GeoArch

Report 2007/22

Archaeometallurgical residues from Richard Lander School (RLS04) and Truro College (TCF05)

Dr Tim Young
3^{rd} March 2008

Archaeometallurgical residues from Richard Lander School (RLS04) and Truro College (TCF05)

Dr T.P. Young

Abstract

The collection of 15kg of archaeometallurgical residues included 13.1kg of slags and associated ceramics, approximately 2kg of iron ore and 0.1kg of tin ore. In-situ metalworking evidence was extremely limited, with a deposit of hammerscale in House 6 the most likely example. However, the evidence for iron production at the site in the Late Iron Age is compelling, with macroscopic smelting slags occurring widely across the site, a cache of iron ore in House 1, and with chemical analysis suggesting that the iron-working residues were derived from bloom refining.

House 1 and associated structure 1 yielded residues from both iron smelting and smithing, House 5 yielded smelting residues and House 6 produced evidence for smelting, smithing and Cu-alloy working. Houses 3, 4, and 9 contained only small quantities of residues.

Internal features in House 1, and to a much lesser extent House 4, yielded quantities of a goethite iron ore. This ore is probably a local gossan iron ore. Chemical analysis shows that this ore is similar to that which had been smelted on the site. The burnt pit containing the ore in House 1 is of uncertain nature, but might be a metallurgical hearth or furnace.

The iron smelting slags are indicative of smelting within a non-slag tapping furnace with a basal slagpit. The basal pit was packed with large pieces of charcoal, or more likely wood, which is common feature of British slagpit furnaces. Such furnaces appear to be the norm for Iron Age iron smelting in Britain. Mass-balance analysis of the smelting slags suggests a high yield of iron from the ore (77%). Such a value is much higher than calculated for other early iron-smelting furnaces in Britain. It is not clear, however, whether the slags analysed would be truly representative of the bulk slag composition, so this result must be treated with some caution.

Features in the area of the Bronze Age activity, Area F, yielded no slags, but the fill of posthole 6608 (C6607) contained four broken pebbles of tin ore.

A small quantity of residue was recovered from the area (B2) of Early-Middle Iron Age activity. Much of this was an extremely low density sinter-like material, reminiscent of materials from domestic hearths or ovens on other sites and is not likely to have had a metallurgical origin.

Contents

Methods

This report presents the final results of the investigation of archaeometallurgical residues from the two adjacent sites at the Richard Lander School (RLS04) and Truro College (TCF05).

All the macroscopic material from these two collections was inspected visually (and with a low-powered stereo-microscope where necessary) and described for the evaluation phase (Young 2006a and 2006b) The summary catalogue of the whole assemblage is presented again here in unified form. Following the evaluations, materials were selected for additional analytical investigation to allow a fuller interpretation of the processes undertaken at the site.

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

Chemical analysis was undertaken using two techniques. The major elements (Si, Al, Fe, Mn, Mg, Ca, Na, K, Ti, and P) were determined by X-Ray Fluorescence using fused beads, on the Open University Earth Science Department's Wavelength-Dispersive X-Ray Fluorescence (WD-XRF) system. Whole-specimen chemical analysis for minor and trace elements (Sc, Ti, V, Cr, Mn, Fe, Co, Zn, Ga, Rb, Sr, Y, Zr, Nb, Mo, Sn, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th and U) was undertaken using samples in solution on the ThermoElemental X-series Inductively-Coupled Plasma Mass Spectrometer (ICP-MS) in the School of Earth, Ocean and Planetary Sciences, Cardiff University. All sample batches for chemical analysis are run with internationally certified standards.

Energy dispersive X-Ray Fluorescence was undertaken using the Eagle II ED-XRF system at English Heritage's laboratories at Fort Cumberland, Portsmouth, England

Description of residues

Iron smelting residues

Residues identified as being derived from iron smelting comprised 9.2kg of the total assemblage of 13kg. Of this, 7.59kg of smelting slags were recovered from the ringditch of House 5.

The smelting slags were typical of those produced during iron smelting in a low-shaft furnace with a basal slag-pit, being mainly dense, well flowed slags, with accumulations of flow lobes. In common with other examples of this style of furnace, the slags suggested that the basal pit was packed with large pieces of charcoal or, more likely, wood, now represented as moulds in the dense slag.

The assemblage contains several slabs of material, which have been generated by interaction between descending slag (evidence by numerous descending slag prills) and the floor of the furnace. Commonly on sites where bog ores were being smelted (perhaps the most common source of ore in described Iron Age furnaces) the base of the pit becomes coated in a porous sinter; the lack of such material in this assemblage provides supporting circumstantial evidence for the smelting of rock ores (like those from House 1 and 4).

Microscopic investigation of the smelting slags shows that most are dominated by fayalite. The cores of the main phase fayalite (iron-rich olivine, an iron silicate, with end-member composition Fe_2SiO_4) crystals may bear cotectic wustite (iron oxide; FeO), whereas the margins may have cotectic hercynite (an iron-aluminium spinel; $FeAl_2O_4$). Interstitial areas contain a cotectite of leucite (a potassium aluminium silicate; $KAlSi_2O_6$) and wustite alongside minor amounts of hercynite, apatite and further fayalite.

Details

RLS-1

This specimen is a large block of well flown slag with a stalagmitic form, expanding downwards over some large fuel moulds.

The microstructure shows a moderate degree of alteration at the surface, leading to skeletal structure (Plate 1, areas 1,3,4). The specimen shows textural evidence internally for accumulation as a succession of flow lobes (Plate 1, area 2).

The microstructure (Plate 1, area 6) typically consists of elongate crystals of fayalite with syntectic dendritic wustite, overgrown by further fayalite with syntectic blocky hercynite. These elongate structures may be up to 2mm in length and 100µm width. The interstices are dominated by a rounded leucite-wustite cotectite, with small localised patches of a fine fayalite-hercynite cotectite.

The fayalite composition varies from Fa97Fo3 with 0.6% Ca and 7.4% Mn substitution in the inner zones associated with wustite, through Fa99Fo1, 1.0% Ca, 7.2% Mn substitution at the outer limits of the wustite, to Fa99Fo1, 3.0% Ca and 6.3% Mn substitution associated with the hercynite.

The hercynite shows 14-15% magnetite, with minor Mn and Ti substitution.

The leucite shows 7-8% substitution of Na for K.

RLS-2b

This specimen showed a dense slag surrounding fuel moulds, grading into a slag bearing some coarse quartzo-feldspathic grains. It is interpreted as a slag forming near the wall of the slagpit on the blowing side.

The chemical analysis was taken from the dense iron slag (RLS-2a), whereas the sample for investigation on the electron microscope was from the zone of interaction with the wall materials.

The investigated microstructure shows a dominantly glassy material bearing partially melted quartz and feldspar grains. In some areas the glassy matrix bears quench textured olivine (Plate 1d), which grades from equant carious crystals up to 500µm in diameter, down to delicate feathery dendrites. The olivine ranges from 86-90Fa (ferro-hortonolite), with less than 0.2% Ca and 3.5-3.9% Mn substitution.

RLS-3

This sample is a dense iron slag bearing large fuel moulds. In hand specimen it shows a contact with wall of the slagpit.

As with RLS-1, this slag shows internal curved margins indicative of development as multiple flow lobes. The texture varies somewhat between lobes, but typically (Plate 2a) has primary wustite, overlain by fayalite, locally itself overlain or accompanied by subhedral hercynite (16% magnetite). Only in rather limited areas is an initial fayalite-wustite cotectite developed. Fayalite is typically Fa96Fo4, with 0.2% Ca and 6.5% Mn substitution in the core and Fa99Fo1, with up to 1% Ca and 5.7-5.9% Mn substitution on the margins. Interstitial materials are variable, but include a leucite-wustite cotectite, hercynite and an apatite with both alkali (sodium and potassium) and iron substitution.

RLS-4b

This specimen includes an area of slag/wall contact. The wall shows some impregnation by iron. The slag shows some suggestion of being rather altered in hand specimen.

The specimen also shows internal curved surfaces, showing the accumulation of flow lobes. Primary wustite is common, with only localised areas showing an initial wustite-fayalite syntectic

Where the contact with the wall is seen in the SEM specimen, the slag close to the wall is dominated by the early wustite. The olivine in the wustite-rich areas close to the wall varies from Fa97Fo3 with 0.3% Ca and 8.1%Mn substitution. There is an interstitial glass, which appears to be very silicic but is highly weathered, bearing late fayalite dendrites (Fa99Fo1, Ca 0.7 and Mn7.7% substitution).

Away from the wall the cores of olivine associated with wustite is Fa96Fo4 with 0.3%Ca and 7.3%Mn substitution. Olivine without wustite is similarly Fa96Fo4, with 0.4%Ca and 7.2%Mn substitution. The outer margins of the same olivine crystals are Fa99Fo1, also with 0.4%Ca and 7.2%Mn substitution. The interstitial zones are complex with a slightly more calcic anhedral fayalite (Fa100, with 1.2-1.4% Ca and 6.3-6.7% Mn substitution), locally subhedral hercynite and a rounded leucite-?wustite cotectite. The leucite shows about a 4% substitution of Na. The hercynite is 12-15% magnetite with minor Mn and Ti substitution.

TCF-1

This specimen is a small slag prill, suggesting vertical slag flow through the fuel bed. In microscopic examination it shows a completely different microstructure to the other smelting slags.

The margins of the lobe are formed by a thin layer (up to 50µm) of dense magnetite, which supports inwardly directed dendrites of typically angular form, cross sections of which common appear as carious rhombic shapes. These dendrites extend inwards for 150-500µm in the plane of the section. The inner tips of the dendrites are skeletal, and so appear as blades in the section. The outer surface of the magnetite shell bears small (up to 200µm diameter) sub-hemispherical blebs of finely dendritic magnetite.

The magnetite dendrites are replaced inwardly by the typical rounded form of wustite dendrites. The transition of mineralogy is abrupt and appears to cross-cut individual bodies in the section.

Both oxide phases are followed by elongate crystals of fayalite up to 200µm in length and 40µm wide.

The magnetite shows about 6% galaxite (MnAl2O4) solid solution in the shell of the prill, with up to 5% in the external hemispherical blebs, but dropping to about 2% substitution in the inward dendrites. The wustite has about 1-2% Mn substitution.

The fayalite show a composition of Fa100 with 1.2% Ca and 8.0% Mn substitution within the zone of magnetite dendrites, with the crystals in a more internal position being Fa97Fo3 with 0.9-1.2% Ca and 7.1-7.5% Mn substitution.

The specimen also shows angular inclusion in which the microstructure is a slightly vesicular texture dominated by large rounded wustite dendrites, and a smaller proportion of later fayalite. These inclusions would appear to be partly reacted ore fragments.

