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Analysis of residues from Penrhyn
Quarry, Bethesda (G2534/ HD24-001)

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Abstract

This report details the investigation of archaeometallurgical residues from an excavation at Penrhyn Quarry, Bethesda, by the Gwynedd Archaeological Trust, now Heneb. A total 38.5kg of archaeometallurgical residues was recovered in association with a small, at least partially slag-tapping, bloomery furnace of early medieval age.

The slags indicate a smelting technique in which a rod or poker was used to encourage slag flow, in order to tap at least a proportion of the smelting slag. The tapped slags probably comprised a relatively low volume and cooled within the small tapping channel before being moved to a waste pit. The use of rodding in this way is common in Roman smelting, particularly in larger furnaces and it is likely the technique employed at Penrhyn Quarry was derived from those earlier processes.

Analysis suggests that the bog iron ore smelted at Penrhyn Quarry was aluminous, moderately rich in manganese and bearing some phosphorus and arsenic. In combination with an aluminous furnace ceramic, this drove the smelting reaction to produced slags outside the usual range of composition that would have had unusually high viscosities and liquidus temperatures. The use of rodding might have been particularly important in order to tap any slag under these unusual conditions. The extremely aluminous nature of some of the slags may have been exacerbated due to the non-equilibrium origin of these materials, with the rodding allowing drainage of more siliceous slags of higher fluidity, leaving a granular, porous slag resulting from the fractional crystallisation of hercynite. Such fractionation has not been linked to the technique of working of a bloomery furnace before and reflects a smelting operation on the very limits of feasibility.

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Methods

Project rationale and history

This report details the investigation of archaeometallurgical residues from an excavation at Penrhyn Quarry, Bethesda, by the Gwynedd Archaeological Trust, now Heneb (Project G2534/HD24-001). A total of 38.5kg of archaeometallurgical residues was recovered in association with a small, at least partially slag-tapping, bloomery furnace.

Archaeometallurgical residues from the project were catalogued (Table 1) and assessed in August/September 2025 (Young 2025) and a programme of further analysis recommended:

It is recommended that the focus of the laboratory work is provided by the bulk elemental analysis of examples of the various residue facies that are best-preserved (which will be examples in the most part from (4007)). Microstructural investigation by aSEM will be limited to key pieces where this technique can provide additional information.

Samples should be chosen as follows:

6 bulk analyses (by XRF/ICP-MS)

- 1 x flow slag*
 - 2 x 'rough' slag*
 - 2 x bowl slag*
 - 1 x hearth lining*

3 SEM mounts

- 1 x 'rough' slag*
- 1 x bowl slag*
- 1 x bowl with iron/SHC*

The samples chosen to address this programme are listed in Table 4. The recommended analysis was conducted in late autumn/winter 2025.

Analytical methods

Bulk elemental analysis by XRF and ICP-MS

Bulk chemical analysis was undertaken using two techniques. The major and minor elements (Si, Al, Fe, Mn, Mg, Ca, Na, K, Ti, P and S) were determined on a fused bead using wavelength-dispersive X-Ray fluorescence (WD-XRF). Whole-specimen chemical analysis for thirty-six trace elements (Be, Sc, V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Mo, Sn, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Th, and U) were undertaken using a sample in solution by Inductively-coupled Plasma Mass Spectrometry (ICP-MS). Both XRF and ICP-MS analyses were commissioned from ChemoStrat Ltd (Welshpool, UK).

For XRF analysis, samples were ground using a tungsten carbide shatter mill, dried at 105°C overnight and then 0.5g was mixed with 6.5g of 50:50 LiT/LiM flux and fused to produce a glass disk using a Claisse M4 Fluxy automatic fused disk maker. The samples were analysed using a Bruker S4 WDXRF using the default wavelengths for the elements identified. Calibration was via a selection of iron slag reference materials and geological reference materials.

Samples for trace elemental analysis by ICP-MS were drawn from a second aliquot of the powdered material using the alkali fusion method (Jarvis & Jarvis 1992a and 1992b; Pearce *et al.* 1999). Once prepared, the

samples were then all subjected to analysis using a Thermo Scientific XSERIES 2 ICP-MS. Data quality was strictly monitored in terms of precision and accuracy by five international rock standards of known concentration and varying compositions which are run after every 20 unknown samples. In addition, external monitoring of data quality is carried out four times a year via the GeoPt round robin proficiency testing program (<http://www.geoanalyst.org/overview.html>).

The results of the elemental analyses are presented in Tables 5 and 6 of this report.

Microanalysis and imaging by aSEM

Polished blocks for investigation on the SEM were prepared in the School of Earth and Ocean Sciences, Cardiff University. Electron microscopy was undertaken on the Zeiss Sigma HD Field Emission Gun Analytical Scanning Electron Microscope (aSEM) in the School of Earth and Ocean Sciences, Cardiff University. Images presented here are backscattered electron photomicrographs (BSEM) to illustrate microstructures and for the recording of loci of microanalysis. Microanalysis was undertaken using the system's energy-dispersive x-ray analysis system (EDS) controlled by Aztec software. The Astimex olivine, pyrope and magnetite standards were employed calibration process. The assistance of Dr Duncan Muir is gratefully acknowledged.

All EDS analyses were collected with all elements analysed (including oxygen, but not carbon; all samples were carbon-coated). Area analytical totals were frequently far from 100%, because the analytical system is designed to provide totals of 100% from spot analyses in the centre of the field. The area analyses required for this project are not standardised in the same way and will diverge from a total of 100% (either above or below, depending on the location of the area with respect to the centre of the field). 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 for area analyses have therefore been constructed with elements expressed as oxides in weight% calculated stoichiometrically and normalised, except for mineral structure calculations, where the measured oxygen has been used.

Analyses of olivine have been quoted using the following convention: the proportions of iron and magnesium have been used to first define the relative proportions of forsterite (Fo; Mg_2SiO_4) and fayalite (Fa; Fe_2SiO_4) in the form Fa_nFo_m , where $n+m = 100$. The proportions of calcium and manganese have then been taken to calculate percentage substitutions into the olivine. The substitution of phosphorus for silicon was calculated as atoms per formula unit (APFU), based on four oxygens and where the formula unit ideally has a single silicon atom. Fayalite with a value of more than 0.03 APFU phosphorus (i.e. 3% substitution) is defined as phosphoran fayalite (Boesenberg & Hewins 2010).

The microanalytical data are presented in Appendix A (expressed as elemental wt%, all elements measured). SEM images of all areas are included in Appendix B, including, where appropriate, details of the analysed points/areas on SEI images. For ease of comparison with the bulk elemental analyses, the microanalyses of small areas of presrepresentative textures are provided in Table 7.

Nomenclature

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.

Radiocarbon dating

All dates quoted in this report (unless specifically attributed as quotes) have been recalibrated using OxCal 4.4 with the IntCal20 calibration curve, rounded out to 10 years, and quoted as 2σ , unless specifically stated.

Results

General

The furnace, an associated pit, and other adjacent deposits produced a modest archaeometallurgical residue assemblage totalling 38.5 kg. Preservation was highly variable, with some material appearing very fresh but other material was extremely poorly preserved. It is assumed that this differential preservation is associated with the location of the residue with respect to the groundwater level.

This residue assemblage almost entirely derives from bloomery ironmaking but is unusual in many respects. It has been divided here into five broad classes of material: flow slags, slag rods, rough/granular internal slags, slag bowls and furnace ceramic (Tables 3 and 4).

The abundant flow slags (41% of the assemblage) have morphologies closely resembling tapslugs (i.e. slags that have been tapped from the furnace to cool outside the structure) but they lack the typical maroon surface colour of tapslugs and may have cooled in the narrow tapping channel in a less than fully oxygenated environment. Some 5% of the assemblage comprises slag rods. A very high proportion of the residues appear to have cooled inside the furnace (51% of the assemblage), although this total includes some material likely to be smithing rather than smelting.

Dating

Four relevant dates have been supplied by Heneb:

Oak bark from (4040), the lower fill of large pit [4017], SUERC-133902 (GU71296R), 1601±18 BP (calibrated to 420-540 cal. AD).

Oak bark from (4040), the lower fill of large pit [4017], SUERC-133903 (GU71297R), 1476±18 BP (calibrated to 560-650 cal. AD).

Rosaceae charcoal from (4015), SUERC-133906 (GU71298R), 1750±17 BP (calibrated to 240-370 cal. AD). Context (4015) is described as an 'occupation layer', but it, at least in part, overlay the fills of pit [4017] and may therefore relate to redistribution of a primary waste dump through trample and wash.

A charred cereal grain from cultivation soil (4023), SUERC-133907 (GU71299R), 1910±17 BP (calibrated to 70-210 cal. AD). This is approximately 30m SW of the smelting site.

The non-overlapping dates from the carbonised bark samples from the lower fill of pit [4017] are problematic. It is very unlikely that a single furnace of this type would remain in use for an extended period of time (and see Discussion below). However, once metallurgical activity (or charcoal production) has taken place, it may create a rich reservoir of material within a site that can dominate subsequent charcoal assemblages. The dates suggest that smelting took place within the 6th-7th centuries in an area of previous Roman activity.

Description of residue facies

Flow slags: approximately 41% of the residues were flow slags, probably largely slags tapped from the furnace. They were divided into two groups – those with smooth upper surfaces and those with rough surfaces. Flow slags with smooth surfaces may occur in both slag-tapping and non-tapping furnaces. The rough-surfaced flow slags would be more typical of flows travelling through the fuel or ash bed – and are accordingly more common in non-tapping furnaces than in tapping furnaces.

A high proportion of the flow slags showed no reddening (which is normally an indicator that the slags have been tapped and cooled in the open air outside the furnace) of the surfaces of the flow lobes. However, the presence of a high proportion of manganese may reduce the degree of reddening – and that may be a factor here. The flow slags typically suggested flow in a narrow space – there were no big tapslag cakes (the largest block of flow slag weighed only 300g) and many had a rather narrow shape in plan.

The composition of the flow slags was investigated in more detail through sample PQB2, taken from a large piece (185g) of smooth-surfaced, tapslag-like, flow-slag from context (4007), find <70>. This piece shows a high manganese content (7.0% expressed as MnO), a total iron content equivalent to 60.7% FeO and $\text{SiO}_2/\text{Al}_2\text{O}_3$ of 1.73. With SiO_2 at 21.2% and Al_2O_3 at 12.3%, this is an exceptionally aluminous slag, plotting well within the hercynite field on the SiO_2 - Al_2O_3 -FeO ternary diagram (Figure 1).

Slag rods: 30 pieces of slag rods, weighing a total of 1.9kg (4.8% of the total) were recovered. The rods showed rough or dimpled surfaces, probably indicative of cooling in an ash bed. They were generally 15-25mm in diameter. They are interpreted as a slag fills of holes created with a poker or rod through the ash, fuel and slag in the base of the tapping arch and bowl in order to create a path through which slag might flow from the furnace.

Similarly-sized tool marks occurred on the base of internal slag bowls and may present the distal end of these rodded holes.

The composition of a typical flow rod was investigated through sample PQB3, taken from a cluster of amalgamated slag rods in a 343g fragment from (4007), find <82>. This piece shows a very high manganese content (14.2% expressed as MnO), a total iron content equivalent to 60.7% FeO and $\text{SiO}_2/\text{Al}_2\text{O}_3$ of 2.75. With SiO_2 at 21.2% and Al_2O_3 at 12.3%, this is a somewhat aluminous slag, plotting just within the hercynite field on the SiO_2 - Al_2O_3 -FeO ternary diagram (Figure 1).

Rough/granular slags: these slags typically occurred in rather irregularly rounded lumps. The degree of weathering prevents close description of the surface textures, but this group includes both apparently granular slags (perhaps reflecting a coarse-grained olivine and therefore a slag that had cooled within the furnace) and some that appear rough because of a higher degree of fine porosity.

Some of the slags with this surface texture, perhaps those that had formed towards the front of the furnace, had intercalated flow slags.

The composition of an example of a rough slag (PQB4, taken from a 73g piece from context (4007), find <70>) shows a moderately high manganese content (3.6% expressed as MnO) and a high total iron content equivalent to 66.7% FeO. With SiO₂ at 10.3% and Al₂O₃ at 11.1%, this is an exceptionally aluminous slag, with SiO₂/Al₂O₃ of 0.93, and plots well within the hercynite field on the SiO₂-Al₂O₃-FeO ternary diagram (Figure 1).

Slag bowls: most of the slag bowls are interpreted as examples of slags forming in the base and against the lower sides of the furnace. Context (4015) produced a relatively complete example (albeit in three fragments; <97>) weighing 812g. The detailed morphology of the base suggested that it had formed against the angle of the base of the wall. It seems likely that these denser internal slags are associated with the rear, blowing, wall of the furnace, and with fresh slag descending close to that wall.

The composition and microstructure of the slag bowls was investigated through two samples: PQB5 from a bowl with tool marks on the base (context (4007), 267g piece <62>), and PQB6 from a bowl fragment (a 645g piece from context (4007), find <81>) containing a substantial component of, largely weathered, metallic iron. For the purposes of the microstructural investigation, a further sample, primarily of iron rather than slag, was taken from the same bowl as PQB6 and mounted as sample PQB7.

Sample PQB5 was taken from an example of a tool-mark on the base of a slag bowl. Although tool marks are known both from smelting slags and smithing slags, the analysis of sample PQB5 indicates an origin in smelting, for it has an elevated manganese content (2.47%, expressed as MnO). It also shares a REE profile with the flow slag sample PQB2 and the coalesced rod sample PQB3. The bulk SiO₂/Al₂O₃ was 2.75, similar to that recorded for the sample PQB3 (a bundle of amalgamated slag rods).

The analysis of sample PQB5 indicates an origin in smelting, for it has an elevated manganese content (2.47%, expressed as MnO). It also shares a REE profile with the flow slag sample PQB2 and the coalesced rod sample PQB3. The bulk SiO₂/Al₂O₃ was 2.75, similar to that recorded for the sample PQB3 (a bundle of amalgamated slag rods) and is likewise plots close to the fayalite/hercynite divide on the SiO₂-Al₂O₃-FeO ternary diagram (Figure 1).

In some examples, however, an alternative origin as smithing hearth cakes cannot entirely be excluded. Sample PQB6 was taken from a slag bowl that has large inclusions of metallic iron and was thus possibly having origin in smithing. The fragment was a plano-convex block, partly 'exploded' from alteration of the weathering metallic iron it contained. The piece was

120x70x70mm. Its top was very slightly dished and rusty; the base shows dimpled or micropirillous slags.

The sample was divided into three subsamples, two from slag rich areas (designated PQB6; one for bulk elemental analysis and one for investigation on the SEM) and one from a metallic iron-rich area, designated PQB7).

The bulk XRF analysis of sample PQB6 shows FeO of 79.0%, with 10.6% SiO₂ and 3.5% Al₂O₃, with a very modest MnO content of 0.4%. This differs from the other bulk slag samples in many ways and has a composition more compatible with that of a smithing slag. The iron-dominated subsample PQB7 shows a very similar composition for the slag surrounding the iron. The SEM mount of the slag-rich part of the sample, PQB6, shows a very different composition, with the EDS analyses corresponding very closely in composition to those from PQB5, and to the XRF bulk analysis of sample PQB2.

It would therefore appear that this slag cake is likely to contain discrete areas of slag from both smithing and smelting, both originally containing much metallic iron. One possible interpretation is that during the smithing of a bloom, a significant fragment of smelting slag was introduced to the smithing hearth (presumably attached to the bloom). An alternative interpretation is that the bloomsmithing was undertaken in an incompletely cleaned furnace, with the newly-formed smithing slag becoming attached to, and incorporating within its bowl, old smelting slag remaining in the furnace. This second possibility would appear the more likely, since there is no evidence for remelting of the smelting slag component.

The materials identified as being associated with smithing form a coherent compositional group. The analyses of the various components of sample PQB7, together with the XRF analysis of PQB6, form a linear array on the SiO₂-Al₂O₃-FeO ternary diagram, (Figure 10). Several of the individual slag components of PQB6 plot well within the hercynite field on the SiO₂-Al₂O₃-FeO ternary diagram, lying close to various of the smelting slag analyses (Figure 2).

Furnace lining: pieces of the furnace ceramic were relatively rare (just 3% of the assemblage). In general, they provided little information on furnace construction or morphology. Most of the furnace ceramic derived from the floor of the furnace (4042); here one fragment showed an evenly vitrified front face, but the rear shows an arcuate discontinuity in the underlying ceramic that might just represent the margin of a pre-formed tuyère block.

The composition of the hearth ceramic was addressed through the analysis of sample PQB1, a 121g piece of relatively unaltered material spalled from back of vitrified face (4007) <64>. This showed a slightly aluminous composition (SiO₂ = 70.5%, Al₂O₃ = 13.5; SiO₂/Al₂O₃ = 5.2).

The analysis of PQB1 plots on the silica-mullite join on the SiO₂-Al₂O₃-FeO ternary diagram (figures 1 and 2).

Microstructural details

Sample PQB5: this sample was taken as a cross-section of a rounded ridge on the underside of a 267g piece from context (4007), find <62>. The ridge was approximately 25mm wide and 15mm deep (Figure 3).

The ridge is interpreted as a toolmark, the cast of a trough made by an implement (most likely the distal end of a rod being used to clear though the tap arch) in the floor of the furnace.

The unsampled upper parts of the piece showed an overlying dense slag sheet 30mm thick, with its top not an original surface, but rather a series of unroofed tabular vesicles.

The tool-mark shows somewhat radial tubular vesicles, with the central vertical examples at least 10mm in length.

The lower 4mm of the piece, but most markedly the outermost 1mm, shows the effect of quenching, with tightly-packed, margin-normal olivine crystals (Figure 3; these zones are marked by the dashed lines).

The marginal zone shows numerous small clasts, including quartz and ceramic grains, together with particles of dense iron oxides, altered iron, spinel-rich particles, mineralised charcoal and other relict materials. These grains show varying degrees of reaction with, and assimilation into, the slag filling the tool-mark.

The slag in the upper part of the core of the tool-mark (i.e. away from the influence of the margin) shows a texture with primary hercynite (Figure 4 a,b). This reflects an aluminous composition (typical composition with SiO_2 of 28.6 wt%, Al_2O_3 11.8%, MnO 2.3% and FeO 52.7%, giving $\text{SiO}_2/\text{Al}_2\text{O}_3 = 2.4$) The hercynite is present as abundant euhedral and subhedral grains of up to 30 μm . This is followed by elongate fayalite olivine of up to approximately 1mm in length, often with further cotectic hercynite. The fayalite is carious and divided into small blocky units of up to approximately 200 μm . Areas interstitial to the olivine are glassy, with fine dendrites of olivine and wustite. There are a few very rare examples of late-stage olivine crystals that have cotectic wustite.

In detail, the hercynite comprises approximately 90% hercynite end-member and 10% magnetite end-member, with minor levels of magnesium and titanium substitution and trace levels of vanadium. The olivine (Figure 7) has a very restricted range of composition from $\text{Fa}_{97}\text{Fo}_3$ to Fa_{100} , calcium substitution rising from 0.4% in core regions up to approximately 2.0% on come crystal margins. Manganese substitution falls from 5.1% to 3.6% across the same regions. Phosphorus substitution for silicon is mostly below 1.5% and entirely below 3%, meaning that none of the fayalite is phosphoran (*sensu* Boesenberg & Hewins 2010).

A similar composition and microstructure continue down towards the base, with the main slag above the quench zone showing splaying sub-vertical olivine crystals, possibly as much as 1mm in length. The quenched layer is much finer-grained. The boundaries of the slightly and strongly quenched parts of the margin are demarked by the red dashed lines in Figure 3.

The largest of the iron-rich particles present on the lower margin is approximately 1.0mm by 0.5mm in the section; most are just slightly smaller. There are three different microstructures present in these particles. The first (Figure 4, c) is a rather vermicular, spongy texture which before alteration was probably dominantly metallic iron. This texture resembles examples of partially reduced ore fragments seen elsewhere.

The second is a porous structure, but not so spongy in appearance, with the iron oxide becoming more dense around internal voids (these particles commonly have an irregular central void) and the outer margins until (the third texture) it resembles hammerscale (Figure 4, d, lower part). These two, related microstructures, are granular with angular iron oxide grains, and with larger regions of coarse-grained wustite-magnetite in textures very similar to those seen in hammerscale, with exsolution of magnetite from wustite during cooling. It is unclear whether these two textures are simply variants of a single texture and have the same origin or present, or whether they represent partially reduced ore and oxidised iron respectively. The denser parts of both textures contain small particles of iron arsenide (Figure 4, d white spots).

It appears likely that there are two forms particle present. Some (e.g. Figure 4, c) have diffuse margins and are internally spongy: they probably represent iron particles within the slag, whereas some (e.g. that seen in Figure 4, d) have sharp margins and probably represent discrete iron oxide particles that lay on the floor of the initial void created by the rodding, only subsequently becoming incorporated with the slag. The iron oxide particles of both types show $\text{SiO}_2/\text{Al}_2\text{O}_3$ of 1 or less (typically 0.3 or less; Figure 1).

Sample PQB6: this was taken (Figure 5) from a porous section of a 645g fragment of a crudely plano-convex slag cake from (4007), find <81> (a dense, iron bearing section of the same cake was sampled as PQB7, see below).

The coarse porosity is due in part to the presence of poorly-preserved charcoal (Figure 5, close to upper edge) but appears mostly due to the loss of former inclusions of metallic iron. These range up in size to approximately 4mm within the prepared sample.

The upper part of the section shows a composition with a very high iron content (typical composition with SiO_2 of 8.0 wt%, Al_2O_3 4.7%, MnO 2.1% and FeO 81.9%, giving $\text{SiO}_2/\text{Al}_2\text{O}_3 = 1.7$) reflected by the dominance of wustite. The microstructure has abundant small (mostly less than 1mm) zones of porous secondary iron minerals (Figure 4, e), many of which show adjacent subhedral hercynite grains. These features suggest that the small altered inclusions were originally metallic iron (with the hercynite having nucleated on the iron). The areas around these inclusions tend to be heavily altered.

The microstructure is, however, dominated by wustite in rounded blebs or pseudo-dendrites (Figure 4, e). The wustite occurs in zones approximately 1mm across. The gaps between the blebs and the wider gaps between the clusters of blebs reveals show a microstructure of elongate olivine bearing cotectic hercynite, with interstitial glass bearing very fine olivine dendrites. The coarse early hercynite grains overlay the wustite.

Within this zone lies the end of a fragment of mineralised charcoal, approximately 5mm across. Around the margin of the charcoal there is a zone 100-300 μm wide of secondary minerals indicative of a former film of metallic iron. Outside this, there is a zone up to a millimetre wide lacking in wustite with a coarse microstructure of altered blebs originally metallic iron (probably forming a further two concentric films), euhedral to subhedral hercynite, followed by fayalite. Bulk analysis of this zone shows a composition close to that of the slag in PQB5 (typical composition with

SiO₂ of 17.3 wt%, Al₂O₃ 9.58%, MnO 2.1% and FeO 55.9%, giving SiO₂/Al₂O₃ = 1.8)

In the lower part of the section, a larger area of siliceous slag (typical composition with SiO₂ of 20.6 wt%, Al₂O₃ 7.0%, MnO 2.3% and FeO 61.3%, giving SiO₂/Al₂O₃ = 1.8) partially surrounds larger former iron inclusions as well as smaller charcoal fragments. The altered iron inclusions show rims of dense wustite with rounded elongate protrusions (Figure 4, f). Small blebs adjacent to these include examples which were apparently both of iron and wustite. The slag here shows early euhedral and subhedral hercynite, but the earliest olivine is commonly in a cotectic with wustite. The outer parts of the olivine are typically free of cotectic phases although the relationship with some of the hercynite is ambiguous. The interstitial areas are glass with fine olivine dendrites.

The composition of the hercynite varies little across the sample. In the upper areas (both those wustite dominated and the slag surrounding the charcoal particle) the mineral has 87-90% hercynite end-member and 10-13% magnetite. In the lower part of the sample, the variation is 90-92% hercynite and just 8-9% magnetite.

The variation in the olivine composition is more significant (Figure 7). In the upper part of the sample the magnesium substitution is limited, with a range from Fa_{93.2} Fo_{6.8} to Fa_{96.5} Fo_{3.5}. Calcium substitution in the olives of the marginal zone around the charcoal fragment show a typical trend from 0.8% to 1.0% over this range, but with an apparently more random range of in the wustite-dominated slag from 0.9% to 1.8%. Manganese substitution is elevated at 6.5% in both contexts.

In the lower part of the sample, phosphorus substitution is more consistent and even lower, at 0.4% to 1.1%. Magnesium substitution provides a range from Fa_{93.5} Fo_{6.5} to Fa_{98.0} Fo_{2.0}. Within this range values from Fa_{93.5} to approximately Fa₉₆ occur in olivine with cotectic wustite and from Fa₉₆ to Fa₉₈ in the 'clear' outer parts of the olivine. Calcium substitution follows a typical enrichment curve across this range from 0.7% to 1.1%. Manganese substitution follows a decline from 5.5% to 5.0% across the same range (and is confluent with that in the more iron-rich olivine from sample PQB5).

The high bulk manganese content of the material and the accordingly high level manganese substitution in the olivine clearly indicate that these slags are derived from smelting.

Sample PQB7: this was taken from a dense, rusty, section with some surviving areas of metallic iron from a 645g fragment of a crudely plano-convex slag cake from (4007), find <81> (a porous of the same cake was sampled as PQB6, see above).

The sample (Figure 6) shows two distinct microstructural components: In the upper part (as illustrated; the way-up of this piece is uncertain) there is a wustite-hercynite-fayalite slag with porosity, which at least in part is suggestive of the locations of former metallic iron particles of up to approximately 2.5mm. In the lower part as mounted, the slag is dominated by wustite, which carries irregularly-shaped former metallic iron particles (with metallic iron surviving locally) of up to at least 7mm and possibly much more (Figure 4, g). The wustite is in rounded blebs and crude pseudo-dendrites from 50µm to 500µm. Small,

rounded, areas of olivine-dominated slag are suggestive of gaps (vesicles?) in the early formed wustite that became filled by more siliceous material later in the cooling. The wustite-dominated zone shows a typical composition of SiO₂ of 4.7 wt%, Al₂O₃ 3.3%, MnO 0.6% and FeO 84.8%, giving SiO₂/Al₂O₃ = 1.4.

The upper, more siliceous, slag (Figure 4, h) shows, following the iron, stout rounded dendrites of wustite with lengths of up to approximately 0.5mm developed locally. This is followed by elongate crystals of fayalite of a similar size, which form the primary phase in areas without wustite dendrites (e.g. close to some of the iron inclusions in the upper left of the sample). The interstitial areas are glassy with very fine dendrites of olivine. A typical composition for the wustite-bearing areas in this zone would be SiO₂ of 16.8 wt%, Al₂O₃ 6.6%, MnO 0.4% and FeO 74.3%, giving SiO₂/Al₂O₃ = 2.5. Close to some of the iron droplets (see below), the slag loses its wustite and her the slag composition becomes SiO₂ of 29.0 wt%, Al₂O₃ 9.1%, MnO 0.5% and FeO 56.2%, giving SiO₂/Al₂O₃ = 3.2.

On the margin of the wustite-dominated area, the same microstructure can be observed to follow the wustite (Figure 4, h). At least some of the gaps in the coverage of wustite must have been early vesicles, for they show this texture. Others have fillings of secondary iron oxides - and although most of these were probably originally filled by metallic iron, they were not necessarily all so.

In the siliceous slag in the upper part of the sample, the olivine shows a distinctive composition (Figure 7). In almost all analyses phosphorus was below detection. Magnesium substitution was limited (as in other samples from this site), giving a range of composition from Fa_{93.6} Fo_{6.4} to Fa_{99.3} Fo_{0.7}. Calcium substitution increased from 0.35% to 0.6% (an enrichment curve intermediate between those from PQB5 and the lower part of PQB7). Manganese substitution was very low and almost constant at 1%.

The surviving iron in the large fragment in the lower part of the sample (Figure 4, g) is ferritic, with large equant grains of up to approximately 160µm. The backscattered electron contrast shows little evidence for variation in carbon content. Phosphorus was below detection in EDS, but arsenic was present at a fairly constant level at approximately 0.5%. The microstructure was constant from the centre of the piece towards a surviving embayed margin against the wustite slag. Other altered iron particles in this zone of the sample appeared to have mostly been rounded and mostly smaller than 1mm. although alteration made observation difficult it appeared that many of the iron particles were irregular in shape, but it was unclear to what extent they may have been anastomosing.

The iron in the upper olivine-rich slag appeared broadly similar. Here, however, there appeared more evidence for droplet-like bodies. In one area bright zones in the backscattered imagery suggested the presence of cementite-bearing interstitial regions between rounded ferrite cells, presumably dendrite elements – suggesting a cast microstructure.

This difference in the nature of the iron suggests that in the lower part, with its intimately mixed wustite slag, represents a relict bloom fragment, but that within the slag is suggestive of remelted droplets. In both areas, the low manganese content of the slag and the accordingly low level of manganese substitution in the olivine, strongly suggest that they are smithing slags.

Bulk elemental analysis details

The determination of bulk chemistry of small areas by EDS (Figure 2), as described above, is complemented by the bulk analysis of larger subsamples, providing data not only for the major elements by XRF (Table 5), but also for trace elements by ICP-MS (Table 6).

As discussed above for the EDS analysis, the major element oxide chemistry is dominated by Al_2O_3 , SiO_2 , MnO and FeO , the sum of the other major element oxides not exceeding 3.6%. The samples are all very aluminous – the slags all having a $\text{SiO}_2:\text{Al}_2\text{O}_3$ ratio of 3 or less and even the hearth ceramic only has a ratio of 5.2.

This aluminous composition means that most XRF and EDS determinations for PQB2, PQB3, PQB4 and PQB5 lie on the hercynite side of the divide between hercynite and wustite/fayalite, as do some of the EDS determinations for PQB6 (Figures 1 and 2). The remainder of the EDS analyses from PQB6 and those for PQB7 lie on or very close to the divide (Figure 10).

Of the other major elements, manganese is very variable within the analyses. Samples PQB4 and PQB5 show moderately elevated contents (3.62% and 2.25 % respectively, expressed as MnO), while samples PQB2 and PQB3 are strongly elevated (7.04 and 14.18% respectively).

In general, the smelting slag samples exhibited rather low concentrations of the analysed trace elements. Vanadium and chromium show rather similar distributions, with both showing particular concentration in PQB4. In contrast, Barium was particularly low in PQB4 but slightly elevated in PQB3 and PQB5, thus not showing a strongly correlation with manganese.

Uranium and thorium occur in a fairly constant ratio (U/Th of between 0.11 and 0.16), but at low concentrations ($\text{Th} < 13.1\text{ppm}$, $\text{U} < 1.7\text{ppm}$).

