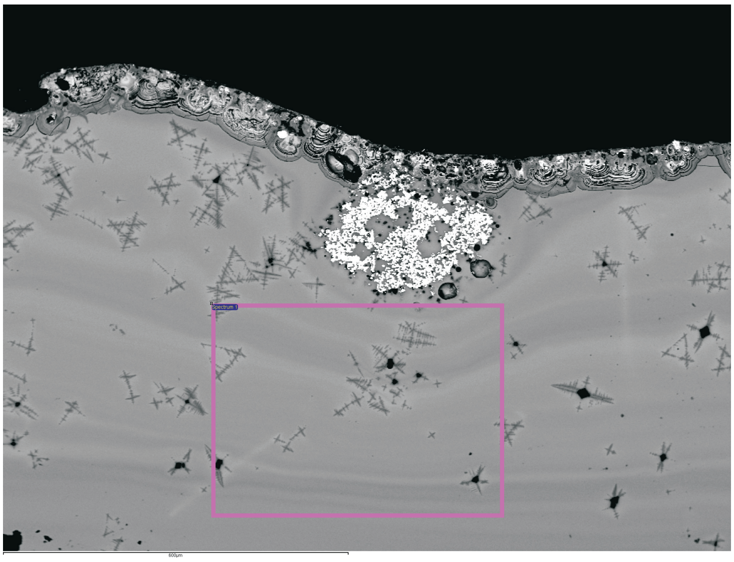
sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN17	3	# 1	point	0.81														1.42							99.67	101.91
AVN17	3	# 2	point	0.83														1.09							98.91	100.82
AVN17	3	# 3	point	0.81														0.97							101.18	102.95
AVN17	3	# 4	point	17.57														18.02							60.97	96.56
AVN17	3	# 5	point	17.13		1.15											2.02	13.52							61.30	95.12
AVN17	3	# 6	point	17.34		1.06											1.90	13.98							61.80	96.08
AVN17	3	# 7	point	28.38		0.31	2.85	8.30					0.42				0.78	6.84						40.77	9.02	97.66
AVN17	3	# 8	point	32.21	0.29	0.24	3.26	9.85	0.19					0.48			0.72	6.33						45.87	4.34	103.79
AVN17	3	# 9	point	32.02	0.25	0.28	3.11	9.66					0.45	0.61			0.61	6.28						47.58	4.13	104.97
AVN17	3	# 10	point	31.33			0.43	0.74										1.25						74.47	4.45	112.67
AVN17	3	# 11	point	31.88			0.51	0.82										1.31						72.90	4.90	112.33
AVN17	3	# 12	point	30.33			0.77	1.91				0.00						1.92						71.47	4.17	110.57
AVN17	3	# 13	point	27.81			1.14	2.65				0.00		0.75			0.30	2.82						61.01	4.39	100.86
AVN17	3	# 14	point	17.62														18.29							60.77	96.67
AVN17	3	# 15	point	33.76			1.40	2.77				0.00		0.71				2.59						65.52	4.11	110.87
AVN17	3	# 16	point	31.81		10.40	0.38	14.65									3.90	30.35						2.06		93.54
AVN17	3	# 17	point	40.90		2.24	16.38	4.95	0.14					0.47	0.18		1.07	15.47						23.68	2.23	107.74
AVN17	3	# 18	point	45.65		3.14	19.99	3.17						0.44			1.34	17.79						19.21	6.68	117.41
AVN17	3	# 19	point	8.28		0.54											0.98	8.08							69.32	87.20
AVN17	3	# 20	point	23.75		0.37	2.87	6.33				0.00	0.51	0.51			0.79	6.25						42.05	7.15	90.57
AVN17	3	# 21	point	39.52		9.52	1.07	14.02									3.42	28.94						10.25	1.12	107.84
AVN17	3	# 22	point	56.21	0.51	0.47	4.66	10.68	0.19				0.47	0.52			0.62	6.76						44.46	4.52	130.07
AVN17	4	# 1	area	27.37		0.57	2.71	6.26					0.42	0.58			1.99	11.52						17.55	30.81	99.80
AVN17	4	# 2	area	31.25	0.43	0.91	4.01	9.54	0.23			0.58	0.40	0.92			1.86	11.16						15.72	24.90	101.90
AVN17	5	# 1	area	30.69	0.40	0.84	4.00	9.81				0.53	0.43	1.05			1.80	11.03					0.57	15.68	21.80	98.62
AVN17	5	# 2	point	38.16	0.47	0.70	5.73	14.33	0.23			0.48	0.51	1.24			1.28	10.80						23.27	4.50	101.71
AVN18	1	# 1	area	29.81	0.32	0.88	3.78	9.09	0.38				0.40	0.79			1.75	11.35						15.00	24.79	98.32
AVN18	2	# 1	area	30.26	0.33	0.82	3.71	9.18				0.45	0.30	0.85			1.73	11.31						15.82	24.34	99.10
AVN18	2	# 2	point	13.21			1.15	0.81									0.27	1.66						94.29	3.14	114.54
AVN18	2	# 3	point	37.89	0.57	0.72	5.84	14.87	0.21			0.60	0.55	0.90			1.23	10.44						23.86	3.66	101.33
AVN18	4	# 1	point	36.31	0.49	0.60	5.73	14.67	0.20			0.62	0.50	0.71			1.29	10.64						24.25	3.50	99.52
AVN18	4	# 2	point	15.07			0.62	1.05			0.63							1.39						88.75	3.20	110.71
AVN18	4	# 3	point	3.95			0.29																	101.02		105.25
AVN18	4	# 4	area	5.39			0.72																	100.82		106.92

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN18	4	# 5	point	17.12		1.11											2.73	12.72						0.51	60.27	94.46
AVN18	4	# 6	point	4.19																				100.67		104.86
AVN18	5	# 1	point	35.89	0.40	0.34	4.46	11.77	0.32			0.55	0.47	1.06			0.85	8.69						33.93	8.57	107.31
AVN18	5	# 2	point	39.09	0.55	0.61	5.76	14.37	0.28			0.69	0.51	0.95			1.06	9.70						25.84	4.12	103.53
AVN18	5	# 3	area	27.71	0.37	0.59	2.66	6.38	0.21			0.41	0.27	0.58			1.69	10.37						19.93	29.92	101.10
AVN18	5	# 4	area	31.35	0.37	0.79	3.90	9.64	0.21			0.41	0.31	0.89			1.58	10.94						17.47	22.86	100.72
AVN18	5	# 5	point	41.41	0.66	0.68	5.93	14.98	0.28			0.68	0.57	1.31			1.32	11.89						29.13	9.81	118.64
AVN18	5	# 6	point	37.22	0.37	0.37	4.31	11.40	0.24			0.38	0.59	1.32			0.84	10.19						35.04	11.10	113.38
AVN18	6	# 1	point	3.25														0.31						101.27		104.83
AVN18	6	# 2	point	5.66			0.66																	100.30		106.62
AVN18	6	# 3	point																					97.52		97.52
AVN19	1	# 1	area	30.01	0.39	0.77	3.47	8.49	0.18			0.37	0.42	0.72			1.75	11.27						16.08	24.38	98.31
AVN19	2	# 1	area	31.68	0.40	0.82	3.64	9.06	0.28			0.34	0.35	0.80			1.73	11.28						16.79	25.31	102.48
AVN19	2	# 2	area	30.04	0.38	0.62	3.27	8.04				0.42	0.27	0.68			1.82	11.66					0.72	16.48	25.07	99.46
AVN19	3	# 1	point	4.75			0.29	0.32										0.92						97.72	0.41	104.41
AVN19	3	# 2	point	3.51			0.26																	102.20		105.97
AVN19	3	# 3	point	17.88		1.07			0.00								3.12	12.85							59.63	94.55
AVN19	3	# 4	point	38.35	0.50	0.52	5.17	13.47	0.27			0.64	0.41	1.10			1.59	12.20						21.88	8.10	104.21
AVN19	3	# 5	area	3.13			0.20	0.16										0.34						101.36	0.00	105.19
AVN19	4	# 1	area	30.50		0.81	3.33	8.17	0.19			0.31	0.43	0.64			1.76	11.61		0.00				15.03	27.12	99.90
AVN19	4	# 2	area	28.07	0.29	0.86	2.55	5.50	0.24			0.22	0.32	0.62			1.99	12.34						13.96	35.37	102.33
AVN19	4	# 3	area	29.62	0.28	0.81	3.37	8.43				0.27	0.37	0.71			1.80	12.76					0.64	12.05	26.44	97.54
AVN19	4	# 4	area	29.07		0.84	2.65	5.82				0.28		0.63			1.91	11.54						17.69	32.17	102.63
AVN19	4	# 5	point	4.11			0.38											0.34						100.55	0.00	105.37
AVN19	4	# 6	point	4.99														1.71						90.21	2.68	99.59
AVN19	7	# 1	point	16.08		1.05											0.79	14.68							58.43	91.04
AVN19	7	# 2	point	2.52				0.55										1.36							88.84	93.27
AVN19	7	# 3	point	1.09														0.62							94.79	96.49
AVN19	7	# 4	point	5.67			0.33																	101.39		107.39
AVN19	7	# 5	point	31.79																				77.88		109.66
AVN19	7	# 6	point	4.01			0.25															0.46		101.59		106.31
AVN19	7	# 7	point	29.27																				75.83	0.00	105.10

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN19	7	# 8	point	5.42			0.33											0.55						96.20	0.00	102.50
AVN19	7	# 9	point	30.33														0.36						72.78	0.30	103.77
AVN19	7	# 10	point	7.62				0.71					1.82					0.48						5.59	61.76	77.98
AVN19	7	# 11	point	6.28			0.60																	99.73		106.62
AVN19	7	# 12	point	31.16																				78.22		109.38
AVN19	7	# 13	point	38.82	0.69	0.40	6.08	15.47	0.25			0.83	0.53	1.01			0.86	7.14						23.33	5.43	100.86
AVN19	7	# 14	point	15.85		1.36											1.36	12.29						3.44	54.42	88.72
AVN19	7	# 15	point	33.98			1.25	0.53	0.14									1.97						64.93	6.66	109.46
AVN19	7	# 16	point	12.24														0.48						19.92	60.57	93.22
AVN19	7	# 17	point	30.53																				76.48		107.01
AVN19	7	# 18	point	6.43														0.55	0.57					102.13	1.78	111.47
AVN19	7	# 19	point	5.16			0.36											0.55						93.27	0.47	99.81
AVN19	7	# 20	point	17.25		0.59							2.03				1.65	10.70						2.57	57.36	92.15
AVN20	3	# 1	area	58.23			0.36	55.17																		113.76
AVN20	3	# 2	area	55.84			0.60	50.00																		106.43
AVN20	3	# 3	area	49.59			1.79	44.52										0.26								96.16
AVN20	3	# 4	area	16.96			0.18	15.04																0.22		32.40
AVN20	3	# 5	area	22.06	0.19		1.53	17.07				0.76						0.49						1.35	1.18	44.62
AVN20	3	# 6	area	69.47			1.53	63.12					0.27											0.35		134.73
AVN20	3	# 7	area	66.21	0.33		2.06	58.45				0.39						0.25								127.69
AVN20	3	# 8	area	15.79		0.55	2.07	4.75					0.20	0.48			0.88	5.61						6.86	11.47	48.66
AVN20	3	# 9	area	40.99	0.60	0.95	5.99	13.76	0.28				0.57	1.01			2.17	13.27						17.73	26.92	124.26
AVN20	3	# 10	point	67.05				60.52																0.42		127.98
AVN20	3	# 11	point	65.97			1.58	58.73					0.25					0.62						1.18		128.33
AVN20	3	# 12	point	24.59				21.88																		46.47
AVN20	3	# 13	point	16.11				13.93																		30.04
AVN20	3	# 14	point	27.36				24.99																		52.35
AVN20	3	# 15	point	56.21			1.02	0.93										3.03						92.89	8.28	162.37
AVN20	11	# 1	point															31.74						70.93		102.67
AVN20	11	# 2	point															18.58						84.30		102.89
AVN20	11	# 3	point															31.43						71.66		103.09
AVN20	11	# 4	point															19.05						84.99		104.05
AVN20	11	# 5	point	0.74														1.33							101.40	103.48
AVN20	11	# 6	point	0.96														1.47							104.35	106.78
AVN20	11	# 7	point	24.54					0.14	0.19			0.76											59.88	20.23	105.74
AVN20	11	# 8	point	35.52			0.37	0.77		0.14														78.24	1.25	116.29
AVN20	11	# 9	area	36.52			0.35	0.68					0.55					0.29						73.13	4.28	115.81

sample	soi	pt	type	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Rb	Zr	Sn	W	Total
AVN20	11	# 10	area	34.81			0.34	0.63																74.80	2.74	113.32
AVN20	12	# 1	area	32.04			0.49	0.79																67.70	15.23	116.26
AVN20	12	# 2	area	34.29			1.94	0.80					0.40											55.97	6.22	99.63
AVN20	12	# 3	point	3.52			1.03	1.23					0.90				0.40	5.32						3.82	1.03	17.24
AVN20	12	# 4	point	21.11			0.86	0.00					1.36					1.38						49.43	17.13	91.27
AVN20	12	# 5	area	31.69		0.70	1.14						0.41	0.60			1.54	9.13					0.97	34.72	43.79	124.69
AVN20	12	# 6	area	35.51			0.97	0.95			0.16							0.69						63.70	2.18	104.16
AVN20	14	# 1	point	0.95														0.38							103.45	104.79
AVN20	14	# 2	point	18.56		0.52							0.17	0.64			1.22	15.83							62.45	99.39
AVN20	14	# 3	point	27.01		0.49	7.60	0.63					0.45	1.36			1.62	11.12						12.72	34.50	97.52
AVN20	14	# 4	point	37.89			0.24	1.06	0.23				0.62					0.45						71.05	5.00	116.54
AVN20	14	# 5	point	21.19	0.43	0.67	2.36	4.90	0.29				0.54	0.33			1.67	11.13						8.94	39.33	91.76
AVN20	14	# 6	point	20.18		0.65								0.36			1.38	14.60						3.93	60.13	101.23
AVN20	15	# 1	area	26.53	0.27	0.83	3.25	7.71	0.20				0.48	0.86			1.38	9.51						11.40	20.06	82.48
AVN20	15	# 2	area	30.53		0.44	2.02	1.20	0.13				0.58	0.80			0.79	5.15						30.64	19.97	92.26
AVN20	15	# 3	area	40.23			1.48	0.91					0.72					1.68						67.83	12.76	125.61
AVN20	16	# 1	area	35.54	0.38	0.53		4.31	0.21				0.47	0.95			1.23	5.82						37.00	26.22	112.68
AVN20	16	# 2	area	45.36	1.13	0.17	4.98	28.16	0.21			2.67					0.25	2.67						8.47	4.74	98.81
AVN20	16	# 3	point	22.16		0.85		0.00									1.76	11.04					1.29	15.36	51.09	103.55
AVN20	16	# 4	area	41.83	1.15	0.58	5.46	21.16	0.31			2.19					0.89	5.87						11.29	10.82	101.56
AVN20	16	# 5	point	49.65				43.97																		93.61
AVN20	16	# 6	point	24.81				2.86		0.31														82.09		110.06
AVN20	17	# 1	point	21.71		0.79		0.00	0.59				0.32				1.81	10.98						15.94	50.83	102.97
AVN20	17	# 2	point	24.98	0.42	0.86		0.00	0.41	0.27			1.67	0.30			1.79	10.75					0.77	14.04	50.79	107.04
AVN20	17	# 3	point	42.65	0.99	0.55	5.81	23.00	0.35			2.29					0.82	5.31						11.44	9.19	102.39
AVN20	18	# 1	point	27.60					0.11															70.33	15.42	113.46
AVN20	18	# 2	point	37.79			1.17	0.74										3.47						64.62	8.12	115.90
AVN20	18	# 3	point	18.27		1.29											2.85	12.51							61.24	96.15
AVN20	18	# 4	point	38.74	0.57	0.58	6.10	15.09	0.27	0.70				1.19			1.21	9.84						23.44	4.92	102.65
AVN20	18	# 5	area	32.38	0.34	0.72	3.84	8.77	0.21	0.56				0.92			1.70	10.61						17.53	24.84	102.41

Plate A1



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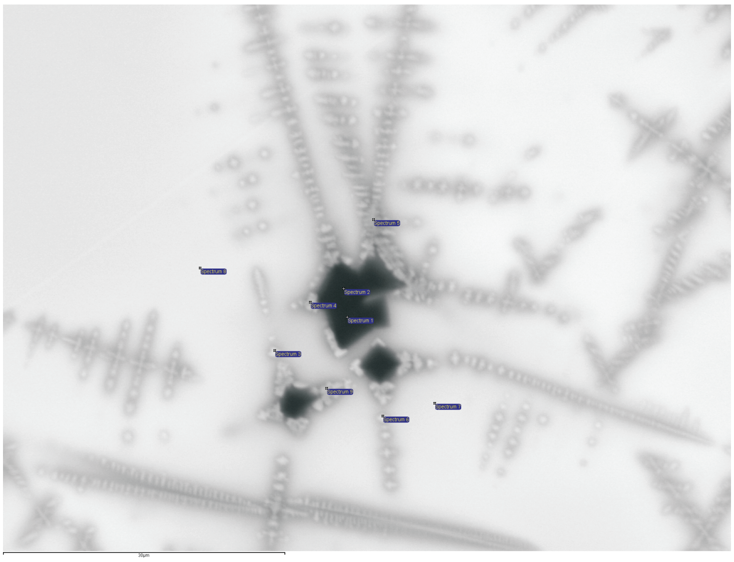

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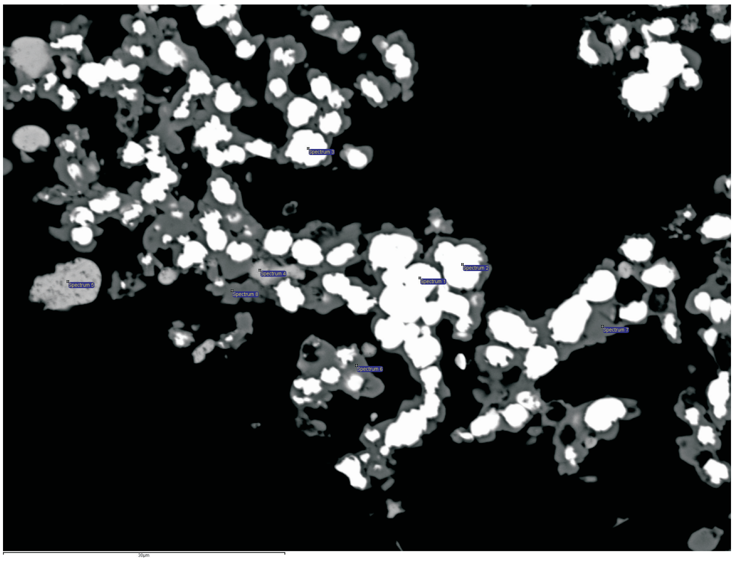