Iron ore

House 1 yielded 22 pieces of iron oxide ore, probably goethite, totalling 1.93kg, from a variety of contexts and 4 small pieces of similar ore (total 24g) were recovered from a posthole in House 4. The ore is layered, with variously alternating bands of more- and less-dense ore (picked out as brown and yellow layers), or alternating coarsely crystalline and botryoidal layers, or even layers of goethite separated by voids. In the large specimens the ore seems to have a “boxstone” morphology. Some associated pieces of low-grade material bear a small proportion of quartz.

The goethitic ore is of uncertain origin, but it is probably significant that the mines which impinged on the site in the 19th century (East Wheal Falmouth) were part of a complex which, slightly to the west, was amongst the most significant producers of iron ore from gossan (the oxidised upper levels of veins of sulphide mineralisation in which iron is concentrated) in the region (Wheal Falmouth and Wheal Sperries produced 10,474 tons of iron from gossan in 1832-4 and 1860-72; Dines, 1956 p. 431). The iron ore is likely therefore to have had a local origin. Unfortunately there is current lack of comparative textural and chemical data for gossan ores from the area.

Details

RLS5

This specimen shows several distinct microtextural components within the overall laminated structure of the iron ore.

The first is a spheroidal texture, with individual spheroids of approximately 20-40µm diameter, each comprising radially-oriented elongate crystals. The spheroids are mainly contained within a closely packed aggregate, with some porosity.

The second is a more coarse-grained texture, with iron oxides (probably mainly goethite) forming complex aggregates of angular, apparently zoned, crystals up to 200µm. These crystals are subhedral and are rooted on the spheroidal texture and partially occlude voids. It is likely, based on the present limited petrographic evidence that these subhedral goethitic bodies may pseudomorphic replacement textures. Scattered within this texture are clay mineral stacks, for which

microanalysis suggests an iron-rich chlorite composition (chamosite).
Residual porosity, where not completely occluded by the coarse goethite pseudomorphs, was locally subsequently infilled with fine-grained manganese minerals. Microanalysis of these suggests that they are cryptomelane.

Some zones of the goethitic textures described above are overgrown by a much finer-grained complexly botryoidal goethite.

RLS6

Textures in this specimen were similar to those in RLS5, but rather more complex. Much of the specimen is laminated and comprises textures dominated by spheroidal and botryoidal goethite. Parts dominated by spheroidal textures are locally very dense and locally bear crystals of quartz of up to 1mm. Some of the voids within the porous texture are filled with cryptomelane.

Iron working residues

Residues from iron-working (smithing) were not particularly abundant on the site, and no well-formed examples of smithing hearth cakes (SHCs) were retrieved. House 6 yielded almost all of the certain macroscopic smelting slags from the site (as well as having a deposit of smithing microresidues, hammerscale). None of the smithing hearth cakes (SHCs) was certainly complete, with the largest fragments (which comprised the majority of their original cakes) weighing 324g and 244g, with two smaller (and just possibly complete) examples weighing 136 and 144g

The microtextures of the smithing slags are heterogeneous. The dominant texture has a primary growth of large, but rather sparse, dendrites of wustite (iron oxide; FeO), followed by large elongate fayalite (iron-rich olivine, an iron silicate, with end-member composition Fe_2SiO_4) crystals, locally with a marginal cotectic hercynite (an iron-aluminium spinel; $FeAl_2O_4$). Interstitial materials are dominated by a cotectite of leucite (a potassium aluminium silicate; $KAlSi_2O_6$) and wustite.

In areas of the slag with small open vesicles, the slag adjacent to the vesicles shows a more complex paragenesis involving leucite, hercynite and rhönite (an aenigmatite group mineral; typically $Ca_2[Mg,Fe^{2+},Fe^{3+},Ti]_6[Si,Al]_6O_{20}$), as well as wustite, fayalite and glass.

Details

RLS-7

This sample shows a heterogeneous, but generally rather coarse-grained microstructure. The primary phase is wustite forming large blebby dendrites, with individual dendrites being of approximately 500µm. The subsequent fayalite forms large complex elongate crystals of up to 1.5mm length and 300µm width. The fayalite shows a high degree of alteration, so only a small amount of analysis was undertaken, but this suggests a composition close to Fa100 with up to 6% Ca substitution. Both Mn and Mg were below detection limits.

The interstitial areas are dominated by large crystals of leucite-wustite cotectite.

The original vesicles and also some interstitial altered areas are partially filled by zoned botryoidal iron oxide cements. It is likely that such cements replace any original glass.

Adjacent to the largest vesicles there are arcuate zones of leucite, which act as a nucleation zone for patches of leucite-wustite cotectite. These leucite zones are interpreted as the margins of former large vesicles.

TCF-2

This specimen has a heterogeneous microstructure with a strong influence from the location of the vesicles. The primary phase is a patchy development of large but sparse wustite dendrites. Individual dendrites are at least 500µm across.

The dominant mineral is the subsequent growth of large elongate fayalite crystals, of at least 1mm length and locally up to 200µm width. Olivine composition is rather variable, but the main elongate crystals appear to be Fa96-Fa100, with 1-1.5% Ca substitution and 0.9-1.2% Mn substitution. Towards the margins of these crystals there is locally a coarse syntectic with hercynite. Here the olivine may be Fa100, with 6.1% Ca and 0.9% Mn substitution. The hercynite has approximately 12% magnetite solid solution and a minor amount of Ti substitution.

Interstitial materials are of three main kinds. Firstly, and possibly more of a vesicle fill than a true interstitial texture, there are zones dominated by leucite (with 5-6% Na substitution), in well formed crystals up to 100µm across. The leucite may be associated with wustite crusts.

The second interstitial texture (probably the most abundant) also bears coarse leucite, but this bears a wustite cotectite.

The third texture are fine fayalite dendrites extending from the preceding main-phase calcic fayalite, and with compositions of up to 8% Ca substitution, but with negligible Mn substitution. The dendrites lie within a glass. Tiny elongate crystals of rhönite are associated with the calcic fayalite dendrites, apparently nucleating on them, but lying almost perpendicular to their length. The rhönite analyses are broadly similar to those of this poorly-known from other sites, but are rather more aluminous and lower in iron. The analyses, although few in number and taken from small crystals, give a range of estimates of composition equivalent to:

$Ca_{1.8\text{-}2.0}(Fe_{3.7\text{-}5.0}\ Ti_{0.1\text{-}0.3}\ Al_{0.8\text{-}2.1})(Si_{3.8\text{-}4.8}\ Al_{1.2\text{-}2.2})O_{20}$

Archaeometallurgical ceramics

Small pieces of vitrified ceramic occurred widely on the site. This material is probably mainly hearth/furnace lining, but possible tuyère occur in the ringditches of houses 5 (258g) and 6 (800g).

The most complete possible tuyère specimen is formed by three conjoining fragments from the ringditch of House 6 (c4501). These form an incomplete example, but indicate a vitrified ellipsoidal face, about 150mm by 100mm. The fabric is dominantly fine-grained, but bears a sparse coarse temper of granitic gravel. The face is vitrified and vesicular to a variable depth (up to 15mm) and the fabric is widely oxidised to a pale orange below the surficial vitrification. The blowhole has a diameter of approximately 18mm. The margins of the piece are inclined outwards away from the face and not particularly well formed. In this example it is possible that the vitrification of the area around the blowhole has caused sufficient induration of the wall beneath to mimic a tuyère. However, the well-marked edges (particularly taken together with the angular material described below) raise the possibility that this specimen is a deliberately pre-formed clay block. Such blocks may either simply facilitate the construction of the blowhole in a hearth wall or they form a protruding tuyère.

Several other ceramic fragments from the same ditch show what appears to be a sharp angle, approximately a right angle, between faces, with the less-vitrified face showing a gentle curvature. This strengthens the argument that these blowhole fragments form part of a pre-constructed tuyère, rather than a blowhole formed directly in the hearth wall.

There are many small fragments of probable vitrified hearth/furnace lining from a wide variety of contexts across the site. A very large number of these show a very dark glass, which bears an abundance of crystals of quartz, sometimes with very little glass binding the abundant crystals.

Concentration of clasts from the wall ceramic into the glassy slag phase is a common phenomenon, but external sources of the crystals might also be possible (e.g. welding flux or even quartz gangue from iron or tin smelting).

Small pieces of vitrified ceramic, presumably hearth/furnace lining were recovered from C1021 in Area B1 and also from C2134 in Area B2. These fragments are not certainly referable to metallurgical process, but are very likely to have been derived from the walls of smelting furnace or smithing hearth.

Crucible

A single fragment of crucible (broken into 2 sherds) was found in c4504, within the ringditch of house 6. The piece is from a large thick-walled crucible. The preserved piece shows a surviving wall height of 30mm, with a maximum thickness seen of 20mm. The rim is stout and rounded, with the wall being 10mm thick just 6mm below the rim. The external surface of wall appears to turn in with a slightly angularity at about 20mm below the rim.

The low degree of curvature of the rim suggests that this crucible was of a “triangular” form. Such crucibles are common in the British Iron Age, their use surviving into the Roman period in less-well Romanised settings.

Tylecote (1986) includes such forms with types A1 (triangular, shallow) and A3 (D-shaped). Insufficient of the present example survives to determine the precise form.

Tin ore

The examples of tin ores are alluvial pebbles bearing material apparently from very coarse-grained veins. The quartz crystals appear to be up to 15mm in length in some pebbles. The pebbles are very dense, indicating a high proportion of cassiterite. Under the SEM (Plate 7) the sample RLS13 shows anhedral quartz up to 1.5mm, set in a mass of small cassiterite crystals which make up the bbulk of the rock.

Other residues

Some of the iron slag (990g), particularly much of the slag in small fragments, is not attributable with confidence to either smelting or smithing. This material includes small isolated horizontal prills, massive vesicular slags, slags rich in small charcoal fragments and material consisting of a single flow lobe.

A rather distinctive facies of low-density slag, which has the appearance of coagulated micro-spheroids, was recovered in small quantities from, amongst others, House 4, Structure 3 and somewhat similar material from House 3. These bear some similarity to sintered material from domestic hearths and ovens recorded by Young (2005a) from Bornais (S. Uist). These slags are not, therefore, necessarily the product of metallurgical activity.

Small pieces of iron slag from Area B1 are not attributable to a specific process with certainty.

One small flow lobe of slag from Ditch 2022 (Area B2) is probably from an iron working process, and taken together with the vitrified hearth lining from this ditch provides some evidence for iron working on the site in the earlier Iron Age.

Residue distribution

In Area F a posthole (C6608) of Bronze Age date contained four broken pebbles of quartz and cassiterite, forming a high-quality ore, from an alluvial source.

Evidence for ironworking in the Early Iron Age is restricted to a very small quantity (one piece of slag and three pieces of hearth lining) from area B2.