The REE were also at low concentrations (total REE (S REE) varying between 60ppm for PQB3 and 124ppm for PQB5, with the furnace ceramic PQB1 containing 224ppm). The upper-crust normalised rare earth element (REE) profiles (Figure 8) from most of samples of slag show a rather flat profile through the HREE but decline towards the LREE with a positive cerium anomaly. A positive cerium anomaly has been noted in the bog iron ores from Crawcwellt (author's unpublished data) and is likely to reflect the scavenging of cerium (the only REE with a solubility affected by its two valence states) by the same redox reactions as generate the bog iron ore. The profile for the furnace ceramic is flat, declining very slightly towards the HREE across the whole group. In detail, within the slag samples, although the profile across the HREE is almost flat, the profiles for PQB2 and PQB4 show a very slight rise across the HREE, whereas PQB3 and PQB5 decline slightly across the HREE. PQB3 and PQB5 share a higher $\text{SiO}_2:\text{Al}_2\text{O}_3$ ratio than PQB2 and PQB4, so this variation may be due to the greater influence of the ceramic on the composition of PQB3 and PQB5.

As described above, the block (a 645g fragment of a crudely plano-convex slag cake from (4007), find <81>) from which PQB6 and 7 were sampled appears to contain regions produced by both smithing and smelting. Microanalysis of sample PQB6 gave analyses of slag compositions indicative of smelting slags similar in composition to the group just described. XRF analysis of sample PQB6, in contrast,

gave just 0.42% MnO . This is very close to the content of MnO reported by EDS microanalysis of slags within sample PQB7 (taken from the same slag cake).

Clearly, there were significant differences between the subsamples of PQB6 used for XRF and for the polished mount of ASEM investigation. The SEM mount of PQB6 appears to be a smelting residue, whereas the bulk elemental analysis for PQB6 appears to be of a smithing residue (similar to the SEM mount PQB7, sampled from the same slag block).

Detailed comment on the trace element chemistry of PQB6 is complicated by the high dilution of the slag component by the (former) metallic iron. The incomplete REE data for PQB6 also declines towards the LREE but lacks a cerium anomaly. This profile accentuates the difference between the bulk analysis of PQB6 and those of the other slag samples. In contrast to the general dilution of the trace elements, PQB6 shows slightly elevated levels of cobalt and zinc.

Interpretation

Interpretation: the smelting

The analysis presented above shows that the iron smelting residues from Penrhyn Quarry differ from typical waste materials from bloomery iron smelting in which slag has been tapped from the furnace, in both the morphology of the residues and in their elemental composition.

The assemblage is characterised by a low proportion of flow slags that have been tapped from the furnace, the small size of individual flow slag accumulations and by the presence of slag rods. The presence of slag rods implies that the furnace was intended to tap slag. The presence of a high proportion of flow slags in narrow amalgamations suggests the passage of those flow slags into the tapping channel, but not into a more substantial 'tapping pit', as is commonly seen.

The presence of a high proportion of flow slags that were not reddened by contact with the atmosphere when hot and by a high proportion of flow slags with rough, rather than smooth 'free' surfaces, probably reflects the chilling of the slag in an ash/fuel dominated tapping channel, rather than simply in the open air.

The slag rods indicate a process that involves considerable active interaction with the progress of the smelt by the smelter implying that the furnace did not tap freely on its own.

The analysis of the residues provides a strong indication of why this was the case: the very aluminous nature of the residues would correspond to both a high liquidus temperature (the temperature at which the melt would be fully liquid) and to an elevated viscosity. In other words, the composition of the slag would make it very difficult to tap.

The bulk compositions recorded for the slag present in the tool mark on the base of a slag bowl PQB5 and for slag rod PQB3 lie very close to the hercynite-fayalite divide and would thus be relatively free-flowing melts with a liquidus temperature below 1200C (Figure 9). The analyses of flow slag PQB2 and particularly of the rough, granular, probable furnace slag PQB4 are, however, much more aluminous. The liquidus temperature for PQB4 is likely to have been well over 1400C. It seems likely that these materials, particularly PQB4, are not slags formed at equilibrium but instead

represent the results of fractionation through fractional crystallisation of hercynite, flowed by partial drainage of the relatively siliceous residual melt. A slag of the composition of PQB4 could be generated through the draining of a fluid slag of a composition close to that of PQB3 from a partially solidified material of a composition intermediate between that of PQB3 and PQB4.

In such a system, the rodding of the solidifying mass to allow the collection, and extraction, of fluid slag might have been essential to prevent the furnace becoming over full of slag, freezing and preventing bloom growth.

Leaving a slag with a higher degree of porosity in the furnace might also have aided the post-smelt cleaning compared with leaving the slag to form a dense untapped mass.

The remains of the furnace are slight, but the form of the channel and external pit with their 'L' shape in plan, is striking and unusual. This arrangement would allow the waste removed from the furnace to be moved sideways into the pit and out of the direct line of the smelter's activity. Such an arrangement is unusual and may indicate that little slag was reaching the end of the tapping channel in a fluid state.

The furnace is moderately small (note: the dimensions discussed here have mostly been digitised from the Post-excavation Project Design, Kenney 2024, figure 14 – for which the scale bar is erroneous: it is 2m, not 1m, in length, but the marginal coordinates are correct). It was 'D' shaped, with the dimensions (Kenney 2024, 26) 0.47m by 0.38m and was 0.12m deep. The straight section of wall to the south was 380mm wide. A straight and locally overhanging, rear wall is likely to be indicative of the side from which the furnace was blown (and in this case corresponds to the direction of maximum space for the bellows).

The channel was not quite perpendicular to the straight wall, was 260mm wide and 130mm deep. It was oxidised over much of its length (approximately 320mm, but only across its whole width for the first 170mm), before the apparent blocking on the edge of the pit – which extended away from the axis of the furnace at right angles along the inside of wall (4014).

The intense scorching of the channel to 170mm outside the basal pit of the furnace may be indicative of the approximate thickness of the furnace superstructure.

Interestingly the excavation records appear to indicate that no superstructure survived around the periphery of the furnace pit and indeed its shallow depth hints at a degree of truncation. Parts of the vitrified interior face of the furnace were recovered as context (4042) lying directly on the floor of the pit, having collapsed inwards.

This has implications for the degradation of the furnace. Firstly, the pit must have been cleared of all its contents at the end of the last smelt to have taken place, and secondly that collapse (or demolition) of the furnace happened before any other significant deposit had accumulated within it.

The channel is short, but perfectly adequate to provide a location for the cooling of the very modest tapped flow slags. Once solidified, they could be easily moved aside into the pit. Having the pit extending off-axis would allow the smelter, probably kneeling in the entrance to the structure, to use a poker through the

arch of the furnace without having to do so above the hot slag, charcoal and other waste. The total distance from a reasonable position to stand or to kneel in the entrance through the wall to the back of the furnace interior is only approximately 1.4m, so makes a safe and comfortable position to work when using a poker of only around 1m in length. It is a very elegant solution to the need for access to manipulate the contents of the furnace in the technique apparently being used here.

After a smelt, presumably both the furnace and the pit would be emptied and cleaned. It is likely that there was a dump (or dumps) of waste somewhere adjacent to the location. The plot of slag distribution (Kenney 2024, Figure 18) hints that the slag may, at least in part, have been piled against the inner side of wall (4014). Subsequent degradation of that dump over time probably provided the spread of slag-rich material that eventually covered the features. The pale upper fill of the cut feature may even similarly represent an earlier redeposition of the outer parts of the degrading clay superstructure to the furnace. Thus the 'occupation layer' may instead simply represent a later redistribution of the slag (and even perhaps the layer on which it had been dumped), rather than a later occupation event – which would simplify interpretation of the radiocarbon dates by allowing older sediments to have been spread laterally over the site of the former furnace.

Interpretation: the smithing

The iron-rich sample PQB6/PQB7 provide evidence that smithing may also have been undertaken on the site, probably using the furnace itself to reheat the bloom for initial compaction, producing residues with components both from smithing and smelting. An alternative, and less likely, interpretation would be that the bloom produced in a smelt reacted with the hearth wall late in the smelt, perhaps during the burn down phase.

The various analysed elements of the smithing assemblage form a linear array on the $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-FeO}$ ternary diagram (Figure 10). This suggests simple mixing of iron with the hearth wall (or a melt derived from the hearth wall with a composition that lay slightly further down the silica:mullite join).

Although the analysis of the furnace ceramic was slightly aluminous, this would be insufficient to explain the highly aluminous slags. A high alumina content must have been present in the ore. The 'clots' present in sample PQB5 show elevated alumina, with alumina present at levels approximately equal to, or higher than that of silica. They may broadly indicate the general composition of the ore.

Discussion

The smelting

The residues from this site occurred in association with the physical remains of the originating furnace and thus provide significant documentation for a very poorly known technology.

Two other Welsh sites have produced rather similar assemblages: Llandre (Ceredigion; Young 2016b,

Jones *et al.* 2018) and, particularly, Cefn Graianog (Gwynedd; Young 2015a, 2015b; McNicol 2016).

Llandre produced a small assemblage (4.6kg) from a waste deposit and a possible furnace. The makeup of the assemblage was very similar to that at Penrhyn. As at Penrhyn Quarry, there were flow slags with both shiny (42% of the assemblage) and rough (7% of the assemblage), in this case gravelly, surfaces. Slag rods were present but were counted within the rough-surfaced flow slags. Residues that were either 'furnace bottom' slags or just possibly smithing hearth cakes comprised 12% of the assemblage. Some 30% of the assemblage was provided by slags that could not be closely identified and 6% by furnace lining. Finally, 2% of the assemblage was provided by fuel ash slags, possibly from an ashy or sintered deposit on the base of the furnace.

The slag was recovered from two cut features within the interior of the enclosure. The lower deposits in the enclosure ditch produced a date 1563 ± 32 BP (UBA-30455) which calibrates to cal. AD 420–560 at 95% confidence on a single oat grain. The metallurgical waste deposit produced a rather younger date of 1221 ± 37 BP (UBA-24080), which calibrates to cal. AD 690–890 at 95% confidence.

Analysis of slag samples from Llandre suggested that the smelting had exploited a manganese-rich bog iron ore (the slags contained around 7% MnO) with a low phosphorus content (the slags contained 0.3% P_2O_5).

At Cefn Graianog multiple zones with features rich in archaeometallurgical residues were identified within an unenclosed settlement. This site has not been fully reported upon, so the dating is not properly refined. The initial archaeometallurgical work focussed on a small amount of microscopic material from the 2012/3 seasons (Young 2015a) that was tentatively interpreted to represent material from non-slag tapping furnaces. This activity was subsequently dated to the 7th–9th centuries. A second round of work examined the more abundant macroscopic material from the 2014 season (totalling 23kg) much of which apparently derived from a slag-tapping process. This assemblage derived from a further four complexes (buildings?) beyond that identified in 2013. One had very little evidence for metallurgy, one had smithing residues, one had smelting residues and one both.

The smelting residues from Cefn Graianog (Young 2015b) were dominated (41% of the assemblage) by varieties of flow slags, including individual prills and slag droplets, as well as aggregated flow slags morphologically resembling tapped slag. A few examples of these flows showed a degree of reddening and one showed deformation, with half of the flow inverted onto the other indicating manipulation of the semi-solidified flow. There was a small quantity of fragments of narrow slag rods and runners (1% of the total assemblage). Intriguingly, the assemblage included approximately 2.4kg of iron ore, but unfortunately this project never moved to the analysis phase.

These two sites form, together with Penrhyn Quarry, a group with very similar characteristics, indicative of a common smelting technique and tradition. They stand in contrast to the slightly later assemblage from South Hook, Dyfed (Crane & Murphy 2010; Young 2006, 2010), which showed larger and wider tapslag flows (up to 0.6 x 0.2m and 3kg) and a complete lack of slag rods. This technology is more similar to, but not identical with, the variety of slag tapping furnace that

became widely employed across southern Britain from the 11th (and possibly 10th) century.

The significance of slag rods has been much debated over recent decades but finds of rods attached to internal slag bowls and a consistent relationship between their recovery and a particular style of Roman furnace has now clarified their origin.

They form as slag infills of holes created by the insertion of a rod or poker into the basal chamber of a bloomery furnace and particularly into the mass of slag that may chill there (commonly referred to as a 'furnace bottom'). Repeated insertions may eventually develop complex multi-rod slag masses as the smelter attempts to permit liquid slag to flow freely away from the base of chamber and out of the furnace.

Such a technique appears to be particularly prevalent in the use of the large Roman furnaces, including those commonly referred to as 'domed' furnaces in the Weald and elsewhere (e.g. Young 2022), and those that produced the 'Cardiff-type' slag assemblage found around the Forest of Dean and South Wales (e.g. Young 2014, 2021a, 2021b). Not all Roman furnaces appear to have been operated in this way, but it is becoming clear that a significant proportion were. This Roman technology is also notable for the relatively low proportion of the slag that ends up as tapslag of conventional appearance (ranging from 28% at Moat Farm Newent, 29% at Kingswood and 33% at Lydney B Phase II to 45% at Cardiff Castle; Young 2023, Young 2017, Young 2021b, Young & Kearns 2011 and Young 2021a respectively). This proportion is directly comparable with that observed at Penrhyn Quarry.

No examples of this technology are yet known, however, from the Roman period in North Wales. Roman period iron smelting in this region is really only documented at Site A, just outside the Bryn y Castell hillfort (Crew 1987, 2009). Here, a sub-circular stone-walled structure (apparently replacing an earlier timber structure), 4m in internal diameter, was dated by archaeomagnetic means to have smelting activity continuing onto the 3rd century AD, and had 500kg of associated residues. There was apparently no evidence that the poorly-preserved furnaces had employed slag-tapping.

The previous interpretation of the technology of the Llandre and Cefn Graianog sites was to see them as potentially providing evidence for the onset of slag tapping techniques, within a region that had been using non-tapping furnaces. That interpretation can now be rejected in favour of seeing these sites instead as using a technique persisting from the Roman period.

If the Penrhyn Quarry smelting is viewed as a part of this tradition, extending back to the 1st century AD in other areas, itself perhaps of approximately 5th–7th century date and followed by the Llandre and Cefn Graianog smelting in the 7th–9th centuries, then the site may form the first direct intermediate evidence for the continuity of the technique.

At Penrhyn Quarry, the use of a smelting technique using rodding may also have made easier the task of smelting a particularly aluminous ore.

The iron ore

The moderately high, but variable, manganese content (2.47%–14.18%) of the slags from Penrhyn Quarry suggests that the ore was also probably very variable

in composition, perhaps from 1.5% to as much as 9.7%, using the enrichment factor discussed below. Bog iron ores are also commonly rich in phosphorus. The evidence from the Penrhyn quarry is that the phosphorus content of the ore smelted at Penrhyn Quarry was modest, with the slag containing 0.62% to 0.77% P_2O_5 .

The uplands bog iron ores in North Wales are known to show a high degree of variability in both their manganese and phosphorus contents.

A road section near Crawcwellt exposes a minor level of Fe-Mn mineralisation close to the base of the soil profile that shows a lateral variation from 0.21% MnO to 18.2% MnO, with less than 0.2% P_2O_5 (author's unpublished data). Crew (1991b) reported that the ores smelted at both Crawcwellt and Bryn y Castell contained up to 3% MnO. Charlton (2007, table 7.1) analysed samples from the excavations at Crawcwellt and demonstrated variability of P_2O_5 between 0.19% and 0.72% with homogenised bulk samples having 0.42 and 0.54%, and of MnO from 0.62 to 7.45% with the bulk homogenised samples having 3.25 and 3.36%

Ores recovered from the medieval smelting site at Llwyn Du similarly showed from 0.47% to 8.61% for ores selected visually as low Mn and from 33.85% to 79.19% MnO for those selected as being high-Mn (Charlton 2007, Crew and Charlton 2007). Charlton also recorded the variation in P_2O_5 from 0.05% to 0.23% for the iron rich ores.

The iron within PQB7 produced analyses with detectable levels of arsenic (typically around 0.5%), but phosphorus was not detected. Such a composition would be compatible with the low levels of phosphorus (<0.8% P_2O_5) present in the slag analyses.

Although the phosphorus contents are low overall, the term 'phosphoric iron' (presumably equivalent in broad terms to Crew's use of the term 'high phosphorus') was taken by Stewart *et al.* (2000) to refer to iron with just 0.05-0.5 wt%P, so even relatively low levels of P in the ore may still, under appropriate reducing conditions, be capable of producing high-P iron during smelting. Phosphorus at 0.05-0.5 wt% would still be considered below detection for EDS.

There is a low, but persistent, presence of arsenic in the materials from Penrhyn Quarry. As well as its presence in the surviving metallic iron in sample PQB7, the iron oxide particles described above, lying on the base of the slag cake in sample PQB5, also showed inclusions of arsenide. The precise origin of these particles is uncertain. The dense sections with polygonal wustite grains, most closely resemble the microstructure of hammerscale (suggesting the represent oxidised metallic iron particles), whereas the internal structure is more open and resembles partially reduced ore. One likely explanation would be that these particles were part-reduced ore grains, with metal-rich outsides, that have then been re-oxidised. Unfortunately, arsenic is not one of the elements routinely sought in the ICP-MS analyses.

Crew (2009) stated that the site at Bryn y Castell produced iron with both high phosphorus and arsenic contents and suggested that a billet from Banc y Coed (with high arsenic) might have been made from the same ore. That statement may have relied on the analyses by ED-XRF by Charlton (2007, table 8.1) which showed variation from 0.51% to 2.31% P_2O_5 , from 0.13% to 0.31% MnO, and from 0.63% to 9.94% As_2O_3 and/or early analyses by AAS by Ian Devine

(quoted by Charlton 2007) giving 2.81-3.05% P_2O_5 , 0.17-0.19% MnO and 1.67% to 2.09% As_2O_3 .

Arsenic has been widely reported in materials from NW Wales. An iron billet from Cefn Du, Anglesey (Young 2001) was reported to have 0.35%P and 0.7-1.2% As.

Metallic prills inside medieval hammerscale (and therefore a poor indicator of original metal composition) from Llanfairfechan (Young 2025) gave analyses with 2-3% As in spheroidal scale and 0.4% in flake scale – presumably representing varying degrees of scavenging during oxidation. Nonetheless this suggests use of arsenic-bearing iron.

The BGS map of arsenic in soils (accessible using the UKSO viewer; <https://mapapps2.bgs.ac.uk/ukso/home.html>) shows a large arsenic anomaly, centred on Yr Wyddfa reaching over 170mg/kg. Bryn y Castell lies to the SE of this anomaly (with soil concentrations at around 25mg/kg) and Penrhyn Quarry lies on the NE side of the anomaly (with soil concentrations at around 35mg/kg). The observations of the smelting residues from Penrhyn Quarry are thus compatible with a local origin for the ore.

A mass balance model for the smelting

Given the uncertainty of the ore composition, the variability of the slag composition and the degree of fractional crystallisation it may have experienced, the calculation of a mass balance relationship cannot be undertaken rigorously. However, a possible model is shown in Figure 9. The geometric construction shown here (methodology after Young 2016a) shows a 'smelting mixture' (*sensu* Thomas & Young 1999a, 1999b) constructed from the intersection of a tie-line between an Al-rich particle in PQB2 and ceramic PQB1 with an enrichment vector extending from the FeO pole to the bulk slag of PQB2. The smelting mixture is this 19.8% furnace ceramic and 80.2% model ore. The enrichment factor 'E' is thus 1.46. This permits calculation that 28.8g of ceramic plus 117.0g of ore produced 100g of slag and 35.2g of iron. Since the model ore contains 91.5% FeO, then the yield of iron (the extractive efficiency) is just 33%. If the surviving slag assemblage contains approximately 30kg of slag from smelting, that would be equivalent to the production of 11kg of raw bloom; the yield of usable iron might around half that. Such a figure is, of course, purely illustrative and the assumptions involved in its calculation are all insecure.

One problem with the slag assemblage comprising such small fragments, is that it is not possible to know with any confidence how much slag was created in a single smelt. If the 812g piece from (4015) is a complete bowl, and if the overall assemblage is representative, then the bowl represents 20% of the bowl material on site, that would suggest it would have been part of a total slag production from a smelt of around 7.6kg- which would in turn suggest production of a raw bloom of approximately 2.7kg – which compares well with the approximately 2kg blooms produced by Crew in his experiments to replicate the Iron Age iron smelting undertaken at Crawcwellt West (Crew 1991a, 1991b, 1998). Crew estimated that about 5.5kg of slag derived from a single cycle of smelting/smithing at Crawcwellt. Such calculations would imply that the surviving slag assemblage at Penrhyn Quarry could be the waste from between just 5 and 7 smelts.

Although these arguments are only approximate, they suggest iron production in the early medieval at

Penrhyn Quarry was on a very similar basis to that at Crawcwellt in the Iron Age, with production of small (approximately 2kg) blooms. That the activity was conducted within a circular shelter, also mirrors the earlier situation at both Bryn y Castell and Crawcwellt. Although no slag was apparently tapped on those earlier sites, the furnaces did have prominent furnace arches and a degree of slag manipulation would have been possible – even if there is no evidence for it.

The limited evidence for smelting at the site runs counter to the variation between the various radiocarbon dates. It would seem likely that smelting was restricted to a very short time period and an association with the younger date obtained from the smelting waste pit would appear most likely.

The smithing

The evidence for smithing at Penrhyn Quarry was extremely limited. No good examples of smithing hearth cakes were recovered and no smithing microresidues were recovered from the waste pit.

Although the investigated area was small, no further accumulations of slag were suspected nearby, and thus a separate smithy seems unlikely.

It would therefore appear that a consolidation of the bloom was probably undertaken within the smelting furnace at the end of the smelt, but that the consolidated bloom was taken elsewhere for further working.

Figure captions

Figure 1. Bulk analyses (by XRF) of samples of materials from Penrhyn Quarry plotted within the ternary system $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-FeO}$ (fields after Schairer and Yagi 1952, fig 6).

Figure 2. Micro-analyses (by EDS) of textures with samples of materials from Penrhyn Quarry plotted within the ternary system $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-FeO}$ (fields after Schairer and Yagi 1952, fig 6).

Figure 3. BSEM image montage of sample PQB5, with interpretative sketch. The sketch shows inclusions of iron (yellow) and quartz (blue) within the slag (grey). The red dashed lines indicate the zones of marginal quenching as described in the text.

Figure 4. BSEM images of samples from Penrhyn Quarry.

- Slag in the core of the toolmark on the base of the slag bowl, showing a texture of mm-scale elongate fayalite overlying primary hercynite. PQB5, Site 2. Scalebar 1mm.
- Detail from centre of field of view of (a), showing euhedral hercynite overlain by a hercynite-fayalite cotectic (with rare example of a fayalite-wustite cotectic), followed by interstitial areas with fine olivine in glass. PQB5, Site 4. Scalebar 100 μm .
- Inclusion of spongy (vermicular) metallic iron, much of which has weathered leaving porosity. PQB5, Site 12. Scalebar 100 μm .
- Discrete iron oxide inclusion on the base of the toolmark, the outer-parts of which have a coarse, hammerscale-like, texture containing blebs of iron arsenide (white). PQB5, Site 18. Scalebar 100 μm .
- Wustite-dominated microstructure (upper left of sample as illustrated in Figure 5); the rounded patches of void-rich secondary iron minerals probably present the locations of former metallic iron inclusions. PQB6, Site 2. Scalebar 1mm.
- Area of complex texture, with former iron inclusions presented both by porous secondary minerals and by denser oxide zones with prills extending out in slag matrix; the slag shows primary euhedral hercynite overlain by fa fayalite-wustite cotectic, followed by interstitial areas with quench-textured olivine in glass. PQB6, Site 7. Scalebar 1mm.
- Surviving area of metallic iron, with altered margin, in contact with wustite-dominated slag. PQB7, Site 5. Scalebar 1mm.
- Highly altered iron (lower left), in contact with wustite-dominated slag, in turn overlain by a slag with elongate fayalite, fine grained interstitial areas bear delicate wustite dendrites. . PQB7, Site 9. Scalebar 1mm.

Figure 5. BSEM image montage of sample PQB6, with interpretative sketch. The sketch shows an inclusion of mineralised charcoal (dark grey), wustite-dominated

slag (yellow), complex dense zones largely after metallic iron (green) and more porous zones of secondary minerals, probably also after metallic iron (orange).

Figure 6. BSEM image montage of sample PQB7, with interpretative sketch. The sketch shows wustite-dominated slag (yellow), zones largely after metallic iron (grey), surviving metallic iron (white) and zones of mostly fayalitic slag (green).

Figure 7. graphs of olivine composition.

The percentage of (Fe+Mg) substitution by Mn and by Ca (i.e. in the octahedral sites) and that of Si by P (in the tetrahedral sites) are shown, each plotted against the percentage of Fe to (Fe+Mg) (i.e. the percentage of fayalite (Fa) in the fayalite to forsterite (Fo) in the solid solution).

Figure 8. Upper crust-normalised rare earth element (REE) profiles (normalisation after Taylor & McLennan 1981) for samples from Penrhyn Quarry.

Figure 9. Graphical model for the construction of a mass balance for smelting residues from Penrhyn Quarry. The brown dotted line indicates a tie-line between possible compositions for the ore and the furnace ceramic. The black arrow indicates the vector for enrichment of the other elements as iron is extracted from the smelting mixture (the composition of which lies at the intersection of the tie-line and the enrichment vector) by formation of a metallic bloom. For details see text.

The green arrow indicates the direction of fractionation induced by crystallisation of hercynite of the observed composition (open circle) to produce the two different compositions of slag within PQB6. A similar mechanism is interpreted to have produced the strongly aluminous samples PQB2 and PQB4, compared to PQB3 and PQB5.

Figure 10. Graphical model for the development of the smithing residues from Penrhyn Quarry. For details see text.

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Table 1: summary catalogue of material. All weights in g. Assm = assemblage of fine debris/particles. SHC = smithing hearth cake

C	F	label	item wt	item no	notes
TP32	79		50	7	rough slags
			20	3	smooth surface flow slags
			22	2	rough surfaced flow slags
4006	1	slag	12	2	smooth surfaced flow slag
4006	2	slag	23	3	smooth surface flow slag
4006	6	slag	82	4	smooth surfaced flow slag
			6	2	rough, porous slag
			6	1	stone/concretion
4006	11	slag	41	1	smooth surfaced flow slag
4006	14	slag	68	1	granular rough slag lump
			11	2	granular slags containing flow lobes
4006	47	slag	86	5	smooth surfaced flow slags
			112	1	block of brown weathered slag with flow lobes emerging from front; base also shows lobe contacts; with inclined base; base passes into gravelly material on one edge - approaching burr?
			25	3	rough slags
			2	assm	dust and debris
4007	3	slag	17	2	smooth surfaced flow slag
			8	1	rough, porous slag
4007	4	slag	60	2	smooth flow slag
			9	1	dense smooth charcoal mould bearing slag
			11	1	low density vesicular slag, possibly from a rod
4007	5	slag	9	assm	dust and debris
			41	1	foot of wall dense slag with hint of non-wetted flow lobes on one side
4007	7	slag	130	6	smooth surfaced flow slag
			70	1	rough, porous slag
4007	8	slag	29	6	low density rough slag
			18	5	smooth surfaced flow slag
			3	assm	dust and debris
4007	9	slag	34	5	smooth surfaced flow slag

4007	10	lag	10	1	rough flow slag
			6	1	porous, rough slag
4007	12	slag	377	1	indurated and vitrified sandy gravel with some slag adhering, presumably from lower part of blowing wall, may be multilayer
			120	1	dense slag block, probably foot of wall FB
4007	13	slag	55	1	charcoal mould rich slag, in the form (probably) of a channel, 40mm wide by 25mm deep
			15	1	smooth surfaced flow slag
4007	15	slag	29	1	smooth surfaced flow slag
4007	16	slag	58	2	granular slag containing flow slag lobes
4007	17	slag	181	5	smooth surfaced flow slag, one large piece 124g is possibly reddened and like tapslag cake
			19	10	low density, porous, rough slags
			7	assm	dust and debris
4007	18	slag	14	1	smooth surfaced flow slag
4007	19	slag	26	1	smooth surfaced flow slag (probably reddened)
4007	20	slag	8	1	rough slag now crushed
4007	21	slag	56	6	rough slags
			15	2	smooth surfaced flow slags
4007	22	slag	7	1	porous, rough slag
4007	23	slag	29	1	smooth surfaced flow slag with occasional fuel dimples on upper surface
4007	24	slag	88	1	smooth surfaced flow slag, in narrow V-shaped runner base
4007	27	slag	24	3	smooth surfaced flow slag
			17	1	rough slag
4007	28	slag	27	2	rough slags
4007	25	slag	46	1	smooth surfaced flow slag
4007	26	slag	41	3	smooth surfaced flow slag
			30	2	rough surfaced flow slag
4007	29	slag	484	1	dense slag block, appear to be foot of wall, wall finely dimpled, lower slag has large rounded vesicles,
4007	30	slag	18	1	slag/concretion attached to stone

			4	1	rough slag
4007	31	slag	27	2	dimpled slag fragments
4007	32	slag	26	1	dimpled/granular slag lump
4007	33	slag	7	1	dimpled slag lump
			15	1	smooth surfaced flow slag
			30	2	rough slag lumps containing flow lobes
4007	34	slag	91	1	granular slag piece of irregular form
4007	35	slag	23	3	rough-surfaced flow slag
			13	2	rough slag
4007	36	slag	22	1	smooth surfaced flow slag
			30	1	rotten/burnt stone
4007	37	slag	65	1	dimpled/granular slag lump (moderately fresh)
4007	38	slag	48	1	pad of homogeneous slag in contact with more granular material (below?)
			12	4	rough slag debris
			20	1	rough-surfaced flow slag
			8	1	stone
			6	1	low density pale slag with large vesicles
4007	39	slag	40	2	dimpled rough slag lumps
			16	2	smooth surfaced flow slag
			2	1	rough slag or concretion
4007	40	slag	16	2	smooth surfaced flow slags
4007	41	slag	16	1	rough-surfaced flow slag
			29	1	dimpled slag lump
			74	1	twisted sheet of burr attachment (needs cleaning)
4007	42	slag	222	13	smooth surfaced flow slag
			200	14	rough/dimpled slags
4007	44	slag	236	7	smooth surfaced flow slags (fresh)
			95	8	rough slags
			3	assm	dust and debris
4007	45	slag	6	1	smooth surfaced flow slag
			24	4	rough slag
			10	3	slag balls or small concretions

4007	46	slag	25	1	dimpled/granular slag lump (moderately fresh)
			7	1	smooth surfaced flow slag
4007	48	slag	4	1	poorly prilly rough slag
4007	49	slag	60	5	rough slags, some dense
			34	3	smooth surfaced flow slags
			30	2	rough flow slags, lobes embedded in other material
4007	50	slag	176	10	smooth surfaced flow slags
			122	11	rough slags, some in bulbous lobes
			3	assm	dust and debris
4007	51	slag	160	2	pieces with vitrified indurated wall (burr) abutted by rusty slags
			130	5	smooth surfaced flow slags
			56	4	rough slags
			126	1	block that appears to have two merged slag rods/tool marks
			27	2	stones
			23	assm	dust and debris
4007	53	slag	5	1	dimpled surface, probably from smooth surfaced flow slag
4007	54	slag	139	10	rough flow slags
			29	3	smooth flow slags
			51	10	rough slags
			7	assm	dust and debris
4007	55	slag	19	3	indeterminate slag fragments
			3	2	poor flow slags
4007	56	slag	400	15	dimpled slag nubs
			145	21	other rough slags
			228	23	smooth surfaced flow slags
			11	1	burr-like fragment
			23	assm	dust and debris
4007	57	slag	68	11	smooth surfaced flow slags
			21	4	poor flow lobed material
			180	5	dimpled/granular rough slag lumps
			28	1	vitrified oxidised fired wall
			7	assm	dust and debris
4007	58	slag	568	19	rough slags, includes many pieces with dimpled surfaces
			455	21	smooth-surfaced flow slags, some slightly reddened?