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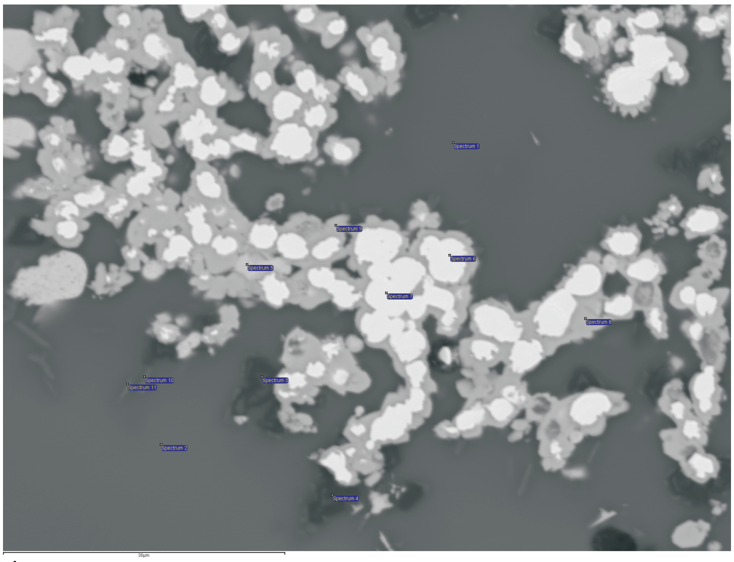

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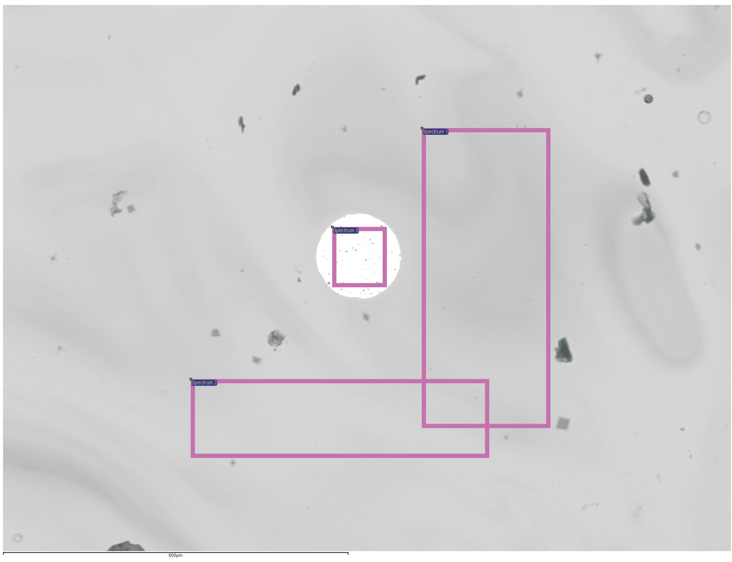

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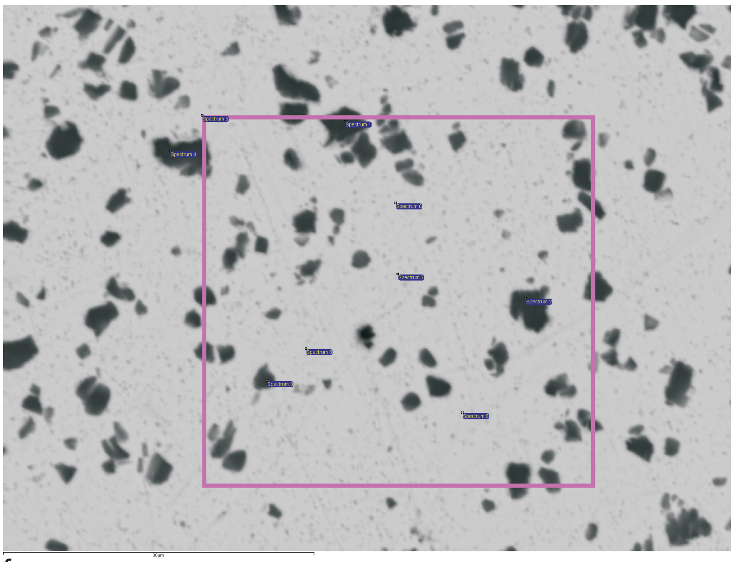

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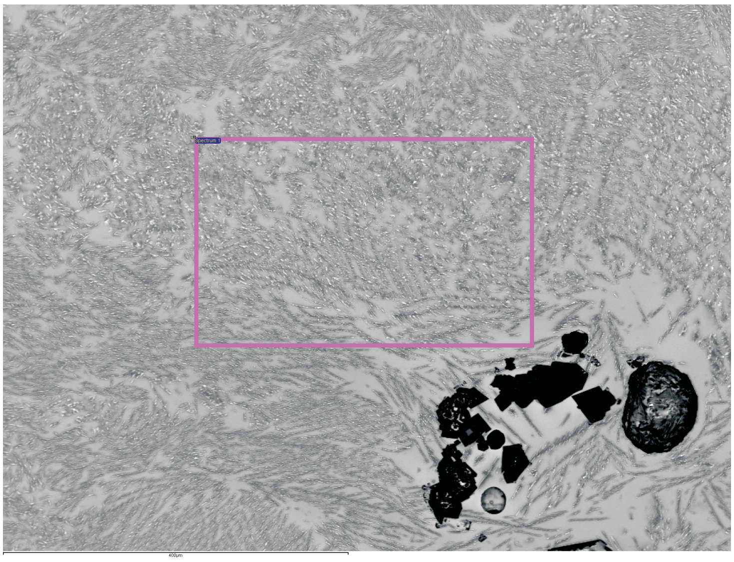

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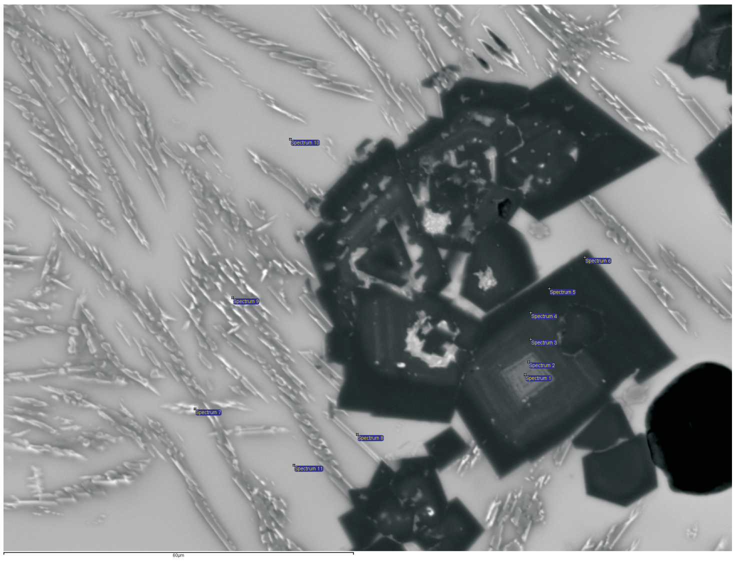

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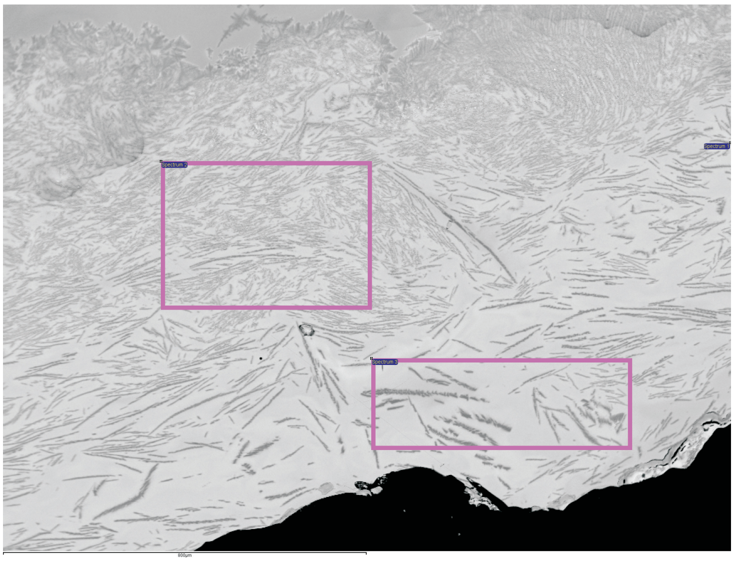

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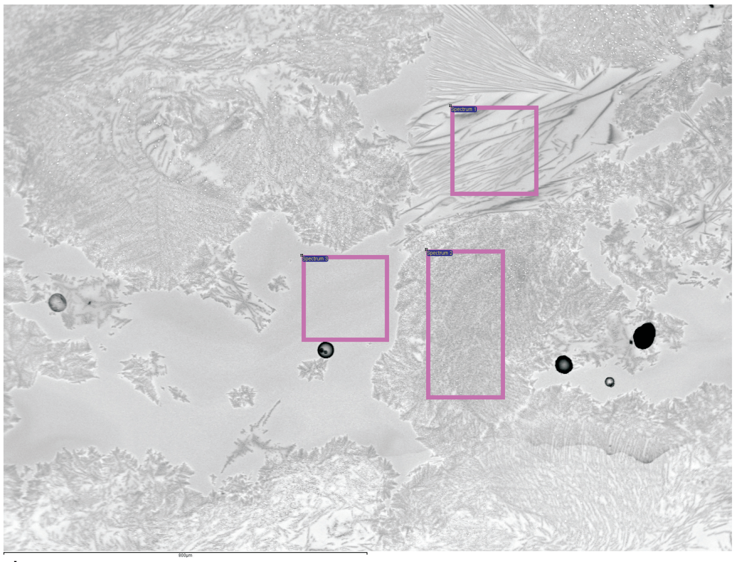

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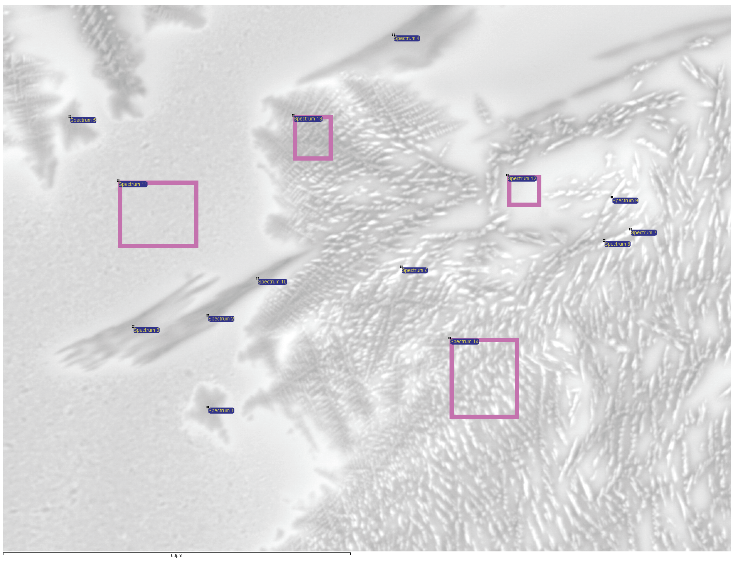

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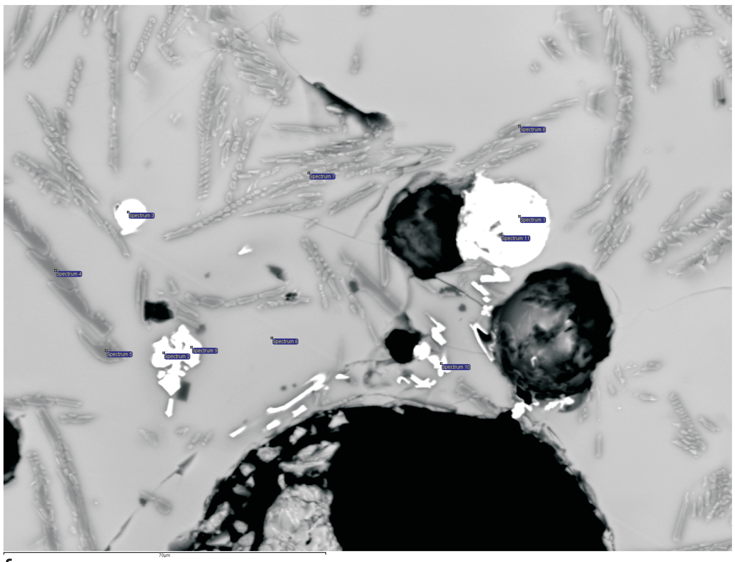

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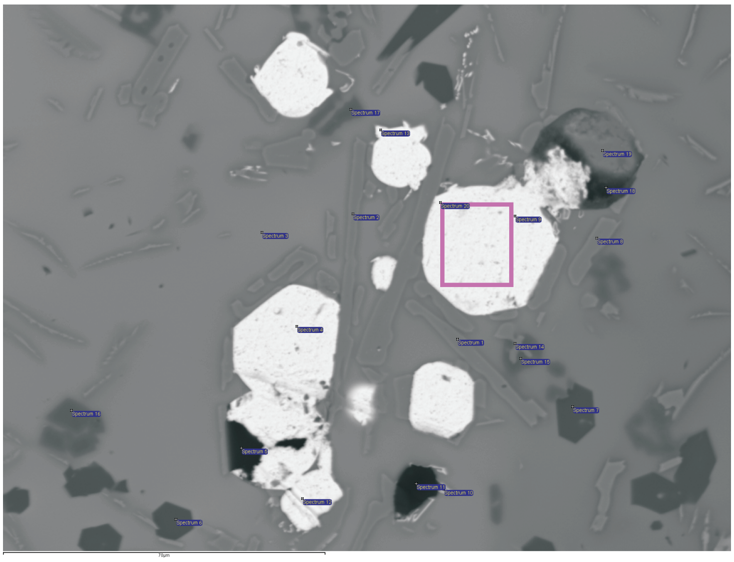

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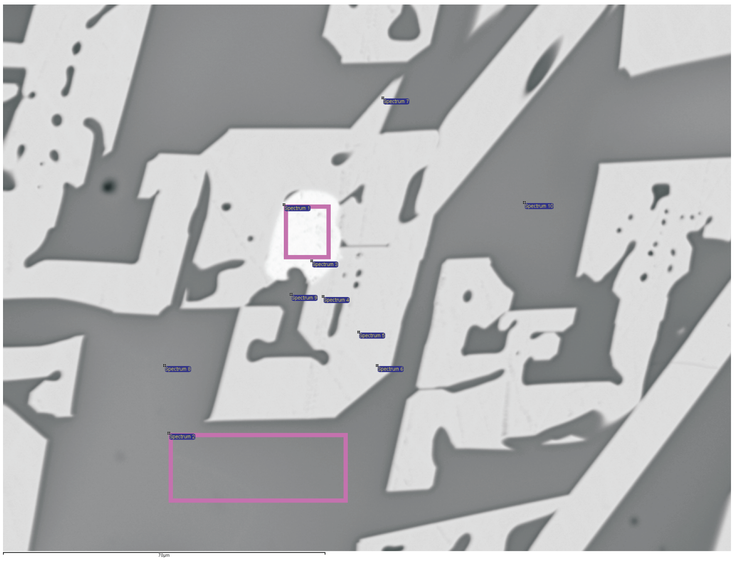

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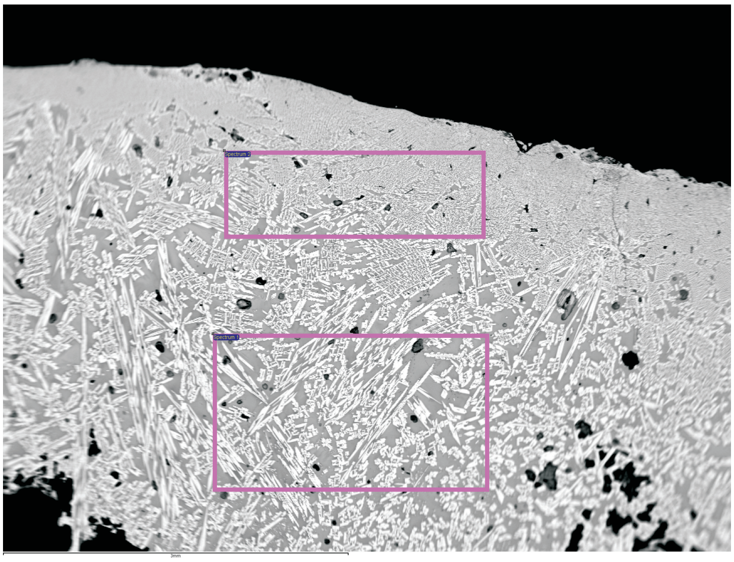

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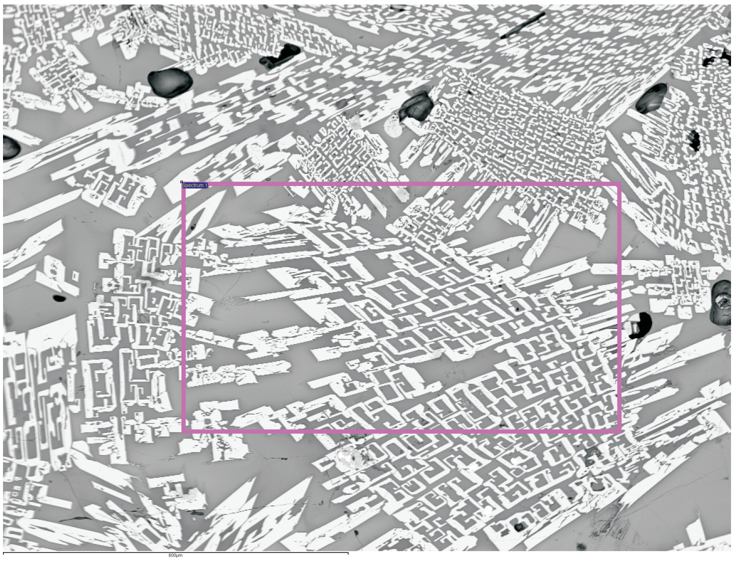

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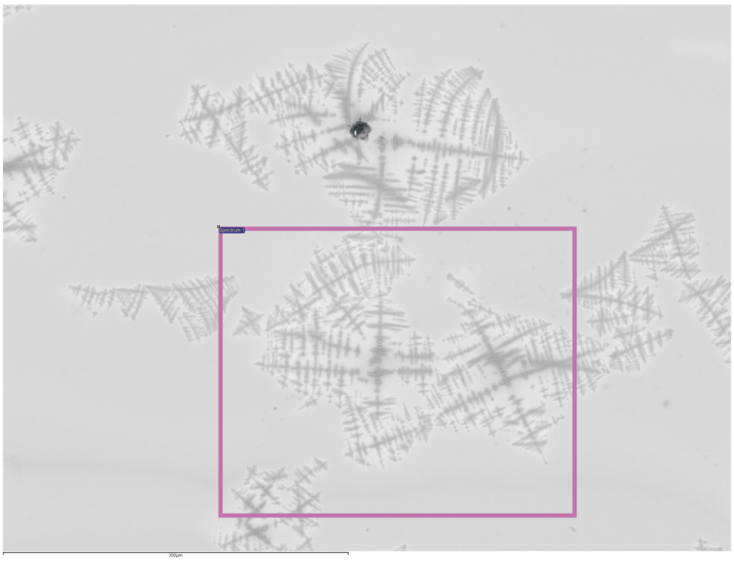