The evidence for iron production was restricted to the Late Iron Age unenclosed settlement. House 1 yielded 22 pieces of iron oxide ore from a variety of contexts. Much of this (9 pieces, 1.73kg) came from C4093, the fill of the hearth/furnace below 4036. The slag assemblage from House 1 was small (543g), so it is unlikely iron smelting was undertaken in the structure, despite the assemblage of circular pits with burnt fills. Although the ore was recovered from one of these “hearths”, it does not appear to have been burnt, and may have not been involved in the burning activity. It is conceivable that the pits might have been used to roast ore prior to smelting as was commonly done with iron ores, but there is no direct evidence of this, although two tiny pieces of ore from the ringditch (total 8g) did contain haematite and might have been roasted. The related Structure 1 yielded approximately 690g of mixed iron smelting and smithing residues, including an SHC produced during bloom refining.

House 3 produced only a small slag assemblage, with a single block of iron smelting slag from the ringditch providing 806g of the 910g assemblage.

4 small pieces of goethite ore (total 24g) were recovered from posthole 3151 in House 4, but the total slag assemblage from the house was only 42g.

House 5 was characterised by a large quantity (7.58kg) of iron smelting slag, accompanied by three fragments of tuyère, within the ringditch. The ringditch also contained a large quantity of stone, so it is possible the smelting slags were brought in from elsewhere with the stone. There was no indication of a smelting furnace associated with the structure.

House 6 provided evidence for a range of metallurgical activities, although the volume of residue recovered was small and therefore the scale of the activities is hard to establish. Iron working (smithing) is indicated by the occurrence of a deposit of hammerscale within the house (possibly an accumulation on the working floor), and by smithing slags in the ringditch. 387g of indeterminate hearth lining and 800g of blowhole/ tuyère material from the house give evidence for the nature of the hearth. Sherds of a small crucible and some copper alloy residues suggest that some copper-alloy working was also carried out in this house. House 6 did not provide direct evidence for a hearth.

House 9 yielded just 93g of residues.

Ditch 7011 produced a block of slag and attached wall from the basal pit of a smelting furnace.

Chemical composition of iron production residues

Iron Ores

Two examples of iron ores were analysed (RLS5 and RLS6). The two analyses are very similar. They have an Fe_2O_3 content of approximately 81%, and MnO content of 1.1-1.4%. The content observed petrographically is reflected in a SiO_2 content of 2.6-3.4%, with alumina being very low at 0.2-0.4%. P_2O_5 is about 1%.

Trace element contents are uniformly low, with U at 0.08ppm being particularly so.

The rare earth elements show a profile with strong depletion of the light elements (LREE) relative to upper crust, whereas the heavy elements (HREE) are just slightly below upper crust levels (Figure 1). There is a mild positive Eu anomaly.

Technical ceramics

Three samples of fired clay (RLS8, 10, 12) with various degrees of vitrification were analysed, together with a sample of glassy lining slag rich in relict quartzo-feldspathic crystals (RLS 11). The least iron-rich of these (RLS10) has SiO_2 of 68% and Al_2O_3 of 20%.

REE profiles (normalised to upper crust) are broadly horizontal and very slightly enriched (Figure 3).

Smelting slags

The smelting slags (RLS-1 ,2a, 3, 4a) have a fairly small range compositions, with FeO ranging from 62-69wt%, SiO_2 from 14-21wt% and Al_2O_3 from 3-4wt%. SiO_2/Al_2O_3 varies from 4,3 to 5.2. MnO is moderately high, ranging from 3.0-3.4wt%. Other elements are present in fairly low concentrations (<1wt% for MgO, CaO, Na_2O K_2O, TiO_2, P_2O_5).

REE profiles of slags RLS 1, 2a, 3 and 4b are parallel to that of the ore samples (RLS5, 6). When normalised to upper crust the LREE are just below parity with the HREE markedly enriched (Figure 1). Slag prill TCF1, in contrast, plots with the ore samples.

The REE profile of TCF1 normalised against the average ore analysis is slightly LREE-enriched, but approximately at the same concentrations as the ores. The other smelting slags plot with an enrichments factor of 4-5 over the ores (Figure 2).

Smithing Slags

The major element chemical composition of the two analysed SHCs is similar to that of the smelting slags, 67-71% FeO, 17-19% SiO_2 and 3.2-4.0% Al_2O_3. The SHCs do, however, show lower concentrations of Mn (MnO of 0.10 and 0.41%) and P (P_2O_5 of 0.19 and 0.38%).

The trace elements V, Zn and Y appear in the smithing slags at lower concentrations than in the smelting slags, whereas Cr and Cu are somewhat elevated in the smithing slags.

The rare earth elements of the SHCs show relatively flat upper-crust normalised profiles, but show a slight relative depletion of the light REE, giving an overall slight inclination towards the light elements. The overall concentration of REE is markedly lower than upper crust (Figure 3).

Modelling of chemical data

Mass Balance for smelting

Although the number of samples from the site is rather limited, none the less an attempt has been made to construct a mass balance model for the iron smelting, following the methodology of Thomas & Young (1999a and b).

This technique uses the chemical composition of the iron ore and of the furnace materials, together with a typical wood ash composition as inputs to the reaction. The products of the reaction are metallic iron and slag. The products are more difficult to model, since the bulk composition of the slag produced can only be estimated from the observed chemical composition of the recovered fragments. It also must be remembered that the metallic iron produced will not only include that within the bloom, but also any other iron produced as small fragments. The bloom will, in addition, contain slag. Thus the estimate of the amount of iron produced is only an approximation of the size of the raw bloom.

The technique involves some assumptions of furnace behaviour, particularly (1) that furnace lining is absorbed into the reaction wholesale and not strongly fractioned, (2) that recycling of slag is not undertaken and (3) that there are no other inputs or products (the system must be closed). Each of these assumptions may not necessarily be true, indeed it is quite possible that none is. Therefore the result of the modelling must only be considered indicative.

The most important assumption for modelling an assemblage is that the analysed components must be representative and must be related. Although identifying elements from a single smelt would be ideal, incorporating elements from similar smelts. In the present study the smelting slags show a very strong chemical relationship to the ore. The furnace materials (fired clay RLS 10 and possible tuyère RLS 9 in particular) are very similar to each other, and match the ceramic input to the iron working slags, suggesting they are representative of the ceramic materials being employed on site for furnace/hearth construction.

For this site the ore composition was taken as the average of the two analysed samples (RLS 5 and RLS 6), the lining composition was taken as that of the fired clay sample RLS 10, and the slag was taken as the average of the four smelting slag samples (RLS 1, RLS 2a, RLS 3 and RLS 4a). The fuel ash composition used was sample FC15, which has been used for other similar calculations.

Although the fit of the major elemental data within the model was not perfect, the rare earth elements suggest a “best-fit” solution with an enrichment factor of 3.2 with a 96% contribution from the ore, a very small (0.15%) contribution from fuel ash and a 3.85% contribution from the furnace materials. These indicate the extraction of 77% of the iron within the ore into the metallic state (*efficiency'* of Thomas & Young 1999a and b). 1kg of raw ore would have produced about 440g of metallic iron and 260g of slag. The REE solution appears particularly well defined because of the large contrast between the concentrations of light rare earth elements (LREE) in the ceramic and in the ore, despite having rather similar concentrations of the heavy rare earth elements (HREE).

This mass balance solution is somewhat remarkable, for it shows a low level of input from the furnace lining and a very high *efficiency'*. At face value this indicates furnace conditions close to those reported from large late medieval bloomeries, rather than for earlier furnaces. The selection of the estimate of the bulk slag composition as simply the of the average of the four selected smelting slags is problematic. None of the specimens derives from the main part of the slag mass (which was not preserved here), so the degree to which these slags are representative is uncertain.

The results are certainly in contrast to the only other mass balance calculation for Iron Age slags from SW England, for those from Trevelgue Head, in Dungworth (forthcoming). He calculates a furnace lining contribution of 21%, a 1.6% contribution from fuel ash and 78% from the ore, with a 55% yield of iron from that available.

Mass Balance for SHCs

The upper crust-normalised REE profiles for the two analysed examples of SHCs are intermediate between those of the ceramic-dominated material and those of the ore-influenced smelting slags. However, the profiles show overall relative depletion of REE with respect to both of these groups.

In smelting slags a mix of components from the ore and ceramic furnace linings is concentrated through segregation and separation of metallic iron (Thomas & Young 1999a and 1999b). The REE profile for a smelting slag therefore lies above the profile produced by mixing the two sources.

In a simple case of a smithing slag formed by reaction of metallic iron with melted hearth lining, the REE profile would be parallel to that of the lining, but diluted through addition of the iron.

Neither of these two scenarios is demonstrated by the REE profiles of samples RLS7 and TCF2. They show, particularly in the case of TCF2, influence of a component similar to the ore, with relatively depleted LREE, high Eu and a fairly flat HREE profile.

Although such a profile could conceivably be generated through reaction between the bloom and the furnace wall in the late stages of a smelt, a far more likely origin would be during a smithing operation, in which hearth ceramic has reacted with both metallic iron and entrained slag inclusions.

This pattern has been modelled in terms of a mixture of smelting slag (using the average of the 5 analysed smelting slags) and ceramic (using the average of the 5 lining-influenced slags). A simple mixing produces a close fit to the REE profile, where the mixture entails 7% smelting slag, 17% ceramic and 76% iron oxide.

Modelling of major element composition using a similar model is less successful. A reasonably good fit is obtained with 13% smelting slag, 28% lining and 59% iron oxide. However, even at this composition there are several significant differences between the real and modelled slag, particularly the Si:Al ratio. The major elements would be more influenced by the incorporation of fuel ash (which has a very low REE content

Modelling of such a system with the lack evidence for slag inclusion composition can only be taken as tentatively indicative, but the fact that solutions can be found even under these non-ideal conditions suggests that the basic tenet of a mixing model between ceramic, iron and slag inclusions is viable. It suggests that the REE profile is unlikely to be strongly influenced by contributions from the ash or from any flux used. Moreover, the general scale of the results of this modelling suggest an approximately 10% contribution to the smithing slag from a source with the composition of the smelting slags described previously. In other words the material mixed with hearth ceramic to form the slag can be modelled a mixture of between 11 and 23% smelting slag with metallic iron. To achieve such a contribution from the removal of slag inclusions from finished iron seems extremely unlikely (inclusions are less than 1% of typical bloomery iron), but could be achieved during the working down of the raw bloom (during which process the proportion of inclusions in the iron may be reduced from >5% down to <1%, and discrete slag lumps may be lost from the outside of the bloom).

It is therefore suggested that the SHCs are the residues from bloomsmithing rather than blacksmithing.

Interpretation

Iron Production

Although no certain smelting furnaces were identified on the site, the residues clearly indicate that iron smelting was being undertaken here.