			17	assm	dust and debris
4007	59	slag	160	5	dimpled slag lumps
			139	3	dimpled material passing up into flow-lobed top
			264	11	smooth surfaced flow slags
			23	2	rough flow slags
			47	1	piece of basal crust to 15mm with tubular vesicles
			36	9	other rough slags
			5	assm	dust and debris
4007	60	slag	326	34	rough slags, includes many pieces with dimpled surfaces
			220	17	flow slags
			18	assm	dust and debris
4007	61		210	19	smooth surfaced flow slag
			252	11	rough/granular slags
			140	10	rough surfaced flow slags and flow slags with fuel mould contacts
4007	62		267	1	side of deep cake/bowl, base is large tool mark, c25mm across, 20mm deep, overlain by 30mm dense slag, top looks a little like unroofed vesicles
			40	1	fragment of c25mm rod, low density
			392	8	dense flow lag with smooth surfaces
			200	8	rough slag with internal prills or other evidence for flowage
			138	3	rough/granular slag lumps
4007	63		141	5	rough slags
			122	3	rough surfaced flow slags
			170	4	smooth surfaced flow slags
4007	64		162	6	rough surfaced flow slags
			58	5	smooth surfaced flow slags
			122	1	vittrified oxidised lining
			232	1	lip of slag bowl with indurated, almost burr-like contact; crust 25mm thick
			30	1	rough slag lump
			45	1	finger-like dense slag flow lobe; smooth below partial rough coating - could be tip of runner
			51	1	dense slag rod; 22mm wide by 15 deep
			75	1	elongate dimpled lump, possibly including rod/tool mark
4007	65		21	3	smooth surfaced flow slag
			79	1	curved piece, 90x35x30mm, appears to be slagged ceramic or stone; one face less vittrified, object has internal radius c80mm and is 25mm wide
4007	66		4	1	vittrified lining
			16	2	smooth surfaced flow slag
			29	3	rough surfaced flow slag
			16	3	rough slag

4007	67	23	1	slag spike; dense flow slag in single prill coming to a point, possibly reddened
		18	1	complexly vitrified lining fragment
		100	7	smooth surfaced flow slag
		46	2	dimpled/rough/granular slag
		66	1	dimpled low-density slag; probably from upper margin of plano-convex cake
4007	68	73	1	extremely dense slag spike, formed of prilly/dimpled slag - probably tip of rod insertion (fresh)
		188	5	smooth surfaced flow slags
		16	2	rough surfaced flow slags
		87	5	rough/granular slags
		47	1	rough/granular slag in lobate form - coalesced tool marks?
4007	69	182	1	fragment of slag bowl with large fuel moulds; dimpled curving lower contact
		48	1	flow slag prill encased in rough slag
		90	1	smooth surfaced flow slag
4007	70	134	4	rough slags
		11	1	rough slag with morphology suggesting it is the base of tool mark or rod
		507	11	smooth surfaced flow slags (fresh) (largest piece 185g)
		22	3	rough slags with signs of flow
4007	71	293	2	large pieces of low-density, nodular, furnace bottom material
		87	1	elongate piece with prill of smooth surfaces, flow slag overlying two parallel dimpled rods
		100	1	part of a dense plano-convex cake; internal texture similar to more complete example from (4015); lots of moulds of fine charcoal dust,
		143	1	(broken in 2) slag runner, main fill 50x20mm, with up to 15mm of rough slag on top
4007	72	275	14	smooth surfaced flow slags (fresh)
		42	1	slagged vitrified oxidised fired wall
		111	1	110mm long slag rod, rather rectangular section, 25-35mm wide, 17-30mm deep
		65	1	dense flow slag with dimpled surface, possibly a rod fragment
		34	1	rough surfaced slag, possibly tip of rod
		40	1	dimpled slag lump
		32	1	rough slags with flow lobes
4007	73	100	5	rough surfaced flow slag
		200	8	smooth surfaced flow slag
		19	2	rough slag
		13	1	vitrified oxidised lining
4007	74	47	2	rough/dimpled/granular slags
		42	2	dimpled, prilly rough slag with fuel moulds
		166	8	smooth surfaced flow slag (fresh)
4007	75	309	25	smooth surface flow slags
		30	1	slag peel from oxidised fire wall
		60	3	dense flow slags with rough surfaces

			80	9	rough slags with signs of flowage
			152	11	rough/dimpled/granular slags
			75	2	fragments of slag rod, 45mm and 30mm wide
4007	76	stone	10	1	burnt stone, well glazed in wood ash glaze
4007	77		81	9	flow slags with rough surfaces or fuel contacts
			16	3	smooth surfaced flow slag
			61	3	rough granular slag pieces
4007	78		49	2	rough slags
			6	1	smooth surfaced flow slags
			3	2	rough slags with signs of flow
4007	81		645	1	partly exploded plano-convex block; iron bearing furnace slag or SHC; 120x70x70mm; top very slightly dished, rusty; base shows dimpled or micropirily slags
			100	1	possible margin of plano-convex slag with raised lip; not even impossibly part of object above; dimpled slag base, rough on top
			56	1	rounded low-density rough slag lump
4007	82		300	3	smooth surfaced flow slag
			343	1	dimpled slag sheet - probably includes multiple rod like tool fills
			148	1	irregular lump of dense dark slag, dimpled base fuel impressions on top
			6	2	small fragments probably broken from above pieces
4007	83		286	8	dimpled rough slags (fresh)
			105	3	rough slags with indications of flow
			340	13	smooth surfaced flow slags (fresh)
4007	84		67	1	large lobed smooth surfaced flow slag (fresh)
4007	86		49	3	smooth surfaced flow slag (fresh)
4015	87		18	2	rough/granular slags
4015	88		65	1	large lobe of smooth surfaced flow slag (fresh)
4015	89		55	4	rough slags with some flow lobes
			10	1	rough/granular slags
4015	90		173	17	rough/granular slags
			168	4	smooth surfaced flow slags
4015	91		139	23	rough/granular slags
			195	9	smooth surfaced flow slags
			69	7	rough slags with some lobing
4015	92		58	7	smooth surfaced flow slags

			22	5	rough slags with some lobing
			132	8	rough/granular slags
4015	94		44	7	poor rough flow lobes and rough slag containing flow lobes
			8	1	possible small rough rod fragment
			43	1	straight smooth flow slag or rod termination
			66	2	smooth surfaced flow slag
			84	7	rough and dimpled slag
4015	95		139	13	smooth surfaced flow slag
			26	1	smooth surfaced flow slag on dimpled runner, 35mm wide and 15mm deep
			94	9	rough slags with flow lobes and other indications of flow
			118	10	rough/granular slags
4015	96		124	9	smooth surfaced flow slag
			75	6	rough/granular slags
			23	3	rough/granular slags containing poor flow lobes
			10	2	lining with attached slag/concretion
4015	97		812	1	plano convex cake in three fragments; probably from foot of wall rather than bottom of pit; where weathered, shows abundance of very fine charcoal debris, base dimpled and with fine charcoal debris, top is fracture not original, probably furnace slag not SHC
4015	98	slag	333	18	smooth surfaced flow slag
			46	1	smooth surface flow slag lying on a dimpled slag rod
			41	1	rough surfaced slag rod overlain by small lobes of smooth slag
			24	1	rough slag with an arcuate core - could be a rod but uncertain
			146	12	rough and dimpled slags
			34	2	dense flow slag-like slags but lacking any external surface, so could be puddles
			9	1	hearth lining?
			5	1	rough surfaced slag prill
4015	99	slag	480	16	smooth-surface flow slags
			147	10	rough slags
			38	1	possible hearth lining
			32	1	probable slag rod, dimpled base, flowed top, 20mm diameter maximum
			53	1	dense slag fragment, possibly a worn rod fragment
			16	3	rough slags with some poor flow lobes
4015	100		43	5	smooth surfaced flow slags
			40	13	rough/granular slags
			67	8	rough surfaced flow slags and rough slags with some flow
4015	101		84	4	smooth surfaced flow slag
			6	1	oxidised fired vitrified lining
			83	4	rough/granular slag
			19	3	rough slag containing flow oboes

			10	1	small fragment of dimpled dense crust - probably from a dense flow slag
4015	102		287	20	smooth surfaced flow slag
			94	19	rough/granular slag
			23	5	rough slag containing flow lobes
			33	1	smooth surfaced flow slag overlies rough tube - just possibly a rod fragment
			2	1	rough flow lobe or rod
4015	103		29	1	rough/granular slag
			182	8	rough surfaced flow slags
			189	12	smooth surfaced flow slags
4015	104	slag	63	5	dense flow slags
			72	1	granular slag lump, perhaps from base of bowl
			19	5	poor flow slags in rough matrix
4015	105		434	28	smooth surfaced flow slag
			58	5	rough surfaced flow slags
			157	11	rough/granular slags
4015	106	slag	300	1	part of channelled flow slag cake - resembles proper tapslag but only slight hint of reddening
			312	2	rough slag lumps with possible rod-like components
			46	1	low density, charcoal mould-rich, tubular lump
			100	1	slightly dimpled almost plano-convex lump, very porous
4015	107	slag	359	21	smooth surfaced flow slags
			121	3	dense slags - unclear if from flow slags or a puddle
			38	3	rough slags with hint of flowage
			254	6	large pieces of rough slags
4015	108	clay	9	1	vitrified oxidised lining
4015	109	slag	133	2	large lobed dense flow slags, smooth surfaced
4015	110	slag	217	6	lumps of irregular rough/granular slags
			178	4	very dense but rough surfaced flow slags
			66	4	smooth surface flow slags
			23	1	possible very narrow slag rod
			11	1	dimpled slag piece, possibly a flow slag
4015	111	slag	264	5	dense slag that has flowed and is smooth-surfaced. Not classic flow slags though
			72	7	poorly developed and rough surfaced flow slags
			126	6	dimpled, variably dense, variably charcoal bearing, irregular rough slag pieces
4015	112	slag	360	8	dimpled, variably dense, variably charcoal bearing, irregular rough slag pieces
			165	4	dense slag, all with some indications of flow

			35	1	sheet of rough slag, possibly showing tool mark, or rounded foot of wall
4015	124 <6>	magnetic	9	assm	mostly stone
4015	125 <6>	slag	40	16	rough slags
			8	2	rough surfaced flow slag
			1	1	rusty concretion
4015	126 <8>	magnetic	30	assm	mostly slag, commonly rusty
4015	127 <8>	slag	6	4	rough slag
4015	128 <10>	magnetic f	46	assm	mixture of stone and slag debris
4015	129 <10>	slag	44	19	rough slag debris
			8	1	stone
4015	130 <12>	magnetic fines	319	assm	mixture of stone and slag debris
4015	131 <12>	slag	100	15	smooth surfaced flow slag
			211	78	amorphous slag fragments
			8	assm	dust and debris
4015	132 <14>	slag	146	11	rough surfaced flow slag
			62	16	smooth surfaced flow slag
			86	33	rough slags
			2	2	stones
			1	assm	dust and debris
4015	133 <14>	fines - magnetic	211	assm	mostly slag
4015	138 <17>	magnetic fines	293	assm	mixture of stone and slag debris
4015	139 <17>	slag	43	7	smooth-surfaced flow slag
			19	8	rough flow slags and dimpled material
			8	4	rough slags
			22	9	concretionary material
			<1	2	charcoal
4016	80		53	4	rough slag with flow lobes
			25	1	broken in 2, rough slag rod low density, 20x8x75mm
			54	4	smooth surfaced flow slag
4016	118 <2>	slag	28	58	rough slags
			21	19	flow slags, including spheroids
			3	assm	dust and debris

4016	119 <2>	slag	465	46	smooth surface flow slag
			470	114	rough slags
			41	5	iron-rich concretions
			3	1	lining?
			18	3	concretions
			1	1	stone
			30	assm	dust and debris
4016	120 <2>	furnace lining	8	1	lining or stone?
			19	1	dimpled slag with iron
			12	1	lining, probably from burr region with slag
4016	111 <2>	magnetic	1839	assm	dark, rusty fine material - much concretionary but some may be sinter
4018	123 <4>	magnetic	6	assm	mostly stone
4023	122 <3>	slag	1	2	charcoal bearing rusty concretions
4040	113	slag	475	24	smooth-surfaced flow slag
			195	2	plano-convex lump, flow slag on top, prilly slag with charcoal below
			114	2	basal slag with possible tool marks
			168	18	low density slags - rusty FB fragments
			56	assm	dust and bits
4040	115		430	1	large FB fragment
			295	14	rough slag lumps, mostly probably FB fragments
			333	11	smooth-surfaced flow slag
			71	assm	dust and bits
4040	134 <5>	magnetic	1146	assm	fine material, mostly fine slag debris?
4040	135	slag	800	84	smooth-surfaced flow slag
			283	34	rough flowed slag
			211	2	furnace bottom fragments with attached wall
			43	1	furnace bottom fragment with charcoal
			152	4	stones
			14	2	slag with oxidised lining attached
			820	170	rough, massive and porous slags
			87	assm	dust and bits
4040	135 <15>	slag	700	66	smooth-surfaced flow slag
			81	15	rough flowed slags
			869	247	rough slag lumps
			40	assm	dust and bits

4040	135	slag	1092	12	poorly preserved FB fragments, some large
			350	2	slag lumps with a component of coarse, rough flow lobes
			149	2	rounded concretionary lumps
			20	1	stone or vitrified sand
			5	2	slag prills
			46	1	porous slag rod, 27mm diameter, 70mm long
			100	1	dimpled slag sheet with possible upper impression of slag rod
			56	assm	dust and debris
4040	136 <15>	furnace	6	3	thin sheets of vitrified oxidised lining
4041	116	slag blocking channel	440	13	low density prilly slag mass - presumably FB
			160	1	rusty low density slag lump, not obviously prilly
			39	4	smooth-surfaced flow slag
			78	assm	dust and debris
4042	114	floor of [3204]	700	15	ceramic, one large piece shows vitrification over flat face including possible tuyère, better seen to rear
			294	assm	dust and debris

Table 2: facies of archaeometallurgical residue by context. Weights in g.

C	flow slag				rod		rough/granular				bowl		?bowl/SHC		furnace ceramic		total	
	smooth		rough		wt	no	with lobes		without lobes		wt	no	wt	no	wt	no	wt	no
	wt	no	wt	no			wt	no	wt	no								
TP32	20	3	22	2					50	7							92	12
4006	244	15					123	3	99	6							466	24
4007	6464	319	855	57	1300	16	882	49	4845	283	2554	17	693	2	336	8	17595	751
4015	4061	228	999	59	272	9	598	59	3281	328	847	2			72	6	10130	691
4016	540	69			25	1	53	4	517	173	12	1			11	2	1158	250
4040	2313	187	364	49	260	4	713	22	3119	444	641	3			20	5	7430	714
4041	39	4							600	14							639	18
4042															700	15	700	15
total	13681	825	2240	167	1857	30	2369	137	12511	1255	4054	23	693	2	1139	36	38544	2475

Table 3: proportion of residue facies (by weight) by context.

Context	Tapped	Rod	Internal/ SHC	Lining	Total wt (g)	Context notes
TP32	45.7%	0.0%	54.3%	0.0%	92	
4006	52.4%	0.0%	47.6%	0.0%	346	modern silt run off
4007	40.8%	7.3%	50.1%	1.9%	18049	peat: finds believed to come from (4015)
4015	50.3%	2.7%	47.0%	0.7%	10130	occupation deposit over Pit 4017
4016	47.1%	2.2%	50.7%	1.0%	1158	upper fill Pit 4017 and channel to furnace
4040	36.1%	3.5%	60.4%	0.3%	7430	lower fill Pit 4017
4041	6.1%	0.0%	93.9%	0.0%	639	blocking in channel
4042	0.0%	0.0%	0.0%	100.0%	700	concreted material on floor of furnace [3042]
<i>total</i>	<i>41.3%</i>	<i>4.8%</i>	<i>50.9%</i>	<i>3.0%</i>	<i>38544</i>	

Table 4: list of analysed samples

Sample	Source		Elemental analysis	SEM
PQB1	121g piece (4007) <64>	relatively unaltered material spalled from back of vitrified face	Y	
PQB2	185g piece (4007) <70>	flow slag/tapslag	Y	
PQB3	343g piece (4007) <82>	rough slag in sheet formed by coalesced rods	Y	
PQB4	73g piece (4007) <70>	charcoal rich rough slag, rusty	Y	
PQB5	267g piece (4007) <62>	base of bowl with probable rod/tool mark	Y	Y
PQB6	645g piece (4007) <81>	slag	Y	Y
PQB7	645g piece (4007) <81>	piece with iron		Y

Table 5 major element analyses by XRF expressed as wt% for residues from TSSF. Raw measured values, except for calculated columns for FeO (as an alternative to Fe_2O_3). < = below detection.

Sample	source	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	SO ₃	LOI	total
PQB 1	Wall, part of 121g piece <64>	70.50	13.52	8.40	7.56	0.05	1.01	0.09	1.79	3.01	0.45	0.05	<0.15	3.25	102.12
PQB 2	Flow slag/tapslag, 185g piece <70>	21.16	12.25	67.47	60.71	7.04	<0.2	<0.1	0.43	0.65	0.40	0.64	0.22	-4.34	105.70
PQB 3	Coalesced rods, 343g piece <82>	18.74	6.81	67.50	60.74	14.18	0.79	0.26	0.17	0.93	0.24	0.73	0.57	-3.00	107.35
PQB 4	Charcoal-rich rough slag, 73g piece <70>	10.27	11.10	74.16	66.73	3.62	0.50	0.12	<0.1	<0.05	0.22	0.62	0.35	4.62	105.24
PQB 5	Basal toolmark/rod from bowl, 267g piece <62>	26.77	9.72	66.53	59.86	2.47	0.78	<0.1	<0.1	1.08	0.35	0.77	0.33	-4.11	104.36
PQB 6	Iron-bearing slag bowl, 645g piece <81>	10.63	3.52	87.77	78.98	0.42	<0.2	<0.1	1.47	0.58	0.18	0.08	0.32	-0.06	104.59

Table 6a: trace element analyses by ICP-MS. Raw numerical values in ppm. < = below detection.

Sample	Be	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Mo	Sn	Cs	Ba
PQB 1	1.47	18.7	6.4	3.3	<7.34	7.6	63.1	15.68	84.38	36.8	27.70	195.2	11.14	<1.05	<2.81	3.10	348.9
PQB 2	0.92	73.6	41.1	5.4	<7.34	3.5	<6.08	4.90	9.48	17.6	18.58	76.8	4.09	<1.05	<2.81	<0.33	116.7
PQB 3	0.77	54.8	20.7	7.5	<7.34	<3.09	<6.08	3.79	9.83	93.9	9.07	46.6	2.83	<1.05	<2.81	<0.33	309.0
PQB 4	0.50	106.2	110.9	24.4	<7.34	<3.09	<6.08	6.77	2.50	<2.18	11.36	52.9	2.96	2.05	<2.81	<0.33	18.3
PQB 5	1.31	53.9	21.5	2.8	<7.34	<3.09	<6.08	6.04	22.29	52.5	17.57	77.2	4.12	<1.05	<2.81	0.81	202.2
PQB 6	<0.26	16.7	9.0	64.7	<7.34	<3.09	163.9	2.95	8.64	25.5	2.93	22.0	1.94	5.00	<2.81	<0.33	70.3

Table 6b: trace element analyses by ICP-MS (part 2). Raw numerical values in ppm. < = below detection.

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Pb	Th	U
PQB 1	46.86	97.24	11.14	40.52	7.13	1.33	6.03	0.89	5.25	1.03	2.95	0.41	2.82	0.42	5.78	0.78	3.39	13.18	12.16	1.42
PQB 2	11.05	53.32	3.37	14.36	3.32	0.69	3.69	0.60	3.72	0.78	2.33	0.35	2.22	0.35	2.27	<0.28	<2.39	2.46	13.12	1.51
PQB 3	8.02	30.77	2.31	9.25	2.01	0.43	2.09	0.32	1.93	0.38	1.12	0.17	0.97	0.16	1.33	<0.28	<2.39	<1.18	5.68	0.89
PQB 4	6.23	33.66	2.23	9.84	2.52	0.54	2.58	0.42	2.64	0.52	1.61	0.25	1.58	0.24	1.61	<0.28	<2.39	2.40	10.05	1.45
PQB 5	17.63	62.04	4.92	19.67	4.41	0.93	4.41	0.70	3.90	0.77	2.16	0.31	1.90	0.29	2.37	0.33	<2.39	<1.18	11.57	1.70
PQB 6	<5.05	6.70	0.83	3.00	0.60	<0.19	<0.58	<0.22	<0.57	<0.26	<0.41	<0.13	0.38	<0.13	0.71	<0.28	<2.39	<1.18	1.53	<0.28

Table 7. Area analysis by EDS. Cl, Cr, V and Cu were also sought, but were not above detection in any of these analyses. < = below detection

Sample	Site	description	#	Na ₂ O	MOg	Al ₂ O ₃	SiO ₂	P ₂ O ₅	SO ₃	K ₂ O	CaO	TiO ₂	MnO	FeO	As ₂ O ₃	Total
PQB5	2	Typical bulk slag	#626	1.48	0.44	11.44	28.49	1.12	0.24	1.90	1.24	0.38	2.29	52.88	<	101.92
PQB5	4	Bulk slag (small area only)	#627	1.98	0.25	12.54	29.22	1.26	0.28	2.24	1.63	0.46	2.07	51.24	<	103.18
PQB5	5	Typical bulk slag	#666	1.29	0.49	11.34	28.21	0.97	0.19	1.60	1.13	0.35	2.39	53.87	<	101.82
PQB5	8	Typical bulk slightly quenched slag	#701	0.15	0.42	10.60	21.03	1.20	<	0.15	0.52	0.33	2.15	55.26	<	91.81
PQB5	8	Bulk slag, quenched internal	#702	<	0.38	9.53	20.15	0.86	0.13	<	0.27	0.30	1.90	56.96	<	90.48
PQB5	8	Bulk slag, quenched, margin on base	#703	<	0.35	10.59	17.90	0.73	0.14	<	0.28	0.36	1.71	55.51	<	87.58
PQB5	11	Typical bulk slag, base above slightly quenched slag	#721	<	0.39	9.52	21.55	0.96	<	<	0.40	0.36	2.19	58.53	<	93.90
PQB5	11	Typical bulk slightly quenched slag	#722	<	0.38	10.21	19.42	0.60	0.18	<	0.25	0.30	1.86	57.84	<	91.03
PQB5	11	Typical bulk slightly quenched slag	#723	<	0.44	9.31	20.11	0.53	<	<	0.31	0.37	1.90	58.20	<	91.16
PQB5	11	Typical bulk slightly quenched slag	#724	v	0.35	10.61	19.72	0.68	<	<	0.34	0.34	1.86	55.85	<	89.77
PQB6	2	Typical bulk slag (upper)	#516	0.33	0.61	4.47	8.68	0.31	<	0.28	0.58	0.14	2.23	81.98	<	99.60
PQB6	2	Typical bulk slag (upper)	#517	0.55	0.51	4.91	7.96	0.37	0.19	0.43	0.79	0.11	2.07	80.95	<	98.85
PQB6	2	Typical bulk slag (upper)	#518	0.50	0.57	4.74	7.37	0.41	0.18	0.35	0.70	0.13	2.08	82.62	<	99.67
PQB6	4	Bulk slag rim on charcoal particle, fayalite-rich, near iron	#556	0.29	0.77	11.12	16.42	0.45	0.61	0.36	0.83	0.09	2.18	52.66	<	85.80
PQB6	5	Wustite-rich slag	#557	0.24	0.28	5.41	3.21	0.18	0.38	0.23	0.42	0.11	1.29	73.00	<	84.76
PQB6	5	Bulk slag rim on charcoal particle, fayalite-rich, near iron	#558	0.52	0.61	10.44	14.97	0.33	0.63	0.34	0.79	0.12	1.94	53.86	<	84.56
PQB6	7	Typical bulk slag, fayalite-rich, near iron	#568	<	0.81	7.02	20.62	0.63	0.28	<	0.56	0.12	2.34	61.27	<	93.65
PQB7	5	Wustite-rich slag (small area) adjacent to iron	#371	0.29	0.45	3.41	4.77	0.15	0.26	0.19	0.35	0.10	0.82	83.54	<	94.32
PQB7	5	Wustite-rich slag (small area) adjacent to iron	#378	0.20	0.49	3.25	2.86	<	<	0.10	0.19	0.10	0.76	88.15	<	96.10
PQB7	5	Wustite-rich slag (small area) adjacent to iron	#379	0.25	0.29	3.63	4.70	0.14	0.42	0.17	0.32	0.11	0.41	77.44	<	87.88
PQB7	6	Wustite-bearing fayalitic slag	#380	1.33	0.69	8.38	21.61	0.21	<	1.44	0.93	0.24	0.42	67.42	<	102.66
PQB7	10	Wustite-rich slag (small area)	#464	0.73	0.79	4.89	12.01	0.14	<	0.74	0.47	0.17	0.37	81.18	<	101.50
PQB7	11	Wustite-rich slag	#465	0.22	0.64	2.84	4.85	<	<	0.26	0.17	0.13	0.38	88.74	<	98.22
PQB7	12	Wustite-rich slag	#466	0.34	0.51	3.28	6.18	0.15	<	0.26	0.33	0.13	0.85	86.36	<	98.39
PQB7	13	Fayalitic slag inclusion, inside iron	#468	1.43	0.60	10.00	30.32	0.25	0.13	1.76	1.21	0.18	0.49	55.22	<	101.58
PQB7	13	Fayalitic slag inclusion, inside iron	#469	1.12	0.80	8.27	27.62	0.20	<	1.36	0.87	0.21	0.50	57.23	<	98.19
PQB5	11	Bulk spongy oxide particle	#720	<	<	4.95	3.53	0.24	<	0.06	0.12	0	0.54	73.28	<	82.73
PQB5	12	Bulk spongy oxide particle (small area)	#726	<	<	6.28	6.22	0.56	0.14	<	0.13	0.19	0.87	69.56	1.32	85.26
PQB5	13	Bulk spongy oxide particle (small area)	#733	<	<	6.50	5.12	0.55	0.16	<	0.18	0.24	0.78	72.29	0.76	86.57
PQB5	14	Bulk porous oxide particle	#746	<	<	6.44	0.71	0.16	<	<	0.07	0	0.24	82.48	<	90.10
PQB5	14	Bulk porous oxide particle	#747	<	<	3.02	0.94	0.13	<	<	<	<	0.15	77.95	<	82.19
PQB5	17	Bulk dense oxide texture (small area)	#767	<	<	1.20	<	<	<	<	<	<	<	94.62	<	95.83
PQB5	17	Bulk dense oxide texture (small area)	#768	<	<	1.22	0.14	<	<	<	<	<	0.18	93.92	<	95.45
PQB5	17	Bulk mixed porous/dense oxide particle	#769	<	<	3.70	1.84	<	<	<	0.10	<	0.17	80.70	<	85.62