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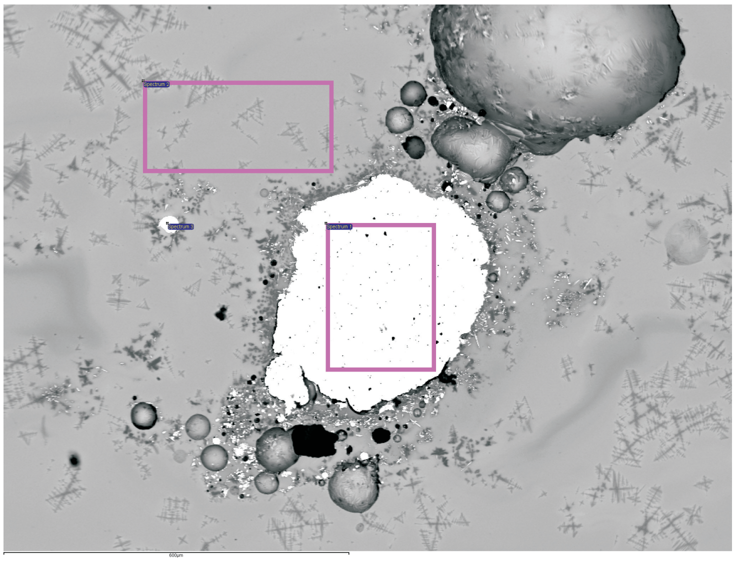

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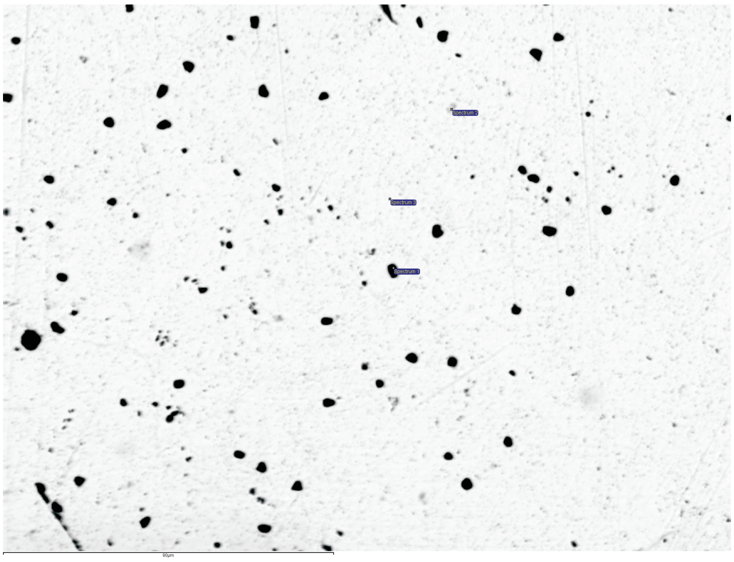

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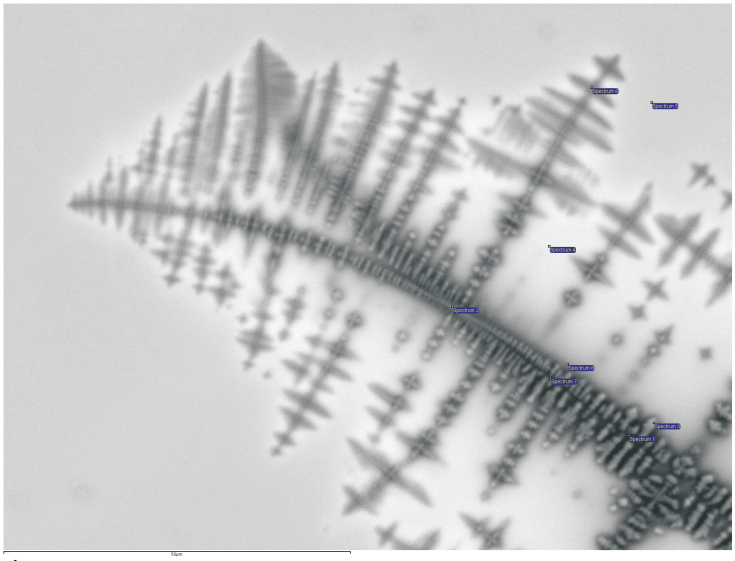

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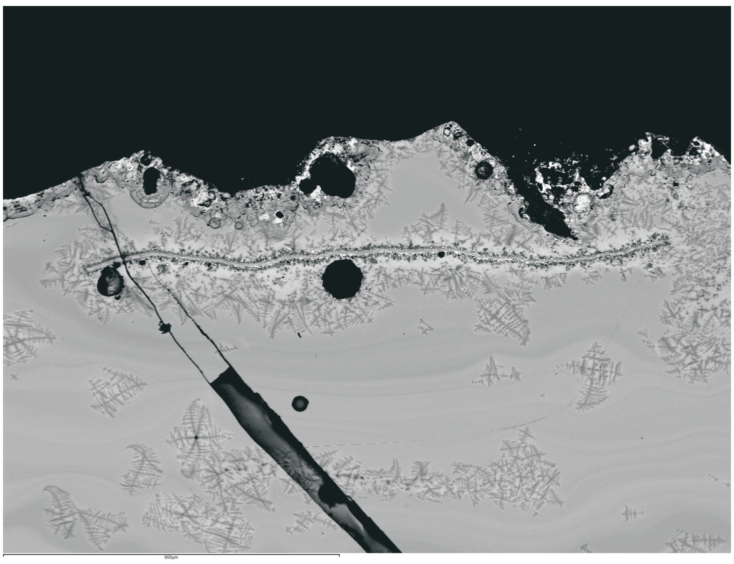

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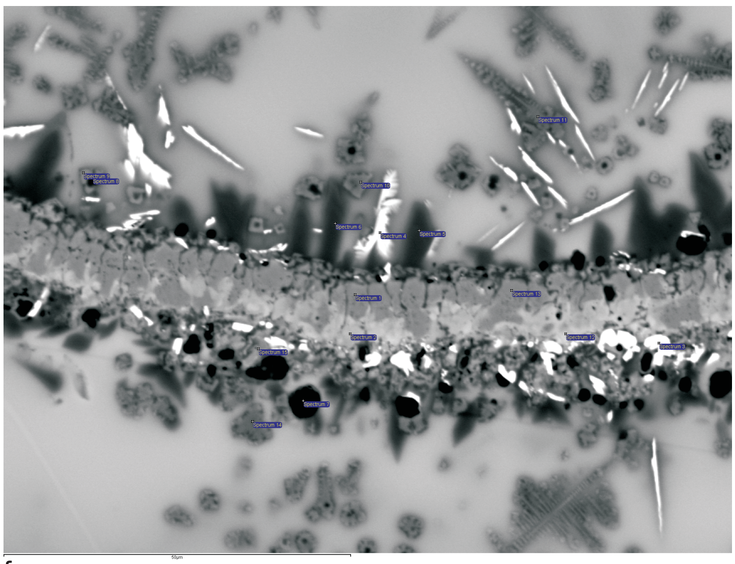

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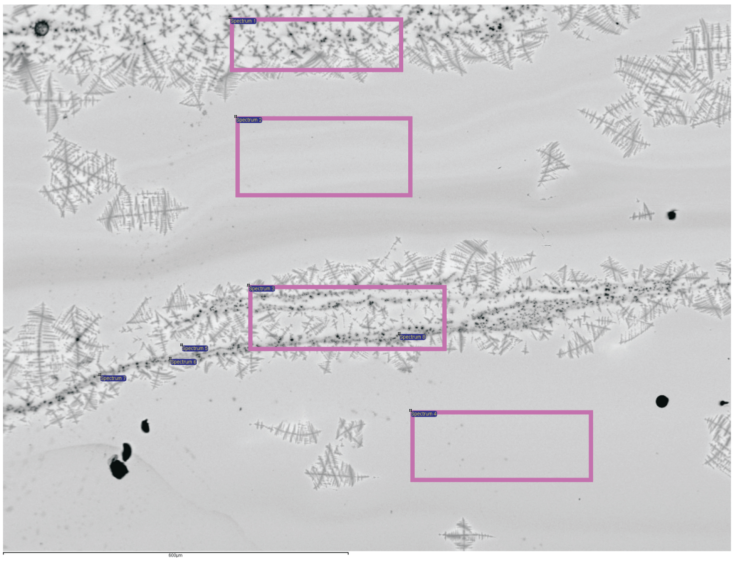

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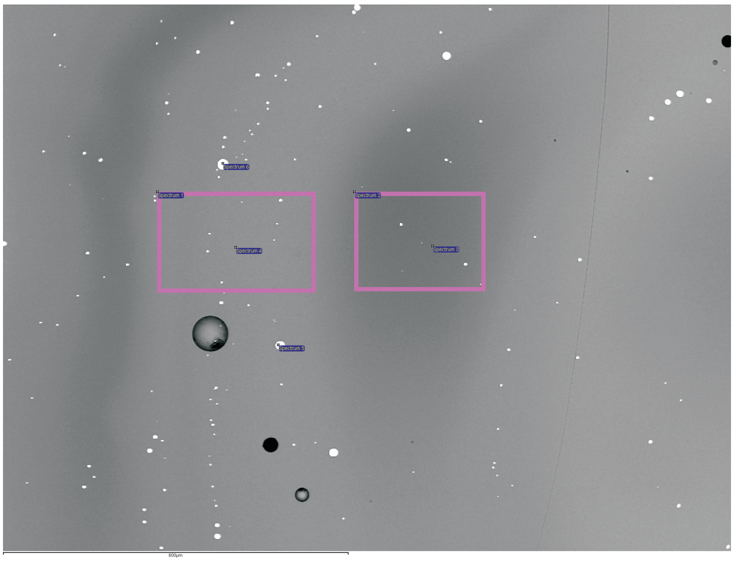
Plate A7



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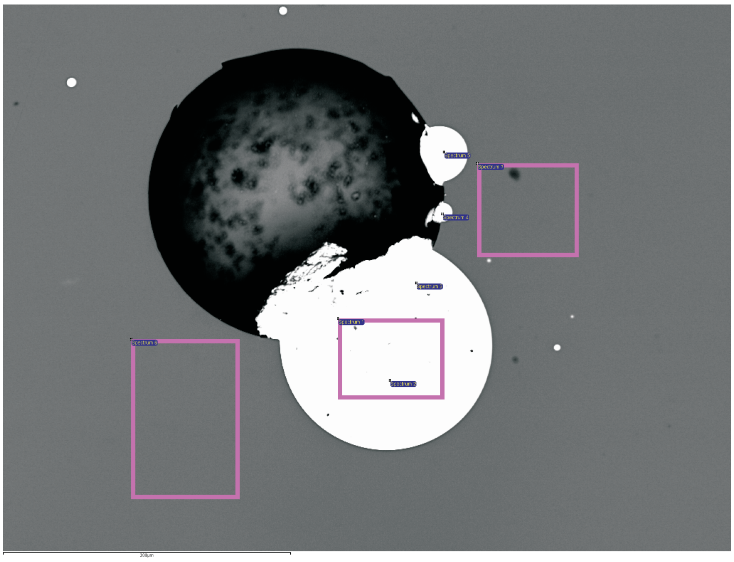

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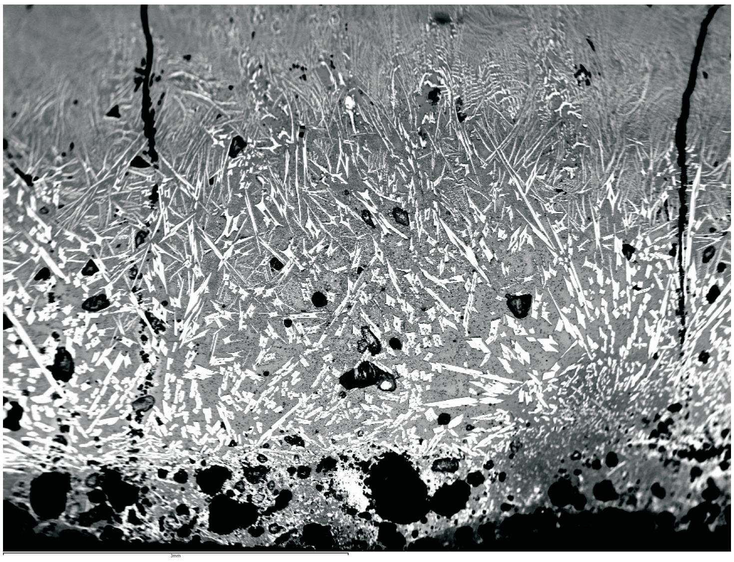

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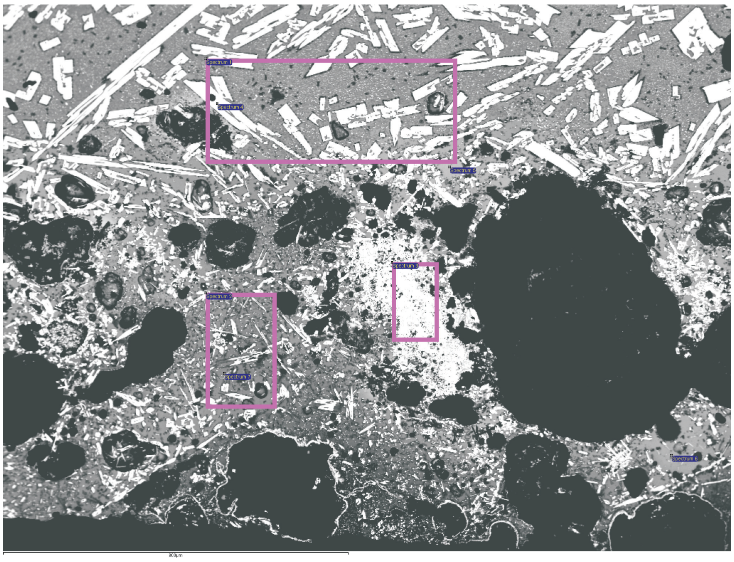

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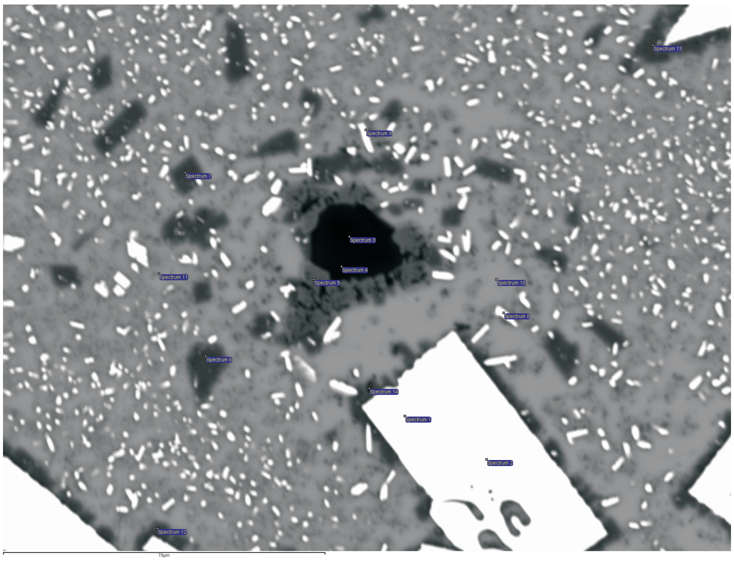

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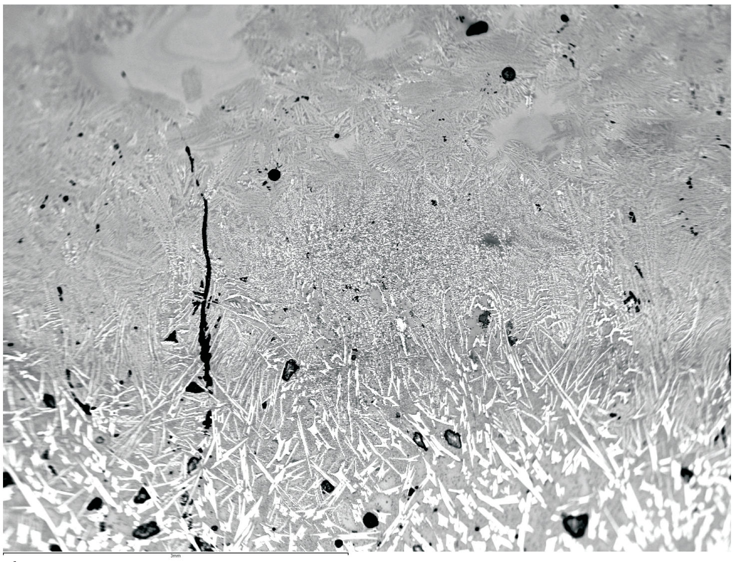

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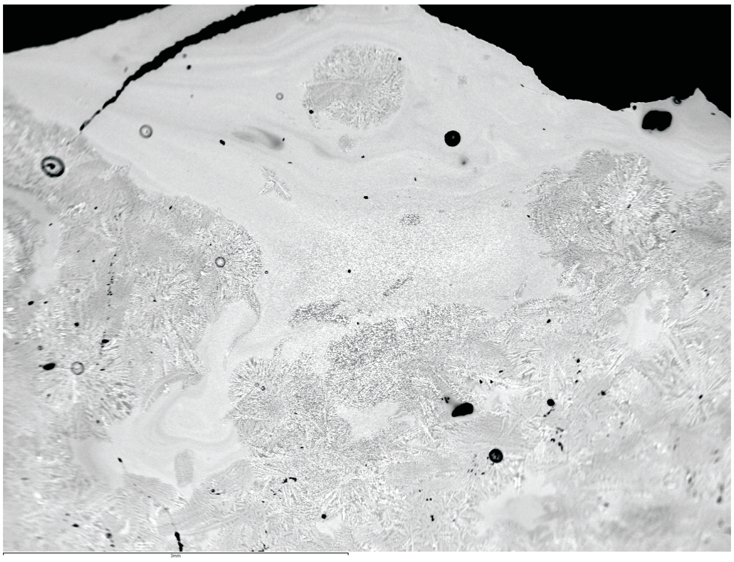

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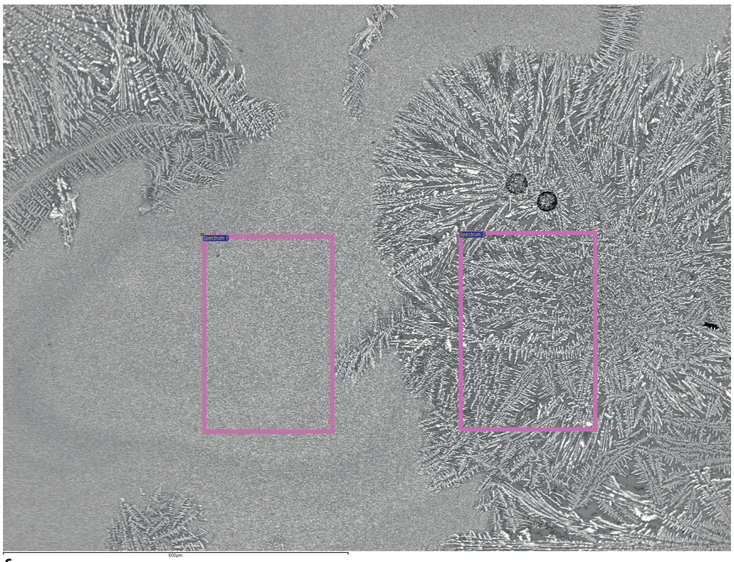