House 5 yielded the largest quantity of smelting slags (7.6kg from its ringditch), and more moderate amounts were associated with houses 1 and 3, with small amounts occurring on other parts of the site. House 1 also yielded a quantity of goethite iron ore, mostly within a hearth or furnace inside the building. The complex features with House 1 are of unresolved origin, with the possibility of being the base of slagpit furnaces, smithing hearths, ore-roasting hearths or even domestic hearths. The questions as to whether the ore was being stored there, if was to be roasted in a hearth within the house, or whether the large quantity of choice ore in a furnace pit was an act of deliberate burial, are at present not resolvable.

Iron was smelted using the low shaft furnaces with basal slag-pits that appear to be the norm for the Iron Age in Britain. The slag from these pits would have been cleared between smelts, and has subsequently become incorporated into a range of contexts across the site. The location of the smelting furnaces remains unknown (although the structures within House 1 cannot be discounted as possible furnace bases).

The details of such slag-pit furnaces have not been fully published, despite being widely recognised. The terminology and typology of these furnaces is muddled and obscured by local usage (see discussion in Pleiner, 2000), but a widespread use of this spectrum of furnace types seems to have occurred across Europe in the first millennium BC. Examples include some from East Yorkshire (Clogg 1999; Halkon 1997), Berkshire (Hartshill Copse, author's unpublished data) and Surrey (Brooklands, Hanworth and Tomalin 1977). There is some evidence that, in the Bristol Channel area at least, the advent of slag tapping furnaces occurred well within the pre-Roman Iron Age, and slag-pit furnaces have not yet been recorded within the sphere of influence of the Forest of Dean orefield (Thomas 2000).

The most complete treatment of non-slag tapping furnaces from the British Iron Age is the study of examples from North Wales by Crew (1987, 1989, 1998) and their subsequent experimental modelling (Crew 1991). These examples do not, however, have a large basal pit, and do not show the moulds of large wood fragments in the basal slags.

Good examples of furnaces of the slag-pit type have now been recognised from the Iron Age of Ireland, where the technology continues in use much longer (Young 2003, 2005b).

Trace element chemistry shows that the smelting slags were derived from similar ore to that found in House 1. This ore shows a boxstone texture, with a laminated, porous structure. The cavities in the ore often show deposits of late-stage manganese minerals, which are reflected in the high Mn contents of the smelting slags. The site lies adjacent to workings associated with East Wheal Falmouth in the 19th century. This mine produced large quantities of gossan and it is likely that the ores from House 1 were worked from such local deposits.

House 1/Structure 1 and House 6 yielded significant quantities of smithing residues. House 6 showed a deposit rich in hammerscale, which may have been a smithing hearth. House 6 also produced a quantity of fired ceramic from a hearth or furnace, including several pieces of what was probably a tuyère. Although the quantities of residues are small, the association between the tuyère and smithing, rather than smelting, is suggested, as has been observed elsewhere (Young 2003).

The small size of few SHCs recovered might suggest blacksmithing rather than bloomsmithing. Chemical analysis of the macroscopic smithing slags, however, suggests that they inherited a significant component of their REE signature from the local iron ore. This is compelling evidence that the smithing slags are residues from bloomsmithing.

None of the smithing hearth cakes (SHCs) was certainly complete, with the largest fragment s (which both comprise the majority of their original cakes) weighing 324g (TCF-2; C1037) and 244g (RLS-7; c4501). Two smaller (and just possibly complete) examples weighed 136g and 144g (from c4517 and c4525 respectively).

There are rather few described assemblages of SHCs of Iron Age date with which to compare these weights. Crew (1998) has summarised the assemblage from Crawcwellt West, Gwynedd, as containing larger SHCs of 300-400g, together with distinctive flat-topped mall cakes of 100-150g. He attributed the larger sizes to bloom refining and the smaller ones to "the final stages of smithing". The SHCs from Truro fit within this same size range, with the larger cakes being compatible with the bloom refining SHCs from Crawcwellt.

Other activities

That the activities in House 6 were not simply associated with the working down of raw blooms is indicated by the occurrence of a small quantity of copper alloy residues and two crucible sherds, indicating that casting of copper alloy was also undertaken here.

Material from the enclosed earlier Iron Age settlement was extremely sparse, and much of it might have been produced in non-metallurgical hearths or ovens. The small amount of possible iron-working residue from this area amounted to only 16g, which is likely to indicate that iron-working was not being undertaken in the immediate area.

The find of tin ore within a posthole in Area F is extremely interesting, but at present there is no direct evidence that tin was being smelted on the site in the Bronze Age. Clearly tin ore was handled on the site, and placement of these pebbles in the posthole may have been deliberate.

References

CLOGG, P. 1999. The Welham Bridge Slag. pp 81-96 *In* P. Halkon and M. Millett, *Rural settlement and Industry: Studies in the Iron Age and Roman Archaeology of Lowland East Yorkshire*. Yorkshire Archaeological Society.

COLLARD, M., DARVILL. T & WATTS, M . 2006. Ironworking in the Bronze Age? Evidence from a 10th century BC Settlement at Hartshill Copse, Upper Bucklebury, West Berkshire. *Proceedings of the Prehistoric Society*, **72**, 367-422.

CREW, P. 1987. Bryn y Castell Hillfort – a Late Prehistoric Iron Working settlement in north-west Wales. *In:* SCOTT, B.G. & CLEERE, H. (eds) *The Crafts of the Blacksmith*. 91-100.

CREW, P. 1989. Crawcwellt West excavations 1986-1989. A late prehistoric ironworking settlement. *Archaeology in Wales*, **29**, 11-16.

CREW, P. 1991. The Experimental Production of Prehistoric Bar Iron, *Historical Metallurgy*, **25**, 21-36

CREW, P. 1998. Excavations at Crawcwellt West, Merioneth, 1990-98: A late prehistoric upland iron-working settlement. *Archaeology in Wales*, **38**, 22-35.

DINES, H.G. 1956. The metalliferous mining region of South-West England. British Geological Survey.

DUNGWORTH, D. 2007. Heckfield, Hampshire: An examination of Middle Iron Age smelting slags English Heritage Research Department Report 104/2007, 12pp.

DUNGWORTH, D. *forthcoming*. 'Examination of metalworking debris from the 1939excavations at Trevelgue Head', *in* Nowakowski, J and Quinnell, H, *TrevelgueHead, Cornwall - an Iron Age cliff-castle: the story of the 1939 excavations by the late C K Croft Andrew*. Truro: Cornwall County Council.

HALKON, P. 1997. Fieldwork on early iron working sites in East Yorkshire. *Historical Metallurgy*, **31**, 12-16.

HANWORTH, R. & TOMALIN, D.J. 1977. *Brooklands, Weybridge: The excavation of an Iron Age and Medieval Site 1964-5 and 1970-1.* Research Volume of the Surrey Archaeological Society, No. 4.

DINES, H.G. 1956. *The metalliferous mining region of South-West England.* British Geological Survey.

PLEINER, R. 2000. *Iron in Archaeology: The European bloomery smelters*, Prague.

TAYLOR, S.R. & McLENNAN, S.M. 1981. The composition and evolution of the continental crust: rare earth element evidence from sedimentary rocks. *Philosophical Transactions of the Royal Society*, **A301**, 381-399.

THOMAS. G.R. 2000. *A chemical and mineralogical investigation of bloomery iron-making in the Bristol Channel orefield, U.K.* Unpublished PhD Thesis, University of Wales.

THOMAS, G.R. & YOUNG, T.P. 1999a. A graphical method to determine furnace efficiency and lining contribution to Romano-British bloomery iron-making slags (Bristol Channel Orefield, UK). *In:* YOUNG, S.M.M., BUDD, P.D., IXER, R.A. and POLLARD, A.M. (eds). *Metals in Antiquity*, British Archaeological Reports International Series, **792**, 223-226. Archaeopress, Oxford.

THOMAS G.R. & YOUNG, T.P. 1999b. Bloomery furnace mass balance and efficiency. In: POLLARD, A.M. (ed) *Geoarchaeology: exploration, environments, resources*, Geological Society of London, Special Publication, 165, 155-164.

YOUNG, T.P. 2003. *Is the Irish iron-smelting bowl furnace a myth? A discussion of new evidence for Irish bloomery iron making.* Geoarch Report 2003/09. 4pp.

YOUNG, T. 2005a. Site Activities: slag and related materials. pp. 174-176. *In:* Sharples, N (ed.), *A Norse Farmstead in the Outer Hebrides. Excavations at Mound 3, Bornais, South Uist*. Cardiff Studies in Archaeology, Oxbow Books, Oxford.

YOUNG, T.P. 2005b. *Evaluation of archaeometallurgical residues from the Heath-Mayfield N7 development (03E0151, 03E0966, 03E0461, 03E0603, 03E0633, 03E0679, 03E0602, 03E0635).* GeoArch Report 2005/12. 28pp.

YOUNG, T.P. 2005. Evaluation of metallurgical residues from Hartshill Copse (HCB01). *GeoArch Report 2005/06*. 7pp + 2 figs.

YOUNG, T.P. 2006a. *Evaluation of archaeometallurgical residues from the Richard Lander School, Truro (RLS 04).* GeoArch Report 2006/06. 15pp.

YOUNG, T.P. 2006b. *Evaluation of archaeometallurgical residues from Truro College playing fields Truro (TCF 05). GeoArch Report 2006/07.* 5pp.

YOUNG, T.P. 2007. Evaluation of archaeometallurgical residues from Berry Ball, Devon. *GeoArch Report 2007/21.* 4pp.

Figure Captions

Figure 1: Analyses of REEs of residues from iron smelting. Data normalised against Upper Crust standard of Taylor & McLennan 1981.

Figure 2: Analyses of REEs of residues from iron smelting. Data normalised against average ore composition

Figure 3: Analyses of REEs of residues from iron smithing and technical ceramics. Data normalised against Upper Crust standard of Taylor & McLennan 1981.

Plate 1: Smelting slag RLS1, areas 1-8

Plate 2: Smelting slag RLS2b, areas 1-3; smelting slag RLS3, areas 1-4

Plate 3: Smelting slag RLS 4 areas 1-6; iron ore RLS5, areas 1-2

Plate 4: Iron ore RLS5, areas 3-9; Iron Ore RLS6, areas 1-2

Plate 5: Iron ore RLS6, areas 3-9

Plate 6: Smithing slag RLS7, areas 1-9; lining slag RLS11, areas 1-3.

Plate 7: Lining slag RLS12 1-4; tin ore RLS13 area 1.

Plate 8: Smelting slag TCF1, areas 1-8.

Plate 9: Smelting slag TCF1, area 9; smithing slag TCF2, areas 1-6.

Plate 10: Smithing slag TCF2, areas 7-10.

All plates are backscattered electron photomicrographs of polished blocks.