Figure 1

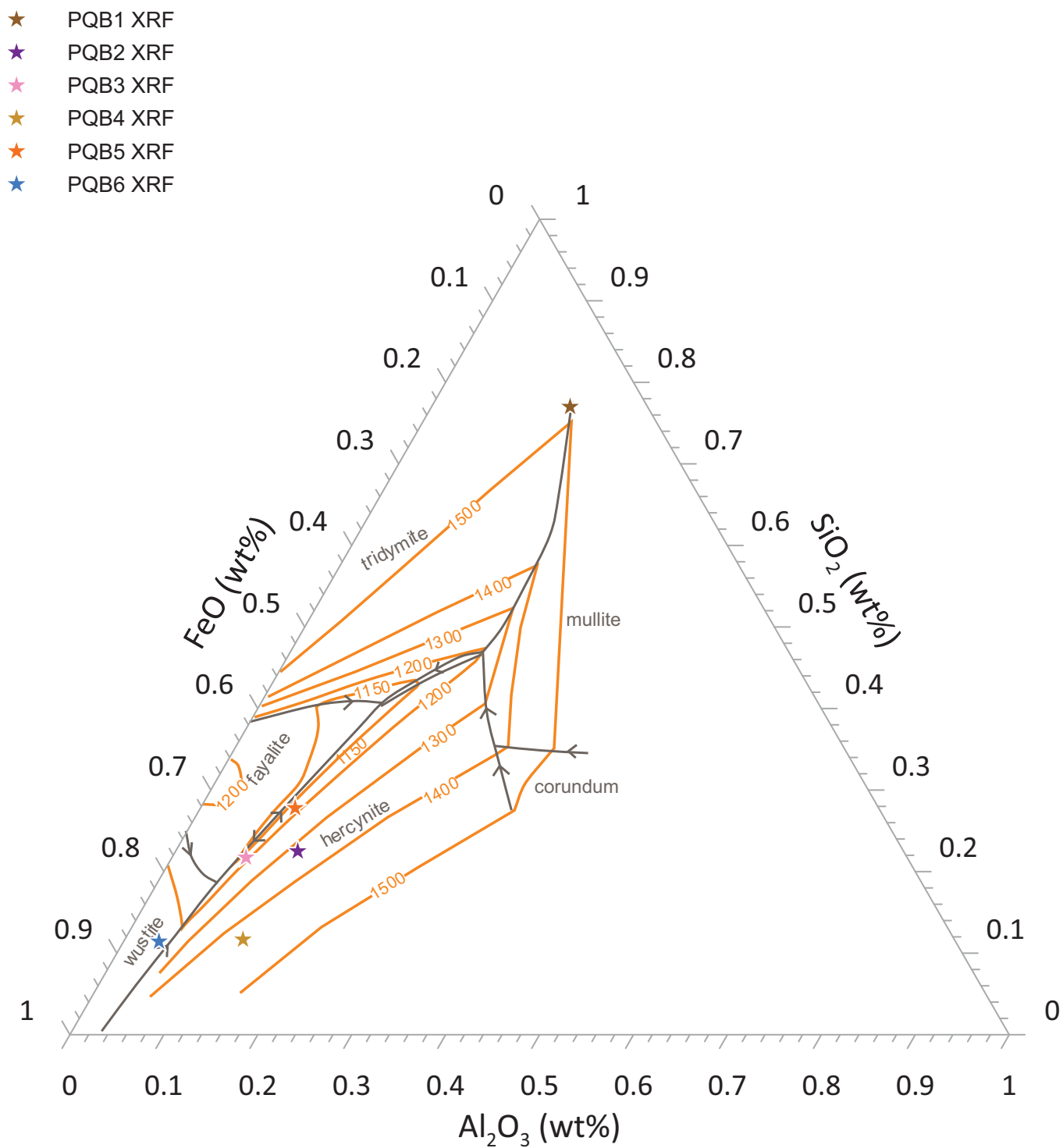


Figure 2

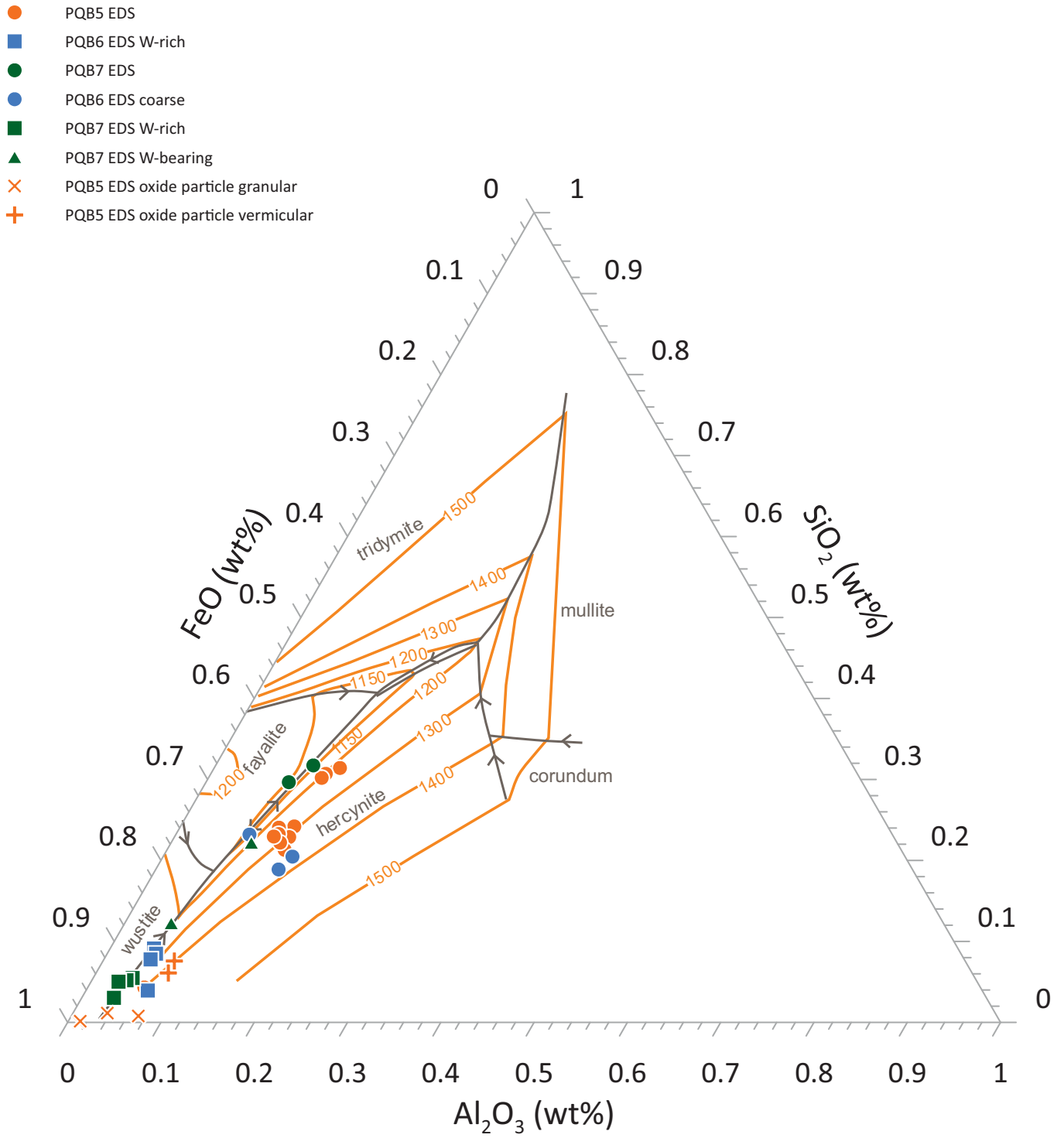


Figure 3

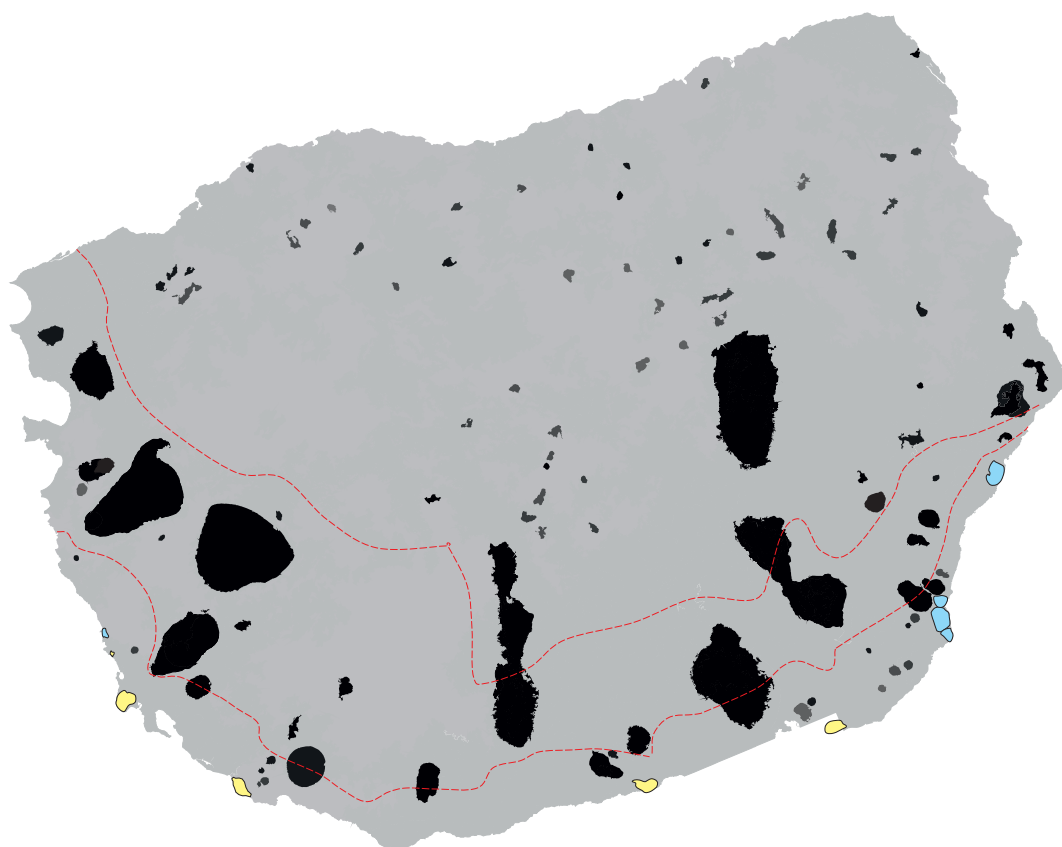
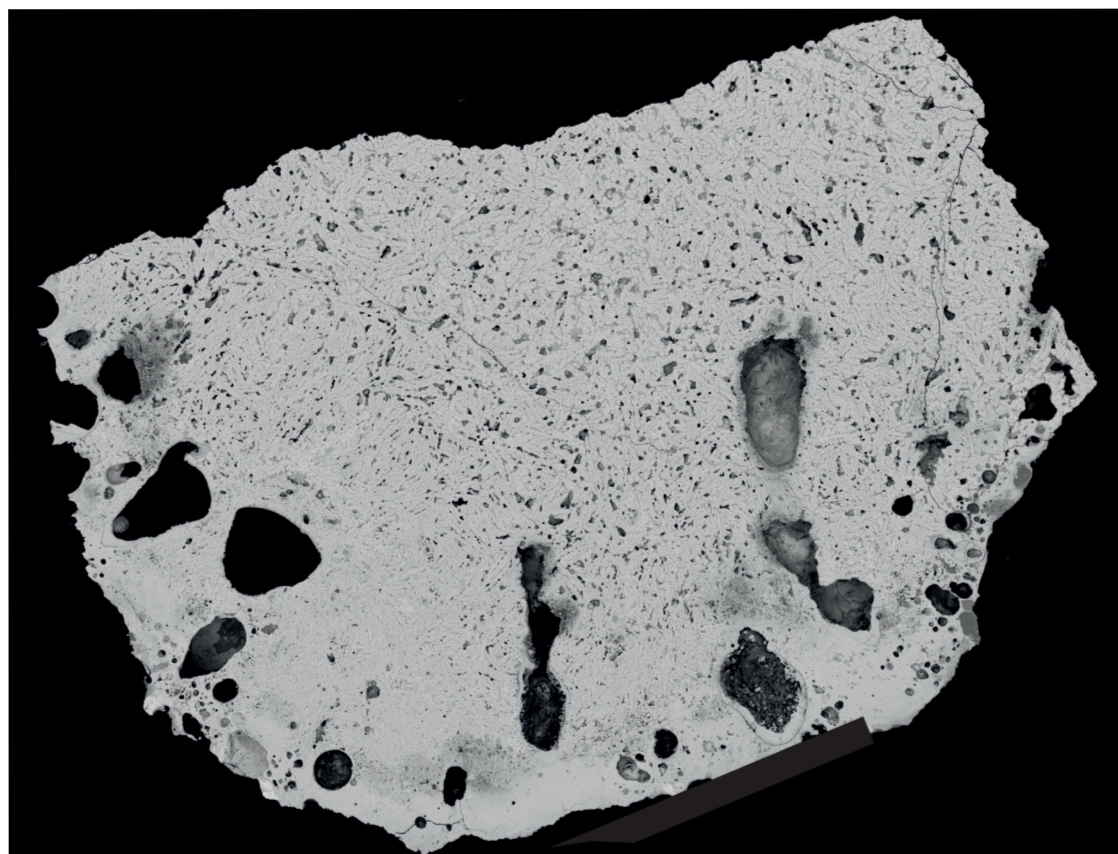


Figure 4

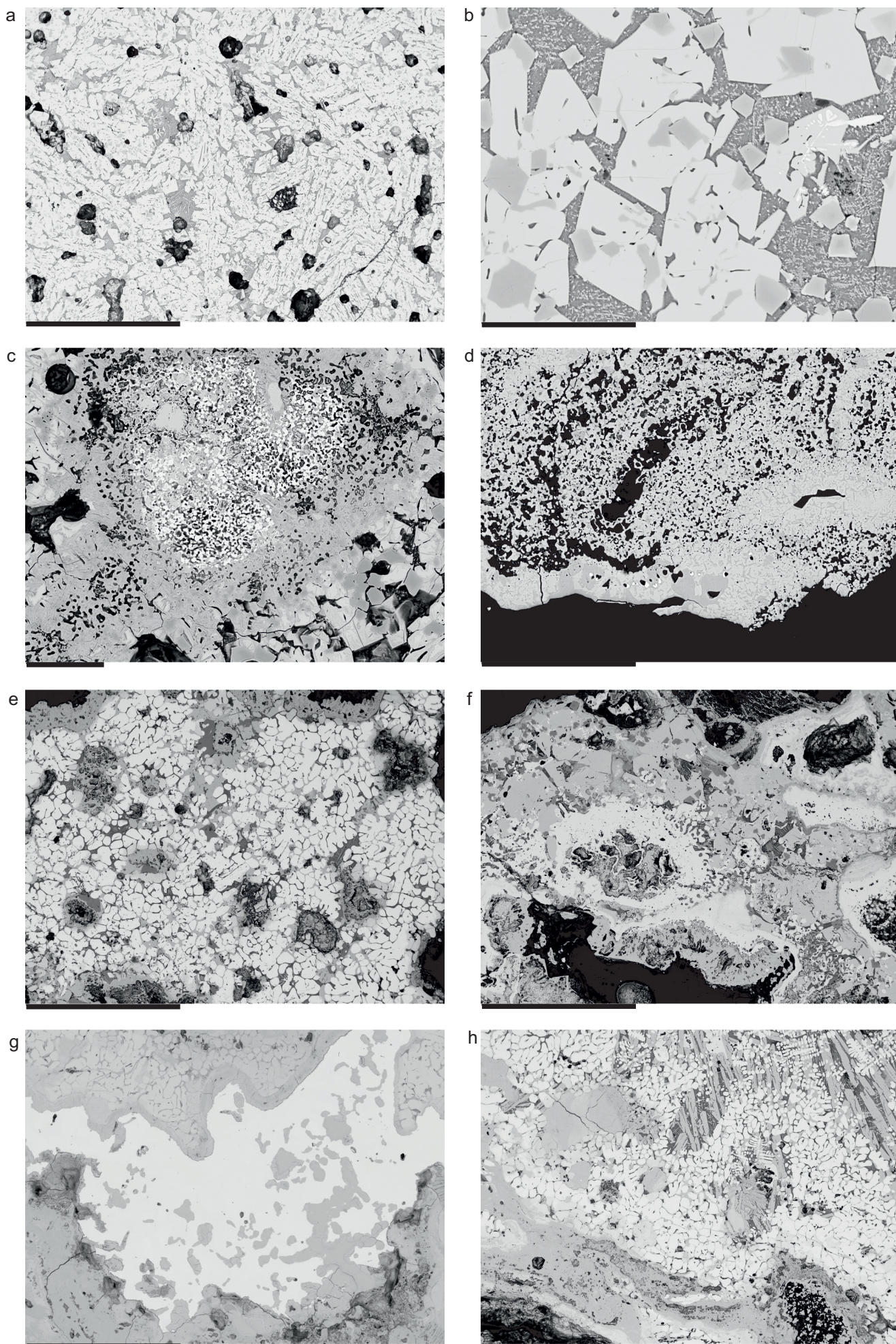


Figure 5

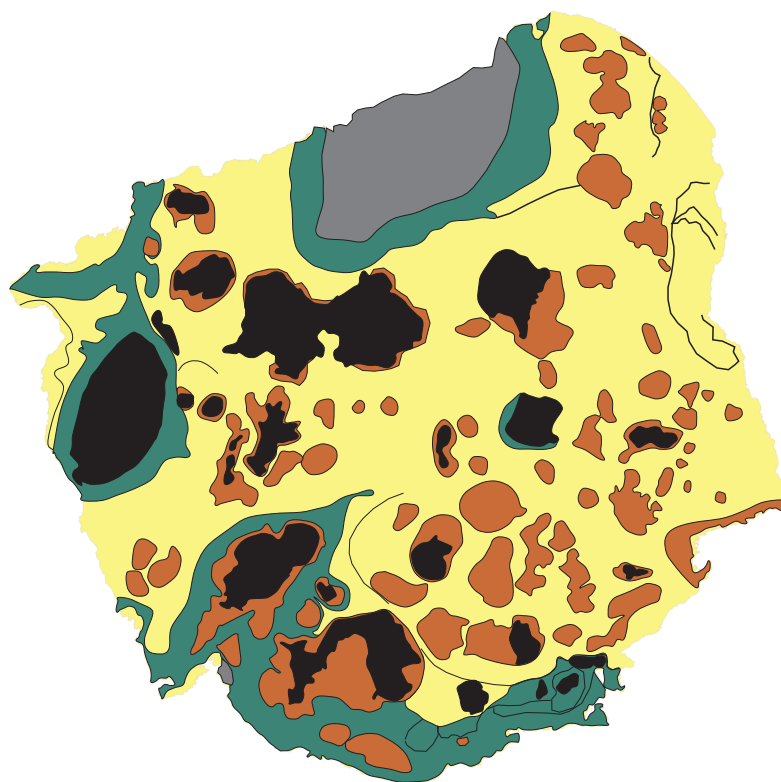
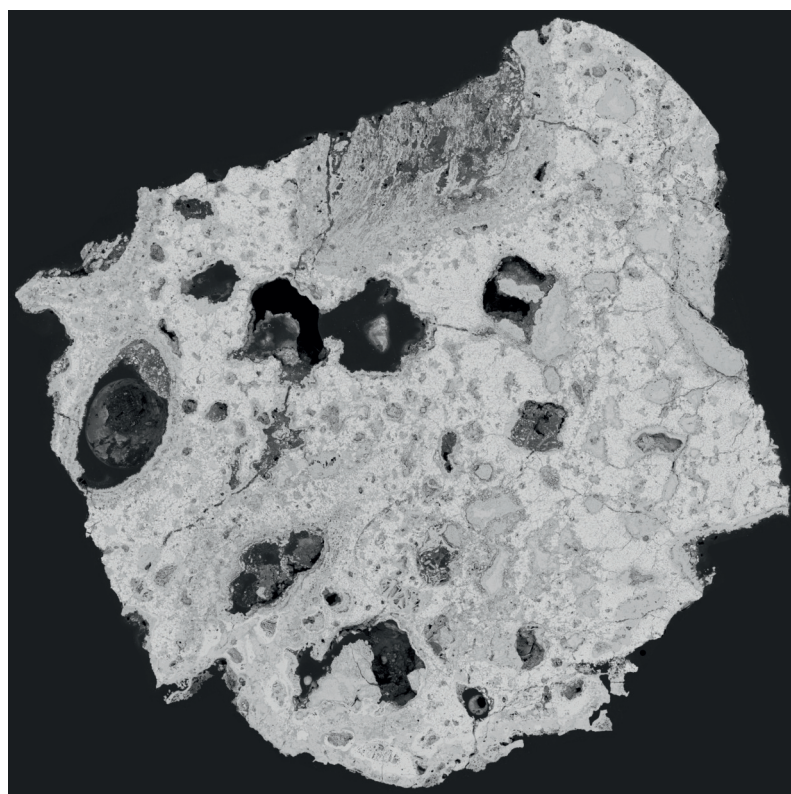
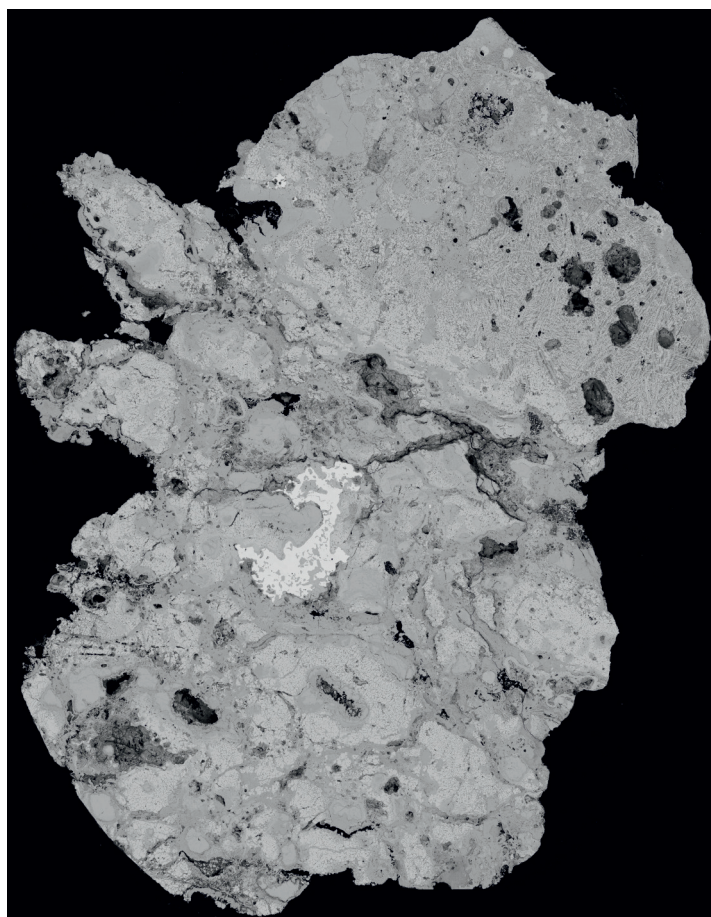