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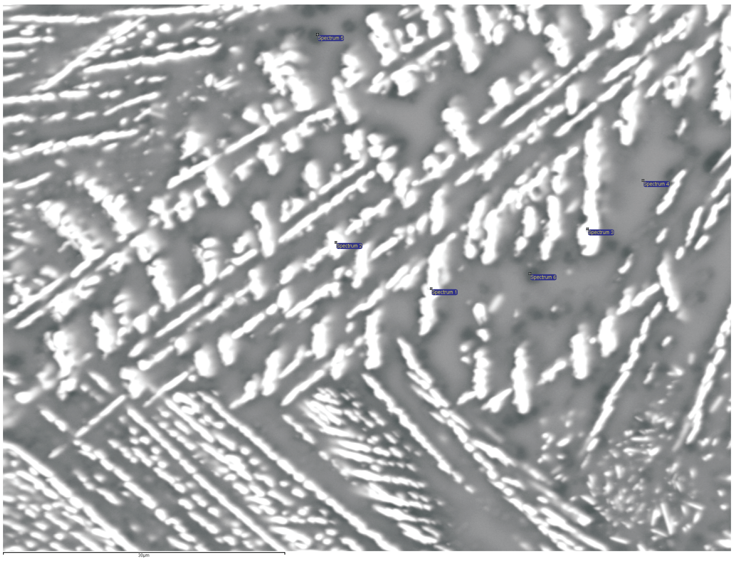
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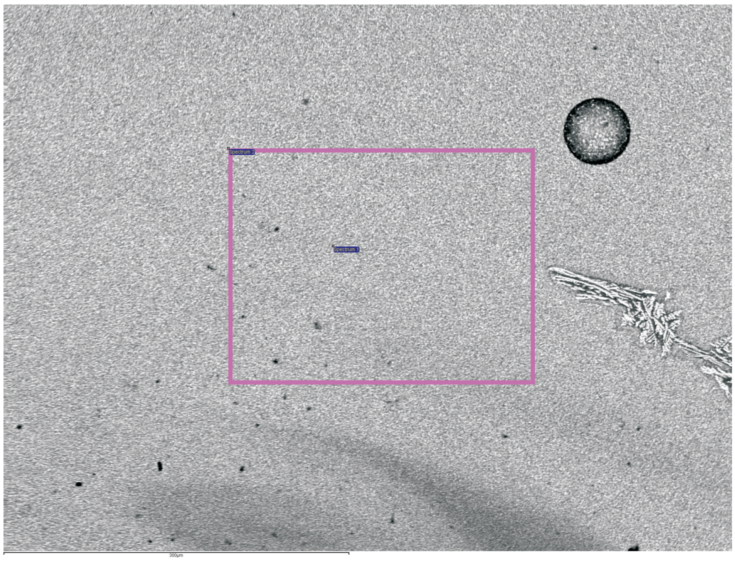
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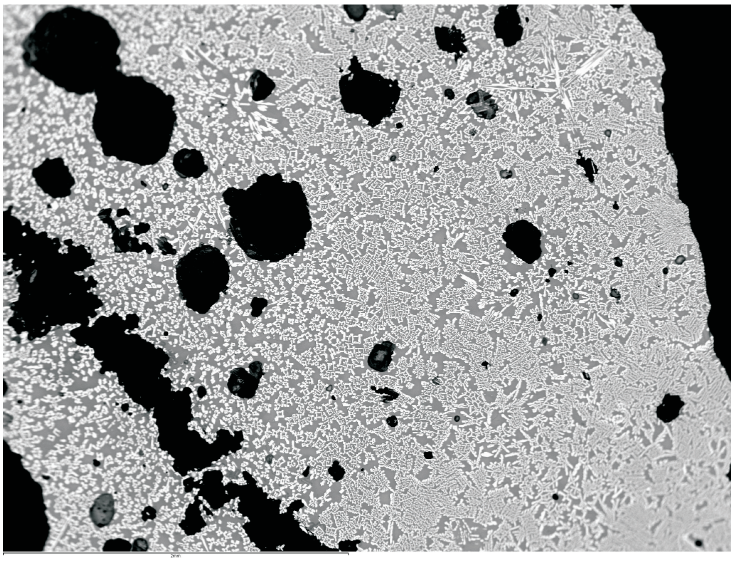
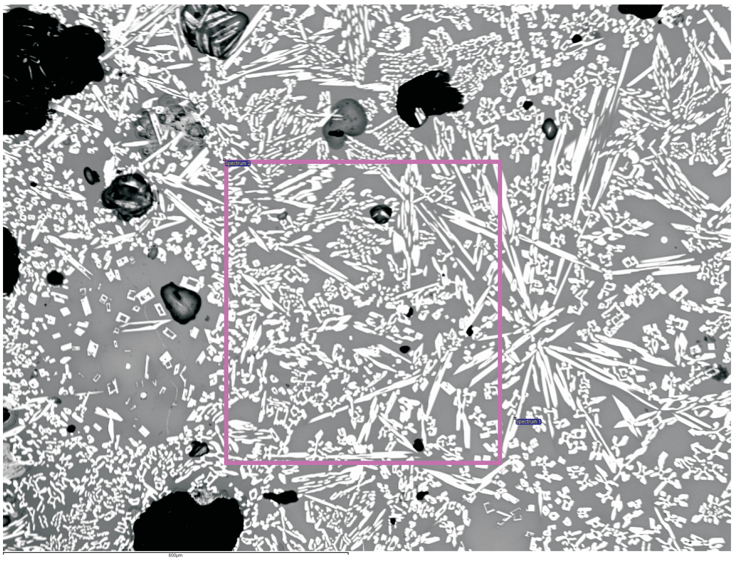

2mm

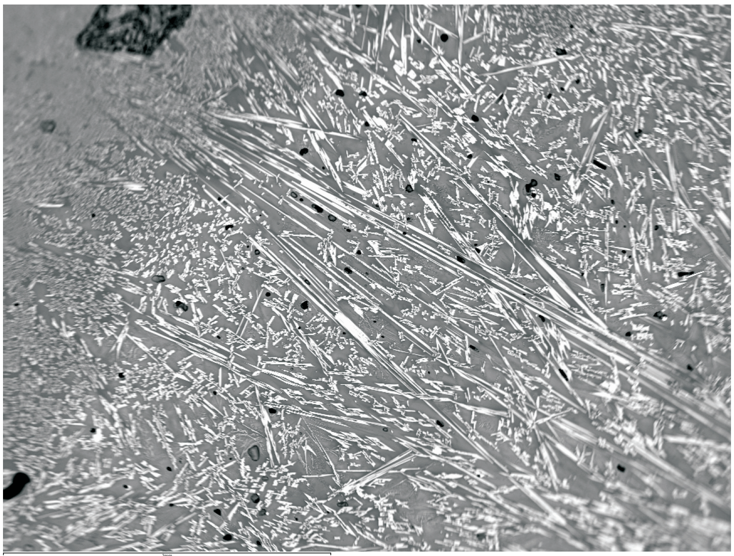
a


Spectrum 1
Spectrum 2
Spectrum 3
Spectrum 4
200μm

b


Spectrum 2
Spectrum 1
600μm

c



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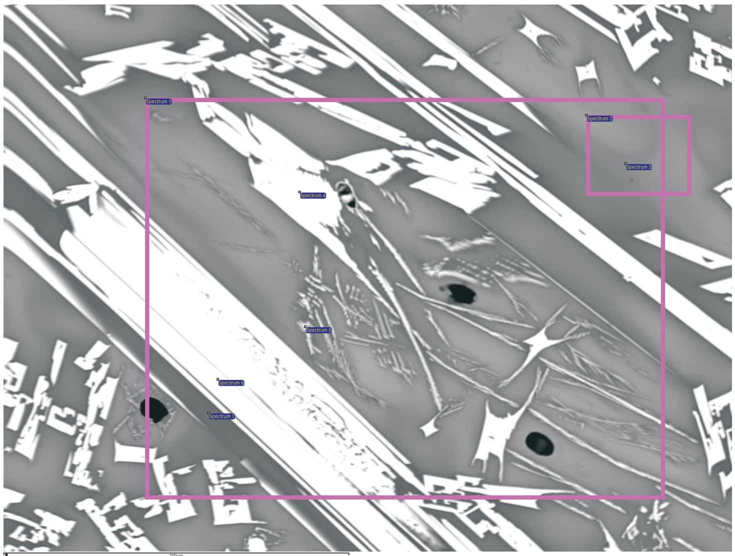

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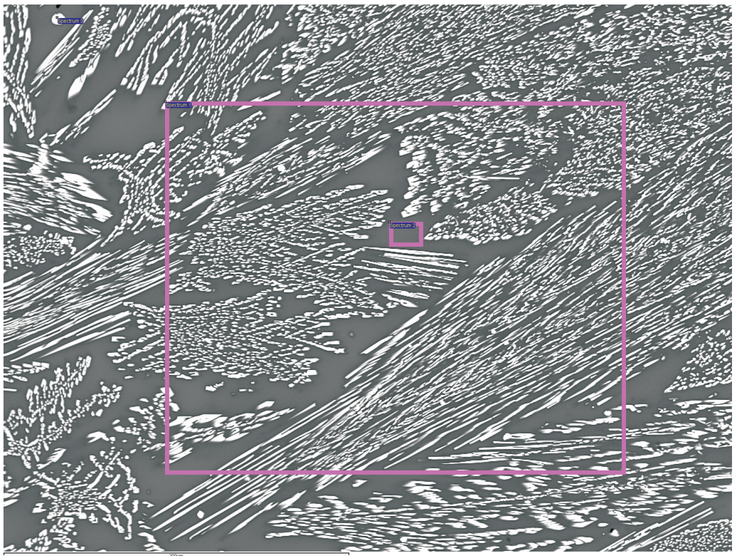

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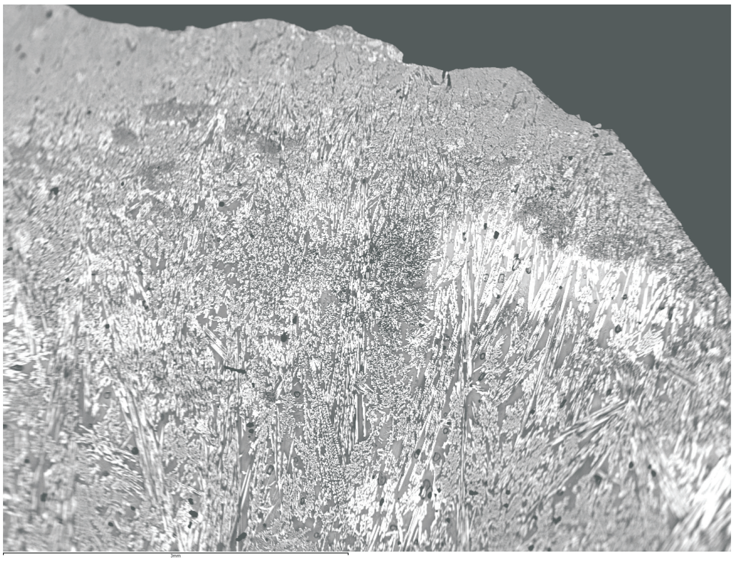
Plate A12



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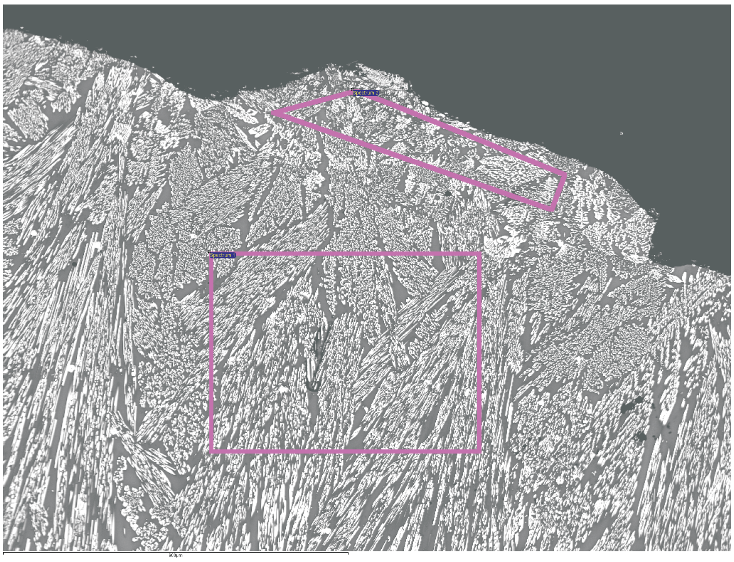

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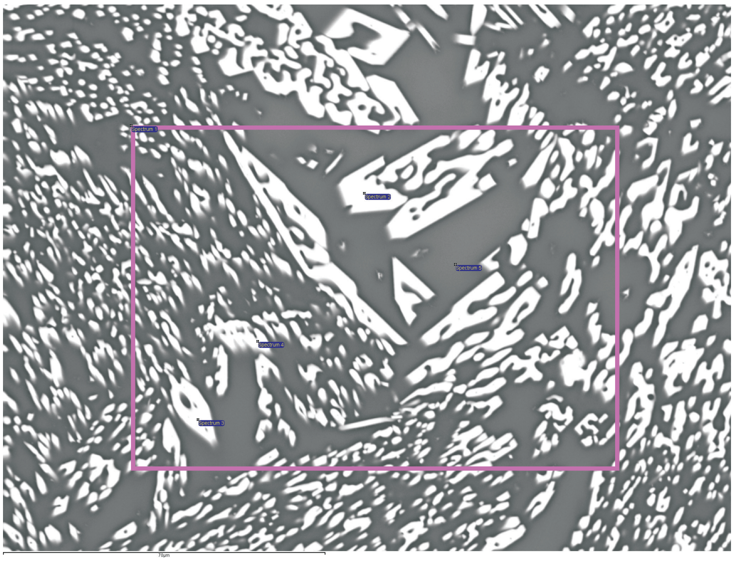

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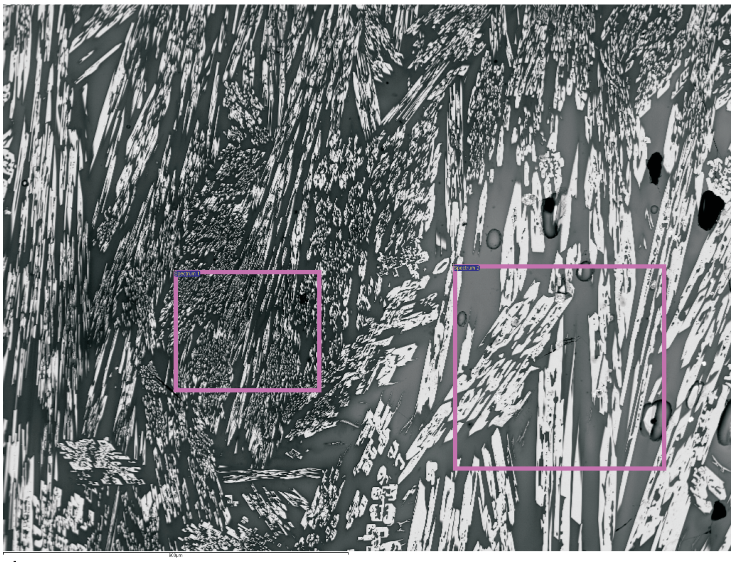

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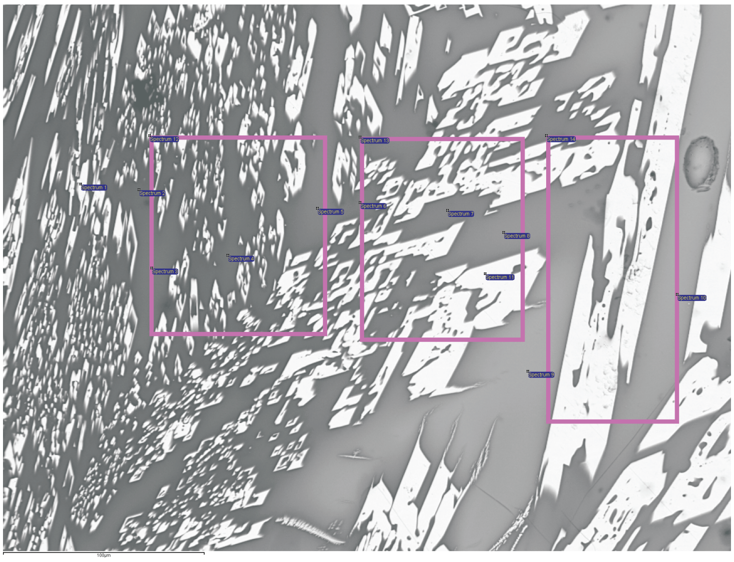

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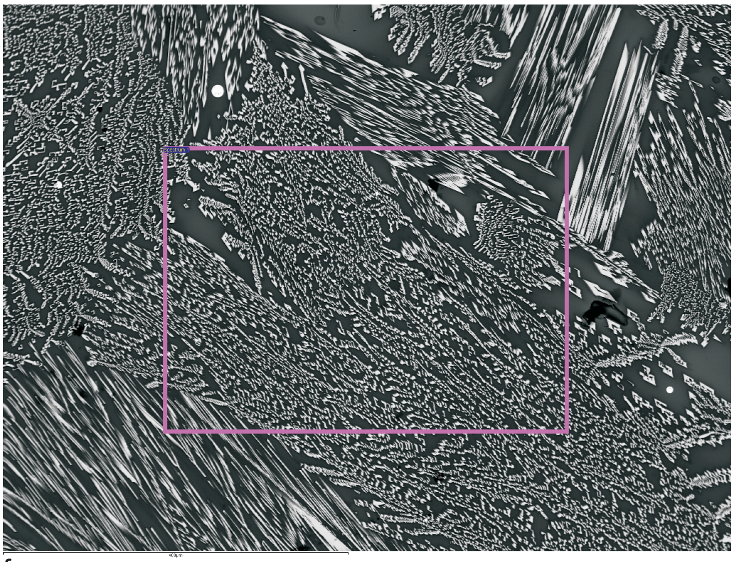

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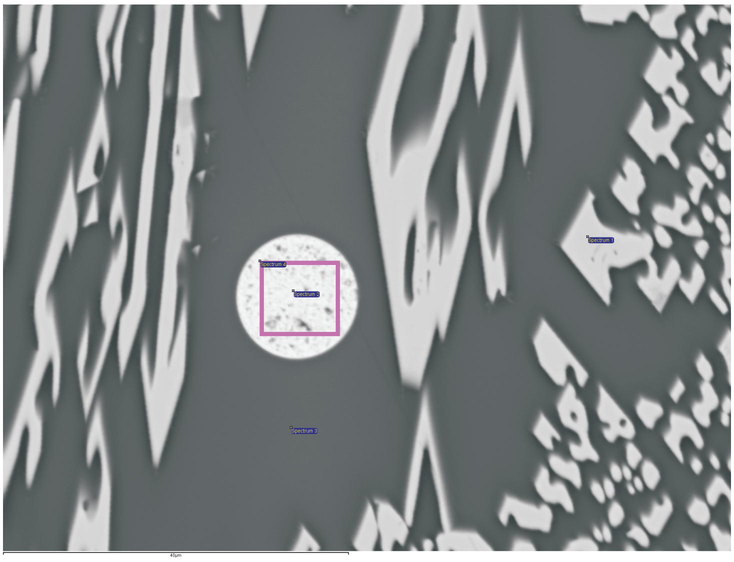
Plate A13



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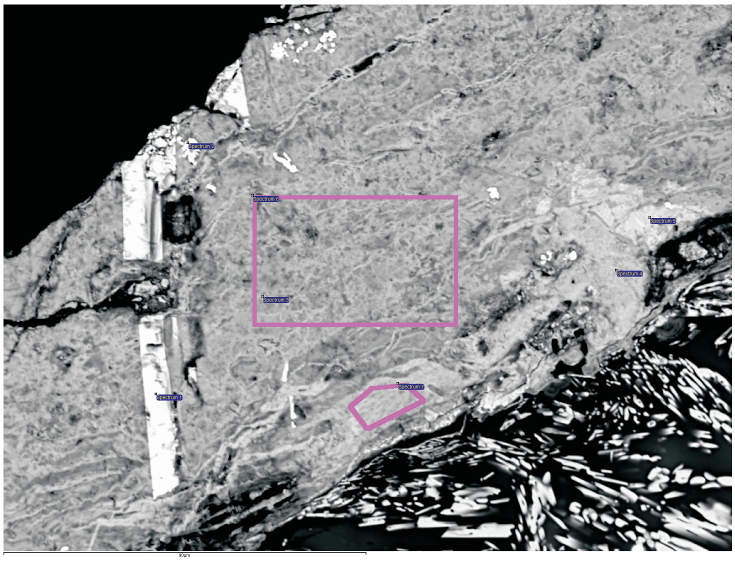