Context	sample	Item weight	Item notes	smelting slag	smithing slag	Indet slag	lining	tuyère	burnt stone	Concn	Iron ore	Cu material	Tin ore	iron
RLS Area A														
House 1														
House 1: Cleaning over 4006 house														
4007		44	piece with rough base and dimpled top, 20mm thick, probably small piece of SHC, but might just be basal furnace layer			44								
		1.9	small worn grain of vesicular grey dense iron slag			1.9								
		0.86	small chip of fired clay				0.86							
		0.85	pale slagged lining				0.85							
4007		4.56	goethite ore - dark goethite in coatings on and through yellow rock								4.56			
		4.43	iron rich rock with quartz veins and vugs								4.43			
4007		4.83	2 pieces of dense grey vesicular iron slag, locally reddish tint, and with zone of abundant quartz grains			4.83								
4007		7.77	goethite ore								7.77			
4007		22.91	irregular block of lining slag with all sorts of ceramic and crystal part melted inclusions, generating white, black, red and blue glasses, one area of surface shows wrinkly ?magnetite coating				22.91							
House 1: Ringditch														
u/s	h1 base of ring gully s side	17.66	broken in 3. Slag with basal contact with lots of quartz, top shows mixing. Internally vesicular, 2 bits from tip of lobe are very vesicular and have platy olivine			17.66								
4001		11.8	corroded iron object											11.8
4001	<200>	1.36	2 coffee bean-like blebs, larger one broken in half, both internally dark and vesicular			1.36								
4001	slot 3	25.37	dished piece of lining with very pale sandy material, below vitrified layer. Vitrified layer rather altered but some brownish glass. Sandy material contains large bleb of Cu-weathering product. Some possible Cu residue on dished vitrified surface too				25.37					*		
		62	irregular slaggy mass, mostly lining-dominated but some fayalitic. Lots of quartz clasts, some finely crystalline slag. Lower face with descending lobes, very irregular			62								
		1.6	goethite ore fragment								1.6			
4001		29.72	layered goethite ore - yellow softer and darker harder layers on 5mm scale, curved concentric surfaces								29.72			
4002	slot 1	22.74	dense vesicular slag fragment, 1 edge rich in charcoal - smithing slag?		22.74									
4013		174	rather degraded slab of slag from floor of hearth or more likely furnace	174										
		92	block of goethite ore with 2 fragments. Crystalline layers plus botryoidal coatings								92			
		8	two small pieces of ore with some haematite - not clear if natural or roasted								8			
		18	5 pieces of microprilly slag with tiny charcoal moulds and flat/dimpled basal surface			18								
		14	2 small cubes probable of smelting slag - charcoal	14										

			impressions on one and arcuate cooling surface on the other						
		2	clinker from bone?						
		4.25	lining slag			4.25			
		5	fine debris, including 2 tiny sherds of pot						
4013		8.3	greenish lining slag full of crystals with multicoloured glass			8.3			
		2.85	2 pieces of weathered dense slag prill		2.85				
4015	slt 10	4.12	corroded Fe object (nail point?)						4.12
		12.03	thin slab of vesicular grey slag - slightly odd looking - some has v dark, v fine equant texture - almost like fine coke		12.03				
4020		78	slab of dense dark slag, base rough, top has charcoal dimples, base convex so could be smithing slag		78				
House 1 - internal features									
House 1 - Fill of posthole 4046									
4047		3.38	small bleb of slag with slag with very dark Fe-slag like surface but probably lining dominated, lots of included rock chips			3.38			
House 1 - Fill of pit 4050									
4051		24.1	lining slag in 3 pieces, black glass (low volume) binding abundant crystals			24.1			
House 1 - Fill of posthole 4054									
4055		34.52	iron rich concretion - may conceal metal/artefact				34.52		
House 1 - Fill of hearth/furnace below 4036									
4093		1730	8 pieces of goethitic ore					173 0	
4093	<239>	0.63	pot						
		1.03	small piece of goethite ore					1.03	
4093	<239>	46	5 pieces of goethite ore					46	
House 3									
House 3 - ringditch									
2501		8.26	dense dark slag bleb with lots of accreted fine organics		8.26				
2510		26.57	dense vesicular slag with large charcoal impressions, one end has lots of quartz, irregular blebby lobe		26.57				
2524		7.62	c14 pieces of pale vesicular lining slag			7.62			
2529	slot 8	7.57	vitrified lining, rear fired pink			7.57			
2530	slot14a	806	rusty furnace bottom slag in 3 pieces, with large included charcoal	806					
2534	slot 2	24	dark slag on red lining. Lots of included large quartz, slightly resinous lustre, superficial glass has rotted yellow			24			
2539	sl15	12.9	2 very weathered dense slag horizontal prills	12.9					
		10.04	grey quartz-rich slags, some streaks of brown glass		10.04				
2541	#16	3.04	fragment of vitrified lining. Rear fired pink			3.04			
2542	sl10	1.57	similar to 3045/3039 - grey glassy vesicular slag with globular texture (cf. Bornais hearth sinters?)		1.57				
House 3 – internal features									
House 3 - fill of posthole 2571									
2572	<424>	2.35	dark slag bleb - rather irregular in shape and rather weathered		2.35				
House 4									
House 4 - Ringditch									
3036	s21		bag of charcoal-rich ashy sediment - a charcoal sample						
3037	<406>	11.8	coarse slag with very large charcoal moulds	11.8					
3039		14.7	low density slags as 3045, pale grey glassy slag		14.7				

3045		12.02	extremely low density lining slags, with very high vesicularity, one part is made of coagulated spheres, 5 pieces		12.02				
House 4 – internal features									
House 4 - Fill of stakehole 3095									
3096	<432>	3.09	unusual glassy slag, dark with reddish tint, lots of included quartz-feldspar and vesicles, piece is well rounded and looks water-rolled. Has generally rather plasticy appearance		3.09				
House 4 - Fill of posthole 3151									
3152	<436>	24	4 pieces of goethite ore					24	
House 4 - Fill of stakehole 3155									
3156		2.26	coke						
House 5									
House 5 - Ringditch									
3501	<601>	2.85	small broken piece of dark vesicular slag - probably a hollow flow lobe		2.85				
3506	slot1a	922	furnace floor slag accumulation, stalactite at one end connected with smooth-topped flow passing over, and into, charcoal bed	922					
		632	furnace wall-foot material with dense slag on edge with lots of coarse quartz, passing into material with pendent prills	632					
		50	3 small pieces broken from above large pieces	50					
3506		2175	large piece of furnace bottom with basal flow, brecciated material on base, glassy slags at one end and quartzite piece fused to top	2175					
		398	basal flow slab, rather weathered, end bent to make rather convex base	398					
		772	rusty iron slag mass- probably another furnace bottom piece but not certain	772					
		178	good slag flows between very large charcoal/wood pieces	178					
		36	small piece of dense slag flow	36					
3506	slot1a	1340	large piece of complexly-flowed basal slag mass, good evidence for large charcoal/wood, base is prilly, 4 other pieces probably derived from this	1340					
3511	sl2a	56	broken up furnace slags - very rusty, some smooth surfaces, lots of friable crusts	56					
3515		924	block of slag enclosing large charcoal pieces - good charcoal present	924					
3516		258	3 pieces of possible tuyère - has lilac colour to one unglazed side				258		
		106	dense well flown slag blebs surrounding large charcoal moulds	106					
House 6									
House 6 - Buried soil									
4502		0.15	tiny lining slag fragment			0.15			
4502		14.23	dense slag in stacked small lobes and prills, not certainly but probably a smelting slag. Had small speck of Cu corrosion in attached soil, but not part of slag		14.23				
4502		11.8	corrosion around small disc? of iron. Concretion rich in hammerscale and charcoal						11.8
House 6 - Ringditch									
4500	u/s	46.62	dense slag in crude lobes - resembles other furnace floor material from this house	46.62					

4501		78	slab of slag with smoothly lobed, possibly blown top. Some ashy and charcoal-rich material adhering, base probably smooth but concreted with charcoal and some slag, probably part of a small SHC		78					
4501		258	large piece of possible tuyère, 20mm hole, face extends 55 in one direction and 35 perpendicularly					258		
		40	small piece of glazed tuyère face					40		
		138	11 lining pieces				138			
		26	dense furnace floor skin	26						
		2	indet. iron slag			2				
4501	batch2	80	same tuyère as above					80		
4501	batch2	132	same tuyère as above					132		
4501	slot 10a	242	major part of small SHC. 120mm diameter and 35mm thick. Base smoothly dimpled, top concave, concreted.		242					
		22	probably broken from above SHC piece		22					
		36	piece of vitrified lining with right angle bend - face strongly vitrified, protruding quartz pebbles are glazed green, side becomes less vitrified. Face has ridge raised along one side, by about 10mm. Side is very slightly concave. Maybe edge of straight-sided tuyère block?					36		
4504		154	substantial slab from wall or floor of bowl-shaped feature. Very dense slag bearing some charcoal and quartz with very abrupt wall contact, some grass-like material in wall side corrosion - but may be secondary. Possibly furnace floor material - but if so then bowl-like floor not flat			154				
4504		18.96	vitrified lining, ceramic wall covered in quartz-rich debris. Larger quartzose fragments have transparent green glaze				18.96			
		9.51	vitrified lining, surface very quartz-rich but also has raised ?magnetite patches, deeply vitrified into fabric				9.51			
		86	possibly from edge of SHC, top covered in charcoal, lower dimpled, lower part of slag grey dense vesicular, upper charcoal-rich with some lining-influenced material on top		86					
		13.08	vitrified and slagged piece of slate, slag has a couple of very large quartz pieces with a clear green glaze			13.08				
		45.19	irregular slag lobe, rough charcoal top, smooth dimpled base - like a tiny SHC			45.19				
		2.63	small fragments of low density slag			2.63				
		17.39	2 sherds from thick-walled crucible						17.39	
		0.11	large dense spheroid			0.11				
		13.32	broken fragment of grey vesicular slag, like possible smithing slags above			13.32				
		3.2	Cu slag- vitrified and oxidised material lying on(?) layer of coarse rounded sand grains						3.2	
		8.21	4 pieces of low density, presumably lining-influenced slag, vesicular, pale, weathered, 1 piece has Cu droplet						8.21	
		6.69	corrosion ball around iron object, accretion has charcoal and flake hammerscale							6.69
		2.62	vitrified and slagged piece of quartz-veined slate			2.62				
		1.22	quartz-rich lining slag, quartz has translucent green glaze				1.22			
		3.56	weakly vitrified lining				3.56			
4512	slot 3a	9.14	lining slag - crystal hash in black glass on slightly pink ceramic				9.14			