Figure 6



5mm

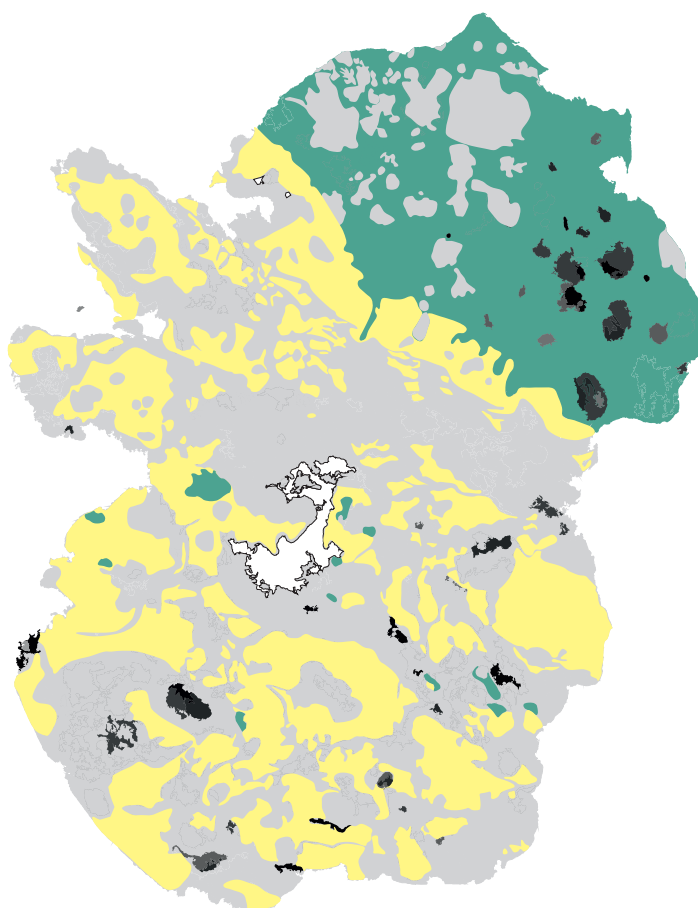


Figure 7

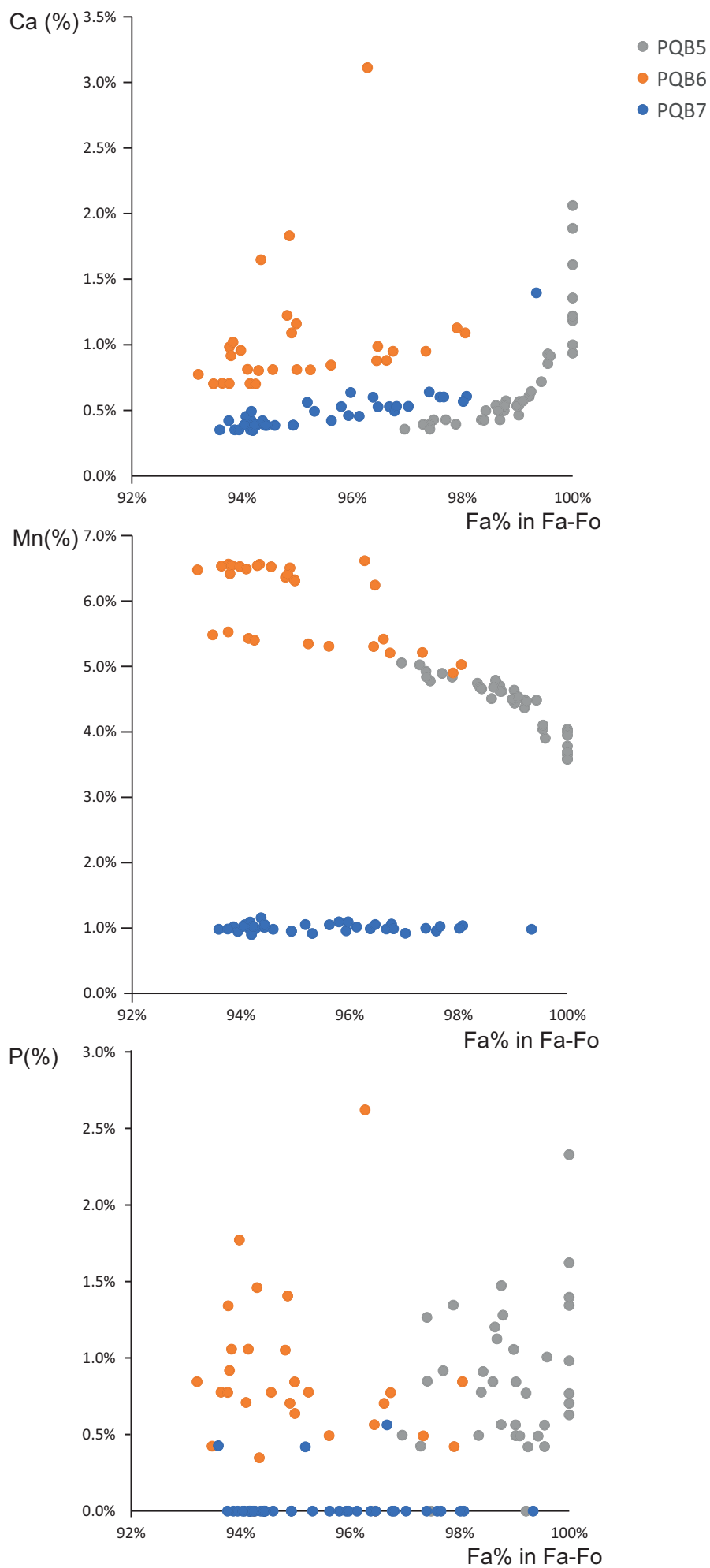


Figure 8

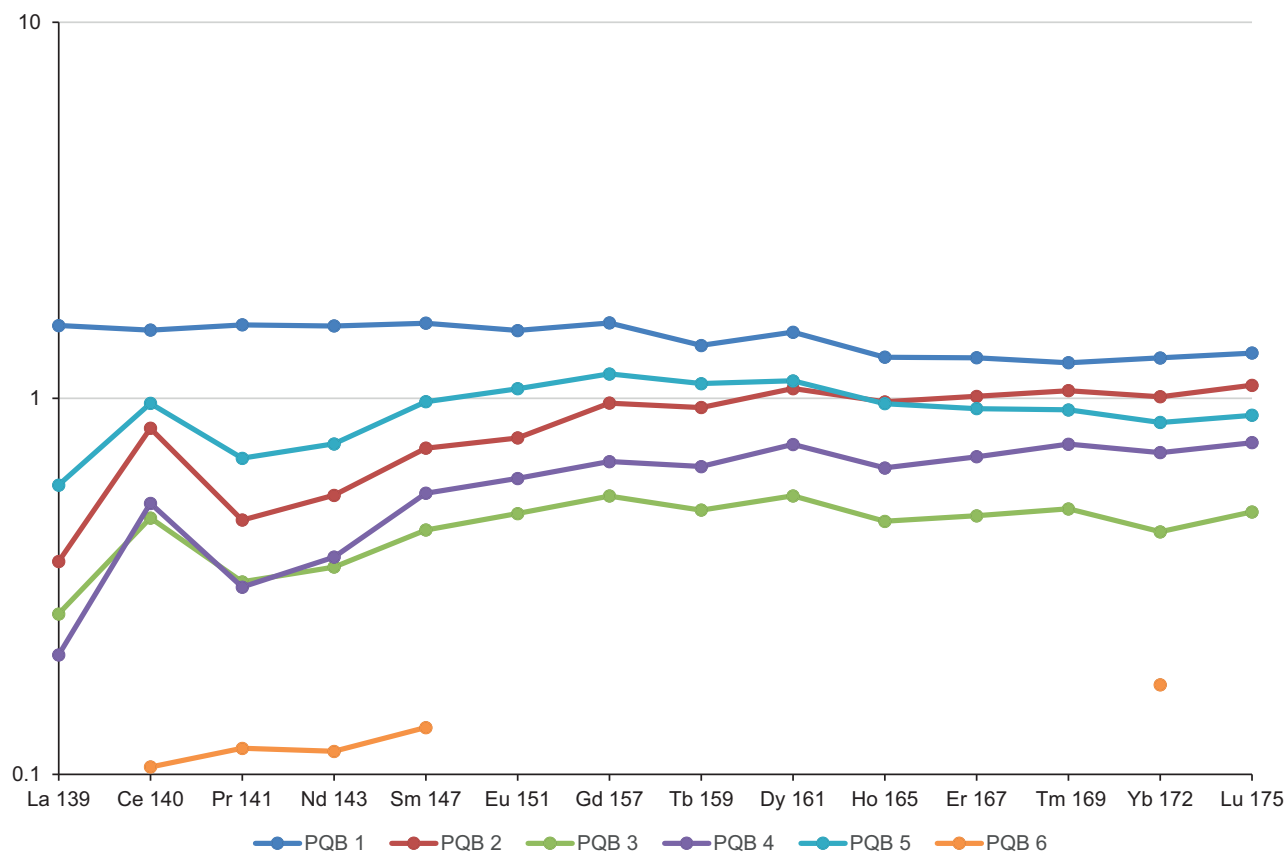


Figure 9

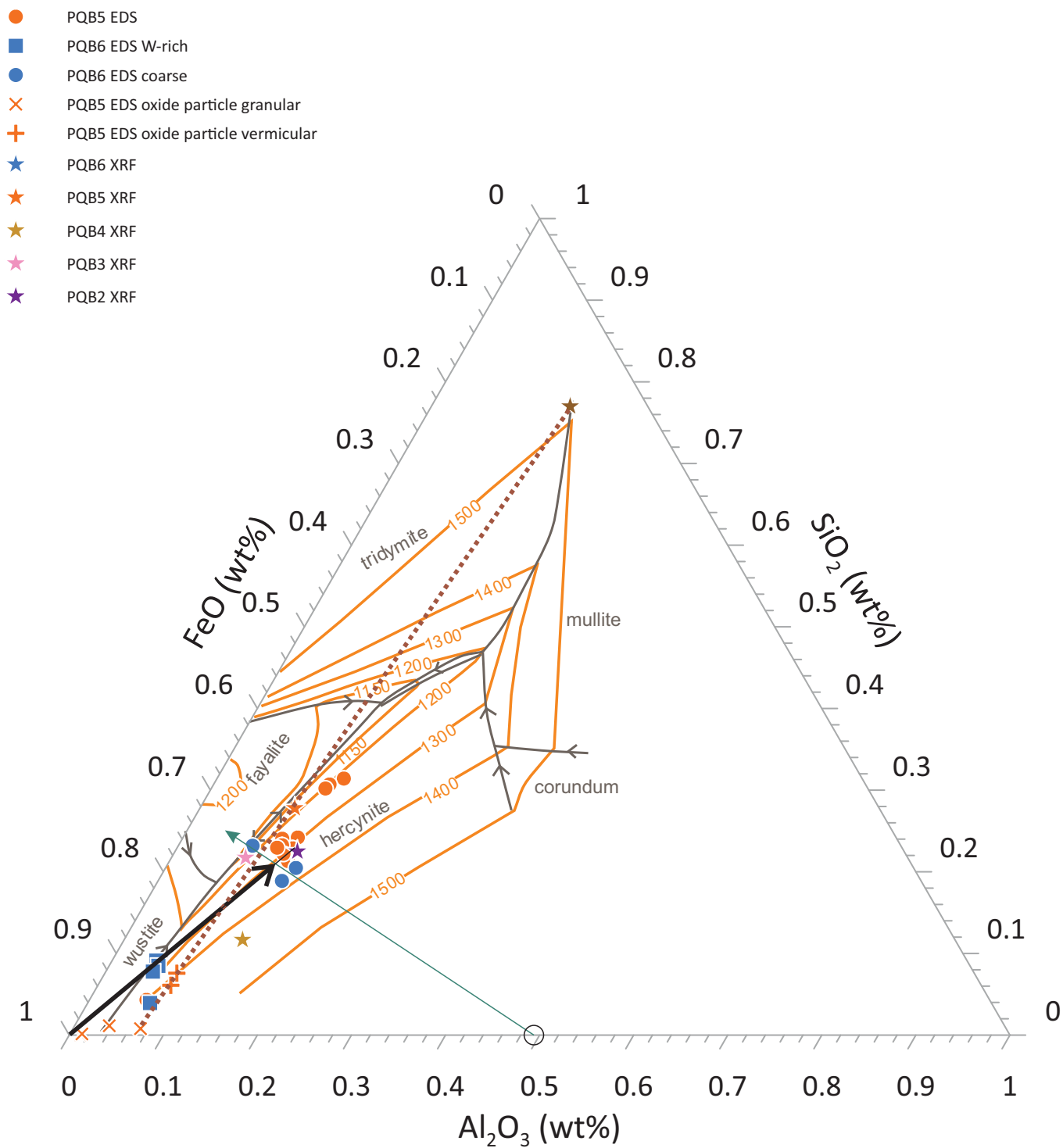
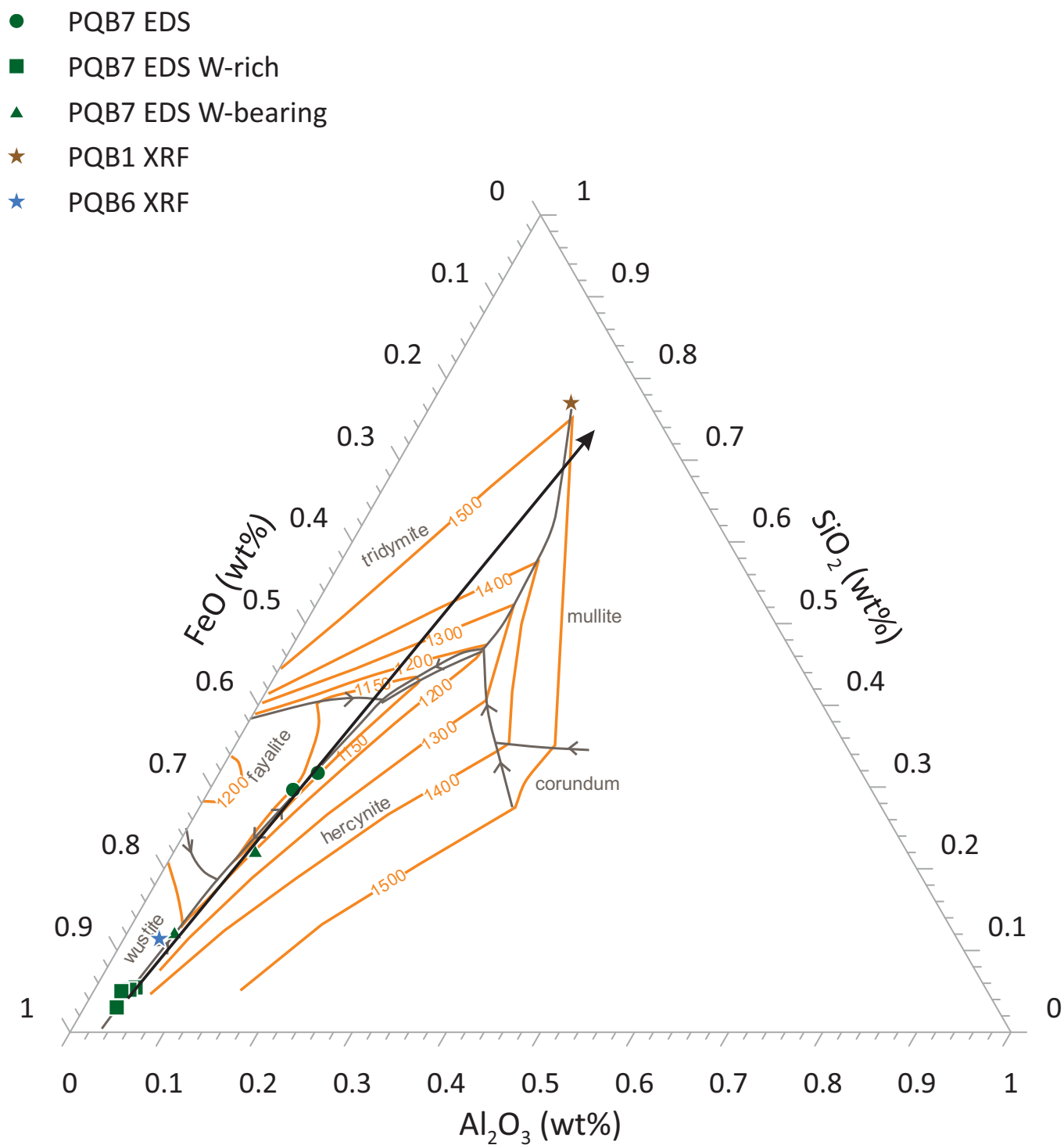


Figure 10



Appendix A

Archive of EDS analyses, collected as 'all elements analysed', presented in elemental wt%

Table A1: EDS analyses from sample TSSF5, collected as 'all elements analysed', presented in elemental wt%. 0 = below detection

Sample	Site	#	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Cu	As	Total
PQB5	Site 2	#626	34.96	1.1	0.27	6.05	13.32	0.49	0.1	0	1.58	0.89	0.23	0	0	1.77	41.1		0	101.86
PQB5	Site 4	#627	35.54	1.47	0.15	6.64	13.66	0.55	0.11	0	1.86	1.16	0.28	0	0	1.6	39.82		0	102.85
PQB5	Site 4	#628	31.5	0	0.1	0.18	13.61	0.07	0	0	0.05	0.36	0	0	0	2.12	50.56		0	98.55
PQB5	Site 4	#629	31.58	0	0.28	0.21	13.59	0.08	0	0	0	0.2	0	0	0	2.5	50.34		0	98.77
PQB5	Site 4	#630	31.82	0	0.47	0.28	13.49	0.2	0	0	0	0.15	0.06	0	0	2.55	49.85		0	98.88
PQB5	Site 4	#631	31.67	0	0.56	0.25	13.66	0	0	0	0	0.16	0	0	0	2.54	49.76		0	98.6
PQB5	Site 4	#632	31.57	0	0.57	0.24	13.53	0.19	0	0	0	0.15	0	0	0	2.6	49.52		0	98.37
PQB5	Site 4	#633	31.7	0	0.51	0.22	13.57	0.14	0	0	0	0.16	0	0	0	2.6	49.71		0	98.59
PQB5	Site 4	#634	31.54	0	0.17	0.2	13.65	0.12	0	0	0	0.23	0	0	0	2.37	50.61		0	98.89
PQB5	Site 4	#635	33.39	0.16	0	0.8	14.05	0.21	0.08	0	0.8	0.93	0.07	0	0	1.67	47.13		0	99.29
PQB5	Site 4	#636	31.7	0	0.17	0.2	13.65	0	0	0	0	0.24	0	0	0	2.31	50.51		0	98.77
PQB5	Site 4	#637	31.76	0	0.31	0.24	13.61	0.13	0	0	0	0.2	0	0	0	2.39	50.38		0	99.04
PQB5	Site 4	#638	31.73	0	0.27	0.26	13.41	0.2	0	0	0	0.22	0.08	0	0	2.44	50.19		0	98.8
PQB5	Site 4	#639	31.87	0	0	0.21	13.35	0.35	0	0	0.07	0.72	0.08	0	0	1.86	49.93		0	98.44
PQB5	Site 4	#640	31.65	0	0	0.18	13.43	0.2	0	0	0	0.62	0.09	0	0	1.93	50.63		0	98.71
PQB5	Site 4	#641	31.42	0	0	0.18	13.64	0.09	0	0	0	0.38	0	0	0	2.12	50.67		0	98.51
PQB5	Site 4	#642	35.49	0.43	0	1.78	14.26	0.61	0.07	0	1.84	1.88	0.13	0	0	1.36	41.11		0	98.95
PQB5	Site 4	#643	31.45	0	0.1	0.21	13.59	0.08	0	0	0	0.32	0	0	0	2.16	50.58		0	98.48
PQB5	Site 4	#644	31.07	0	0.09	0.23	13.1	0.15	0	0	0	0.35	0.07	0	0	2.07	51.02		0	98.16
PQB5	Site 4	#645	35.93	0	0.5	27.27	0.15	0	0	0	0	0	0.3	0.11	0	0.94	34.19		0	99.39
PQB5	Site 4	#646	36.13	0	0.57	27.44	0.15	0	0	0	0	0	0.27	0.12	0	0.94	33.8		0	99.43
PQB5	Site 4	#647	35.25	0	0.21	23.96	0.81	0	0	0	0	0.06	0.67	0	0	0.98	38.4		0	100.33
PQB5	Site 4	#648	35.88	0	0.49	26.49	0.18	0	0	0	0	0	0.3	0.06	0	0.91	34.75		0	99.05
PQB5	Site 4	#649	35.66	0	0.56	27.39	0.17	0	0	0	0	0	0.29	0.13	0	0.93	33.61		0	98.73
PQB5	Site 4	#650	35.65	0	0.41	26.21	0.15	0	0	0	0	0	0.3	0.09	0	0.84	34.94		0	98.57
PQB5	Site 4	#651	32.79	2.54	0	16.84	7.93	1.3	0.26	0	1.97	2	1.16	0	0	0.48	30.25		0	97.51
PQB5	Site 4	#652	35.81	0	0.48	26.33	0.16	0	0	0	0	0	0.39	0	0	0.85	35.27		0	99.28
PQB5	Site 4	#653	34.79	0	0	20.28	0.54	0	0	0	0.13	0.13	1.97	0	0	0.6	41.72		0	100.15
PQB5	Site 4	#654	36.11	0	0.58	27.57	0.16	0	0	0	0.06	0	0.27	0.14	0.07	0.83	33.45		0	99.24

PQB5	Site 4	#655	33.95	0	0	22.27	0.21	0	0	0	0.05	0.05	1.23	0	0	0.63	39.82	0	98.2
PQB5	Site 4	#656	36.06	0.75	0	10.81	2.69	0.47	0.11	0	0.82	0.88	6.01	0	0	0.54	47.17	0	106.31
PQB5	Site 4	#657	24.38	0	0	0.51	0.48	0.1	0	0	0.11	0.2	0.39	0	0	0.5	71.39	0	98.05
PQB5	Site 4	#658	24.18	0	0	0.42	0.33	0	0	0	0.1	0.15	0.77	0	0	0.48	71.27	0	97.7
PQB5	Site 4	#659	40.91	3.53	0	8.85	17.72	3.68	0.26	0	6.75	6.36	0.19	0	0	0.3	9.37	0	97.9
PQB5	Site 4	#660	40.36	3.47	0	11.56	19.1	1.75	0.5	0	7.81	3.16	0.29	0	0	0.24	9.45	0	97.67
PQB5	Site 4	#661	35.13	0	0	23.59	0.21	0	0	0	0.08	0	1.07	0	0	0.73	38.6	0	99.39
PQB5	Site 4	#662	34.2	0.17	0	9.9	1.16	0.2	0	0	0.45	0.4	7.28	0	0	0.57	49.77	0	104.09
PQB5	Site 4	#663	43.87	3.93	0	10.18	19.91	1.79	0.67	0	7.52	4.71	0.23	0	0	0.17	9.03	0	102.01
PQB5	Site 4	#664	41.73	3.77	0	10.33	19.69	1.7	0.24	0	8.1	3.71	0.24	0	0	0.16	6.65	0	96.31
PQB5	Site 4	#665	40.5	3.64	0	10.29	19.18	1.11	0.2	0	8.46	2.36	0.29	0	0	0.21	8.02	0	94.26
PQB5	Site 5	#666	34.46	0.95	0.29	6	13.19	0.43	0.08	0	1.33	0.81	0.21	0	0	1.85	41.86	0	101.45
PQB5	Site 6	#667	31.91	0	0.68	0.25	13.66	0.08	0	0	0	0.14	0	0	0	2.7	49.86	0	99.28
PQB5	Site 6	#668	31.85	0	0.6	0.22	13.66	0.07	0	0	0	0.15	0	0	0	2.67	49.84	0	99.07
PQB5	Site 6	#669	31.66	0	0.12	0.26	13.72	0.07	0	0	0	0.27	0	0	0	2.35	50.41	0	98.87
PQB5	Site 6	#670	31.68	0	0.29	0.23	13.59	0.17	0	0	0	0.17	0	0	0	2.54	50.25	0	98.92
PQB5	Site 6	#671	31.42	0	0.22	0.22	13.55	0.13	0	0	0	0.22	0	0	0	2.35	50.63	0	98.73
PQB5	Site 6	#672	31.66	0	0.22	0.22	13.64	0.08	0	0	0	0.19	0	0	0	2.45	50.55	0	99
PQB5	Site 6	#673	31.69	0	0.58	0.28	13.57	0.12	0	0	0	0.14	0	0	0	2.58	49.93	0	98.89
PQB5	Site 6	#674	31.75	0	0.37	0.23	13.65	0.08	0	0	0	0.17	0	0	0	2.52	50.33	0	99.1
PQB5	Site 6	#675	31.74	0	0.22	0.24	13.65	0.09	0	0	0	0.21	0	0	0	2.37	50.51	0	99.03
PQB5	Site 6	#676	31.77	0	0	0.23	13.74	0.11	0	0	0	0.35	0	0	0	2.1	50.72	0	99.03
PQB5	Site 6	#677	31.54	0	0	0.18	13.53	0.11	0	0	0	0.47	0.09	0	0	1.93	50.58	0	98.43
PQB5	Site 6	#678	31.85	0	0	0.21	13.48	0.25	0	0	0.08	0.78	0.06	0	0	1.87	50.13	0	98.7
PQB5	Site 6	#679	35.41	0	0.17	25.19	0.22	0	0	0	0	0	0.73	0	0	0.82	37.21	0	99.75
PQB5	Site 6	#680	35.53	0	0.11	24.94	0.22	0	0	0	0	0	0.86	0	0	0.86	37.65	0	100.17
PQB5	Site 6	#681	35.42	0	0.12	25.29	0.22	0	0	0	0.05	0	0.68	0	0	0.82	36.88	0	99.49
PQB5	Site 6	#682	35.94	0	0.56	27.73	0.13	0	0	0	0	0	0.18	0.1	0	0.93	33.37	0	98.93
PQB5	Site 7	#683	31.37	0	0	0.24	13.54	0.21	0	0	0.06	0.52	0	0	0	1.99	50.73	0	98.65
PQB5	Site 7	#684	31.57	0	0.22	0.25	13.54	0.16	0	0	0	0.2	0	0	0	2.38	50.44	0	98.77
PQB5	Site 7	#685	31.42	0	0.27	0.28	13.51	0.22	0	0	0	0.21	0	0	0	2.45	50.38	0	98.73
PQB5	Site 7	#686	31.77	0	0.31	0.26	13.53	0.18	0	0	0	0.19	0	0	0	2.48	50.38	0	99.11

PQB5	Site 7	#687	31.55	0	0.36	0.26	13.56	0.12	0	0	0	0.17	0	0	0	2.48	50.56	0	99.07
PQB5	Site 7	#688	31.59	0	0.35	0.26	13.68	0.13	0	0	0	0.19	0	0	0	2.48	50.5	0	99.19
PQB5	Site 7	#689	31.65	0	0.2	0.24	13.67	0.07	0	0	0	0.22	0	0	0	2.4	50.56	0	99.01
PQB5	Site 7	#690	31.69	0	0.16	0.21	13.76	0.07	0	0	0	0.24	0	0	0	2.36	50.67	0	99.16
PQB5	Site 7	#691	31.75	0	0	0.21	13.67	0.15	0	0	0	0.45	0.07	0	0	2.09	50.86	0	99.25
PQB5	Site 7	#692	35.94	0	0.57	27.63	0.14	0	0	0	0	0	0.26	0.13	0	0.92	33.72	0	99.31
PQB5	Site 7	#693	35.99	0	0.55	27.64	0.17	0	0	0	0	0	0.24	0.18	0.47	0.99	32.97	0	99.2
PQB5	Site 7	#694	35.72	0	0.48	26.44	0.25	0	0	0	0	0	0.37	0.07	0	0.92	34.85	0	99.11
PQB5	Site 7	#695	34.66	0	0	21.46	0.56	0	0	0	0	0	1.82	0	0	0.71	40.79	0	99.99
PQB5	Site 7	#696	35.83	0	0.14	26.05	0.18	0	0	0	0	0	0.73	0	0	0.86	35.88	0	99.66
PQB5	Site 7	#697	46.14	3.29	0	10.31	18.84	2.27	0.51	0	8.05	4.59	0.25	0	0	0.16	6.82	0	101.22
PQB5	Site 7	#698	34.74	0.23	0	8.44	1.83	0.25	0.22	0	0.82	0.58	7.45	0	0	0.52	49.15	0	104.22
PQB5	Site 7	#699	43.08	3.19	0	9.87	18.13	2.05	0.32	0	8.06	4.16	0.26	0	0	0.14	6.75	0	96.01
PQB5	Site 7	#700	45.5	3.5	0	9.11	17.32	4.95	0.27	0	7.41	8.74	0.23	0	0	0.15	7.05	0	104.23
PQB5	Site 8	#701	31.85	0.11	0.25	5.6	9.81	0.52	0	0.07	0.13	0.38	0.2	0	0	1.66	43.04	0	93.63
PQB5	Site 8	#702	33.93	0	0.23	5.02	9.36	0.37	0.05	0.06	0	0.19	0.18	0	0	1.48	44.53	0	95.41
PQB5	Site 8	#703	34.18	0	0.21	5.57	8.3	0.32	0.05	0	0	0.2	0.22	0	0	1.34	43.48	0	93.86
PQB5	Site 9	#704	27	0	0	1.59	1.44	0.17	0	0	0	0.08	0.08	0	0	0.42	64.67	0	95.43
PQB5	Site 9	#705	26.83	0	0	7.47	1.1	0.39	0.06	0.08	0	0.14	0.28	0	0	0.36	39.52	0	76.24
PQB5	Site 10	#706	34.64	0	0.34	23.33	0.62	0	0	0	0	0	0.66	0.13	0.06	0.85	38.45	0	99.07
PQB5	Site 10	#707	34.25	0	0.3	21.82	0.48	0	0	0	0	0	0.76	0.1	0.09	0.78	40.23	0	98.81
PQB5	Site 10	#708	35.59	0	0.5	26.37	0.32	0	0	0	0	0	0.45	0.14	0.19	0.9	34.54	0	99
PQB5	Site 10	#709	18.82	0	0	2.73	3.1	0.46	0.08	0.11	0	0.07	0.19	0	0	0.46	37.35	0.18	63.56
PQB5	Site 10	#710	16.75	0	0	1.98	1.9	0.45	0.06	0.14	0	0.07	0.23	0	0	0.27	33.84	0.2	55.89
PQB5	Site 10	#711	16.12	0	0	5.33	2.13	0.37	0.05	0.18	0	0.25	0.19	0	0	0.5	38.82	0.15	64.1
PQB5	Site 10	#712	40.01	0	0.16	24.57	0.58	0	0	0	0	0	0.81	0	0	0.78	39.71	0	106.63
PQB5	Site 10	#713	23.16	0	0	0.38	0.24	0	0	0	0	0	0.06	0	0	0.45	71.71	0	96
PQB5	Site 10	#714	26.93	0	0	0.58	0.21	0.09	0	0	0	0	0	0	0	0.2	68.09	0	96.09
PQB5	Site 10	#715	24.85	0	0	0.5	0.23	0	0	0	0	0	0.07	0	0	0.44	71.24	0	97.33
PQB5	Site 10	#716	26.33	0	0	0.35	0.1	0	0	0	0	0	0	0	0	0.22	69.75	0	96.76
PQB5	Site 10	#717	36.49	0	0	0.41	1.44	0.23	0.13	0	0	0	0	0	0	0.07	54.76	0.15	93.67
PQB5	Site 10	#718	34.66	0	0.59	0.51	13.51	0.25	0	0	0	0.12	0	0	0	2.35	46.32	0	98.3

PQB5	Site 10	#719	35.09	0	0.36	16.07	5.36	0.09	0	0	0	0.12	0.26	0	0	1.63	42.19	0	101.17
PQB5	Site 11	#720	28.16	0	0	2.58	1.63	0.11	0	0	0.05	0.09	0	0	0	0.43	57.67	0	90.71
PQB5	Site 11	#721	33.3	0	0.24	5.03	10.04	0.42	0	0	0	0.29	0.22	0	0	1.71	45.65	0	96.87
PQB5	Site 11	#722	34.79	0	0.23	5.37	9.01	0.26	0.07	0	0	0.18	0.18	0	0	1.45	45.26	0	96.81
PQB5	Site 11	#723	35.09	0	0.26	4.9	9.33	0.23	0	0	0	0.22	0.22	0	0	1.48	45.56	0	97.29
PQB5	Site 11	#724	34.54	0	0.21	5.59	9.15	0.3	0	0	0	0.24	0.21	0	0	1.45	43.7	0	95.39
PQB5	Site 11	#725	29.13	0	0.11	7.84	4	0.39	0.07	0.19	0	0.18	0.28	0	0	0.71	38.96	0	81.85
PQB5	Site 12	#726	29.77	0	0	3.28	2.87	0.24	0.06	0.06	0	0.09	0.11	0	0	0.68	54.66	0.99	92.81
PQB5	Site 13	#727	21.92	0	0	0.53	0.15	0	0	0	0	0	0.18	0	0	0.91	73.61	0	97.29
PQB5	Site 13	#728	22.3	0	0	0.53	0.18	0	0	0	0	0	0.18	0	0	0.9	73.78	0	97.85
PQB5	Site 13	#729	22.85	0	0	0.57	0.27	0	0	0	0	0	0.16	0	0	0.87	70.03	0	94.75
PQB5	Site 13	#730	24.21	0	0	0.56	0.29	0.06	0	0	0	0	0.2	0	0	0.86	71.84	0	98.02
PQB5	Site 13	#732	22.64	0	0.09	0.51	0.16	0	0	0	0	0	0.19	0	0	0.85	73.25	0	97.68
PQB5	Site 13	#733	27.76	0	0	3.41	2.37	0.24	0.06	0.06	0	0.13	0.14	0	0	0.61	56.65	0.57	91.99
PQB5	Site 13	#734	35.58	0	0	24.97	2.96	0.3	0.22	0.18	0	0.44	0	0	0	0.29	27.07	0.43	92.44
PQB5	Site 13	#735	23.03	0	0	5.06	4.69	0.44	0.17	0.22	0	0.28	0.09	0	0	0.36	40.29	0.61	75.22
PQB5	Site 13	#736	18.56	0	0	3.63	3.99	0.34	0.15	0.17	0	0.29	0.08	0	0	0.36	39.06	0.54	67.16
PQB5	Site 13	#737	23.27	0	0.09	7.71	3.83	0.36	0.17	0.2	0	0.27	0.08	0	0	0.33	40.07	0.59	76.98
PQB5	Site 13	#738	34.18	0	0.42	10.01	9.05	0.19	0	0	0	0.15	0.1	0	0	1.62	40.46	0	96.18
PQB5	Site 13	#739	36.53	0	0	1.24	2.81	0.18	0.09	0	0	0.05	0	0	0	0.25	50.6	1.08	92.84
PQB5	Site 13	#740	38.64	0	0.1	3.72	4.87	2.55	0.09	0	0	4.13	0.07	0	0	0.96	41.86	0.92	97.91
PQB5	Site 13	#741	35.81	0	0.26	12.9	6.63	0.19	0	0	0	0.11	0.06	0	0	1.42	42.48	0	99.87
PQB5	Site 13	#742	27.73	0	0	1.71	1.08	0.08	0	0	0	0	0.17	0	0	0.86	71.08	0.2	102.91
PQB5	Site 13	#743	32.95	0	0	3.3	1.73	0.17	0	0.06	0	0.07	0.18	0	0	0.92	64.8	0.29	104.47
PQB5	Site 13	#744	35.03	0	0	2.9	2.1	0.18	0.09	0	0	0.08	0.18	0	0	0.64	61.54	0.56	103.29
PQB5	Site 13	#745	26.75	0	0	0.97	0.7	0.07	0	0	0	0.05	0.18	0	0	0.99	70.16	0	99.87
PQB5	Site 14	#746	24.01	0	0	3.4	0.33	0.07	0	0	0	0.05	0	0	0	0.19	64.34	0	92.37
PQB5	Site 14	#747	25.23	0	0	1.57	0.44	0.05	0	0	0	0	0	0	0	0.12	61.24	0	88.65
PQB5	Site 14	#748	52.2	0	0	0.15	45.79	0	0	0	0.06	0	0	0	0	0	1.18	0	99.37
PQB5	Site 16	#749	22.29	0	0	0.81	0.2	0	0	0	0	0	0	0	0	0.3	73.57	0	97.17
PQB5	Site 16	#750	21.76	0	0	0.85	0.15	0	0	0	0	0	0	0	0	0.31	73.12	0	96.19
PQB5	Site 16	#751	21.79	0	0	0.77	0.21	0	0	0	0	0	0	0	0	0.3	74.43	0	97.51

PQB5	Site 16	#752	22.29	0	0	0.81	0.19	0	0	0	0	0	0	0	0	0.26	73.55	0	97.11	
PQB5	Site 16	#753	21.73	0	0	0.88	0.22	0	0	0	0	0	0	0	0	0.32	73.4	0	96.54	
PQB5	Site 16	#754	26.16	0	0	1.06	0.17	0	0	0	0	0	0	0	0	0.14	68.39	0	95.93	
PQB5	Site 16	#755	26.28	0	0	0.75	0.08	0	0	0	0	0	0	0	0	0.11	69.11	0	96.33	
PQB5	Site 16	#756	25.17	0	0	0.76	0	0	0	0	0	0	0	0	0	0.14	69.44	0	95.51	
PQB5	Site 16	#757	25.31	0	0	0.77	0.15	0	0	0	0	0	0	0	0	0.17	68.42	0	94.82	
PQB5	Site 16	#758	25.07	0	0	1.36	0.18	0	0	0	0	0	0	0	0	0.14	67.96	0	94.7	
PQB5	Site 16	#759	12.14	0	0.45	1.8	0.14	0	0.32	0	0	0	0	0	0	0.1	51.35	0	45.84	112.14
PQB5	Site 16	#760	14.58	0	0.39	3.15	0.17	0.15	0.28	0	0	0.08	0	0	0	0.1	49.91	0	44.4	113.2
PQB5	Site 16	#761	4.14	0	0.59	1.05	0	0	0.12	0	0	0	0	0	0	0	49.72	0.16	52.79	108.56
PQB5	Site 16	#762	15.26	0	0.26	1.92	0.13	0	0.11	0	0	0	0	0	0	0	59.06	0.83	31	108.55
PQB5	Site 16	#763	13.8	0	0.46	3.36	0.14	0	0.12	0	0	0	0	0	0	0	47.66	0	47.82	113.36
PQB5	Site 17	#764	37.88	0	0	0.99	1.58	0.77	0.1	0	0	0	0	0	0	0.13	51.91	0.47	93.83	
PQB5	Site 17	#765	37.56	0	0	0.92	1.45	0.7	0.09	0	0	0	0	0	0	0.12	52.72	0.41	93.96	
PQB5	Site 17	#766	37.47	0	0	0.88	1.47	0.82	0.09	0.06	0	0	0	0	0	0.12	52.33	0.28	93.51	
PQB5	Site 17	#767	22.68	0	0	0.63	0	0	0	0	0	0	0	0	0	0	73.69	0	97.01	
PQB5	Site 17	#768	23.31	0	0	0.65	0.06	0	0	0	0	0	0	0	0	0.14	73.22	0	97.38	
PQB5	Site 17	#769	22.86	0	0	1.95	0.86	0	0	0.06	0	0.07	0	0	0	0.13	62.97	0	88.9	
PQB5	Site 19	#770	3.46	0.14	0.38	0.83	0	0	0.96	0	0	0	0	0	0	0	53.9	0.17	44.36	104.18
PQB5	Site 19	#771	4.44	0	0.35	1.13	0.08	0	0.14	0	0	0	0	0	0	0	58.63	0.17	39.25	104.2
PQB5	Site 19	#772	3.67	0	0.34	1.72	0.08	0	0.62	0	0	0	0	0	0	0	58.98	0	41.11	106.52
PQB5	Site 19	#773	5.18	0	0.35	0.85	0	0	1.12	0	0	0	0	0	0	0	60.38	0	37.21	105.08
PQB5	Site 19	#774	3.44	0	0.31	0.81	0	0	0.19	0.18	0	0	0	0	0	0	61.23	0	40.23	106.4
PQB5	Site 19	#775	4.03	0	0.33	0.78	0	0	0.22	0	0	0	0	0	0	0	61.03	0	39.53	105.92
PQB5	Site 19	#776	24.76	0	0	0.91	0	0	0	0	0	0	0	0	0	0	69.06	0	94.73	
PQB5	Site 19	#777	25.97	0	0	0.59	0	0	0	0	0	0	0	0	0	0	70.15	0	96.71	
PQB5	Site 19	#778	26.11	0	0	0.57	0	0	0	0	0	0	0	0	0	0	70.12	0	96.8	
PQB5	Site 19	#779	25.3	0	0	0.51	0	0	0	0	0	0	0	0	0	0	70.24	0	96.05	
PQB5	Site 19	#780	25.18	0	0	0.53	0	0	0	0	0	0	0	0	0	0	70.85	0	96.57	
PQB5	Site 19	#781	25.53	0	0	0.5	0	0	0	0	0	0	0	0	0	0	70.81	0	96.84	
PQB5	Site 19	#782	25.72	0	0	0.48	0	0	0	0	0	0	0	0	0	0	70.66	0	96.86	
PQB5	Site 19	#783	21.2	0	0	0.56	0	0	0	0	0	0	0	0	0	0	75.47	0	97.24	