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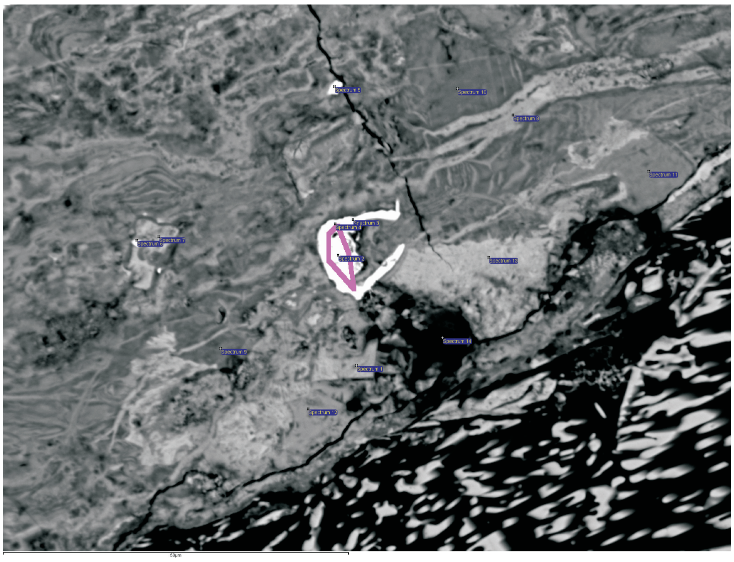

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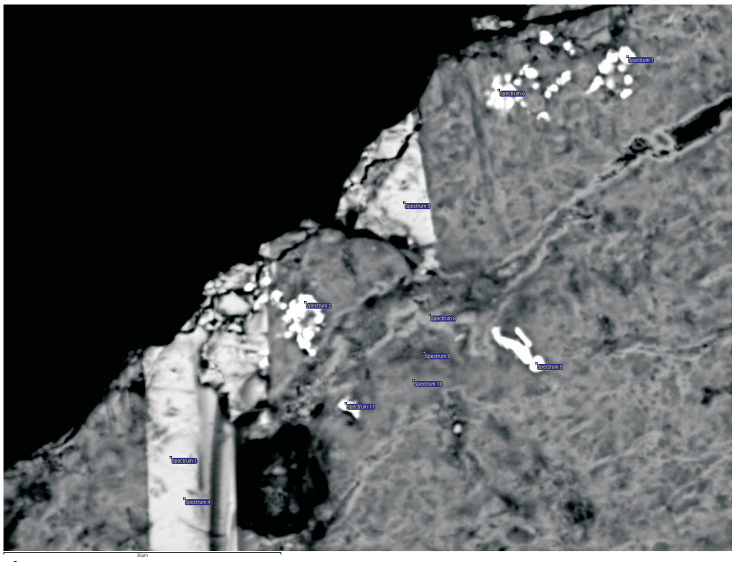

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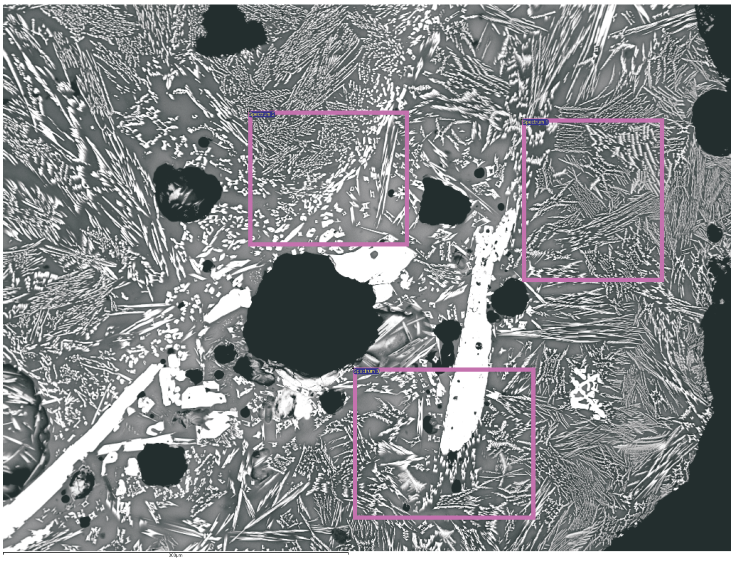

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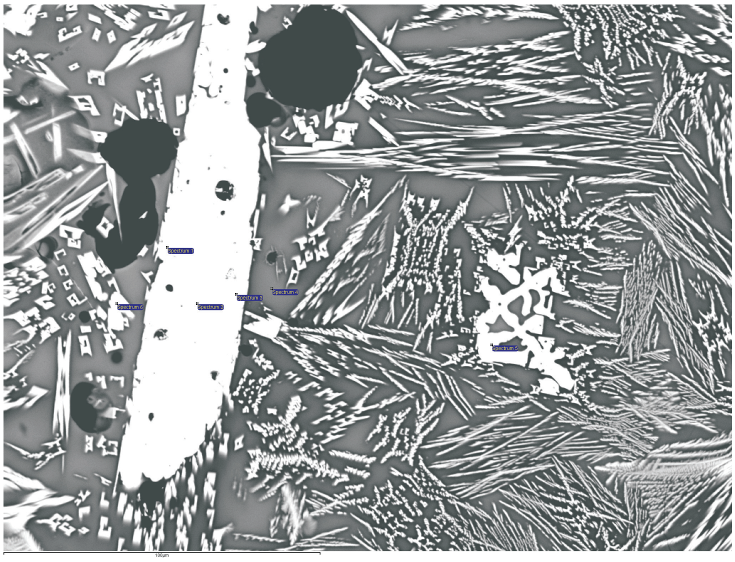

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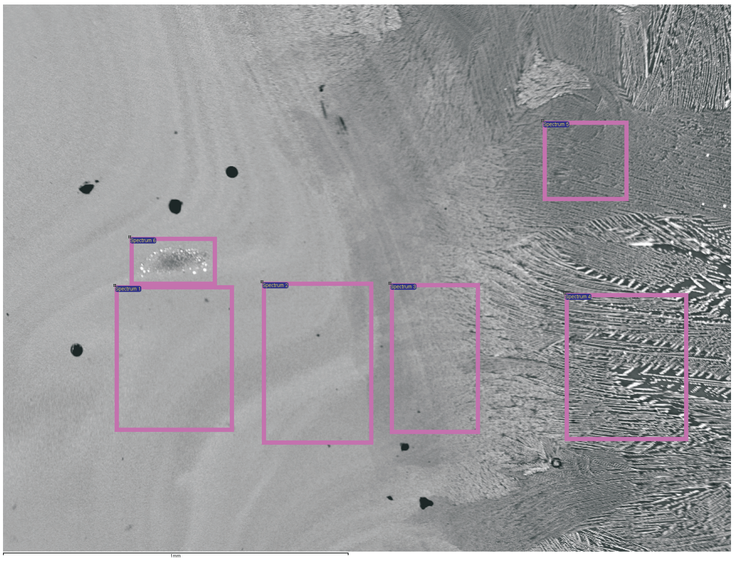

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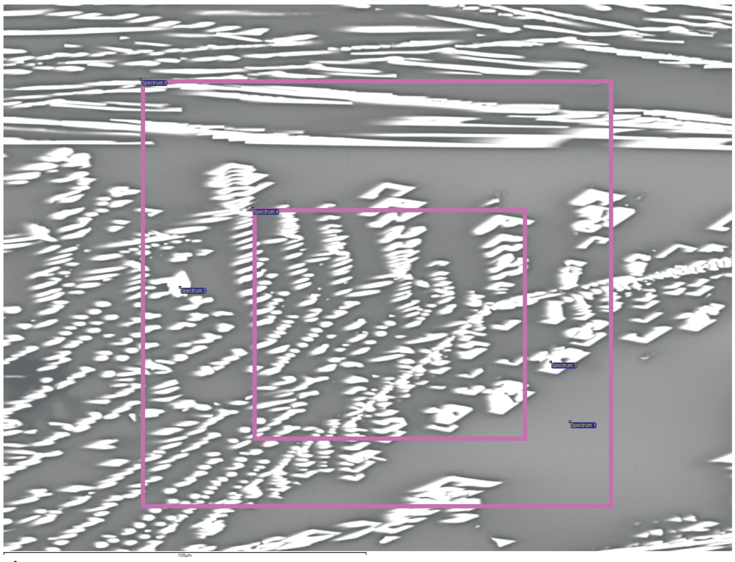

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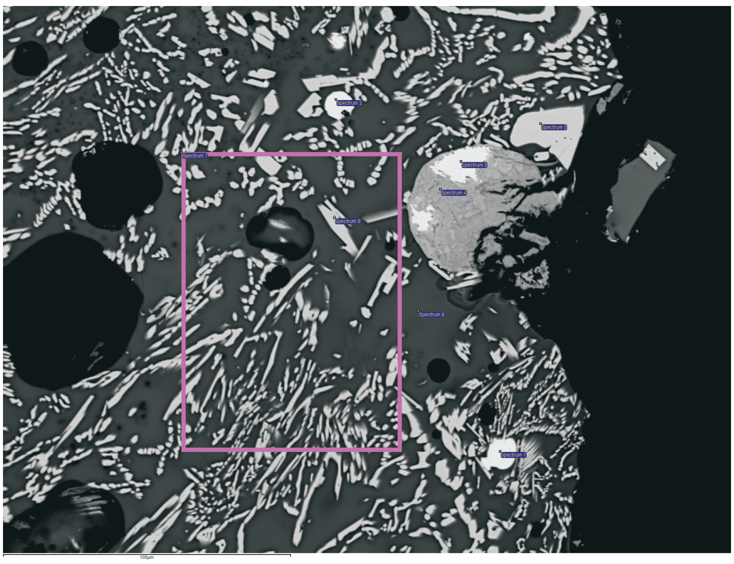

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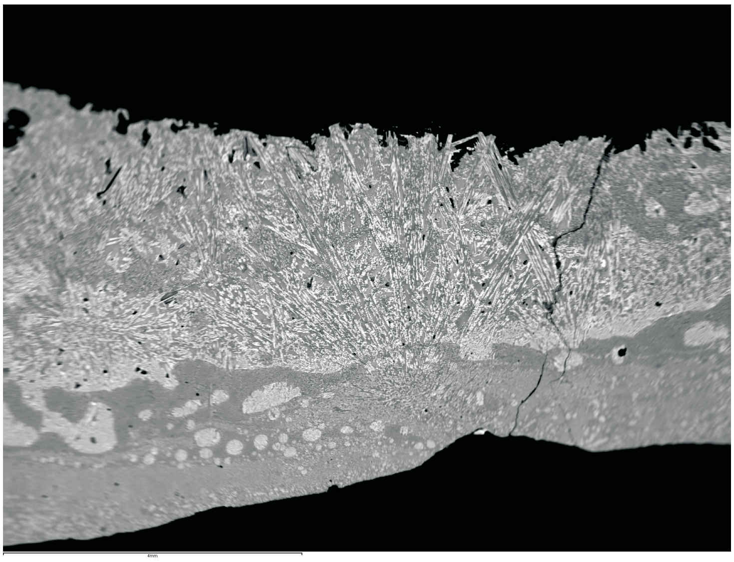

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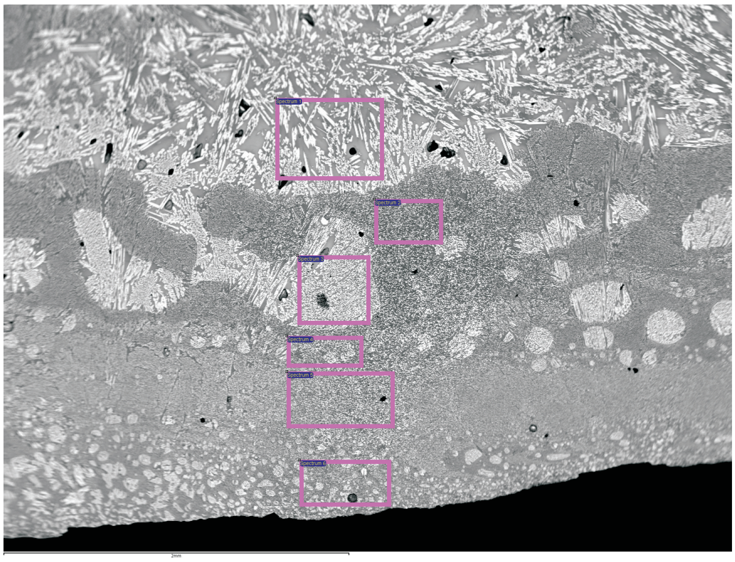

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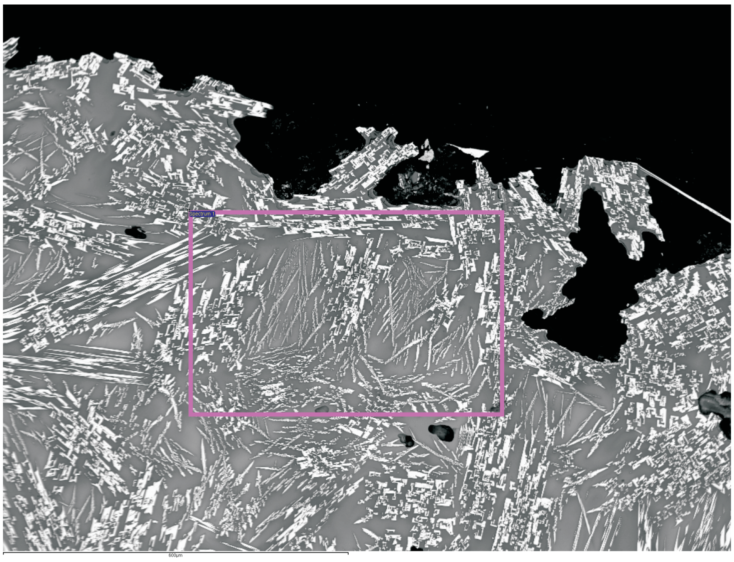

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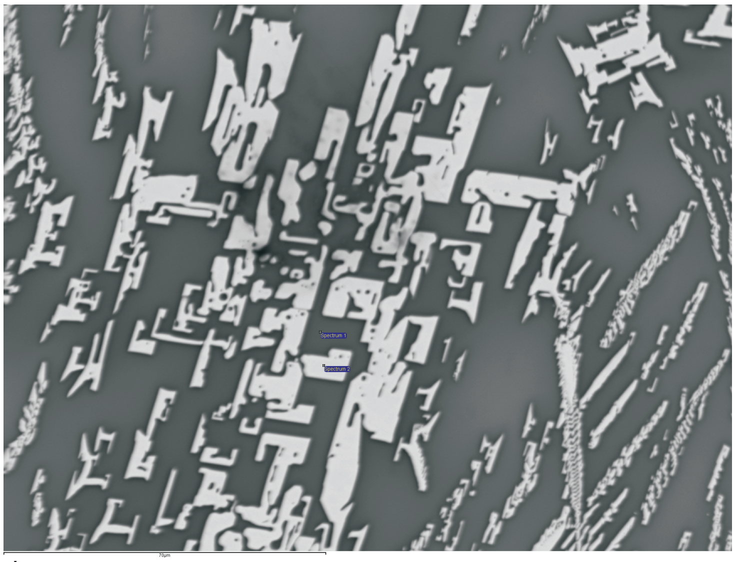

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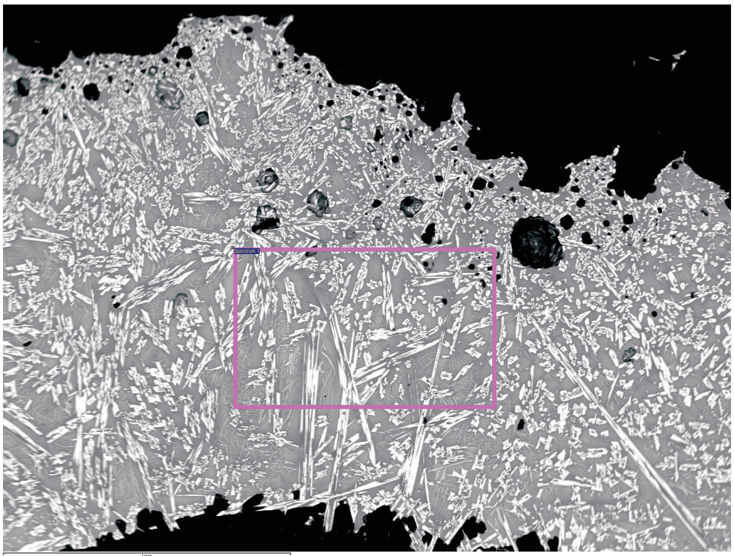

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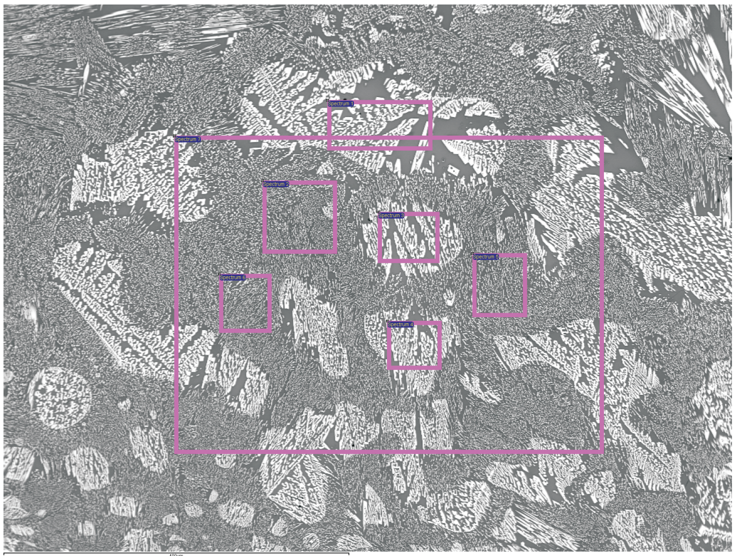