4516	13 slot	3.46	curious honeycomb material with black internal striated surfaces - looks like a fired organic material - probably not slag						
4517		136	probable small SHC, rather covered in accretion in places, and rather irregular. Might be part of larger very thin slabby SHC possibly	136					
		9.64	piece of lining slag with clast-rich black glass, where pebbles protrude from dark glass they have clear green glaze			9.64			
		7.71	rusted vesicular iron slag fragment		7.71				
		4.4	reddish lining with black glassy vitrified layer			4.4			
		4.92	4 small pieces of lining slag			4.92			
4517	<701>	1.38	lining slag			1.38			
		7.43	lining slag			7.43			
4522		6.47	dense grey iron slag in thin sheet with one smooth surface and one with charcoal moulds		6.47				
		12.99	3 pieces of lining and lining slag - varies from sandy to gravelly			12.99			
4522	<704>	2.93	4 pieces of vitrified clay plus debris			2.93			
		0.55	bleb of lining slag - black glass with quartz-feldspar crystals			0.55			
4524	<710>	10.97	fragment of sheet with sediment on base, top with charcoal contact - possibly like basal furnace material from gully		10.97				
		3.23	small rough lobe with microprilly base		3.23				
4524	slot 1	230	1 large, 1 small (2g) pieces of concretion, probably around iron						230
		14	as above						14
		254	15 main pieces plus debris of tuyère/lining - right angle bends hint at tuyère, shale-rich fabric with clasts aligned along possible tuyère axis				254		
		30	slagged quartz-rich stone - like clinker but with quartz-rich bands					30	
		28	4 small pieces of Fe-slag		28				
5424 (=4524 ?)	slot 1a	32.15	vitrified lining. Has deeply vitrified red ceramic overlain by variable glass with patches of fine crystalline ?magnetite. Some of the glass is highly weathered and has turned to a brown leathery powder. This piece needs analysis			32.15			
		82	20 further pieces related to above. The orangey slate-rich ceramic is deeply vitrified red - becoming very hard. Some of this material developed maroon crusts. The reddish material is overlain by a weathered pale grey vesicular slag and by variably altered black glass. Locally with a magnetite?-rich surface			82			
		32	dirt and fines from above			32			
4525	slot 2	144	attachment of SHC to wall. Wall straight, SHC at about 45degrees, transverse in shape 50x100mm, distal part flipped down suggesting extraction damage and maybe removal of another part. SHC has blown top and rather gravelly base - but distinct from wall	144					
		13.21	reduced-fired lining overlain by black glass with crystals.			13.21			
4535	slot 16	82	irregular lobe cf 28g u/s piece. Vesicular iron slag with some concretion with charcoal and flake hammerscale, dimpled lower face	82					

House 6 internal features

House 6 spread of burnt material									
4552	<746>	0.39	vitrified clay				0.39		
House 6 - fill of postpipe 4555									
4556		2.98	4 small pieces of lining slag, some internal patches of red-brown glass, but may not be more than melted stone				2.98		
House 6 - deposit of hammerscale									
4579			good samples of hammerscale - mainly flake but some spheroids						
House 6 - fill of posthole 4592									
4593	<743>	6.68	2 pieces of well flown greenish olivine-rich prill			6.68			
House 6 unstratified									
u/s	h6 entrance 4528 to 4530	28	rather irregular rusty slag lobe with dimpled base (with adhering clay with charcoal and flake hammerscale) and irregular rough top		28				
House 8									
House 8 - ringditch									
5526		15.07	corrosion ball including slag fragments and charcoal - no hammerscale seen					15.07	
House 9									
House 9 - ringditch									
6005	slot18a	35.8	curious lining slag, glass rich in crystals on top, grey crystalline slag below, all very weathered and veined with rust,				35.8		
		13.74	fragment of dense coarse slag with large charcoal moulds-probably a small piece of furnace bottom	13.74					
		8.57	4 small pieces of lining slag, rather rusted, may be derived from 35.8 piece above				8.57		
6030		4.23	small dimpled slag bleb, dense, with charcoal impressions			4.23			
6030 or 6031	h9 sl1	30.23	irregular lump of indeterminate vesicular Fe-slag			30.23			
RLS Area F									
Area F - fill of pit 6500									
6501		0.99	also dust, coked bone probably						
Area F - Fill of pit 6515									
6514		1.32	coke						
Area F - Fill of posthole 6608									
6607		136	4 broken pebbles of tin ore						136
Ditch 7011 (Access Road project)									
7012		320	piece from base of wall in smelting furnace, lobate floor slags have undercut side. Side is so intensely vitrified it has red glassy layer below overlying black glass. This vitrified material is presumably just below burr. Very unusual.	320					
		70	11 bits broken from above	70					
		8.96	small piece indeterminate Fe-slag			8.96			
TCF Area B1									
Lower fill of ditch 1005 (near RLS house 1)									
1021		10.53	greyish lining slag, 3 pieces				10.53		
		28.16	dark vesicular slag from base of hearth/furnace, with lots of slate chips on base, small charcoal moulds on top			28.16			
Ringditch of Structure 1 close to RLS 04 House 1									
1037		324	large slag mass with smooth blown surface over much of the		324				

			piece, rest accreted. Probably part of a moderately large SHC. Concretionary material is red - has the piece been reheated?											
1040		18	reddened piece of probable iron smelting slag, dense slag piece between large charcoal moulds	18										
1043		214	mass of lining slag attached to a lump (just possibly tuyère tip) of red oxidised clay. The slag is of variegated glass with clasts, locally being finely crystalline, as noted in the RLS04 material			214								
1044		14.65	corroded iron artefact - bent nail or part of ring?											14.65
1048		48.64	dense irregular slag with charcoal moulds - most likely a smelting slag	48.64										
1050		8.99	c8 pieces of weathered grey slag, probably lining influenced			8.99								
1055		54	4 pieces of brittle dense descending prill. Dark in colour tending towards purple. Iron smelting slag	54										
1055	sl13	4.31	very worn fragment of vesicular dense iron slag			4.31								
TCF Area B2														
Fill of stakehole 2087														
2088		1.66	coked bone?											
Deposits in ditch 2022														
2134		7.15	3 pieces probably associated, with grey vesicular slag associated with black glassy crystal-hash lining slag				7.15							
2248		7.58	small broken flow lobe of Fe-slag, part glassy part crystalline			7.58								
Deposit in ditch 2010														
2217		0.96	vertical prill of lining material rather similar to the material from 2253/2229			0.96								
Structure 3														
fill of posthole 2228 (charcoal rich)														
2229		50	18 pieces of extremely low density material. Comprises fused blebs of "lining" slag and fused coarse particles. A high temperature ash…? Encased in ashy residue, some of the glass fresh and black but most pale			50								
fill of posthole 2252 ?S3														
2253		1.25	5 pieces of low density material cf 2229			1.25								
				smelting slag	smithing slag	indet. Slag	lining	tuyère	burnt stone	concretion	goethite	Cu materials	Tin ore	iron
			totals	*9204.7*	*1164.74*	*992.96*	*581.82*	*1058*	*30*	*293.59*	*1949.18*	*28.8*	*136*	*49.06*

Table 1. Summary catalogue of archaeometallurgical residues and related materials.
This table is an amalgamation of those in the evaluation reports, with all simply natural materials removed.
All weights in g.

Sample	Techniques	Context	Weight (g)	Description
RLS – 1	Chem./SEM	3506	906	Major slag stalagmite piece with smooth top expanding over charcoal below.
RLS – 2	Chem./SEM	3506	622	Dense slag with crystal-rich gravel – possibly burr region? 2a dense flown slag with charcoal moulds for chemical analysis, 2b gravel-rich material for SEM
RLS – 3	Chem./SEM	3506	176	Dense slag with charcoal moulds.
RLS – 4	2xChem./SEM	3506	394	Slag attached to wall. 4a is slightly iron-contaminated wall. 4b is rather altered slag for chemical work the SEM sample 4 includes the contact of the two.
RLS – 5	Chem./SEM	4093	80	Thickly-layered goethite ore.
RLS – 6	Chem./SEM	4093	280	Thinly-layered goethite ore.
RLS – 7	Chem./SEM	4501	242	SHC. 95x(70)x30mm. Rather platy SHC of irregular plan. Missing part probably very small. Chemical is complete cross section, SEM is taken from centre of bowl
RLS – 8	Chem.	4524	30	Probable tuyère sherd in red grit-rich fabric.
RLS – 9	EDXRF	4504	16	Possible tuyère sherd. 16g.
RLS – 10	Chem.	4501	10	Pale fired clay similar to that attached to vitrified material.
RLS – 11	Chem./SEM	4524	44	Crystal-rich lining slag. 44g.
RLS – 12	Chem./SEM	4501	44	Vitrified material with large crystals; a vitrified equivalent to RLS – 10.
RLS – 13	SEM	6607	40	Cassiterite ore.
TCF – 1	Chem./SEM	1055	54	Iron smelting slag prill.
TCF – 2	Chem./SEM	1037	324	Medium sized SHC. Curious piece probably the proximal end of a medium sized SHC. Smooth but rusted top and has smooth proximal lip and margin too. 95 wide x 75 long surviving. Bowl to 30mm thick. Very dense. Might just be a small part of something larger. SEM sample from just below smooth burr surface. Chemical sample from whole slab.

Table 2. Details of specimens selected for detailed analysis. Chem. = chemical analysis by ICP-MS and XRF, SEM = investigation of microstructure and microanalysis using a polished block under the backscattered electron microscopy with energy dispersive X-ray spectroscopy (EDS), EDXRF = qualitative analysis using energy dispersive XRF.
RLS contexts 3506 is from the ringditch of House 1, context 4093 is a hearth or furnace-fill within House 1, contexts 4501, 4504, 4524 are from the ringditch of House 6 and context 6607 is the fill of posthole c6608. TCF contexts 0155 and 1037 are from the ringditch of Structure 1.