PQB5	Site 19	#784	21.34	0	0	0.53	0.06	0	0	0	0	0	0	0	0	0	75.68	0	97.62
PQB5	Site 19	#785	21.14	0	0	0.55	0	0	0	0	0	0	0	0	0	0	75.59	0	97.28
PQB5	Site 19	#786	21.51	0	0	0.62	0	0	0	0	0	0	0	0	0	0	75.44	0	97.56
PQB5	Site 19	#787	21.16	0	0	0.53	0.08	0	0	0	0	0	0	0	0	0	75.37	0	97.14
PQB6	Site 2	#516	26.08	0.24	0.37	2.37	4.06	0.14	0	0.24	0.23	0.42	0.08		0	1.72	63.7	0	99.65
PQB6	Site 2	#517	25.58	0.41	0.31	2.6	3.72	0.16	0.08	0.25	0.36	0.57	0.07		0	1.61	62.88	0	98.58
PQB6	Site 2	#518	25.54	0.37	0.35	2.51	3.45	0.18	0.07	0.34	0.29	0.5	0.08		0	1.61	64.18	0	99.47
PQB6	Site 2	#519	36.04	0	0.79	27.11	0.17	0	0	0.05	0	0	0.06		0	1.13	34.27	0	99.63
PQB6	Site 2	#520	35.55	0	0.69	26.03	0.2	0	0.07	0.16	0	0.05	0.13		0	1.12	35.53	0	99.51
PQB6	Site 2	#521	35.24	0	0.8	26.14	0.21	0	0	0	0	0	0.11		0	1.13	34.72	0	98.35
PQB6	Site 3	#522	31.55	0	1.16	0.2	13.72	0.16	0	0	0	0.48	0		0	3.46	48.48	0	99.21
PQB6	Site 3	#523	31.7	0	1.12	0.25	13.76	0.13	0	0.08	0	0.47	0		0	3.43	48.52	0	99.46
PQB6	Site 3	#524	31.7	0	1.13	0.26	13.73	0.1	0	0	0	0.43	0		0	3.52	48.31	0	99.19
PQB6	Site 3	#525	32.11	0	0.8	0.29	13.46	0.39	0	0	0.1	1.22	0		0	3.54	47.32	0	99.24
PQB6	Site 3	#526	31.7	0	1.25	0.22	13.95	0.06	0	0	0	0.65	0		0	3.57	47.97	0	99.37
PQB6	Site 3	#527	31.77	0	1.39	0.33	13.67	0.2	0	0	0	0.39	0		0	3.58	48.02	0	99.36
PQB6	Site 3	#528	31.95	0	1.39	0.38	13.79	0.14	0	0	0	0.37	0		0	3.49	48.17	0	99.68
PQB6	Site 3	#529	32	0	1.38	0.27	13.81	0.16	0	0.05	0	0.41	0		0	3.59	48.25	0	99.93
PQB6	Site 3	#530	31.78	0	1.44	0.53	13.59	0.18	0	0.25	0	0.4	0		0	3.45	47.96	0	99.57
PQB6	Site 3	#531	31.97	0	1.33	0.32	13.58	0.27	0	0.11	0	0.38	0		0	3.53	47.73	0	99.21
PQB6	Site 3	#532	35.66	0	0.65	26.65	0.18	0	0	0	0	0	0.1		0	1.13	35.14	0	99.53
PQB6	Site 3	#533	35.92	0	0.77	26.82	0.18	0	0	0	0	0	0.09		0	1.13	34.96	0	99.86
PQB6	Site 3	#534	36.11	0	0.75	27.24	0.11	0	0	0.06	0	0	0.11		0	1.1	34.43	0	99.9
PQB6	Site 3	#535	35.97	0	0.76	27.29	0.14	0	0	0	0	0	0.07		0	1.07	34.14	0	99.45
PQB6	Site 3	#536	22.32	0	0.2	0.59	0.1	0	0	0.07	0	0	0		0	1.38	73.15	0	97.8
PQB6	Site 3	#537	22.72	0	0.14	0.73	0.13	0	0	0	0	0	0.07		0	1.35	73.16	0	98.29
PQB6	Site 3	#538	35.75	0	0.41	26.63	0.48	0	0	0	0	0.08	0.09		0	1.31	35.38	0	100.14
PQB6	Site 3	#539	31.81	0	1.13	0.25	13.72	0.22	0	0	0	0.73	0		0	3.49	48.07	0	99.41
PQB6	Site 4	#540	35.85	0	0.39	26.85	0.1	0	0	0.05	0	0	0.16		0	1.11	34.84	0	99.37
PQB6	Site 4	#541	31.53	0	0.78	0.2	13.7	0	0	0	0	0.39	0		0	3.34	48.74	0	98.68
PQB6	Site 4	#542	31.75	0	1.11	0.28	13.65	0.1	0	0	0	0.33	0		0	3.4	48.48	0	99.1

PQB6	Site 4	#543	36.01	0	0.49	26.89	0.22	0	0	0	0	0	0.15	0	1.15	34.57	0	99.47
PQB6	Site 4	#544	31.99	0	1.32	0.23	13.72	0.11	0	0	0	0.33	0	0	3.52	48.16	0	99.38
PQB6	Site 4	#545	31.97	0	1.21	0.22	13.79	0.12	0	0	0	0.33	0	0	3.54	48.43	0	99.62
PQB6	Site 4	#546	31.25	0	1.26	0.23	13.71	0.22	0	0.07	0	0.32	0	0	3.53	48.03	0	98.62
PQB6	Site 4	#547	31.85	0	1.41	0.22	13.75	0.12	0	0.18	0	0.28	0	0	3.54	47.84	0	99.19
PQB6	Site 4	#548	32.1	0	1.53	0.24	13.9	0.14	0	0.06	0	0.31	0	0	3.55	48.17	0	99.99
PQB6	Site 4	#549	36.02	0	0.82	27.4	0.08	0	0	0	0	0	0.08	0	1.13	33.42	0	98.95
PQB6	Site 4	#550	36.06	0	0.76	27.16	0.1	0	0	0	0	0	0.1	0	1.14	33.84	0	99.17
PQB6	Site 4	#551	33.2	0	0	0.22	0.06	0	0.45	6.99	0.07	0	0	0	0.08	53.17	0	94.24
PQB6	Site 4	#552	33.02	0	0	0.2	0.08	0	0.48	7.17	0.11	0	0	0	0.12	52.65	0	93.83
PQB6	Site 4	#553	30.86	0.18	0	3.13	0.11	0	0.43	6.69	0.07	0	0	0	0	49.76	0	91.22
PQB6	Site 4	#554	28.48	0	0	0.24	0.23	0.1	0.12	1.07	0	0	0	0	0.08	66.15	0	96.46
PQB6	Site 4	#555	24.88	0.2	0	5.25	0.29	0	0.43	6.62	0.22	0.12	0	0	0.11	42.77	0	80.87
PQB6	Site 4	#556	30.42	0.22	0.46	5.87	7.65	0.2	0.24	2.56	0.3	0.6	0.06	0	1.7	41.08	0	91.35
PQB6	Site 5	#557	24.64	0.18	0.17	2.85	1.49	0.08	0.15	7.88	0.19	0.3	0.07	0	1	57.01	0	96.02
PQB6	Site 5	#558	30.39	0.39	0.37	5.51	6.97	0.15	0.25	6.69	0.28	0.57	0.07	0	1.51	42.06	0	95.19
PQB6	Site 5	#559	15.57	0.09	0	1.4	0.64	0.05	0.18	26.19	0.11	0.16	0	0	0.85	38.08	0	83.33
PQB6	Site 5	#560	24.88	0.26	0	4.21	0.57	0	0.81	10.72	0.32	0.24	0	0	0.14	34.5	0	76.66
PQB6	Site 6	#561	32.6	0	0	1.64	0.08	0	0.4	8.01	0	0.22	0	0	0	51.18	0	94.13
PQB6	Site 6	#562	12.4	0	0	0.24	0	0	0.12	29.17	0.07	0.12	0	0	0.15	44	0	86.27
PQB6	Site 6	#563	19.63	0	0	0.26	0	0	0.09	19.57	0.09	0	0	0	0.12	46.44	0	86.19
PQB6	Site 7	#564	26.94	0	0	0.58	0	0	0.15	0.24	0	0	0	0	0.12	68.88	0.17	97.06
PQB6	Site 7	#565	26.82	0	0	3.24	0.14	0.08	0.35	6.93	0	0.08	0	0	0.08	47.54	0.33	85.59
PQB6	Site 7	#566	28.63	0	0	0.5	0.81	0.09	0	0.62	0	0	0	0	0	66.27	0	96.92
PQB6	Site 7	#567	30.31	0	0	2.58	0.12	0	0.43	7.55	0	0.05	0	0	0	48.33	0	89.37
PQB6	Site 7	#568	32.52	0	0.49	3.71	9.6	0.27	0.11	0.49	0	0.4	0.07	0	1.82	47.8	0	97.28
PQB6	Site 8	#569	27	0	0	0.21	0	0	0.07	0.27	0	0	0	0	0	69.89	0.33	97.78
PQB6	Site 8	#570	27.06	0	0	0.16	0	0	0.13	0.16	0	0	0	0	0	69.56	0.33	97.4
PQB6	Site 8	#571	27.52	0	0	0.18	0	0	0.18	0.07	0	0	0	0	0	69.44	0	97.39
PQB6	Site 8	#572	26.91	0	0	0.16	0	0	0.13	0.07	0	0	0	0	0.1	69.78	0	97.15
PQB6	Site 8	#573	27.03	0	0	0.17	0	0	0.11	0.05	0	0	0	0	0.1	69.83	0	97.29
PQB6	Site 8	#574	27.12	0	0	0.14	0	0	0.13	0.05	0	0	0	0	0.19	69.83	0	97.45

PQB6	Site 8	#575	27.31	0	0	0.19	0.07	0	0.13	0.1	0	0	0	0	0.21	69.33	0	97.34
PQB6	Site 8	#576	27.34	0	0	0.22	0	0	0.14	0.07	0	0	0	0	0.1	69.7	0	97.58
PQB6	Site 8	#577	26.77	0	0	0.16	0	0	0.08	0.06	0	0	0	0	0.14	69.89	0	97.09
PQB6	Site 8	#578	27.3	0	0	0.19	0	0	0.09	0.06	0	0	0	0	0.13	69.62	0	97.39
PQB6	Site 8	#579	27.23	0	0	0.19	0	0	0.11	0.38	0	0	0	0	0.14	69.09	0	97.15
PQB6	Site 8	#580	27.24	0	0	0.18	0.08	0.06	0.07	0	0	0	0	0	0.22	69.21	0	97.07
PQB6	Site 8	#581	27.3	0	0	0.18	0.08	0	0.12	0	0	0	0	0	0.1	69.65	0	97.43
PQB6	Site 8	#582	27.44	0	0	0.18	0	0	0.1	0	0	0	0	0	0.2	69.37	0	97.3
PQB6	Site 8	#583	27.93	0	0	0.16	0	0	0.21	0.1	0	0	0	0	0	68.88	0	97.27
PQB6	Site 8	#584	29.01	0	0	0.21	0.95	0.12	0.11	1.1	0	0	0	0	0.43	65.4	0	97.34
PQB6	Site 8	#585	36.51	0	0	0.18	7.32	0.98	0.12	2.19	0	0	0	0	0.14	48.64	0	96.08
PQB6	Site 8	#586	27.3	0	0	0.17	0.11	0	0.15	0.12	0	0	0	0	0.11	68.77	0	96.72
PQB6	Site 8	#587	27.64	0	0	0.17	0.25	0.07	0.09	0.15	0	0	0	0	0.17	68.23	0	96.76
PQB6	Site 8	#588	37.46	0	0	1.35	8.84	0.62	0.3	5.04	0	0.07	0	0	0.08	41.64	0	95.39
PQB6	Site 8	#589	37.75	0	0	1.13	9.42	0.67	0.25	6.11	0	0.06	0	0	0.07	41.05	0	96.51
PQB6	Site 8	#590	31.46	0	0.47	0.2	13.76	0.06	0	0	0	0.45	0	0	2.64	50.35	0	99.4
PQB6	Site 8	#591	31.7	0	0.73	0.18	13.72	0.11	0	0	0	0.37	0	0	2.81	49.89	0	99.53
PQB6	Site 8	#592	31.39	0	0.76	0.2	13.73	0.11	0	0	0	0.35	0	0	2.92	49.76	0	99.22
PQB6	Site 8	#593	31.41	0	0.6	0.2	13.77	0.07	0	0	0	0.38	0	0	2.81	50.14	0	99.39
PQB6	Site 8	#594	31.61	0	0.99	0.22	13.78	0.07	0	0	0	0.33	0	0	2.88	49.51	0	99.39
PQB6	Site 8	#595	31.63	0	1.33	0.24	13.81	0.17	0	0.05	0	0.28	0	0	2.97	49.02	0	99.49
PQB6	Site 8	#596	31.81	0	1.31	0.18	13.89	0	0	0	0	0.29	0	0	2.95	49.17	0	99.59
PQB6	Site 8	#597	31.56	0	0.43	0.2	13.64	0.12	0	0	0	0.43	0	0	2.72	50.48	0	99.57
PQB6	Site 8	#598	31.96	0	0.8	0.2	13.76	0.09	0	0	0	0.35	0	0	2.89	49.96	0	100
PQB6	Site 8	#599	31.69	0	1.08	0.22	13.75	0.12	0	0	0	0.32	0	0	2.91	49.4	0	99.48
PQB6	Site 8	#600	31.94	0	1.41	0.23	13.83	0.12	0	0	0	0.27	0	0	3.02	48.78	0	99.6
PQB6	Site 8	#601	31.93	0	1.48	0.27	13.84	0.07	0	0	0	0.28	0	0	3	48.82	0	99.7
PQB6	Site 8	#602	35.8	0	0.87	26.88	0.11	0	0	0	0	0	0.17	0	1.03	34.79	0	99.66
PQB6	Site 8	#603	35.76	0	0.49	26.58	0.12	0	0	0	0	0	0.23	0	0.91	35.57	0	99.67
PQB6	Site 8	#604	34.96	0	0.88	26.28	0.14	0	0	0.06	0	0	0.16	0	0.99	34.74	0	98.22
PQB6	Site 8	#605	36.31	0	0.46	27.16	0.08	0	0	0	0	0	0.17	0	0.96	35.43	0	100.57
PQB6	Site 8	#606	32.64	0.19	0	0.68	14.06	0.24	0	0	0.19	1.42	0.09	0	2.05	49.61	0	101.16

PQB6	Site 8	#607	32.26	0	0.15	0.44	13.01	0.24	0	0.53	0	0.92	0.07	0	2.09	50.24	0	99.94
PQB6	Site 8	#608	31.73	0	0.12	0.28	13.56	0.18	0	0.14	0	0.84	0.06	0	2.17	50.78	0	99.87
PQB6	Site 8	#609	22.89	0	0	0.55	0.17	0	0	0	0	0	0.49	0	0.8	73.1	0	97.99
PQB6	Site 8	#610	23.05	0	0	0.66	0.19	0	0	0.07	0	0	0.43	0	0.86	72.91	0	98.17
PQB6	Site 9	#611	33.18	0	0	0.79	0.08	0	0.51	7.37	0	0	0	0	0	51.21	0	93.14
PQB6	Site 9	#612	32.48	0	0	0.54	0.06	0	0.58	7.88	0	0	0	0	0.07	51.02	0	92.63
PQB6	Site 9	#613	33	0	0	0.4	0.1	0	0.57	7.59	0	0	0	0	0	51.67	0	93.34
PQB6	Site 9	#614	5.17	0	0	0.18	0	0	0	44.24	0	0	0	0	0.11	37.45	0	87.16
PQB6	Site 9	#615	6.68	0	0	0.24	0	0	0	47.29	0	0.13	0	0	0.11	36.97	0	91.41
PQB6	Site 9	#616	10.7	0	0	0.27	0.05	0	0	44.65	0	0.1	0	0.08	0.14	37.31	0	93.3
PQB6	Site 9	#617	4.4	0	0	0.19	0	0	0	47.12	0	0	0	0.09	0.12	39.36	0	91.28
PQB6	Site 9	#618	26.59	0	0	0.56	0.28	0	0.27	3.98	0.05	0	0.08	0	0.16	63.02	0	94.99
PQB6	Site 9	#619	27.23	0	0	1.2	0.37	0	0.39	4.58	0.08	0	0.1	0	0.22	60.29	0	94.45
PQB6	Site 9	#620	26.03	0	0	0.95	0.36	0	0.3	4.8	0.05	0	0.12	0	0.28	61.89	0	94.78
PQB6	Site 9	#621	25.98	0	0.09	1.02	0.34	0.06	0.25	4.64	0.09	0	0.1	0	0.37	62.71	0	95.65
PQB6	Site 9	#622	22.65	0	0.15	0.73	0.12	0	0	0	0	0	0	0	0.63	74.14	0	98.43
PQB6	Site 9	#623	24.87	0	0.11	0.8	0.32	0	0.14	4.75	0.09	0	0.08	0	0.43	62.49	0	94.06
PQB6	Site 9	#624	24.99	0	0.13	0.86	0.29	0.08	0.06	4.12	0.1	0	0.08	0	0.42	64.05	0	95.19
PQB6	Site 9	#625	22.75	0	0.18	0.72	0.13	0	0	0.05	0	0	0.06	0	0.6	73.85	0	98.35
PQB7	Site 2	#324	0.56	0	0	0.15	0	0	0	0	0	0	0	0	0	97.25	0.55	98.52
PQB7	Site 2	#325	0.5	0	0	0.2	0	0	0	0	0	0	0	0	0	96.83	0.65	98.18
PQB7	Site 2	#326	0.42	0	0	0.13	0	0	0	0	0	0	0	0	0	97.03	0.53	98.12
PQB7	Site 2	#327	0.48	0	0	0.16	0	0	0	0	0	0	0	0	0	97.39	0.31	98.34
PQB7	Site 2	#328	0.6	0	0	0.17	0	0	0	0	0	0	0	0	0	97.59	0.54	98.9
PQB7	Site 2	#329	0.45	0	0	0.15	0	0	0	0	0	0	0	0	0	96.77	0.68	98.05
PQB7	Site 3	#330	0.43	0	0	0.17	0	0	0	0	0	0	0	0	0	97.57	0.53	98.7
PQB7	Site 3	#331	0.44	0	0	0.15	0	0	0	0	0	0	0	0	0	96.18	0.5	97.28
PQB7	Site 3	#333	0.48	0	0	0.2	0	0.07	0	0	0	0	0	0	0	96.5	0.77	98.02
PQB7	Site 3	#334	0.46	0	0	0.16	0	0	0	0	0	0	0	0	0	97.04	0.7	98.37
PQB7	Site 3	#335	0.51	0	0	0.2	0	0	0	0	0	0	0	0	0	97.34	0.44	98.49
PQB7	Site 4	#336	0.53	0	0	0.19	0	0	0	0	0	0	0	0	0	97.87	0.55	99.14

PQB7	Site 4	#337	0.45	0	0	0.14	0	0	0	0	0	0	0	0	0	97.36	0.59	98.53
PQB7	Site 4	#338	0.41	0	0	0.18	0	0	0	0	0	0	0	0	0	97.13	0.66	98.38
PQB7	Site 4	#339	0.51	0	0	0.17	0	0	0	0	0	0	0	0	0	97.78	0.5	98.96
PQB7	Site 4	#340	0.38	0	0	0.15	0	0	0	0	0	0	0	0	0	97.32	0.39	98.24
PQB7	Site 4	#341	0.33	0	0	0.18	0	0	0	0	0	0	0	0	0	97.27	0.4	98.19
PQB7	Site 4	#342	0.49	0	0	0.19	0	0	0	0	0	0	0	0	0	97.3	0.53	98.51
PQB7	Site 4	#343	0.37	0	0	0.19	0	0	0	0	0	0	0	0	0	97.71	0.53	98.8
PQB7	Site 4	#344	0.49	0	0	0.2	0	0	0	0	0	0	0	0	0	97.42	0.74	98.85
PQB7	Site 4	#345	0.36	0	0	0.18	0	0	0	0	0	0	0	0	0	97.56	0.45	98.54
PQB7	Site 4	#346	0.29	0	0	0.2	0	0	0	0	0	0	0	0	0	97.3	0.37	98.16
PQB7	Site 4	#347	0.37	0	0	0.18	0	0	0	0	0	0	0	0	0	97.1	0.53	98.19
PQB7	Site 4	#348	0.46	0	0	0.15	0	0	0	0	0	0	0	0	0	96.92	0.45	97.99
PQB7	Site 4	#349	0.51	0	0	0.17	0	0	0	0	0	0	0	0	0	97.13	0.61	98.41
PQB7	Site 4	#350	0.36	0	0	0.21	0	0	0	0	0	0	0	0	0	96.91	0.66	98.14
PQB7	Site 4	#351	0.4	0	0	0.15	0	0	0	0	0	0	0	0	0	96.97	0.67	98.19
PQB7	Site 4	#352	0.45	0	0	0.17	0	0	0	0	0	0	0	0	0	96.97	0.68	98.27
PQB7	Site 4	#353	0.46	0	0	0.22	0	0	0	0	0	0	0	0	0	97.23	0.62	98.52
PQB7	Site 4	#354	0.54	0	0	0.17	0	0	0	0	0	0	0	0	0	97.27	0.66	98.64
PQB7	Site 4	#355	0.54	0	0	0.18	0	0	0	0	0	0	0	0	0	97.44	0.42	98.57
PQB7	Site 4	#356	0.29	0	0	0.17	0	0	0	0	0	0	0	0	0	97.08	0.71	98.25
PQB7	Site 4	#357	0.52	0	0	0.2	0	0	0	0	0	0	0	0	0	97.45	0.53	98.71
PQB7	Site 4	#358	0.41	0	0	0.2	0	0	0	0	0	0	0	0	0	97.53	0.54	98.67
PQB7	Site 4	#359	0.45	0	0	0.18	0	0	0	0	0	0	0	0	0	97.33	0.44	98.41
PQB7	Site 4	#360	0.42	0	0	0.16	0	0	0	0	0	0	0	0	0	97.35	0.4	98.34
PQB7	Site 4	#361	0.29	0	0	0.14	0	0	0	0	0	0	0	0	0	97.16	0.4	98
PQB7	Site 4	#362	0.38	0	0	0.16	0	0	0	0	0	0	0	0	0	97.12	0.46	98.1
PQB7	Site 4	#363	0.48	0	0	0.2	0	0	0	0	0	0	0	0	0	97.31	0.55	98.53
PQB7	Site 4	#364	0.51	0	0	0.17	0	0	0	0	0	0	0	0	0	97.36	0.43	98.47
PQB7	Site 4	#365	0.38	0	0	0.18	0	0	0	0	0	0	0	0	0	97.33	0.44	98.33
PQB7	Site 4	#366	0.41	0	0	0.18	0	0	0	0	0	0	0	0	0	97.35	0.51	98.45
PQB7	Site 4	#367	0.42	0	0	0.16	0	0	0	0	0	0	0	0	0	97.21	0.65	98.43
PQB7	Site 4	#368	0.48	0	0	0.14	0	0	0	0	0	0	0	0	0	97.39	0.59	98.61

PQB7	Site 4	#369	21.23	0	0.14	16.68	0.23	0	0.07	0.33	0	0	0	0	0	73.82	1.08	113.58
PQB7	Site 4	#370	9.8	0	0.1	1.19	0.11	0	0.1	0.41	0	0	0	0	0	93.75	0.94	106.39
PQB7	Site 5	#371	27.61	0.21	0.27	1.79	2.21	0.07	0.1	0.13	0.16	0.25	0.06	0	0.64	65.34	0	98.84
PQB7	Site 5	#372	23.84	0	0	0.09	0	0	0	16.95	0	0	0	0	0.09	53.37	0	94.33
PQB7	Site 5	#373	25.09	0	0	0.13	0	0	0	15.38	0	0	0	0	0	54.59	0	95.19
PQB7	Site 5	#374	23.7	0	0	0.12	0	0	0	17.25	0	0	0	0	0	53.3	0	94.38
PQB7	Site 5	#375	29.26	0	0	0.14	0.08	0	0	5.96	0	0.11	0	0	0	59.8	0	95.36
PQB7	Site 5	#376	31.58	0	0	0.24	0	0	0.23	11.85	0	0	0	0	0	50.75	0.19	94.85
PQB7	Site 5	#377	24.64	0	0	0.14	0	0	0	16.14	0	0	0	0	0	53.98	0	94.91
PQB7	Site 5	#378	24.69	0.15	0.3	1.71	1.33	0	0	0.05	0.08	0.13	0.06	0	0.59	68.69	0	97.78
PQB7	Site 5	#379	31.36	0.18	0.17	1.88	2.16	0.06	0.17	0.73	0.14	0.23	0.07	0	0.32	61.04	0	98.52
PQB7	Site 6	#380	30.73	0.98	0.42	4.44	10.11	0.09	0	0.06	1.19	0.66	0.15	0	0.32	52.33	0	101.49
PQB7	Site 6	#381	29.07	0	0	0.63	0.11	0	0.09	13.51	0	0	0	0	0	52.01	0	95.42
PQB7	Site 6	#382	33.21	0	0	1.95	0.1	0	0.42	6.96	0.05	0.09	0	0	0	50.39	0	93.17
PQB7	Site 7	#383	31.83	0	1.11	0.32	13.81	0	0	0	0	0.19	0	0	0.49	51.76	0	99.5
PQB7	Site 7	#384	32.08	0	1.36	0.24	13.96	0	0	0	0	0.15	0	0	0.53	51.44	0	99.77
PQB7	Site 7	#385	31.85	0	1.46	0.28	13.91	0	0	0	0	0.13	0	0	0.55	51.28	0	99.46
PQB7	Site 7	#386	31.71	0	1.33	0.25	13.85	0	0	0	0	0.15	0	0	0.55	51.52	0	99.36
PQB7	Site 7	#387	31.21	0	0.91	0.31	13.75	0	0	0	0	0.18	0	0	0.54	51.86	0	98.77
PQB7	Site 7	#388	31.55	0	1.04	0.23	13.8	0	0	0	0	0.17	0	0	0.56	51.9	0	99.24
PQB7	Site 7	#389	31.57	0	0.78	0.32	13.71	0.08	0	0	0	0.21	0	0	0.53	52.18	0	99.38
PQB7	Site 7	#390	31.98	0	0.61	0.36	13.68	0	0	0	0.06	0.26	0.06	0	0.53	52.36	0	99.88
PQB7	Site 7	#391	31.78	0	0.76	0.28	13.88	0	0	0	0.05	0.19	0	0	0.57	52.24	0	99.75
PQB7	Site 7	#392	31.82	0	1.2	0.2	13.98	0	0	0	0	0.15	0	0	0.53	51.71	0	99.59
PQB7	Site 7	#393	31.9	0	1.32	0.25	13.89	0	0	0	0	0.15	0	0	0.55	51.59	0	99.65
PQB7	Site 7	#394	31.75	0	0.98	0.24	13.84	0	0	0	0	0.21	0	0	0.58	51.72	0	99.31
PQB7	Site 7	#395	31.93	0	1.39	0.26	13.93	0	0	0	0	0.14	0	0	0.56	51.53	0	99.74
PQB7	Site 7	#396	31.92	0	1.45	0.26	13.93	0	0	0	0	0.14	0	0	0.52	51.45	0	99.66
PQB7	Site 7	#397	31.86	0	1.53	0.42	13.7	0.06	0	0	0	0.14	0	0	0.54	51.29	0	99.54
PQB7	Site 7	#398	31.75	0	1.28	0.19	13.93	0	0	0	0	0.15	0	0	0.53	51.66	0	99.5
PQB7	Site 7	#399	23.21	0	0.09	0.63	0.29	0	0	0.11	0	0	0.26	0	0.18	72.93	0	97.7
PQB7	Site 7	#400	22.65	0	0	0.52	0.15	0	0	0	0	0	0.24	0	0.18	74.22	0	97.97

PQB7	Site 7	#401	28.5	0	0	0.17	0	0	0.2	0.28	0	0	0	0	0	68.1	0	97.25
PQB7	Site 7	#402	27.09	0	0	0.13	0.07	0	0.11	0	0	0	0	0	0.13	69.83	0	97.36
PQB7	Site 7	#403	27.84	0	0	0.16	0	0	0.18	0.23	0	0	0	0	0.09	68.77	0	97.28
PQB7	Site 7	#404	35.22	0	0	2.2	0.14	0	0.41	5.16	0	0	0	0	0	52.62	0	95.75
PQB7	Site 7	#405	31.42	0	0	1.56	0.11	0	0.41	6.43	0	0	0	0	0	52.47	0	92.4
PQB7	Site 7	#406	40.74	3.14	0	12.75	17.54	0.25	0.11	0	4.4	4.05	0.14	0	0.15	17	0	100.24
PQB7	Site 7	#407	40.89	3.22	0	12.98	17.7	0.23	0.09	0.05	4.92	3.76	0.12	0	0.14	15.03	0	99.14
PQB7	Site 7	#408	41.31	3.2	0	12.56	18.32	0.23	0.11	0	5.22	3.19	0.1	0	0.15	15.98	0	100.38
PQB7	Site 8	#409	33.04	0.11	0.36	1.19	13.82	0.08	0	0	0.61	0.69	0	0	0.47	49.16	0	99.53
PQB7	Site 8	#410	31.71	0	0.56	0.29	13.78	0	0	0	0	0.24	0	0	0.52	52.41	0	99.5
PQB7	Site 8	#411	31.74	0	0.75	0.24	13.82	0	0	0	0	0.2	0	0	0.53	52.14	0	99.43
PQB7	Site 8	#412	32.07	0	0.96	0.23	13.92	0	0	0	0.05	0.18	0	0	0.52	51.99	0	99.92
PQB7	Site 8	#413	31.86	0	1.21	0.24	13.89	0	0	0	0	0.16	0	0	0.52	51.64	0	99.51
PQB7	Site 8	#414	31.75	0	1.32	0.23	13.9	0	0	0	0	0.15	0	0	0.54	51.6	0	99.49
PQB7	Site 8	#415	31.89	0	1.48	0.37	13.75	0	0	0	0	0.17	0	0	0.53	51.23	0	99.43
PQB7	Site 8	#416	31.82	0	1.39	0.21	13.91	0	0	0	0	0.17	0	0	0.54	51.54	0	99.59
PQB7	Site 8	#417	31.7	0	1.4	0.22	13.65	0	0	0	0	0.14	0	0	0.5	52.37	0	99.98
PQB7	Site 8	#418	31.32	0	0.74	0.51	13.21	0.06	0	0	0	0.21	0	0	0.54	52.23	0	98.81
PQB7	Site 8	#419	34.76	0.9	0.35	6.48	13.3	0.1	0	0.06	2.09	0.56	0.08	0	0.34	39.52	0	98.55
PQB7	Site 8	#420	38.02	0.8	0.22	8.76	13.17	0.14	0	0	2.38	1.29	0.15	0	0.36	36.81	0	102.11
PQB7	Site 8	#421	38.35	1.44	0.2	6.43	15.86	0.15	0	0	3.09	1.49	0	0	0.34	34.69	0	102.04
PQB7	Site 8	#422	38.93	1.46	0.15	7.08	15.58	0.14	0	0	3.1	2.17	0.07	0	0.3	31.64	0	100.61
PQB7	Site 8	#423	41.18	3.26	0	12.98	17.71	0.21	0.1	0	4.81	3.38	0.11	0	0.15	15.91	0	99.79
PQB7	Site 8	#424	40.3	3.03	0	12.13	17.94	0.23	0.1	0.1	4.94	3.3	0.09	0	0.12	16.01	0	98.28
PQB7	Site 8	#425	41.18	3.09	0	11.58	19.08	0.3	0.17	0	6	3.62	0.13	0	0.12	12.49	0	97.77
PQB7	Site 8	#426	41.55	3.15	0	11.61	19.82	0.3	0.16	0	6.15	3.67	0.09	0	0.1	12.52	0	99.13
PQB7	Site 8	#427	42.78	0.95	0	20.45	9.49	0.12	0.05	0	2.86	0.71	0.32	0	0.18	29.85	0	107.75
PQB7	Site 8	#428	33.4	2.86	0	7.73	11.77	0.1	0.07	0	3.18	1.14	0.17	0	0.17	48.69	0	109.29
PQB7	Site 8	#429	39.62	2.23	0.1	7.43	17.97	0.21	0.07	0	3.62	1.41	0.07	0	0.38	32.72	0	105.83
PQB7	Site 8	#430	42.82	1.23	0.08	19.78	10.97	0.1	0	0	3.46	0.83	0.24	0	0.19	27.22	0	106.91
PQB7	Site 8	#431	35.82	0.59	0.23	6.96	14.14	0.09	0	0	2.38	0.62	0.05	0	0.33	38.07	0	99.28
PQB7	Site 8	#432	34.41	0.63	0.25	6.64	12.08	0.08	0	0	0.71	0.45	0.12	0	0.38	49.17	0	104.92