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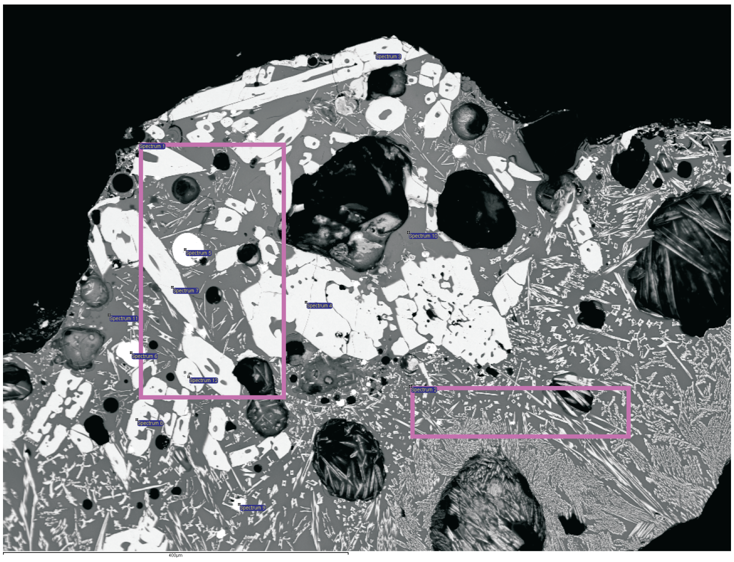
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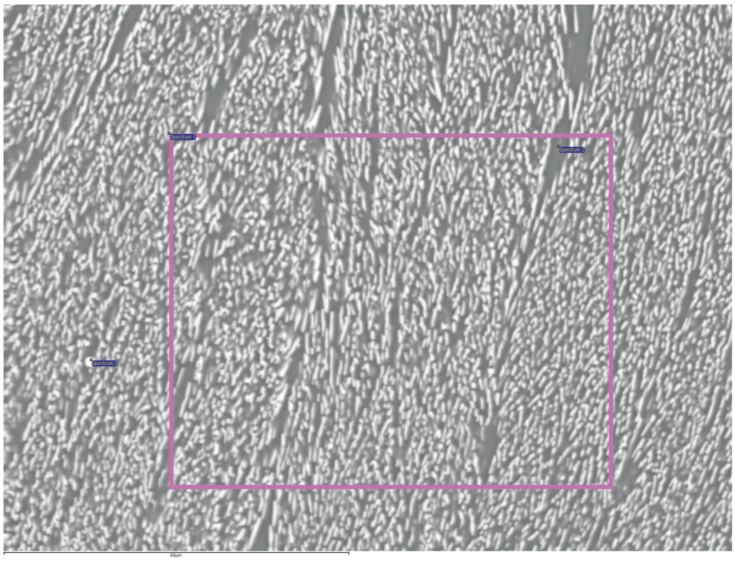
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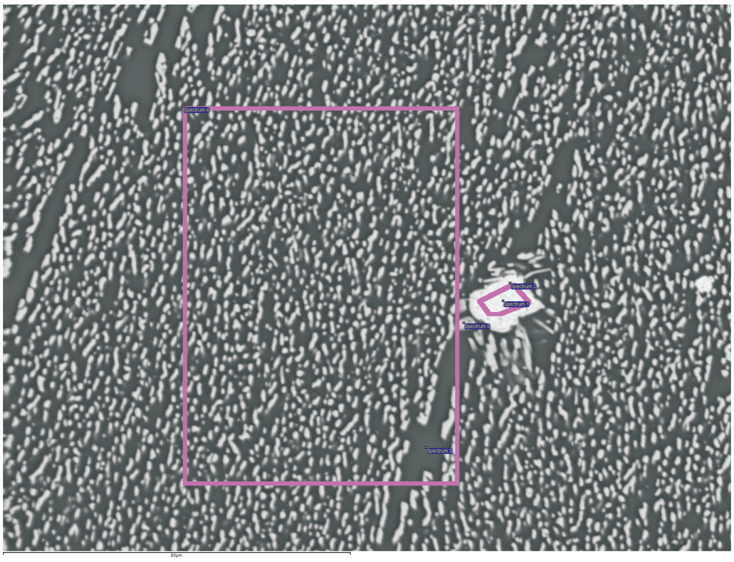
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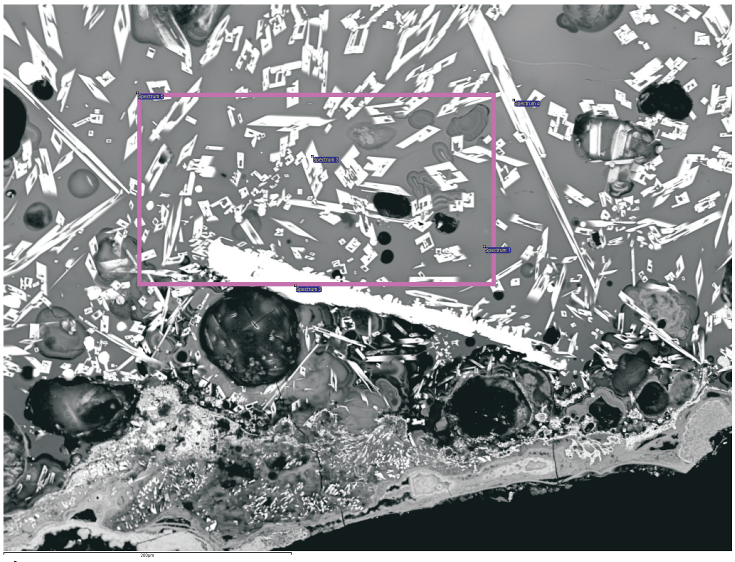
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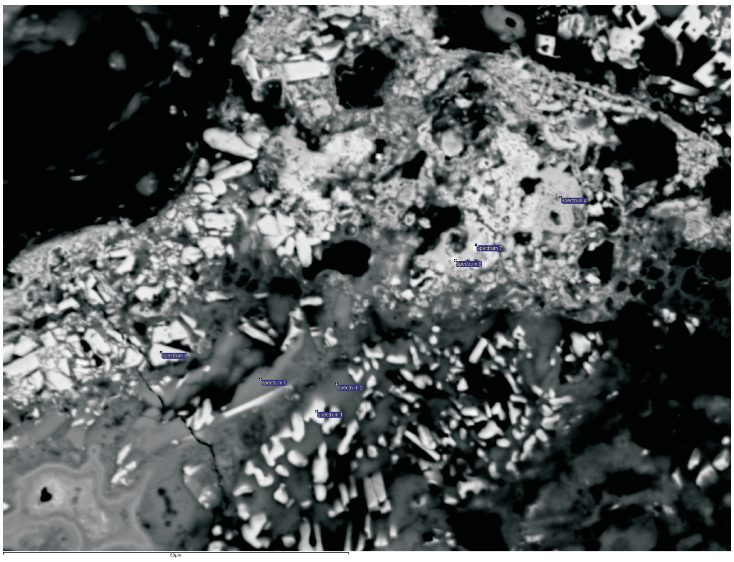
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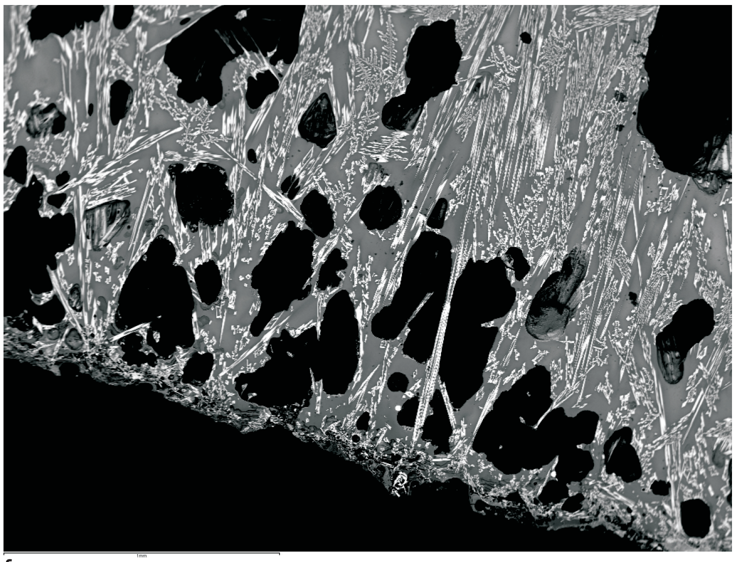
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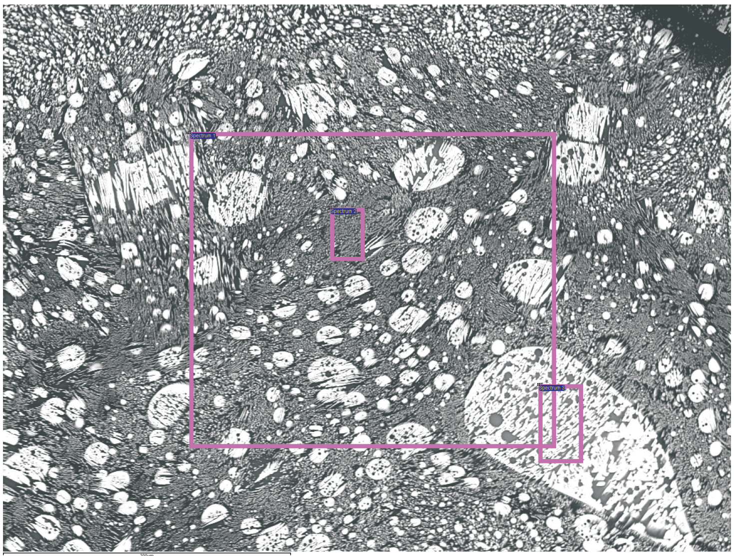
Plate A17



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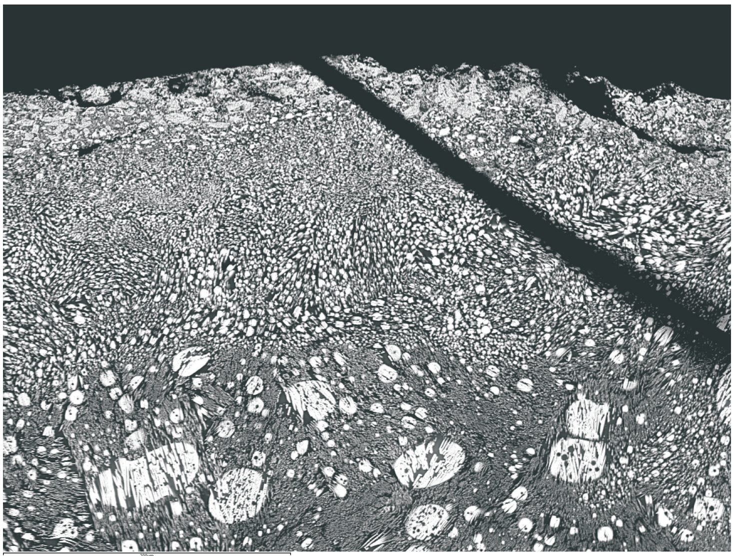

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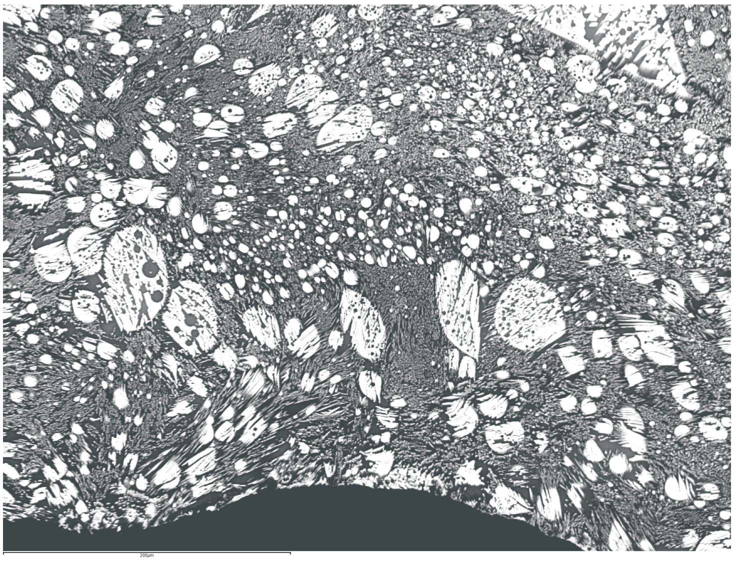

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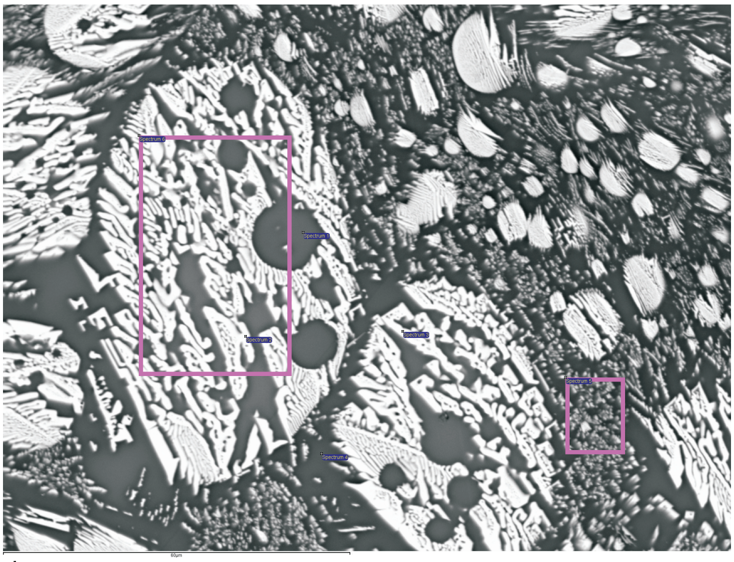

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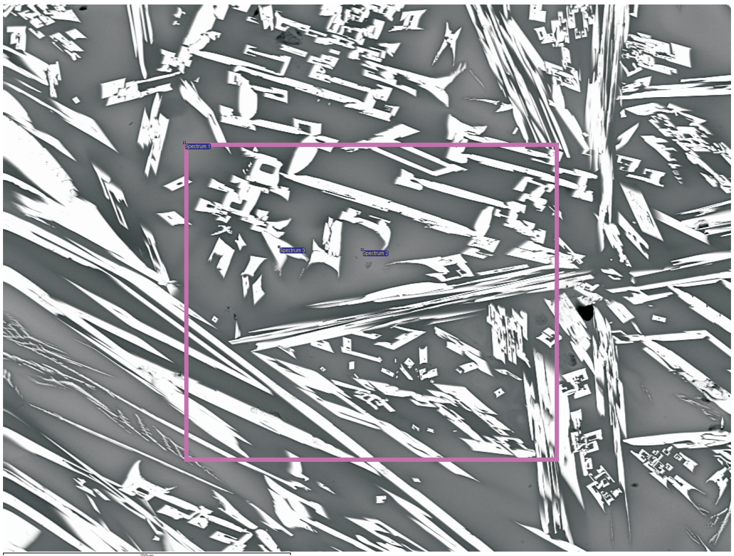

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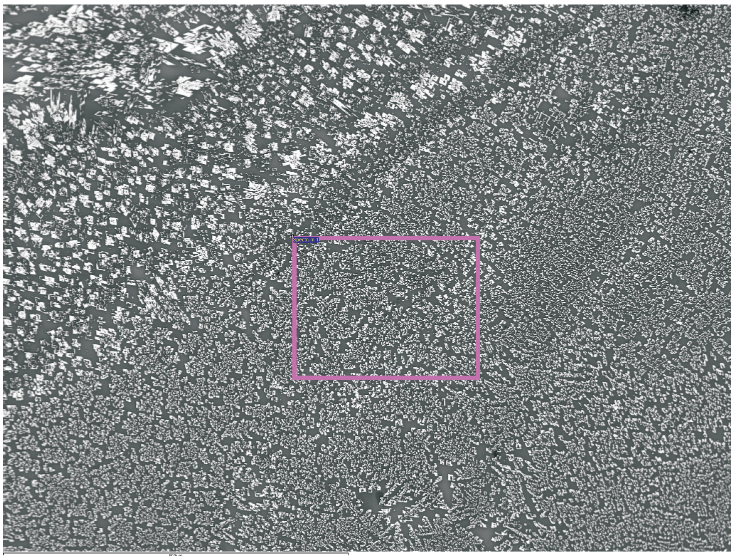

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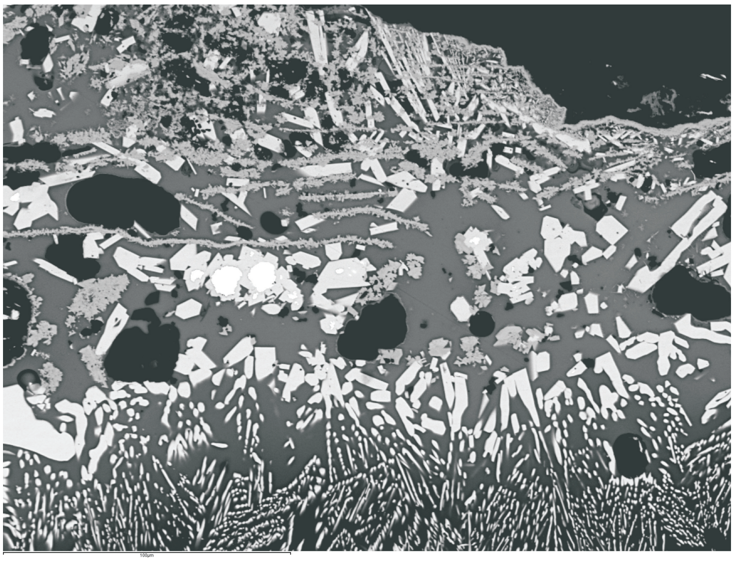
Plate A18



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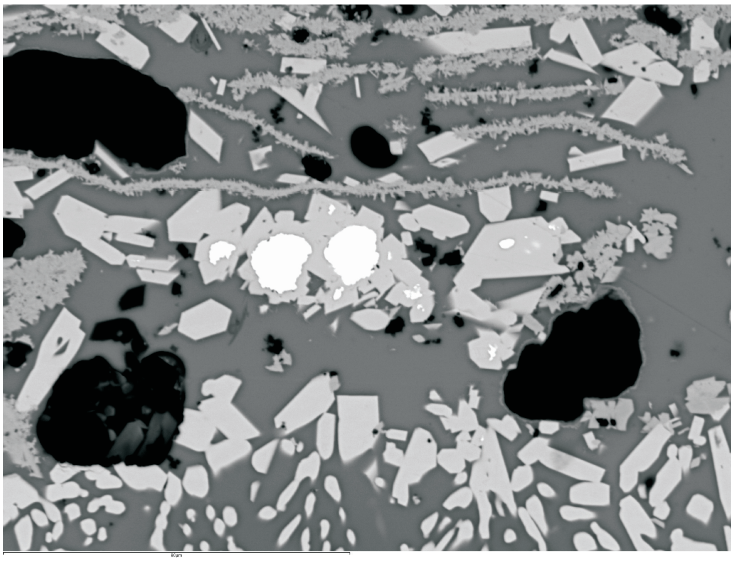

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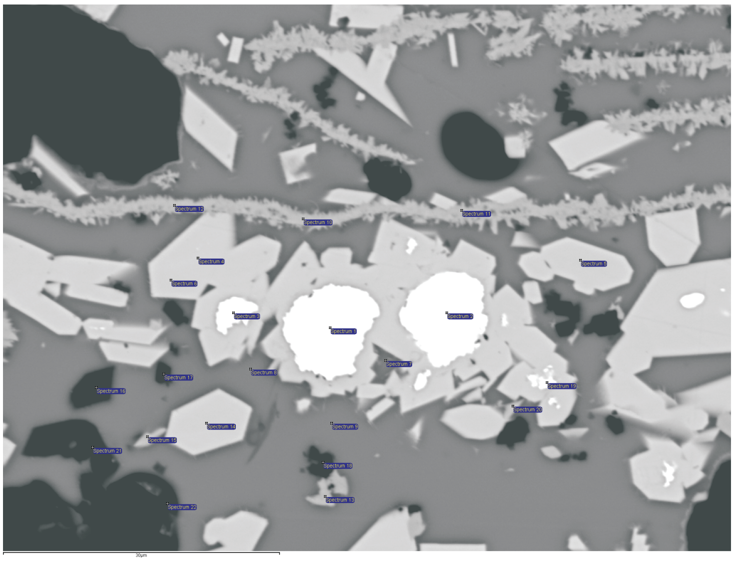