		SiO_2	Al_2O_3	Fe_2O3	*FeO*	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI (observed)	*LOI (Fe as Fe^{II})*	**total**
RLS-1	stalagmitic flow	21.47	4.16	68.62	*61.76*	3.41	0.55	1.07	0.27	0.81	0.47	0.99	-4.96	*1.90*	**97.59**
RLS-2a	burr?	17.72	3.85	74.58	*67.12*	3.41	0.47	0.57	0.28	0.50	0.34	0.99	-4.81	*2.65*	**98.65**
RLS-3	dense slag with charcoal moulds	14.35	2.95	76.66	*68.99*	3.01	0.46	0.52	0.25	0.25	0.41	0.74	-5.26	*2.41*	**94.99**
RLS-4a	slightly contaminated wall	57.79	17.33	16.97	*15.27*	0.52	1.51	0.13	0.32	2.83	0.86	0.22	1.30	*3.00*	**99.88**
RLS-4b	slag attached to wall	16.32	3.77	77.21	*69.49*	3.11	0.47	0.40	0.24	0.56	0.33	0.81	-5.24	*2.48*	**98.67**
RLS-5	ore	2.58	0.41	81.63	*73.46*	1.09	0.08	0.10	0.18	0.04	0.02	0.99	11.81	*19.97*	**99.17**
RLS-6	ore	3.41	0.26	81.09	*72.98*	1.35	0.08	0.10	0.21	0.04	0.01	1.07	11.91	*20.02*	**99.82**
RLS-7	SHC	17.41	3.20	79.94	*71.95*	0.10	0.27	0.47	0.23	0.61	0.23	0.19	-1.58	*6.41*	**101.08**
RLS-8	Tuyère fragment	55.24	23.25	12.88	*11.60*	0.08	0.90	0.17	0.58	3.57	1.00	0.14	2.13	*3.42*	**99.97**
RLS-10	pale fired clay	67.95	19.74	3.69	*3.32*	0.02	0.41	0.21	0.36	3.21	1.11	0.11	2.64	*3.01*	**99.45**
RLS-11	crystal rich lining slag	55.31	26.21	9.03	*8.13*	0.10	1.01	0.28	0.80	4.44	1.11	0.13	1.47	*2.37*	**99.92**
RLS-12	vitrified material similar to RLS-10	61.60	13.93	17.28	*15.55*	0.13	0.60	0.96	0.71	3.55	0.83	0.31	-0.11	*1.62*	**99.82**
TCF-1	slag prill	2.95	0.88	98.36	*88.52*	1.60	0.17	0.27	0.19	0.18	0.08	0.23	-8.05	*1.79*	**96.86**
TCF-2	SHC	18.80	4.06	74.63	*67.17*	0.41	0.46	1.00	0.24	0.78	0.32	0.38	-1.67	*5.79*	**99.48**

Table 3: Major element analyses of samples. Elements expressed as weight% oxide. Iron is expressed in two alternative ways – as Fe_2O_3 and FeO (dashed box). The loss on ignition is quoted both as the observed value and as a value corrected for all iron present in the sample as Fe^{II} (dashed box). Negative loss on ignition is a gain on ignition. Analyses by X-Ray fluorescence on a fused bead.

	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Mo	Sn	Cs	Ba	Hf	Ta	Th	U
RLS-1	17.59	203.54	45.66	1.73	44.63	11.82	100.49	6.45	34.26	111.80	97.35	156.71	7.13	0.59	115.13	7.28	288.93	3.81	0.41	2.45	0.81
RLS-2a	15.23	124.21	20.39	3.34	11.92	8.11	113.58	7.65	20.97	85.10	99.29	159.49	6.84	0.61	6.73	2.55	195.29	3.71	0.35	2.42	0.88
RLS-3	16.81	172.05	496.69	2.00	1057.86	6.66	106.52	6.44	9.59	61.79	68.85	151.80	6.16	0.56	108.96	2.23	158.08	3.43	0.34	1.83	0.59
RLS-4a	16.38	126.17	105.99	20.53	28.10	18.45	244.06	22.74	154.50	60.03	37.90	288.18	16.63	1.05	20.33	10.25	424.86	7.31	1.26	11.98	3.40
RLS-4b	17.97	165.18	22.68	5.25	16.74	8.55	162.32	8.13	25.52	70.21	85.51	155.49	6.29	0.60	8.67	3.73	205.04	3.57	0.34	2.35	0.78
RLS-5	2.75	17.47	5.83	1.85	9.80	8.98	161.56	2.27	0.36	20.41	18.60	76.30	0.99	0.35	5.05	1.60	64.18	2.10	0.07	0.30	0.08
RLS-6	3.98	16.66	4.44	3.81	19.97	12.65	176.25	2.32	1.13	28.54	29.34	84.36	1.15	0.36	6.21	0.37	124.78	2.13	0.07	0.29	0.08
RLS-7	2.01	29.83	25.59	174.93	56.41	51.44	47.69	6.68	24.89	29.84	5.06	169.82	5.75	0.61	10.76	1.01	149.97	3.93	0.32	2.41	0.57
RLS-8	19.30	118.84	124.85	33.53	20.76	39.69	91.18	28.96	156.14	92.09	27.86	297.73	24.88	1.03	11.79	10.47	569.50	7.58	1.40	15.82	3.10
RLS-10	15.45	336.94	101.98	11.81	190.02	32.02	49.06	23.79	141.76	86.40	35.15	402.93	22.08	1.35	18.08	6.68	575.55	9.63	1.45	14.61	3.22
RLS-11	24.07	152.62	147.50	18.67	19.24	28.44	96.19	34.10	223.93	138.53	36.27	345.58	30.11	1.24	3.13	15.64	743.21	8.13	1.56	16.93	3.36
RLS-12	20.48	82.28	85.48	15.88	24.60	92.55	81.83	16.23	143.75	117.85	30.85	294.00	21.04	1.35	6.38	6.70	632.26	8.85	1.13	10.41	2.46
TCF-1	2.77	58.45	11.15	0.50	8.06	8.51	47.44	3.53	2.65	43.63	23.72	93.94	1.79	0.35	7.86	0.25	688.61	2.11	0.12	0.54	0.15
TCF-2	4.83	47.41	36.68	13.85	14.71	38.87	64.69	6.06	30.63	65.31	10.35	159.81	6.53	0.64	11.22	1.54	193.43	3.71	0.39	2.80	0.65

Table 2. Trace element analyses of samples. Elements expressed as wt% element in parts per million (ppm).

	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
RLS-1	28.48	50.60	7.01	29.98	8.78	4.62	12.34	2.08	13.74	2.63	7.89	1.24	7.68	1.31
RLS-2a	28.71	52.57	7.06	30.02	9.00	4.68	12.18	2.10	13.91	2.64	7.99	1.29	7.58	1.32
RLS-3	18.00	32.40	4.39	18.50	5.28	2.84	7.54	1.30	8.82	1.75	5.47	0.89	5.63	0.99
RLS-4a	41.36	83.19	9.82	34.85	6.87	1.71	6.39	1.00	6.01	1.13	3.51	0.56	3.50	0.56
RLS-4b	23.95	43.30	5.90	25.09	7.29	3.95	10.02	1.70	11.32	2.18	6.51	1.04	6.47	1.09
RLS-5	5.20	8.88	1.22	5.56	1.75	1.06	2.58	0.43	2.90	0.56	1.60	0.24	1.32	0.23
RLS-6	7.43	11.45	1.69	7.78	2.36	1.29	3.54	0.53	3.73	0.73	2.03	0.31	1.71	0.31
RLS-7	5.04	10.73	1.28	4.77	0.97	0.21	0.88	0.14	0.91	0.18	0.56	0.10	0.61	0.09
RLS-8	47.77	93.55	11.19	38.72	6.85	1.34	5.16	0.80	4.97	0.92	2.81	0.47	2.89	0.45
RLS-10	45.33	92.24	11.08	39.98	7.75	1.55	6.26	0.96	5.95	1.10	3.37	0.56	3.38	0.51
RLS-11	56.70	107.96	12.93	43.92	7.89	1.56	6.36	0.96	5.90	1.07	3.25	0.57	3.43	0.55
RLS-12	32.58	74.01	8.09	28.74	5.76	1.23	5.12	0.73	4.48	0.82	2.47	0.43	2.66	0.41
TCF-1	8.89	14.66	1.97	8.25	2.47	1.56	3.20	0.52	3.23	0.59	1.74	0.27	1.60	0.26
TCF-2	8.69	17.68	2.15	7.85	1.69	0.53	1.60	0.25	1.60	0.30	0.94	0.15	0.98	0.16

Table 4. Trace element analyses of samples (rare earth elements). Elements expressed as wt% element in parts per million (ppm).

	smelting slag	smithing slag	indet. Slag	lining	tuyère	burnt stone	Slag Total	concretion	iron	Cu materials	Tin ore	Iron ore
RLS Area A												
House 1												
House 1: Cleaning over 4006 house			*51*	*25*			*75*					*17*
House 1: Ringditch	*188*	*23*	*192*	*38*			*441*		*16*			*131*
House 1: internal features				*27*			*27*	*35*				*1777*
Structure 1 (TCF Area B1): Ringditch	*121*	*324*	*227*				*672*		*15*			
Ditch 1005 (TCF area B1)			*28*	*11*			*39*					
House 3												
House 3: ringditch	*819*		*46*	*42*			*908*					
House 3: internal features			*2*				*2*					
House 4												
House 4: Ringditch	*12*		*27*				*39*					
House 4: internal features			*3*				*3*					*24*
House 5												
House 5: Ringditch	*7589*		*3*		*258*		*7850*					
House 6												
House 6: Buried soil			*14*	*0*			*14*		*12*			
House 6: Ringditch	*73*	*790*	*289*	*384*	*800*	*30*	*2366*	*244*	*7*	*29*		
House 6: internal features		*28 (*)*	*7*	*3*			*38*					
House 8												
House 8: ringditch							*0*	*15*				
House 9												
House 9: ringditch	*14*		*34*	*44*			*93*					
RLS Area F												
Area F - Fill of posthole 6608							*0*				*136*	
Ditch 7011 (Access Road project)	*390*		*9*				*399*					
TCF Area B2			*60*	*7*			*67*					
	9205	***1165***	***993***	***582***	***1058***	***30***	***13032***	***294***	***49***	***29***	***136***	***1949***

(*) = and hammerscale deposit

Table 5. Summary of distribution of archaeometallurgical residue by locality. All weights in g.