PQB7	Site 10	#433	34.9	0	0	0.23	0	0	0.28	2.12	0	0	0	0	0	56.63	0	94.16
PQB7	Site 10	#434	35.5	0	0	0.18	0.05	0	0.32	2.45	0	0	0	0	0	56.46	0	94.98
PQB7	Site 10	#435	32.49	0	0	0.11	0	0	0.2	1.12	0	0	0	0	0	62.4	0	96.32
PQB7	Site 10	#436	32.95	0	0	0.15	0	0	0.2	1.21	0	0	0	0	0	61.28	0	95.79
PQB7	Site 10	#437	33.93	0	0	0.1	0.12	0	0.18	2.84	0	0	0	0	0	55.95	0	93.11
PQB7	Site 10	#438	35.09	0	0	0.12	0.09	0	0	0.81	0	0	0	0	0	57.97	0	94.07
PQB7	Site 10	#439	34.67	0	0	0.17	0.15	0	0.28	1.96	0	0	0	0	0	57.38	0	94.61
PQB7	Site 10	#440	35.37	0	0	0.17	0.18	0	0.29	2.17	0	0	0	0	0	56.46	0.61	95.25
PQB7	Site 10	#441	34.4	0	0.21	0.16	2.16	0	0.25	1.94	0	0	0	0	0.1	55.68	0	94.89
PQB7	Site 10	#442	27.34	0	0.15	1.06	0.29	0	0.12	2.55	0	0	0.16	0	0.11	65.89	0	97.68
PQB7	Site 10	#443	28.2	0	0.16	0.93	0.24	0	0.21	1.71	0	0	0.16	0	0.11	65.91	0	97.63
PQB7	Site 10	#444	22.92	0	0.25	0.6	0.14	0	0	0	0	0	0.12	0	0.26	74.2	0	98.47
PQB7	Site 10	#445	22.81	0	0.25	0.63	0.14	0	0	0	0	0	0.1	0	0.23	73.98	0	98.16
PQB7	Site 10	#446	28.29	0	0.1	0.84	0.2	0	0.15	0.86	0	0	0.13	0	0.13	67	0	97.72
PQB7	Site 10	#447	27.17	0	0.16	0.86	0.29	0	0.22	1.54	0	0	0.19	0	0.14	66.44	0	97.02
PQB7	Site 10	#448	25.49	0	0.24	0.79	0.17	0	0.06	0.6	0	0	0.1	0	0.22	71.89	0	99.55
PQB7	Site 10	#449	23.77	0	0.22	0.73	0.12	0	0	0.06	0	0	0.1	0	0.22	73.63	0	98.85
PQB7	Site 10	#450	31.8	0	0.86	0.28	13.83	0	0	0	0	0.24	0	0	0.54	52.15	0	99.7
PQB7	Site 10	#451	31.73	0	1.41	0.29	13.84	0	0	0	0	0.18	0	0	0.57	51.55	0	99.58
PQB7	Site 10	#452	31.82	0	1.34	0.22	13.92	0	0	0	0	0.17	0	0	0.63	51.57	0	99.68
PQB7	Site 10	#453	31.72	0	1.14	0.21	13.87	0.07	0	0	0	0.22	0	0	0.57	51.8	0	99.59
PQB7	Site 10	#454	31.78	0	1.38	0.2	13.98	0	0	0	0	0.19	0	0	0.6	51.14	0	99.27
PQB7	Site 10	#455	31.55	0	1.31	0.28	13.88	0	0	0	0	0.15	0	0	0.57	51.1	0	98.82
PQB7	Site 10	#456	32.07	0	1.41	0.3	13.89	0	0	0	0	0.15	0	0	0.56	51.17	0	99.55
PQB7	Site 10	#457	32.07	0	1.37	0.19	13.98	0	0	0	0	0.16	0	0	0.56	51.37	0	99.69
PQB7	Site 10	#458	31.97	0	0.95	0.28	13.8	0	0	0	0	0.25	0	0	0.6	51.94	0	99.79
PQB7	Site 10	#459	40.24	3.2	0	13.33	16.62	0.33	0.13	0	4.53	3.17	0.11	0	0.17	17.57	0	99.41
PQB7	Site 10	#460	41.44	3.22	0	12.39	18.71	0.33	0.12	0	6.16	3.17	0	0	0.17	14.27	0	99.97
PQB7	Site 10	#461	23.23	0	0.19	0.74	0.13	0	0	0	0	0	0.11	0	0.19	73.82	0	98.42
PQB7	Site 10	#462	22.83	0	0.2	0.72	0.12	0	0	0	0	0	0.1	0	0.2	74.03	0	98.2
PQB7	Site 10	#463	23.11	0	0.16	0.69	0.16	0	0	0	0	0	0.13	0	0.2	73.96	0	98.42
PQB7	Site 10	#464	27.05	0.54	0.48	2.59	5.62	0.06	0	0.06	0.61	0.33	0.1	0	0.29	63.04	0	100.77

PQB7	Site 11	#465	24.85	0.16	0.38	1.5	2.26	0	0	0.34	0.22	0.12	0.08	0	0.29	69.05	0	99.26
PQB7	Site 12	#466	25.51	0.25	0.31	1.73	2.88	0.06	0	0.28	0.22	0.24	0.08	0	0.66	67.2	0	99.43
PQB7	Site 13	#467	34.39	0	0	0.18	0.08	0	0.07	0.42	0	0.06	0	0	0	59.25	0	94.45
PQB7	Site 13	#468	34.26	1.06	0.36	5.29	14.18	0.11	0.05	0	1.46	0.86	0.11	0	0.38	42.9	0	101.02
PQB7	Site 13	#469	33.93	0.83	0.48	4.37	12.89	0.09	0	0.49	1.13	0.63	0.13	0	0.38	44.54	0	99.9
PQB7	Site 14	#470	41.31	3.17	0	11.53	19.35	0.29	0.15	0	5.79	4.01	0.16	0	0.09	14.04	0	99.89
PQB7	Site 14	#471	41.71	3.26	0	12.07	19.58	0.26	0.12	0	6.13	3.85	0.11	0	0.07	12.75	0	99.9
PQB7	Site 14	#472	41.2	3.1	0	11.19	19.48	0.24	0.07	0	5.95	3.72	0.15	0	0.09	14.19	0	99.36
PQB7	Site 14	#473	32.32	0.19	0.17	0.94	14.09	0.07	0	0	0.22	0.55	0	0	0.5	51.93	0	100.97
PQB7	Site 14	#474	32.97	0.34	0.31	1.39	14.34	0	0	0	0.35	0.4	0	0	0.55	51.43	0	102.07
PQB7	Site 14	#475	31.71	0	0.53	0.52	13.69	0	0	0	0	0.25	0	0	0.54	52.26	0	99.5
PQB7	Site 14	#476	32.4	0.19	0.17	0.74	14.13	0	0	0	0.16	0.47	0	0	0.52	52.42	0	101.21
PQB7	Site 14	#477	31.89	0	0.45	0.37	14.03	0	0	0	0.05	0.23	0	0	0.55	52.49	0	100.06
PQB7	Site 14	#478	31.89	0	1.02	0.6	13.49	0	0	0	0	0.16	0.07	0	0.52	51.76	0	99.52
PQB7	Site 14	#479	31.65	0	0.81	0.49	13.68	0	0	0	0	0.18	0	0	0.51	52.03	0	99.36
PQB7	Site 14	#480	31.97	0	0.91	0.6	13.64	0.07	0	0	0	0.23	0.06	0	0.54	51.93	0	99.95
PQB7	Site 14	#481	32.4	0.13	0.99	1.03	13.73	0	0	0	0.25	0.29	0	0	0.53	51.04	0	100.39
PQB7	Site 14	#482	32.04	0	0.95	0.56	13.55	0	0	0	0.17	0.23	0	0	0.5	51.62	0	99.61
PQB7	Site 14	#483	31.51	0	0.83	0.33	13.65	0	0	0	0	0.21	0	0	0.58	52.05	0	99.15
PQB7	Site 14	#484	32.55	0.6	0.14	1.26	14.52	0	0	0	0.31	0.53	0	0	0.51	51.44	0	101.85
PQB7	Site 14	#485	33.7	0.35	0.32	1.59	14.51	0	0	0	0.72	0.67	0	0	0.45	49.72	0	102.03
PQB7	Site 14	#486	31.81	0	0.55	0.29	13.83	0	0	0	0.05	0.23	0	0	0.54	52.58	0	99.89
PQB7	Site 14	#487	31.8	0	0.7	0.42	13.73	0	0	0	0	0.21	0	0	0.49	52.44	0	99.78
PQB7	Site 14	#488	32.86	0	0.98	0.87	13.76	0	0	0	0.47	0.36	0.06	0	0.51	49.93	0	99.82
PQB7	Site 14	#489	32.05	0	1.02	0.79	13.42	0	0	0	0	0.18	0	0	0.52	51.94	0	99.91
PQB7	Site 14	#490	31.98	0	0.93	0.53	13.56	0	0	0	0.06	0.17	0	0	0.55	51.91	0	99.68
PQB7	Site 14	#491	31.67	0	0.46	0.34	13.79	0	0	0	0.06	0.22	0	0	0.54	52.41	0	99.49
PQB7	Site 14	#492	40.64	0.57	0.11	22.03	5.56	0	0	0	1.77	0.38	0.46	0	0.17	33.63	0	105.33
PQB7	Site 14	#493	36.85	0	0.09	23.6	1.4	0	0	0	0.3	0.07	0.72	0	0.17	38.47	0	101.67
PQB7	Site 14	#494	37.29	0.28	0.1	24.95	2.36	0	0	0	0.57	0.19	0.56	0	0.19	36.18	0	102.67
PQB7	Site 14	#495	39.89	0.64	0	25.16	4.73	0	0	0	1.11	0.56	0.52	0	0.15	34.25	0	107.01
PQB7	Site 14	#496	33.02	0.4	0.12	1.82	13.08	0.12	0	0	0.73	0.66	0.24	0	0.43	49.29	0	99.9

PQB7	Site 14	#497	20.89	0	0	0.28	0	0	0	0.26	0	0	0	0	0	74.63	0.3	96.35
PQB7	Site 14	#498	22.51	0	0	0.24	0	0	0.19	0.28	0	0	0	0	0	71.38	0.89	95.48
PQB7	Site 14	#499	19.62	0	0	0.29	0	0	0	0.16	0	0	0	0	0	70.48	1.32	91.88
PQB7	Site 14	#500	25.69	0.17	0	1.14	0.87	0	0.07	0.1	0.17	0.09	0.13	0	0	69.89	0	98.31
PQB7	Site 14	#501	34.85	0	0	1.15	1.2	0	0	0.23	0	0.06	0.28	0	0.09	60.61	0	98.47
PQB7	Site 14	#502	35.59	0	0	0.17	0.11	0	0.11	0.22	0	0	0	0	0	58.75	0	94.95
PQB7	Site 14	#503	35.89	0	0	0.19	0	0	0	0.56	0	0	0	0	0	57.18	0.51	94.33
PQB7	Site 14	#504	37.06	0.28	0	2.58	1.14	0	0.09	0.37	0.13	0.08	0.42	0	0	57.26	0	99.41
PQB7	Site 14	#505	35.89	0	0	0.2	0.14	0	0.07	0.62	0	0	0	0	0	56.91	0	93.82
PQB7	Site 14	#506	30.38	0.9	0.16	5.13	4.91	0	0	0	0.55	0.35	0.52	0	0.16	64.72	0	107.78
PQB7	Site 14	#507	29.98	0.35	0.16	2.12	6.25	0.1	0.06	0	0.61	0.42	0.32	0	0.2	63.59	0	104.15
PQB7	Site 14	#508	36.63	0	0.09	25.1	1.23	0	0	0	0.17	0.09	0.62	0	0.13	37.9	0	101.97
PQB7	Site 14	#509	41.28	0.18	0.13	25.11	1.53	0	0	0.05	0.29	0.08	0.6	0	0.19	38.47	0	107.9
PQB7	Site 14	#510	31.9	0	0.82	0.82	13.61	0	0	0	0.08	0.25	0.06	0	0.53	52.13	0	100.2
PQB7	Site 14	#512	33.29	0	0	0.17	0	0	0	0.35	0	0.05	0	0	0	58.91	0.79	93.57
PQB7	Site 14	#511	34.23	0.37	0	6.61	3.87	0	0.39	0.39	0.94	0.5	1.01	0	0	41.53	0	89.83
PQB7	Site 14	#513	35.27	0	0	0.17	0	0	0	0.26	0	0	0	0	0	58.53	0.59	94.82
PQB7	Site 14	#514	36.13	0	0	0.17	0	0	0	0.32	0	0	0	0	0	57.82	1.81	96.24
PQB7	Site 14	#515	36.39	0	0	0.19	0	0	0	0.51	0	0	0	0	0	56.37	1.86	95.32

Appendix B

Archive of backscattered electron images, showing locations of EDS analyses

Archive plate captions

Plate A1 BSEM image montage of sample PQB5

Plate A2 BSEM images of sample PQB5

- i. Site 2. Analysis 626
- j. Site 3.
- k. Site 4. Analyses 627-665
- l. Site 5. Analysis 666
- m. Site 6. Analyses 667-682
- n. Site 7. Analyses 683-700
- o. Site 8. Analyses 701-703
- p. Site 9. Analyses 704-705

Plate A3 BSEM images of sample PQB5

- a. Site 10. Analyses 706-719
- b. Site 11. Analyses 720-725
- c. Site 12. Analysis 726
- d. Site 13. Analyses 727-745
- e. Site 14. Analyses 746-748
- f. Site 15.
- g. Site 16. Analyses 749-763
- h. Site 17. Analyses 764-769

Plate A4 BSEM images of sample PQB5

- a. Site 18.
- b. Site 19. Analyses 770-787

Plate A5 BSEM image montage of sample PQB6

Plate A6 BSEM images of sample PQB6

- a. Site 2. Analyses 516-521
- b. Site 3. Analyses 527-539
- c. Site 4. Analyses 540-556
- d. Site 5. Analyses 557-560
- e. Site 6. Analyses 561-563
- f. Site 7. Analyses 564-568
- g. Site 8. Analyses 569-610
- h. Site 9. Analyses 611-625

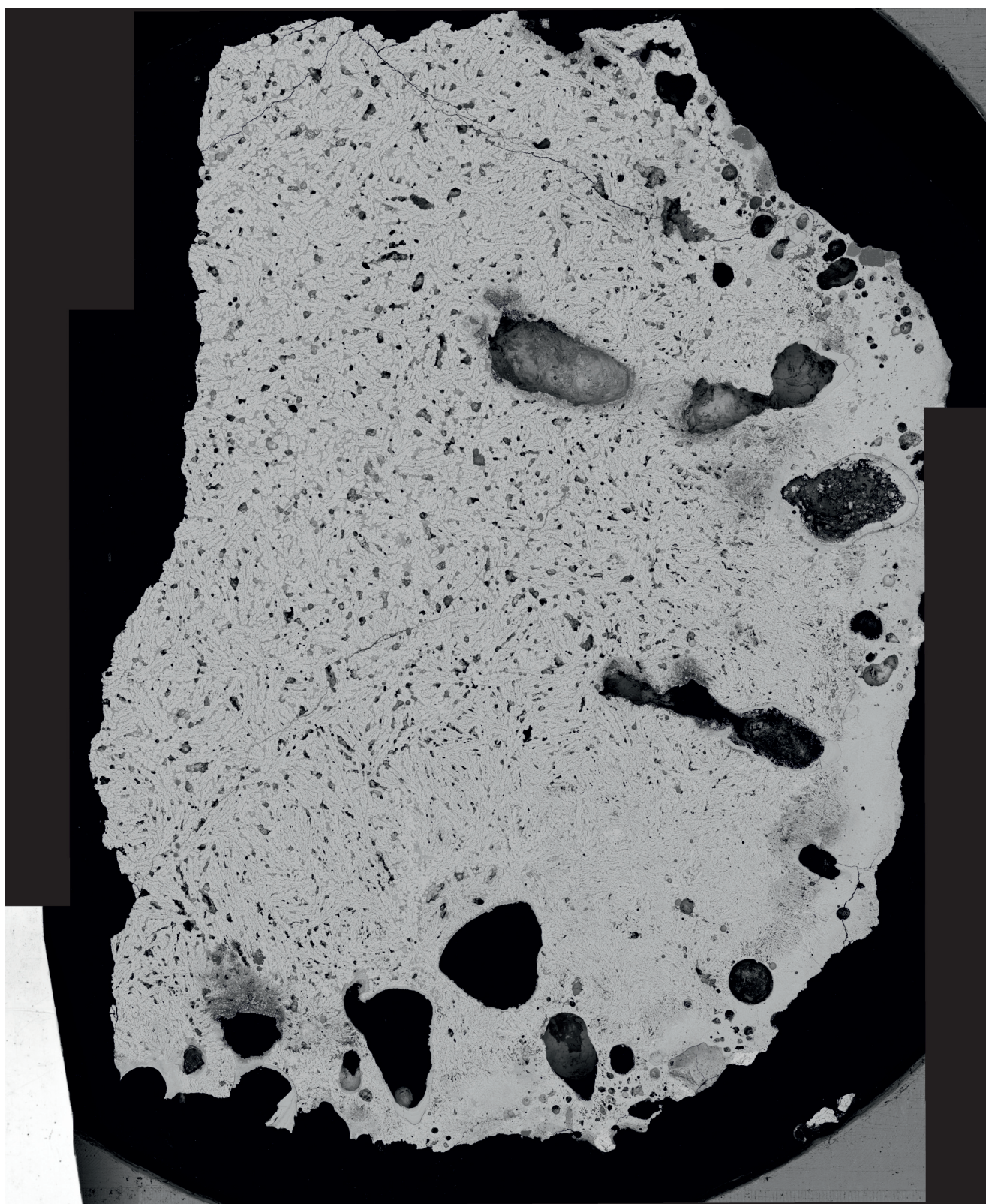
Plate A7 BSEM image montage of sample PQB7

Plate A8 BSEM images of sample PQB7

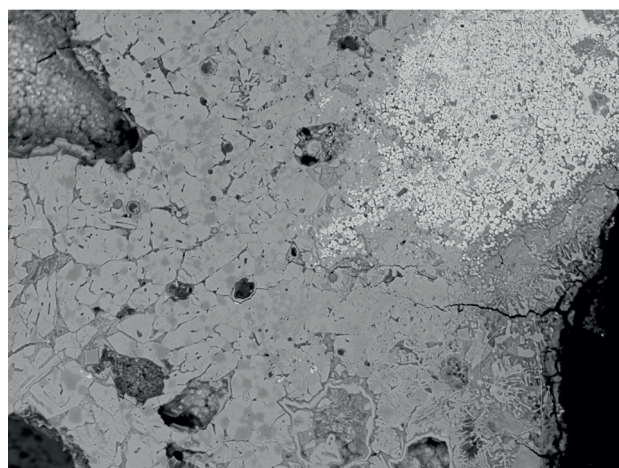
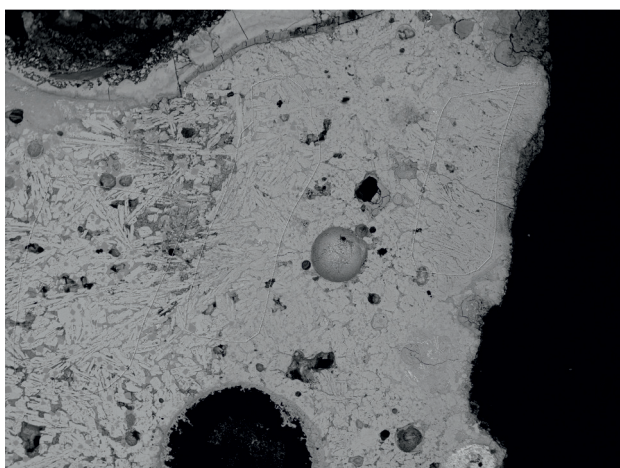
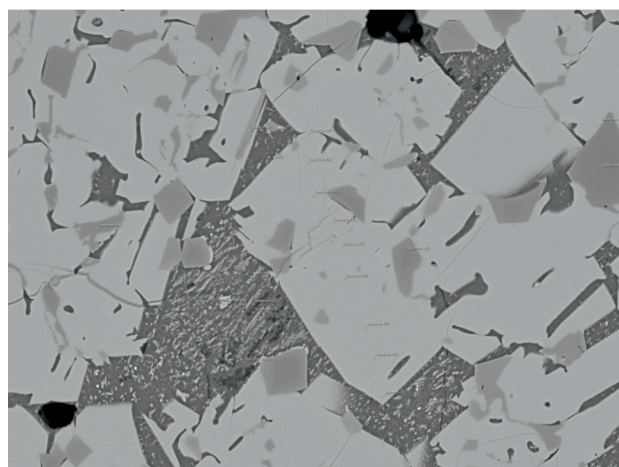
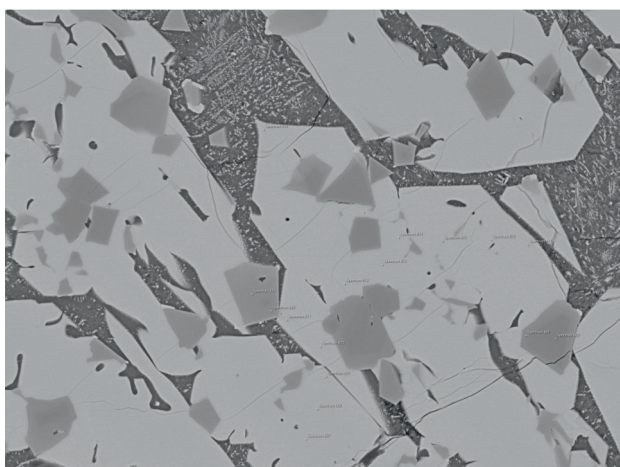
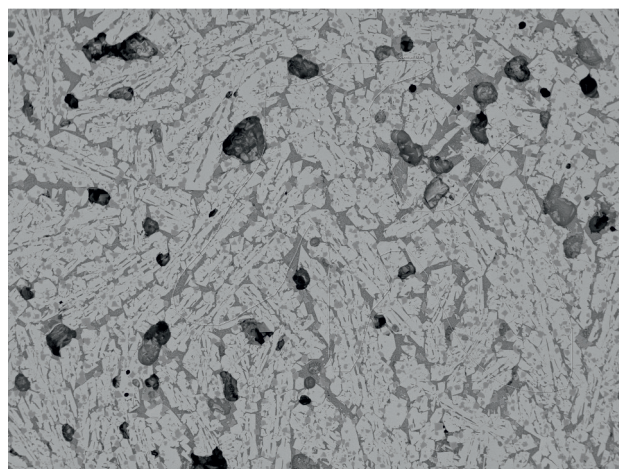
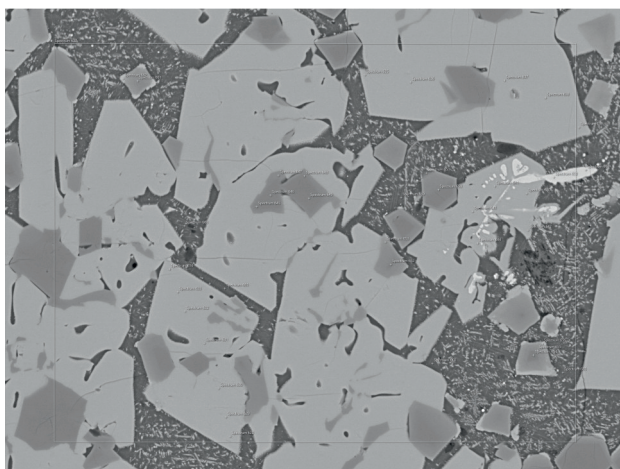
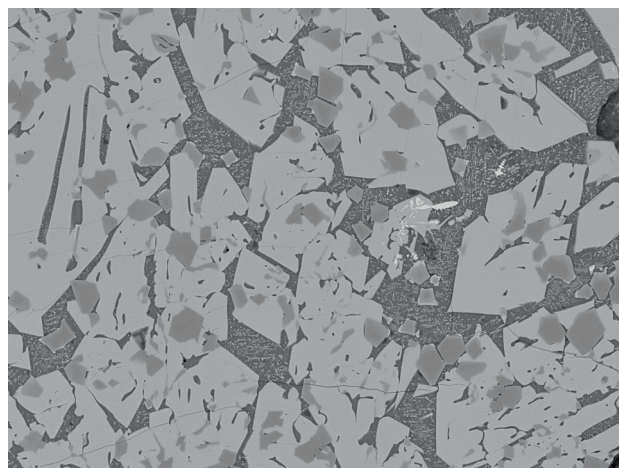
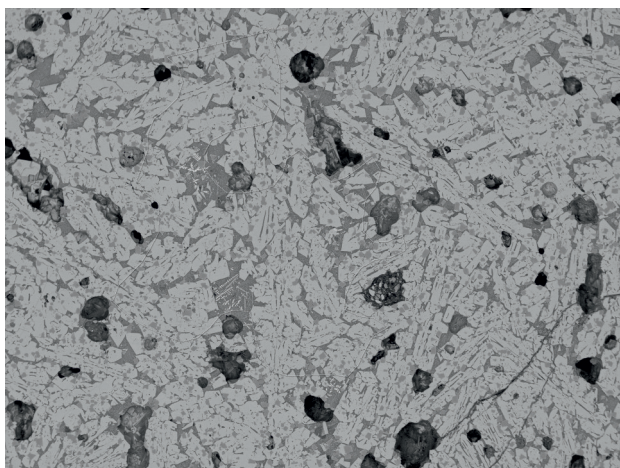
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- b. Site 3. Analyses 330-335
- c. Site 4. Analyses 336-370
- d. Site 5. Analyses 371-379
- e. Site 6. Analyses 380-382
- f. Site 7. Analyses 383-408
- g. Site 8. Analyses 409-432
- h. Site 9.