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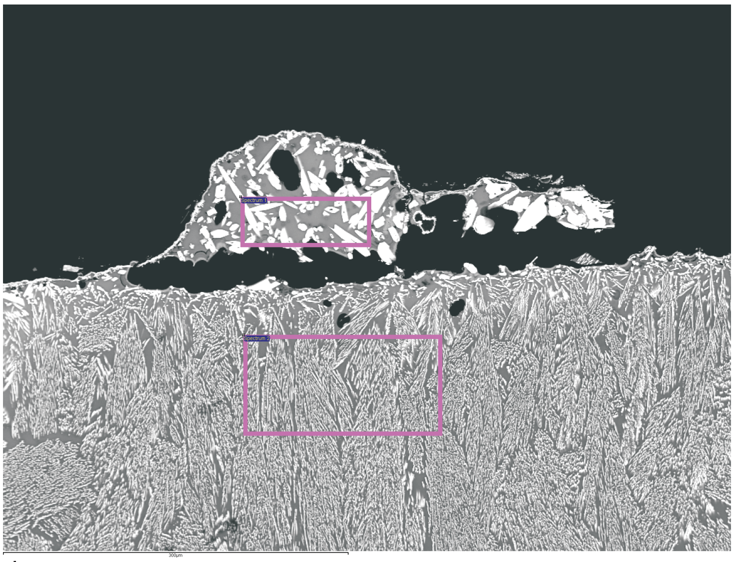

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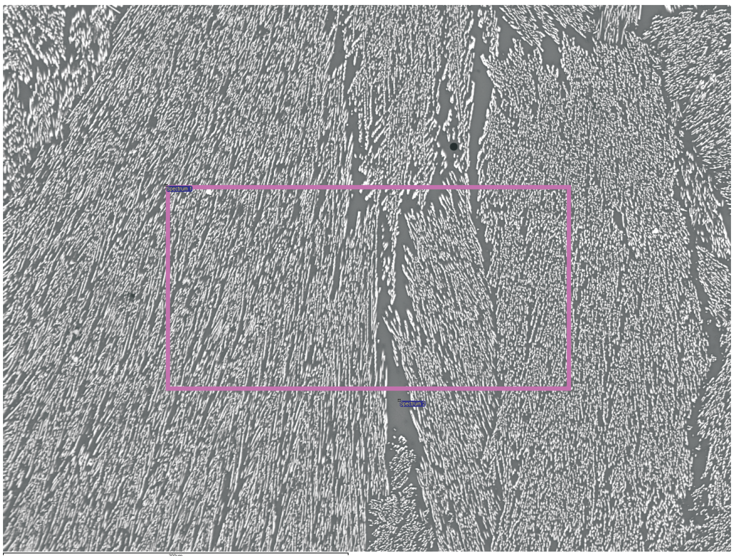

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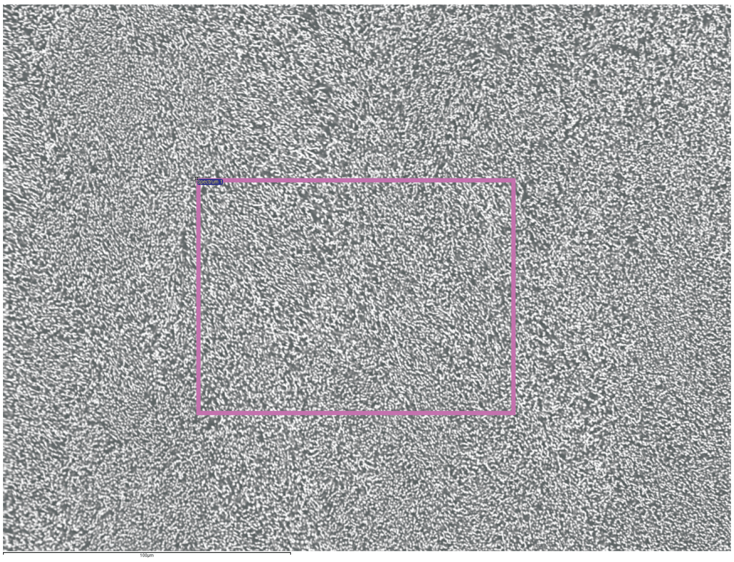
Plate A19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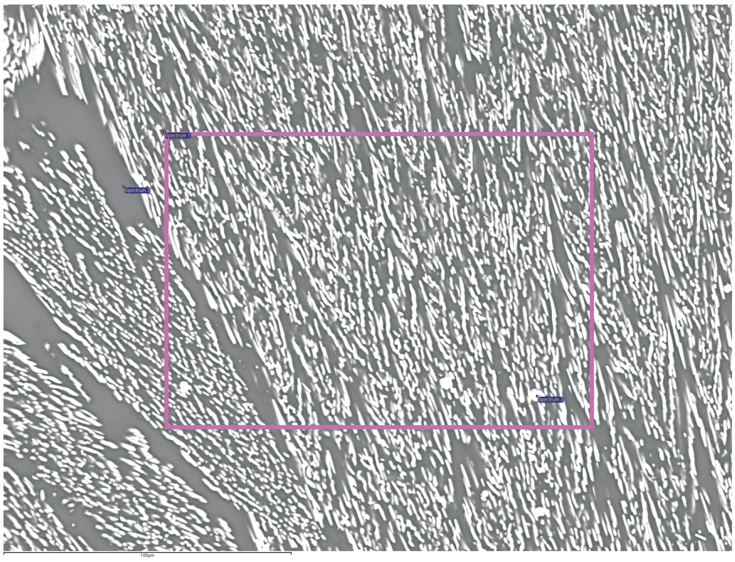
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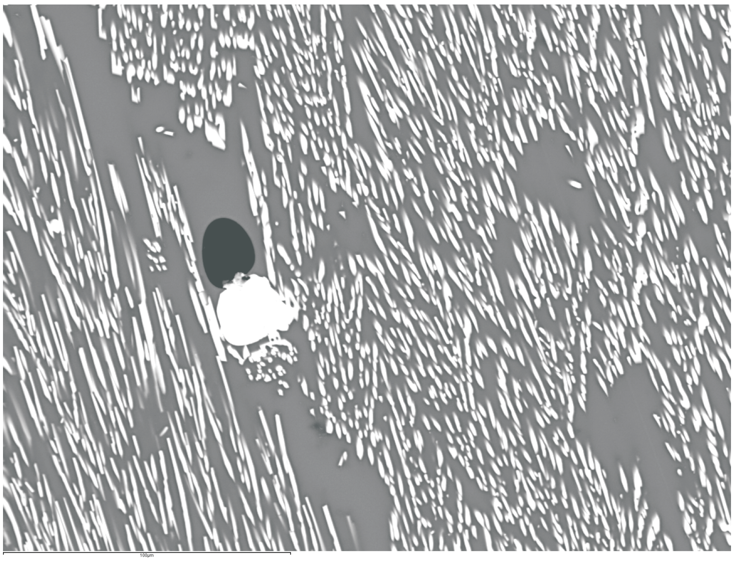
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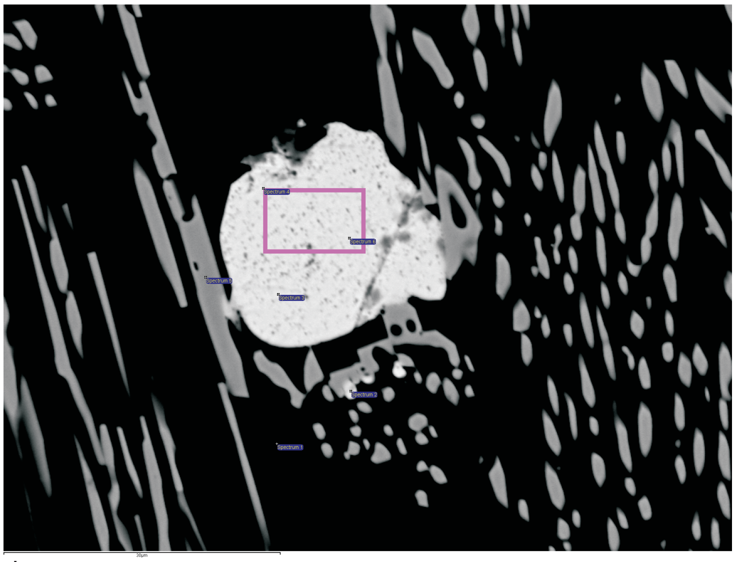
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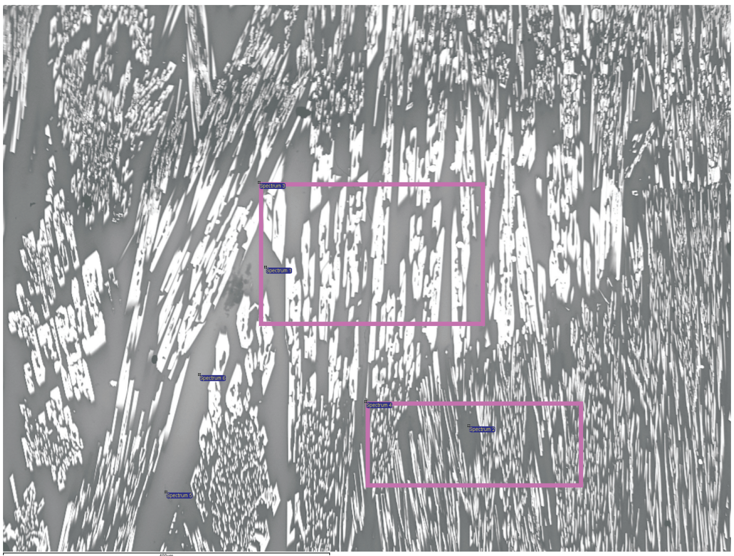
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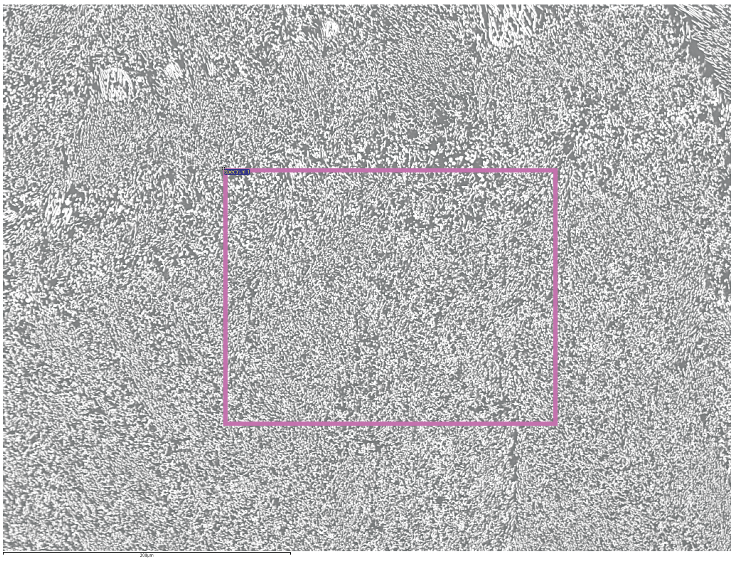
Plate A20



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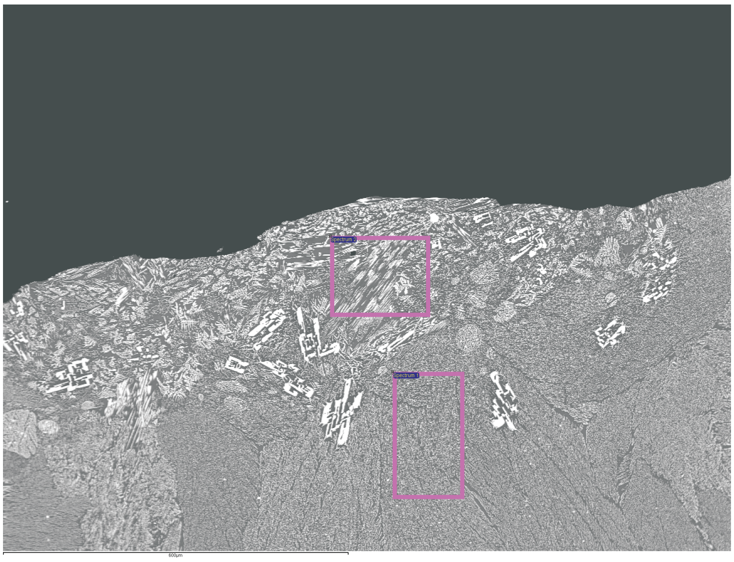

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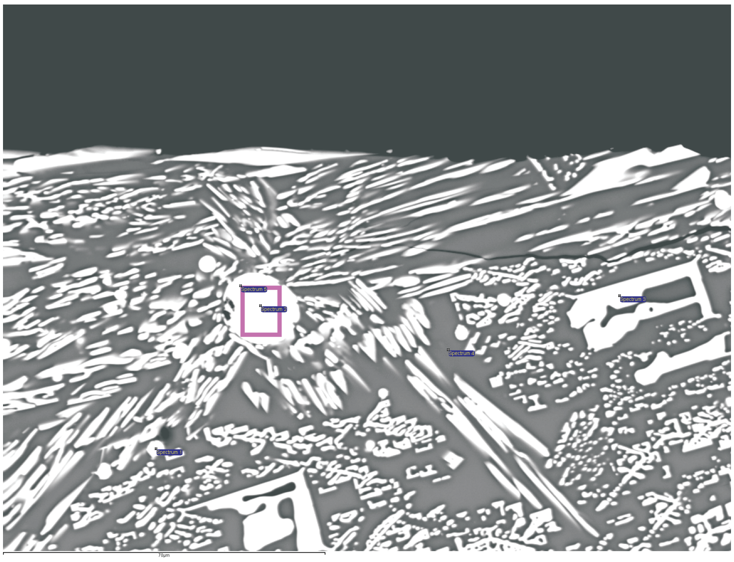

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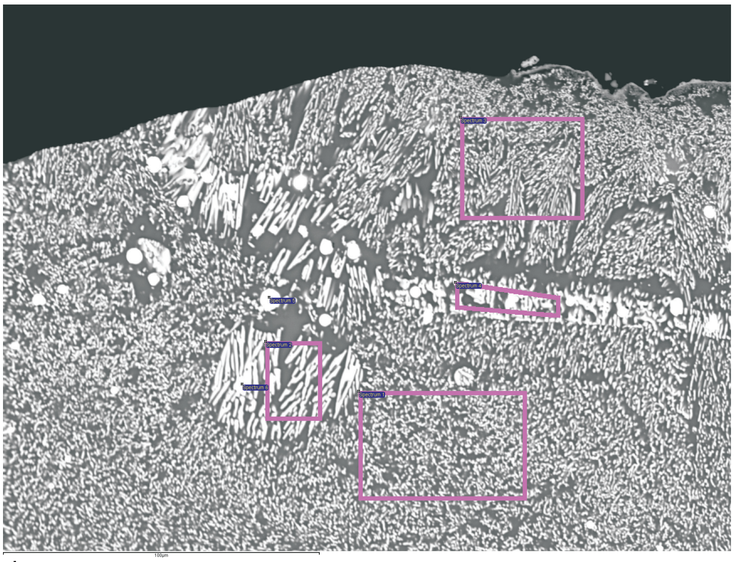

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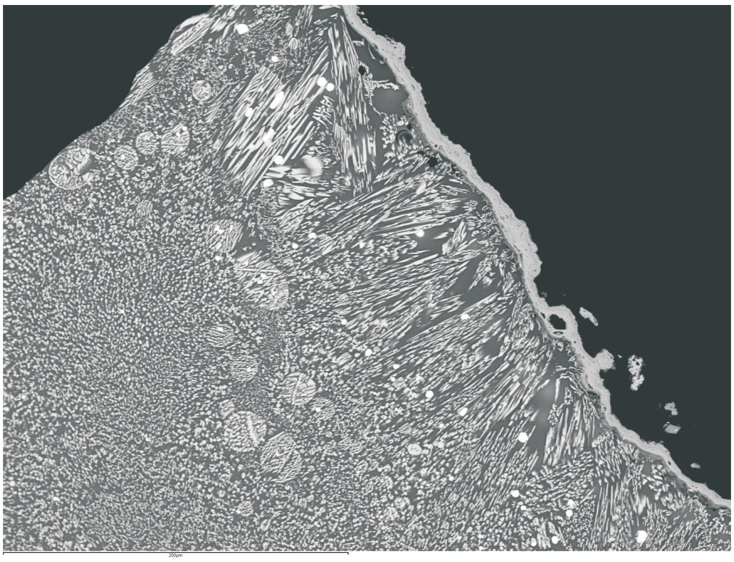

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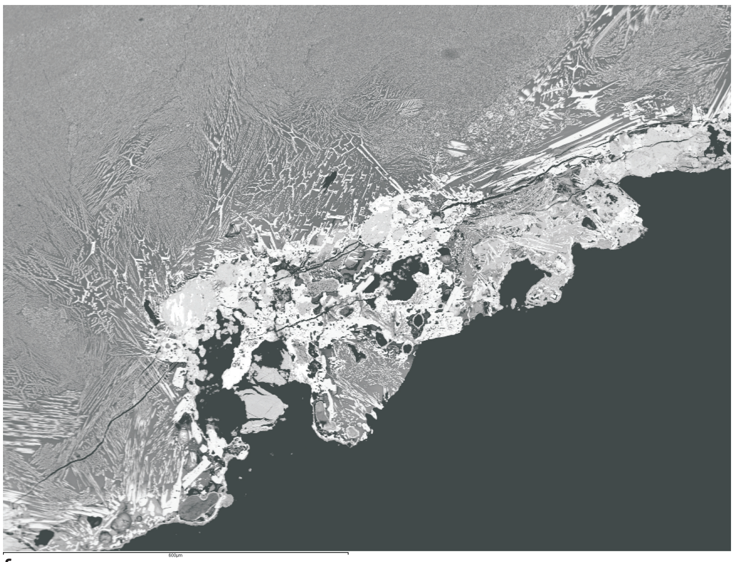

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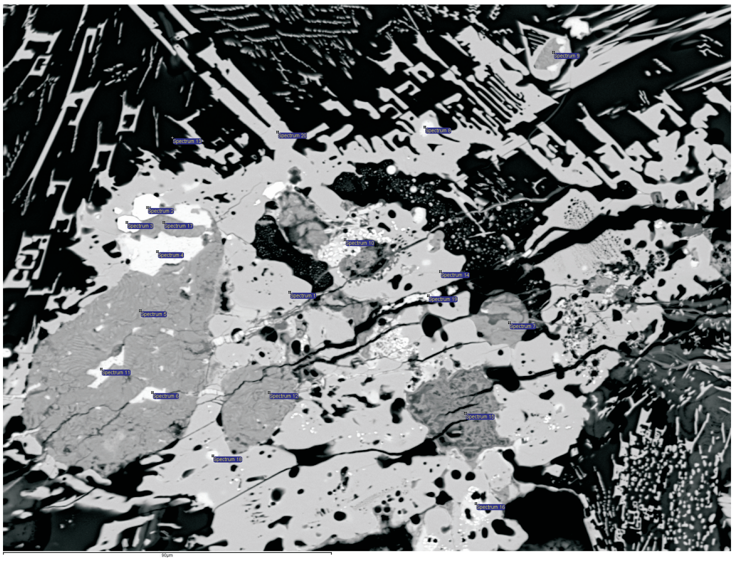