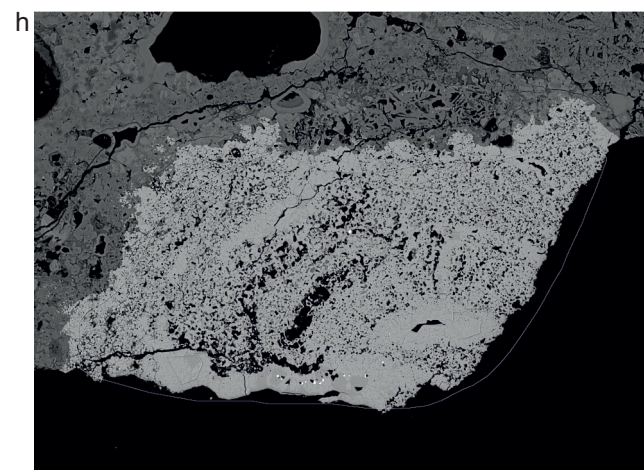
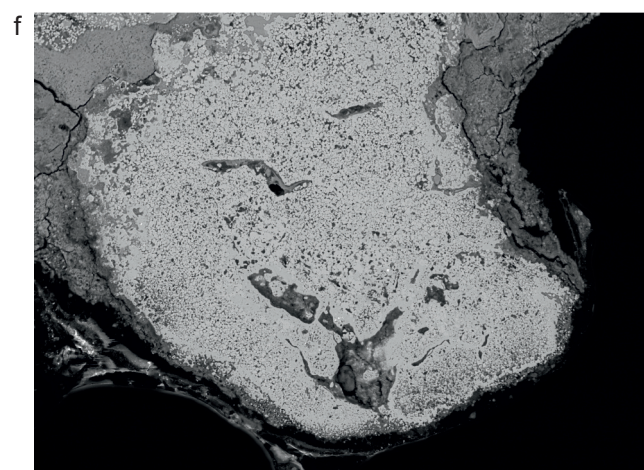
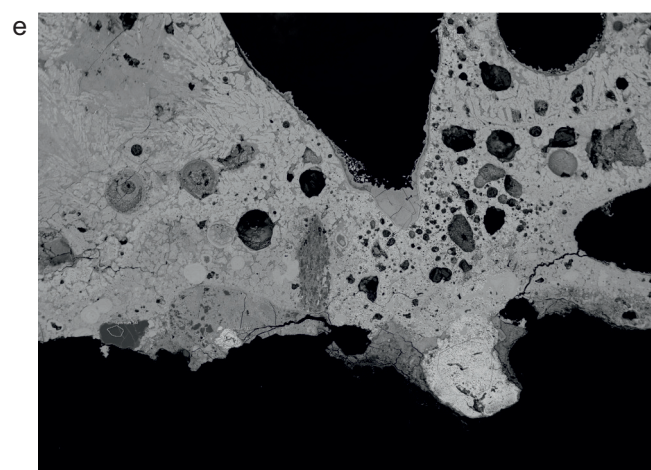
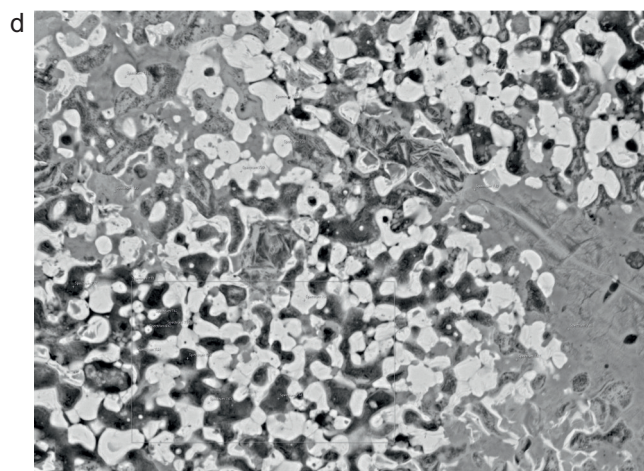
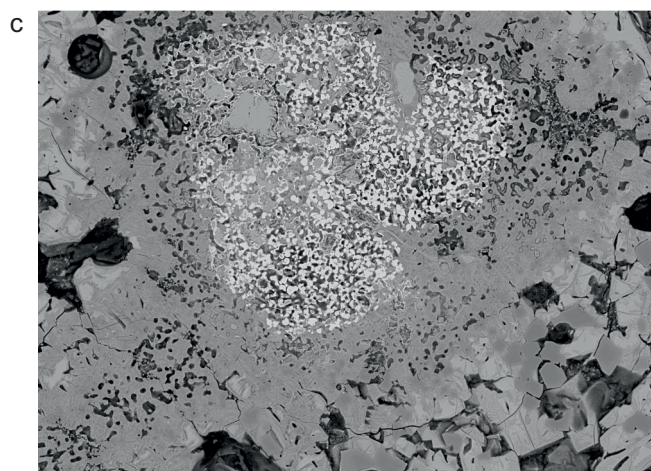
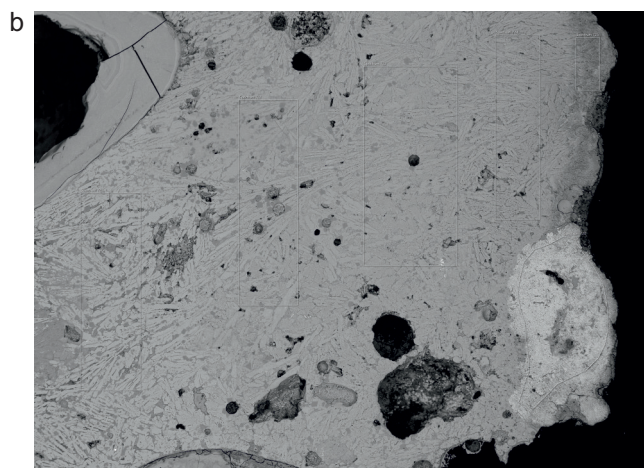
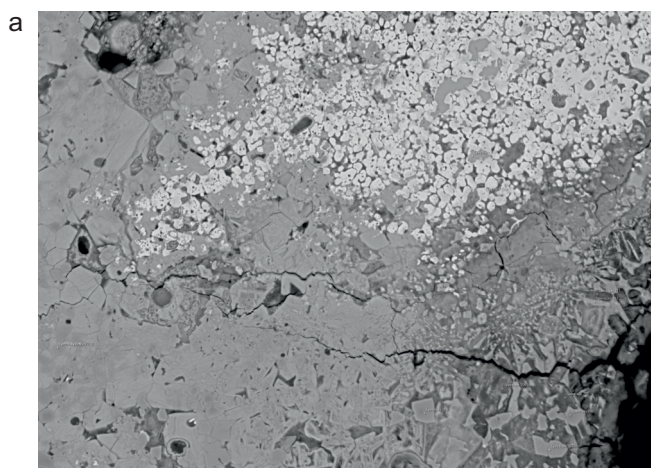
Plate A9 BSEM images of sample PQB7

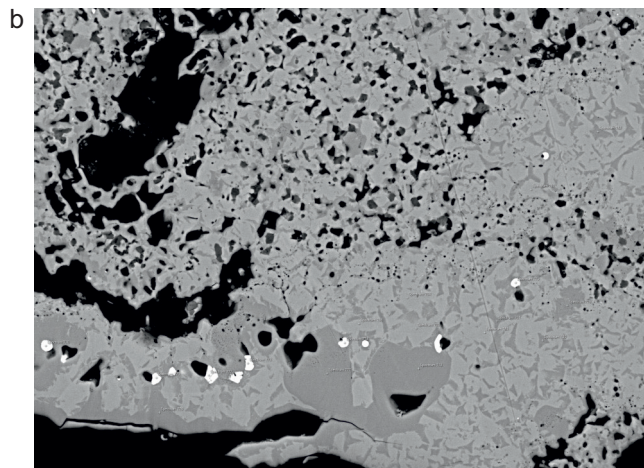
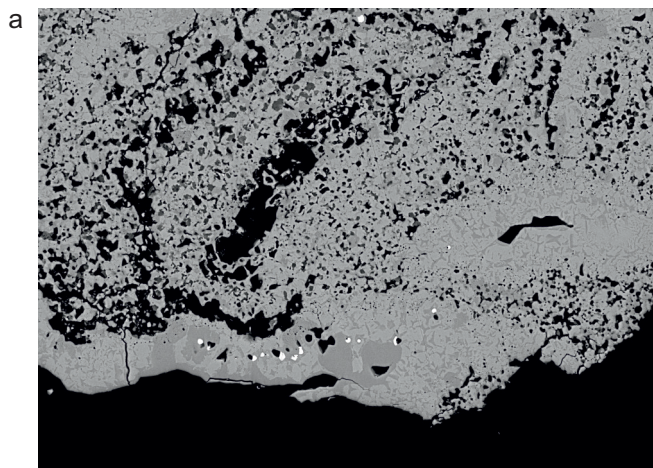
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- b. Site 11. Analysis 465
- c. Site 12. Analysis 466
- d. Site 13. Analyses 467-469
- e. Site 14. Analyses 470-515

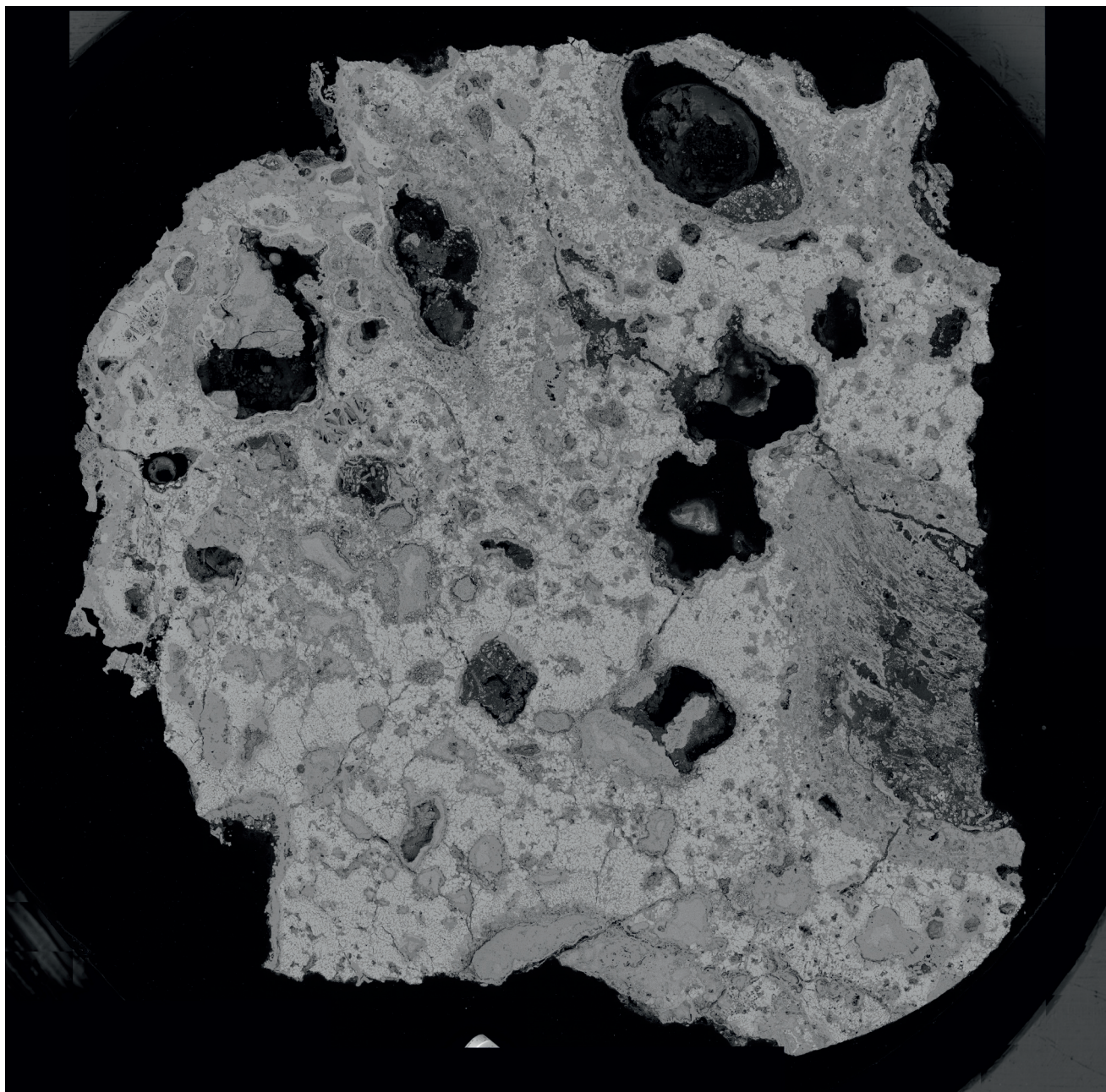


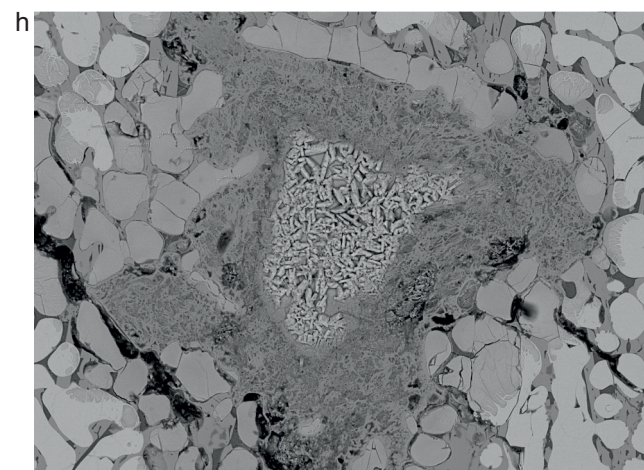
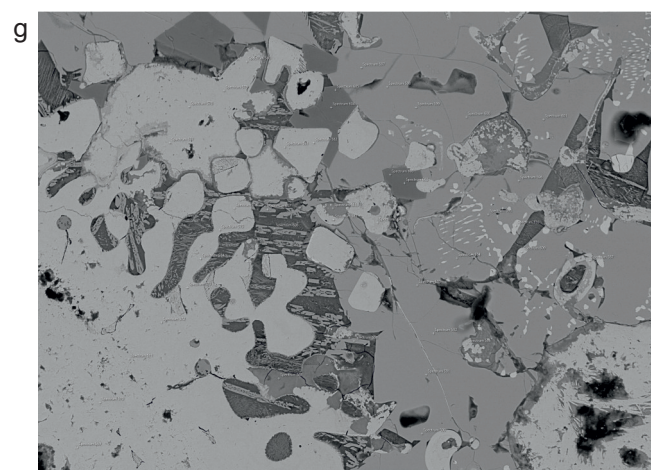
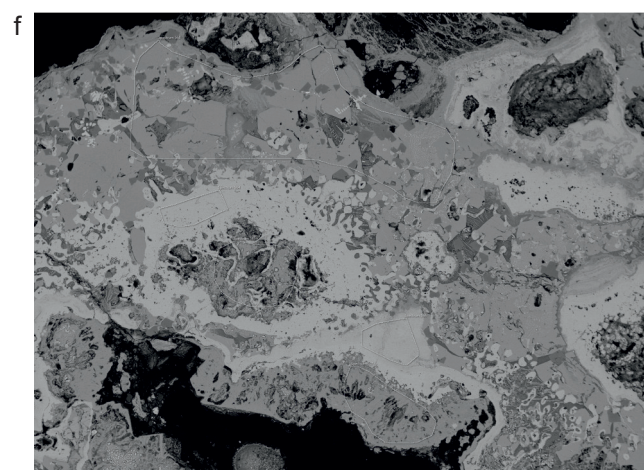
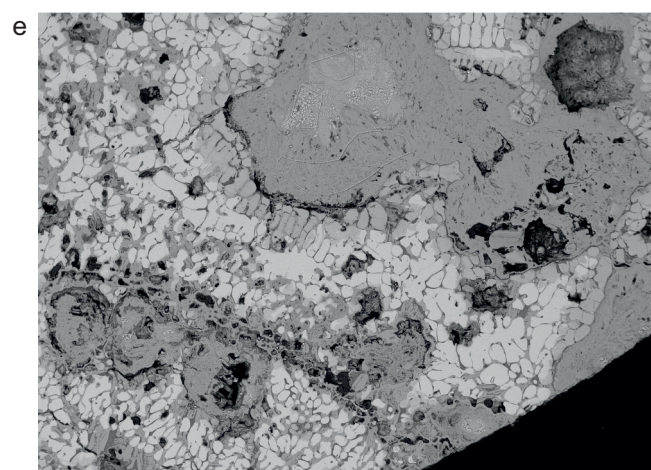
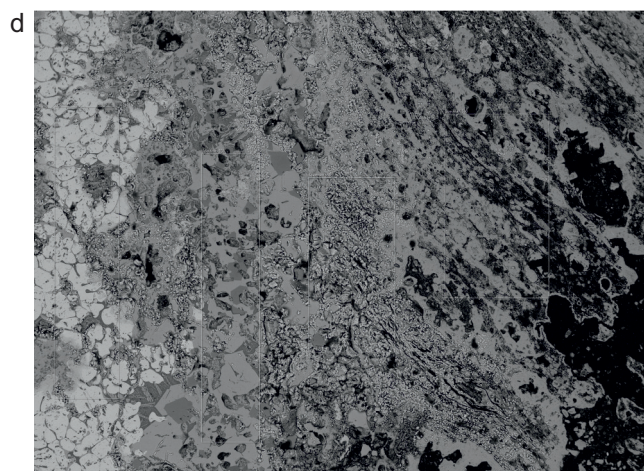
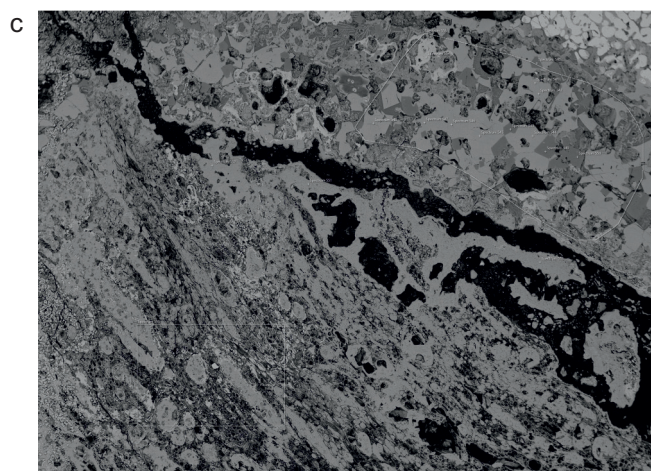
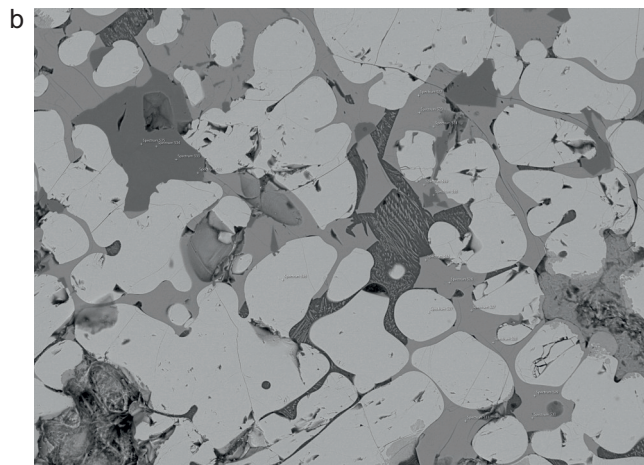
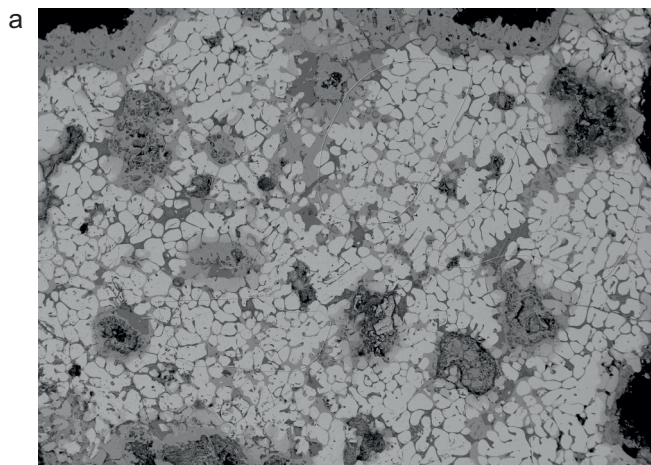
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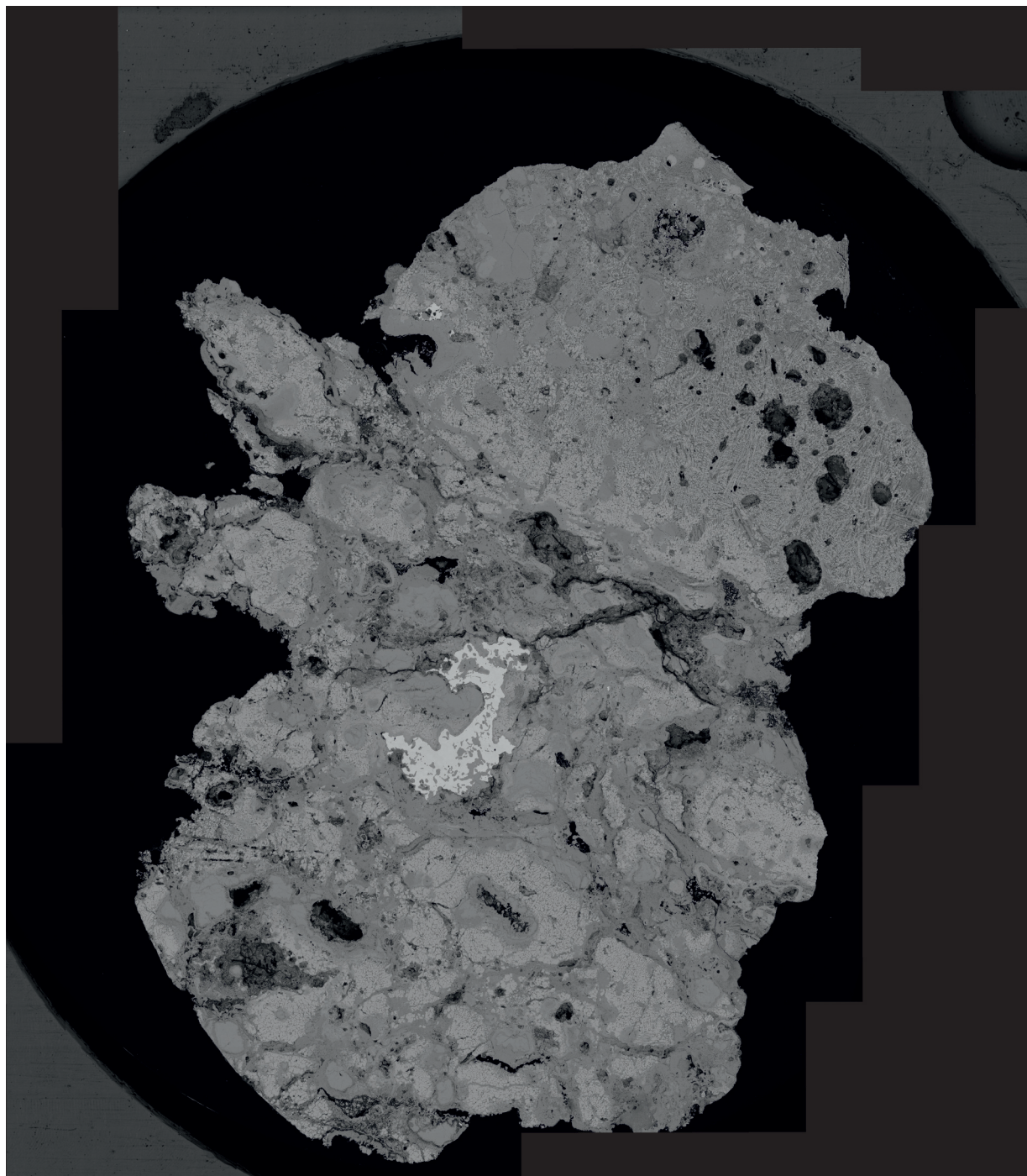


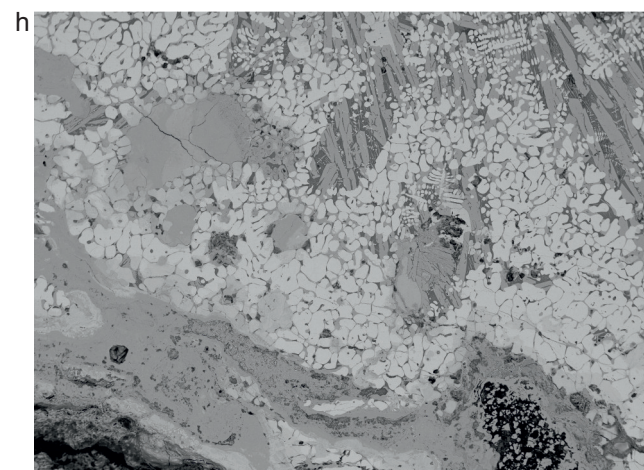
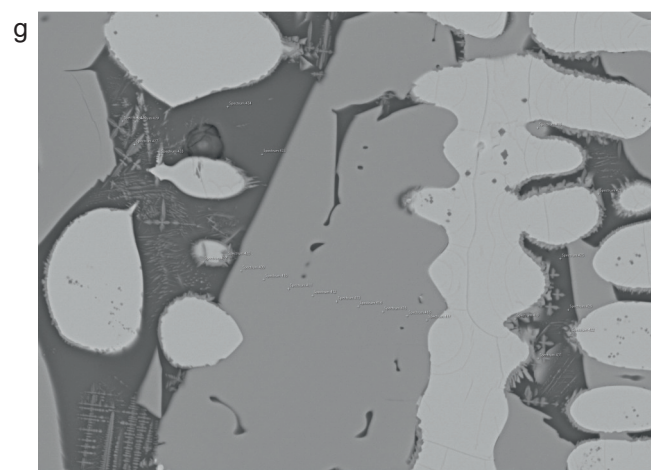
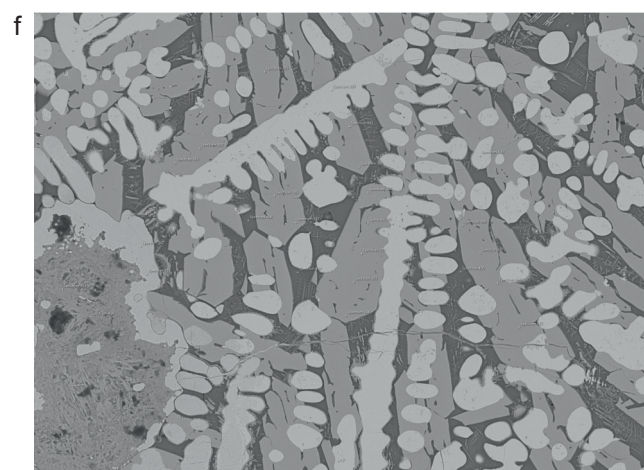
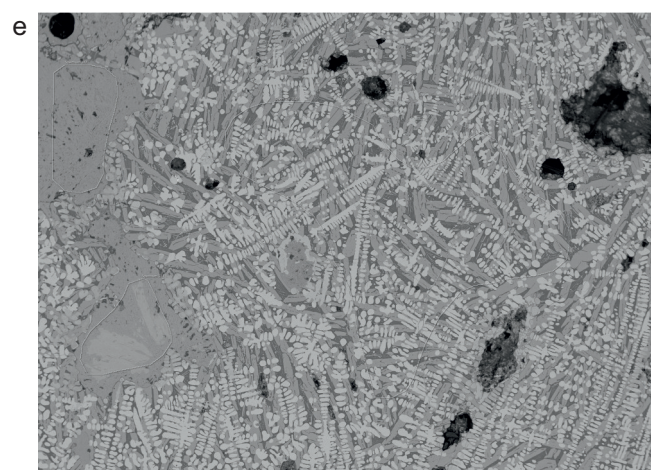
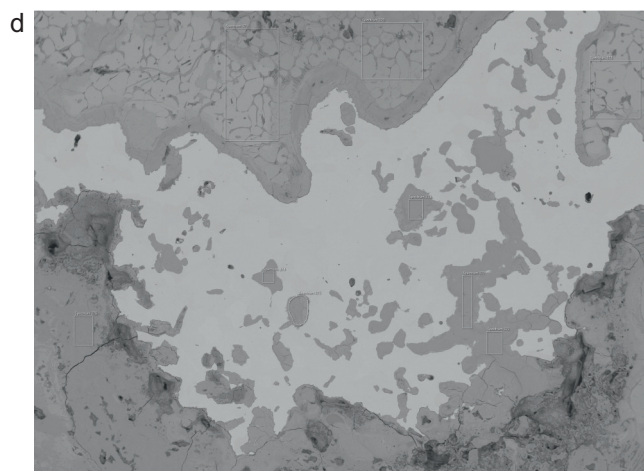
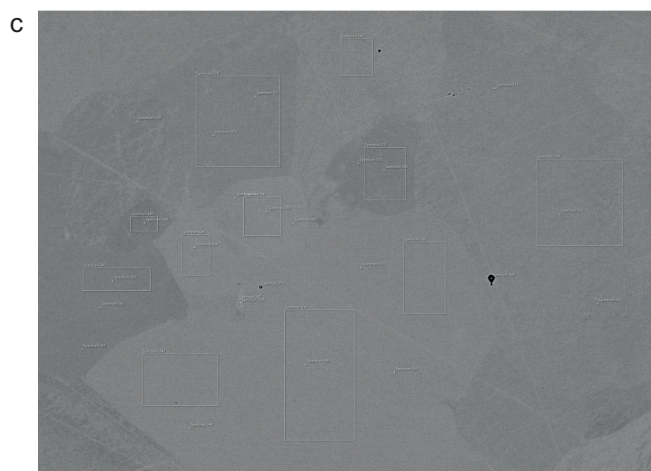


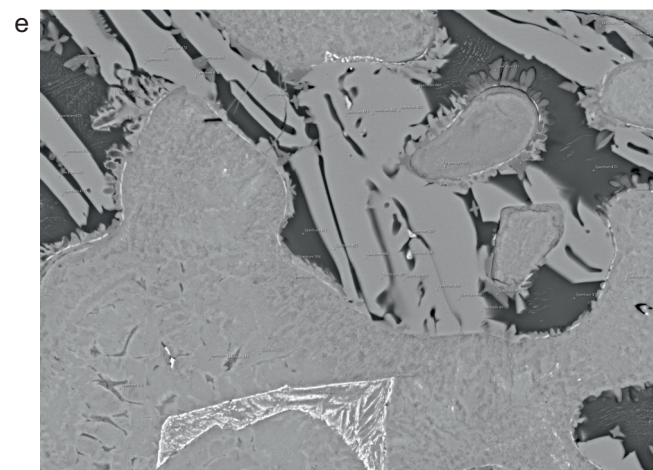
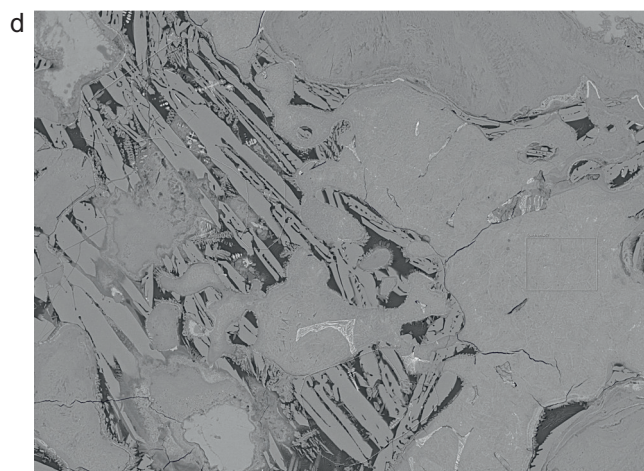
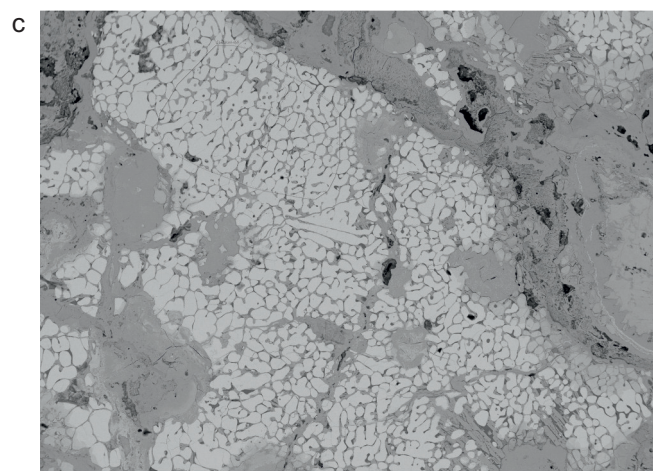
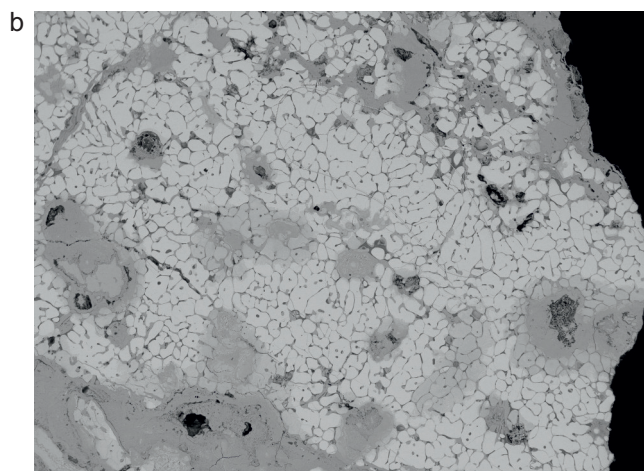
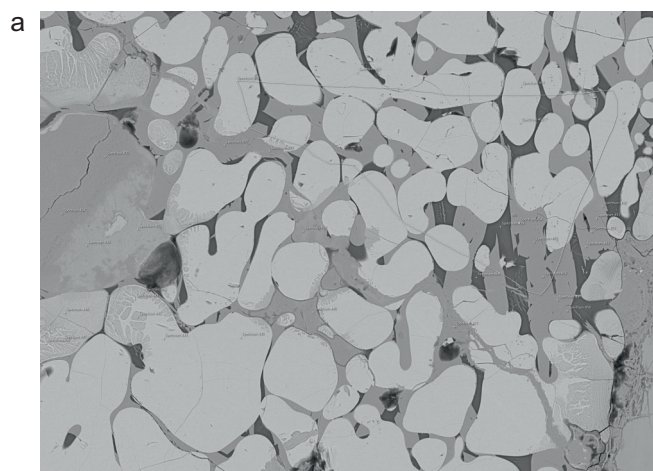












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