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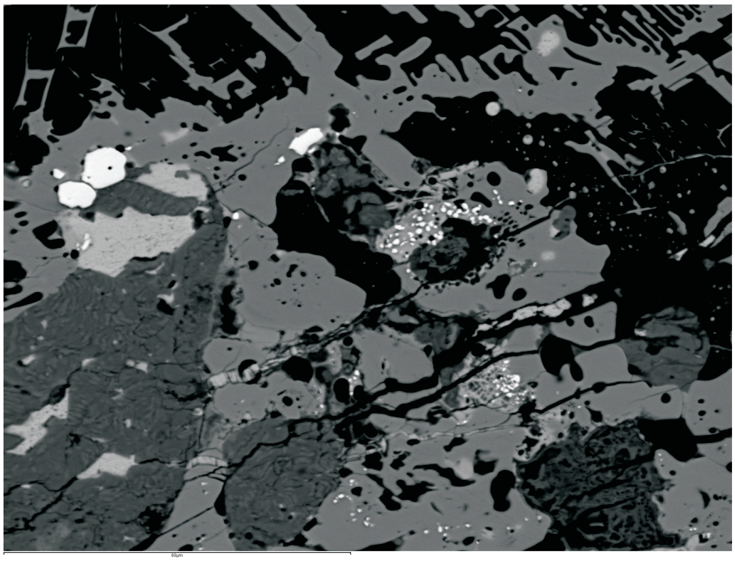

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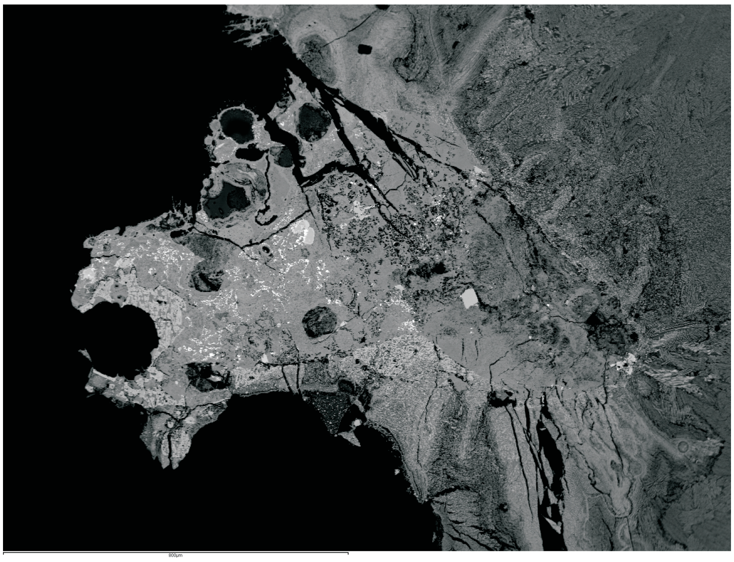
Plate A22



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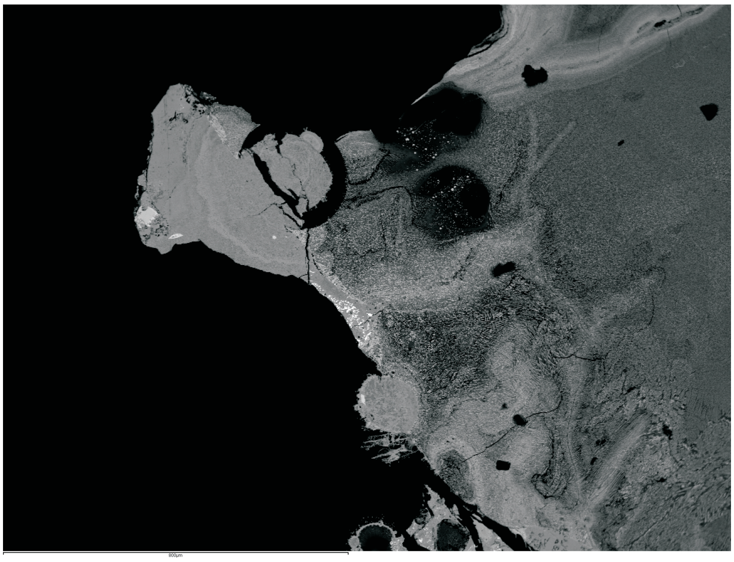

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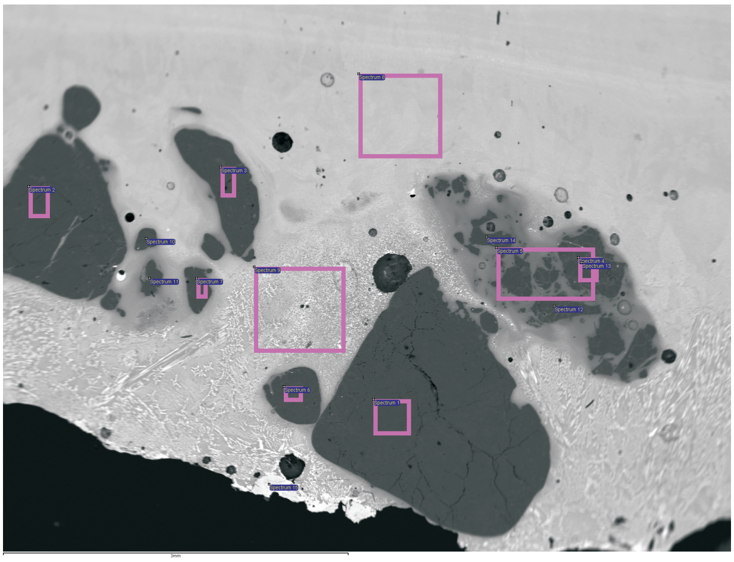

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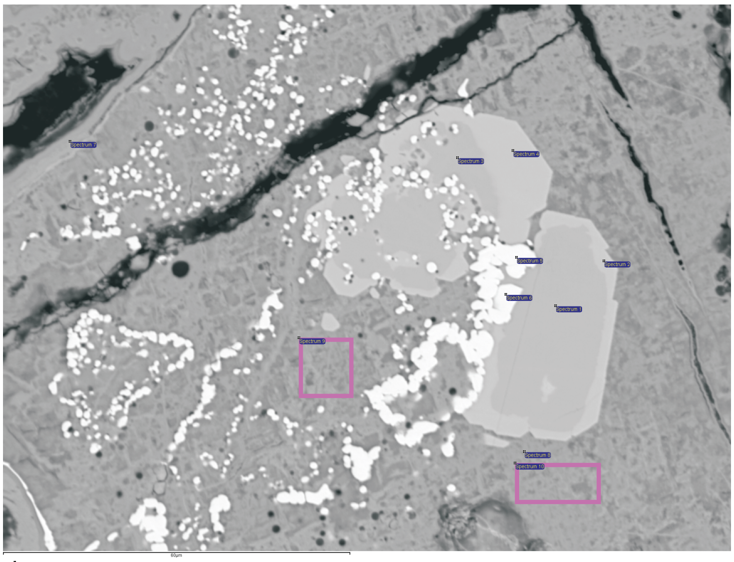

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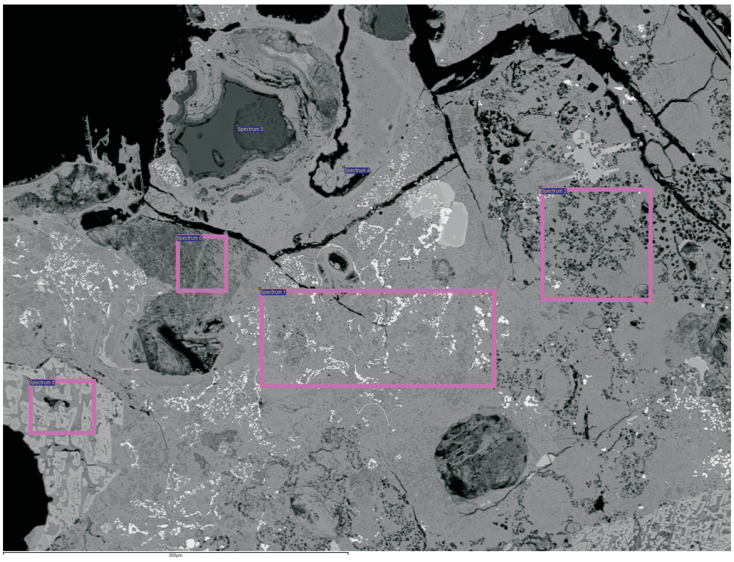

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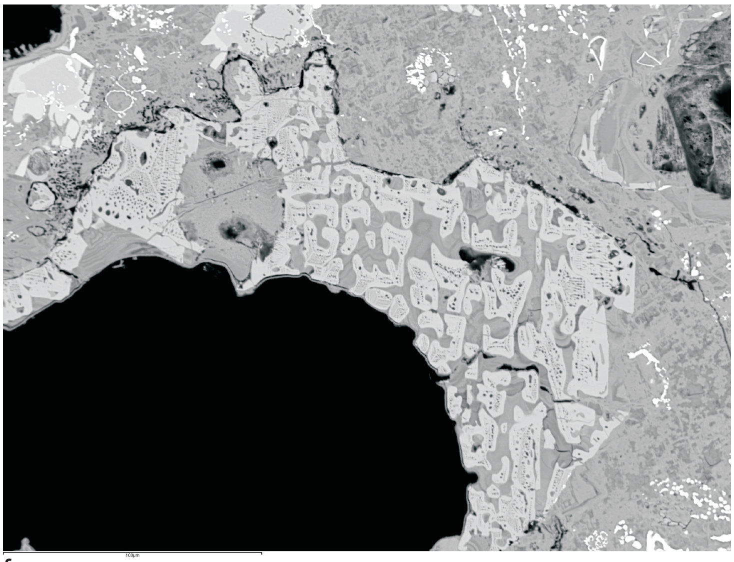

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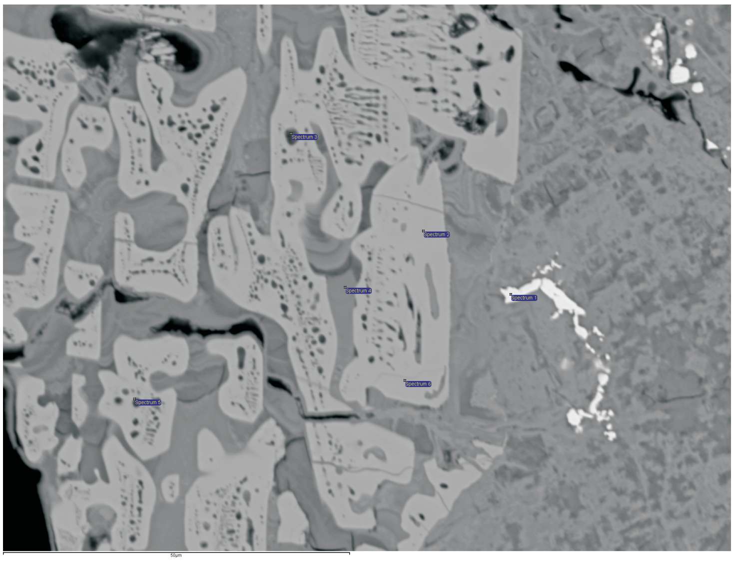

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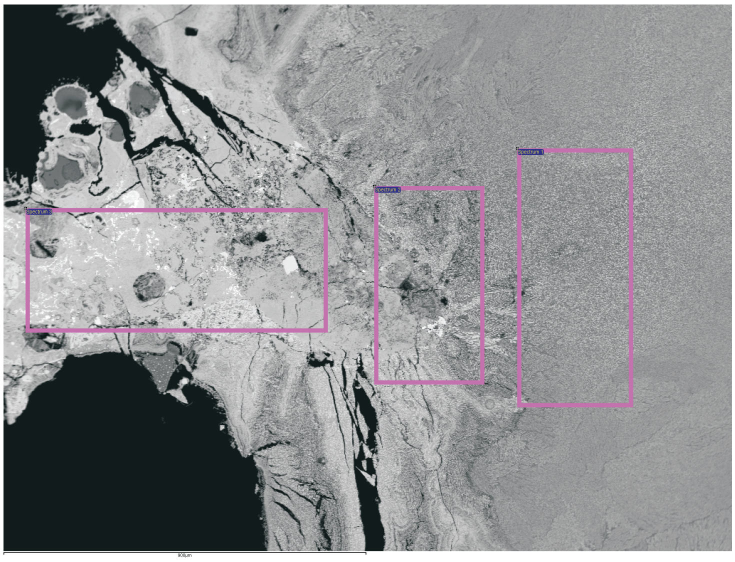

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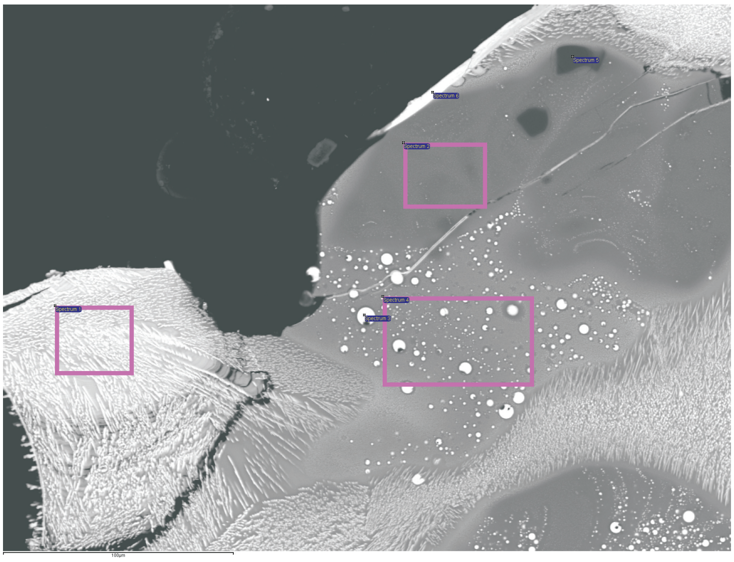

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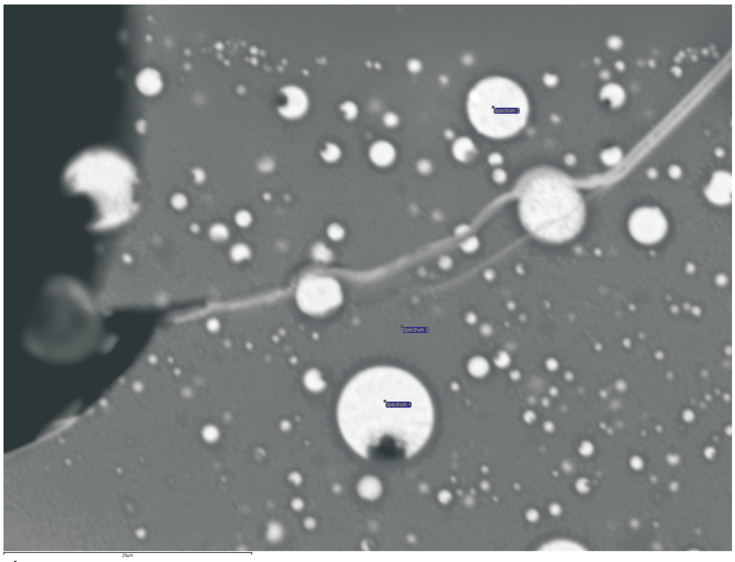

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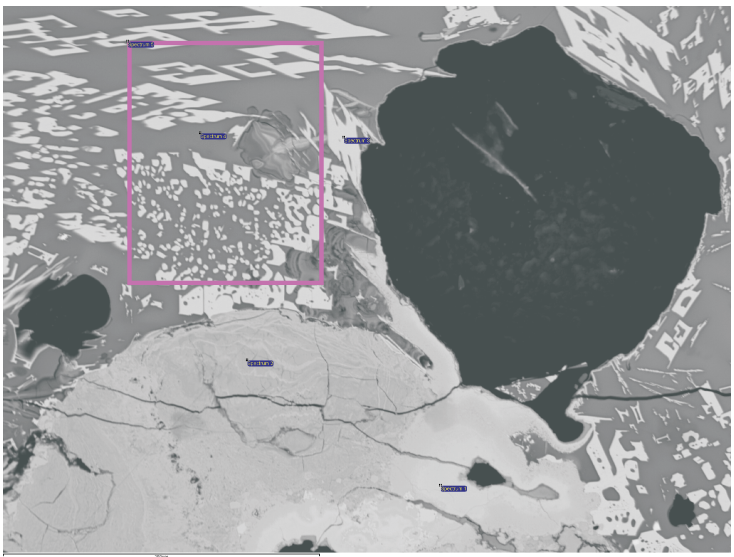

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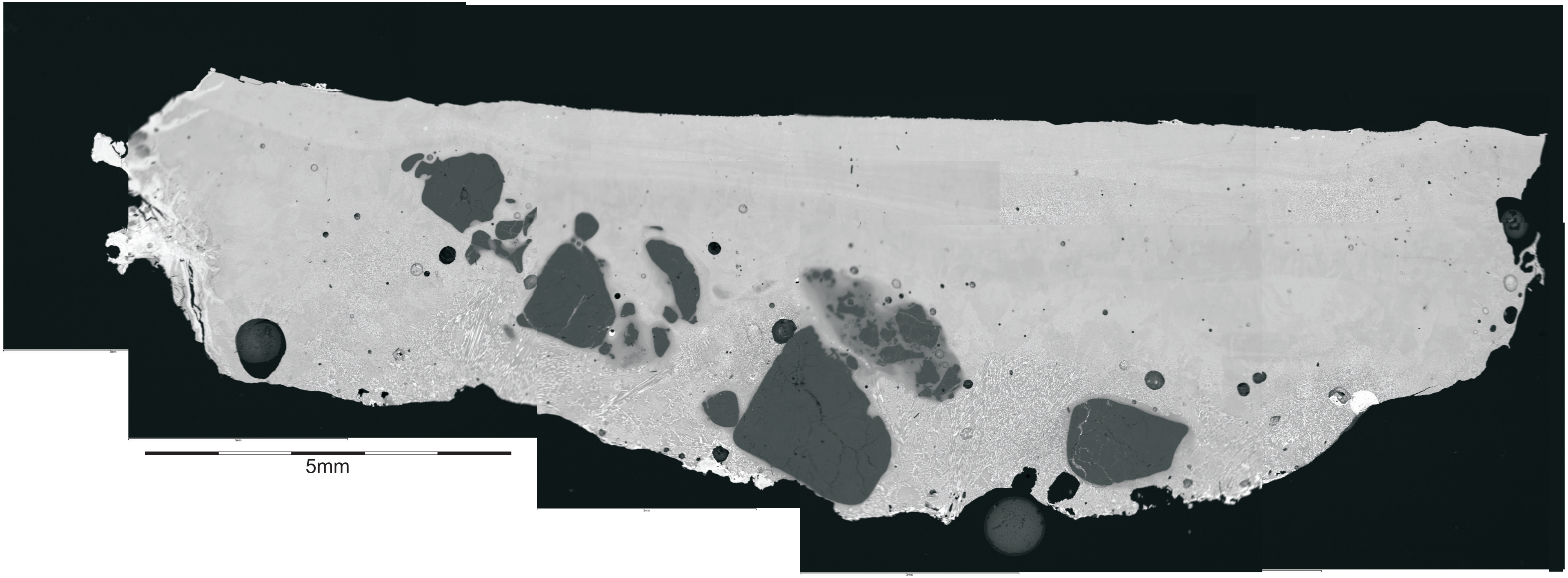
Plate 24



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