Sample	Site	Point	Oxygen by	Atom% Na	Mg	Al	Si	P	S	K	Ca	Ti	Mn	Fe	Br	O	total wt%	Fa	%Ca subs	%Mn subs
RLS1	7	1	stoich	0.2	0.7	0.2	14.0	0.0		0.0	0.2	0.0	2.1	25.6		57.0	101.3	97	0.6	7.4
RLS1	7	12	stoich	0.2	0.4	0.2	13.7	0.2		0.0	0.2	0.0	2.1	26.1		57.0	100.6	98	0.7	7.4
RLS1	7	2	stoich	0.1	0.9	0.2	13.3	0.1		0.0	0.2	0.1	2.2	26.3		56.8	102.5	97	0.6	7.4
RLS1	7	3	stoich	0.1	0.7	0.1	13.9	0.1		0.0	0.2	0.0	2.2	25.7		57.0	102.0	97	0.6	7.8
RLS1	7	4	stoich	0.1	0.3	0.1	13.9	0.1		0.0	0.3	0.0	2.1	26.0		57.1	101.6	99	0.9	7.2
RLS1	7	5	stoich	0.2	0.2	0.2	13.7	0.2		0.0	0.6	0.0	1.8	25.9		57.0	101.4	99	2.2	6.5
RLS1	7	6	stoich	0.1	0.0	0.2	13.9	0.2		0.1	0.7	0.0	2.0	25.8		57.1	100.3	100	2.5	6.9
RLS1	7	7	stoich	0.2	0.0	0.2	13.9	0.2		0.1	0.8	0.1	1.8	25.5		57.2	101.5	100	3.0	6.3
RLS1	8	2	stoich		0.6	0.2	13.9	0.1			0.2	0.0	2.1	25.9		57.1	100.2	98	0.7	7.3
RLS1	8	3	stoich		0.9	0.2	13.8	0.1			0.2	0.1	2.2	25.4		57.1	100.3	97	0.6	7.6
RLS1	8	4	stoich		0.3	0.2	13.9	0.1			0.3	0.0	2.1	25.9		57.1	99.9	99	1.1	7.3
RLS1	8	5	stoich		0.6	0.1	14.2	0.0			0.2	0.0	2.1	25.6		57.1	100.5	98	0.8	7.2
RLS1	8	8	stoich		0.3	0.2	13.9	0.1			0.3	0.0	2.1	26.0		57.1	99.2	99	1.1	7.3
RLS2b	1	1	stoich	0.1	2.7	0.1	13.9	0.0		0.0	0.0	0.0	1.1	25.0		57.0	97.9	90	0.0	3.8
RLS2b	1	2	stoich	0.2	3.1	0.1	13.7	0.2		0.0	0.0	0.0	1.1	24.5		57.0	97.6	89	0.2	3.9
RLS2b	1	3	stoich	0.1	3.8	0.1	13.9	0.1		0.0	0.0	0.0	1.0	23.9		57.0	98.5	86	0.0	3.5
RLS2b	1	6	stoich	0.2	3.5	0.1	13.8	0.1		0.0	0.0	0.0	1.1	24.2		57.0	97.5	87	0.1	3.8
RLS3	3	1	stoich	0.1	0.8	0.2	13.8	0.1		0.0	0.1	0.0	1.9	25.9		57.0	95.6	97	0.5	6.6
RLS3	3	2	stoich	0.1	0.3	0.2	13.7	0.1		0.0	0.1	0.0	1.7	26.7		57.0	95.0	99	0.4	5.9
RLS3	3	7	stoich	0.0	0.3	0.3	13.9	0.2		0.0	0.2	0.0	1.6	26.2		57.2	95.5	99	0.8	5.7
RLS3	3	8	stoich	0.1	0.9	0.1	13.8	0.0		0.0	0.1	0.0	1.9	26.2		56.9	94.5	97	0.3	6.5
RLS3	4	1	stoich	0.1	1.0	0.1	13.9	0.1		0.0	0.1	0.0	1.9	25.8		57.0	99.8	96	0.2	6.6
RLS3	4	2	stoich	-0.1	0.2	0.2	13.7	0.2		0.1	0.4	0.0	1.7	26.5		57.1	99.2	99	1.4	5.8
RLS3	4	8	stoich	0.3	0.1	0.3	13.5	0.5		0.0	0.3	0.0	1.7	26.2		57.1	100.1	99	1.1	6.1
RLS4	3	1	stoich	0.1	0.8	-0.2	13.9	0.0		0.0	0.1	0.0	2.1	26.0	0.2	56.8	100.4	97	0.3	7.4
RLS4	3	11	stoich	0.0	1.2	-0.1	13.9	0.1		0.0	0.1	0.0	2.1	25.5	0.1	57.0	100.8	96	0.3	7.3
RLS4	3	5	stoich	0.1	0.0	0.1	13.2	0.8		0.1	0.4	0.1	1.8	26.1	0.2	57.2	100.2	100	1.2	6.3
RLS4	3	6	stoich	0.1	1.1	0.0	14.1	0.0		0.0	0.1	0.0	2.1	25.5	0.1	57.0	100.2	96	0.4	7.2
RLS4	3	7	stoich	0.2	0.3	-0.4	13.7	0.4		0.0	0.1	0.0	2.1	26.3	0.5	56.8	100.9	99	0.4	7.2
RLS4	3	8	stoich	0.3	0.0	-0.1	13.9	1.0		0.0	0.4	0.0	1.8	24.9	0.3	57.5	97.2	100	1.4	6.7
RLS4	4	1	stoich	0.1	0.8	-0.2	14.0	0.2	0.0	0.0	0.1	0.0	2.3	25.5	0.3	56.9	100.9	97	0.3	8.1
RLS4	4	2	stoich	0.0	0.3	-0.2	14.1	0.5	0.0	0.0	0.2	0.0	2.2	25.2	0.4	57.2	97.7	99	0.6	7.8
RLS4	4	5	stoich	0.1	0.2	0.4	14.4	1.2	0.1	0.0	0.2	0.0	2.0	23.1	0.3	58.0	94.9	99	0.7	7.7
RLS4	6	1	stoich		0.8	-0.1	13.9	0.3			0.1		2.5	25.4	0.2	57.0	100.1	97	0.3	8.8
RLS4	6	2	stoich		0.8	-0.1	13.9	0.1			0.1		2.6	25.4	0.2	56.9	100.3	97	0.4	9.0
RLS4	6	3	stoich		0.8	-0.4	13.7	0.4			0.1		2.7	25.4	0.5	56.8	100.7	97	0.5	9.3
RLS4	6	4	stoich		0.8	-0.1	13.8	0.3			0.1		2.7	25.2	0.3	57.0	100.9	97	0.5	9.3
TCF1	2	4	analysed		0.9	0.3	15.2	0.2			0.3		2.3	28.3		52.6	93.9	97	1.0	7.1
TCF1	2	5	analysed		0.6		15.0	0.2			0.4		2.3	28.1		53.4	90.5	98	1.2	7.3
TCF1	2	6	analysed		0.8	0.3	14.8	0.2			0.3		2.3	28.1		53.2	90.8	97	0.9	7.4
TCF1	2	7	analysed		0.7		14.8	0.4			0.3		2.4	28.3		53.0	93.6	98	0.9	7.4
TCF1	2	8	analysed		0.6	0.3	15.1	0.2			0.3		2.2	28.4		53.0	90.1	98	1.0	7.1
TCF1	4	10	analysed		0.5		14.9	0.3			0.4		2.4	28.2		53.3	90.2	98	1.2	7.6
TCF1	4	11	analysed		0.5		15.2				0.4		2.4	28.1		53.4	90.4	98	1.2	7.7

Table 6. Olivine compositions determined by EDS. (continued below)

Sample	Site	Point	Oxygen by	Atom%													total wt%	Fa	%Ca subs	%Mn subs
				Na	Mg	Al	Si	P	S	K	Ca	Ti	Mn	Fe	Br	O				
TCF1	4	12	analysed		0.4		14.6	0.4			0.5		2.2	27.6		54.2	90.7	99	1.6	7.2
TCF1	4	13	analysed		0.4		14.9	0.3			0.3		2.4	28.4		53.2	90.3	99	0.8	7.7
TCF1	4	14	analysed		0.4		15.0	0.2			0.4		2.5	28.3		53.0	92.0	99	1.3	7.9
TCF1	4	15	analysed		0.5		14.9	0.2			0.3		2.3	28.0		53.7	91.5	98	0.9	7.4
TCF1	4	9	analysed		0.4	0.2	15.1				0.5		2.4	27.9		53.3	90.7	99	1.5	7.8
TCF1	5	2	analysed		0.4		14.9	0.2			0.4		2.5	28.1		53.4	91.0	99	1.3	7.9
TCF1	5	4	analysed		0.5		14.8	0.2			0.4		2.5	28.2		53.3	90.2	98	1.2	7.9
TCF2	10	1	analysed		1.3	0.3	14.2	0.2			0.6		0.3	28.3		54.8	93.9	96	2.0	0.9
TCF2	10	2	analysed		1.1	0.2	14.7				0.5		0.3	28.5		54.8	93.6	96	1.6	0.9
TCF2	10	3	analysed		1.3		14.6				0.5		0.4	27.8	0.2	55.2	94.5	95	1.6	1.3
TCF2	10	4	analysed		0.4	0.4	14.3	0.3			1.1		0.3	28.2		55.0	93.4	99	3.7	1.1
TCF2	10	5	analysed		0.3	1.0	14.1	0.2			1.5		0.3	27.6		55.1	92.0	99	4.9	1.1
TCF2	10	6	analysed		0.4	0.5	14.5				1.2	0.1	0.3	28.1		54.9	92.6	99	4.1	1.1
TCF2	10	7	analysed		0.3	0.6	14.4				1.6	0.1	0.3	27.6		55.1	94.2	99	5.2	1.1
TCF2	2	6	analysed		1.0	0.6	14.7				0.4		0.3	28.7		54.2	94.7	96	1.4	0.9
TCF2	2	7	analysed		1.2	0.7	14.7				0.5		0.3	28.0		54.5	95.0	96	1.7	1.0
TCF2	4	10	analysed		1.3	0.3	14.8				0.3		0.4	28.3		54.7	93.9	96	1.0	1.2
TCF2	4	11	analysed		1.1		15.0				0.4		0.3	28.5		54.6	92.2	96	1.2	1.0
TCF2	4	12	analysed		0.6		14.9				0.7		0.3	28.8		54.7	89.6	98	2.3	0.9
TCF2	4	7	analysed			0.4	14.7				1.8		0.3	28.1		54.7	96.7	100	6.1	0.9
TCF2	4	8	analysed		1.1		15.1				0.3		0.3	28.8		54.4	99.3	96	1.1	0.9
TCF2	4	9	analysed		1.2		15.0				0.3		0.3	28.7		54.5	92.8	96	1.1	1.1
TCF2	5	1	analysed		0.8	3.0	14.0				0.5		0.3	27.7		53.5	85.6	97	1.8	0.9
TCF2	5	2	analysed		1.0	0.4	14.4				0.4		0.3	26.7		56.7	85.0	96	1.4	1.0
TCF2	5	3	analysed		0.7	0.2	14.3	0.2			0.5		0.3	25.8		58.1	95.0	97	1.7	1.0
TCF2	5	4	analysed		0.5	1.0	14.3	0.1			0.6		0.2	25.5		57.8	102.6	98	2.1	0.9
TCF2	5	5	analysed		0.9	0.4	14.4				0.3		0.3	25.7		58.1	100.0	97	1.1	1.0
TCF2	6	2	analysed		0.2	0.4	14.4	0.2			1.1		0.2	24.2		59.3	96.7	99	4.2	0.8
TCF2	6	3	analysed		0.2	2.1	13.7	0.4	0.1		1.5		0.2	23.3		58.6	94.1	99	5.9	0.7
TCF2	6	4	analysed			6.2	16.7	0.4			1.0			11.6		64.1	99.0	100	8.0	0.0
TCF2	6	7	analysed			3.5	14.1	0.4	0.1		1.6		0.1	18.7		61.4	101.9	100	7.7	0.6
TCF2	7	10	analysed		0.6		15.0	0.2			1.5		0.4	27.9		54.4	95.3	98	5.1	1.3
TCF2	7	11	analysed		1.4	1.8	14.5				0.7		0.4	28.8		52.5	96.0	95	2.1	1.3
TCF2	7	12	analysed		0.4	0.3	14.8	0.2			1.5		0.4	28.6		53.9	90.9	99	4.8	1.3
TCF2	7	13	analysed	0.6	0.3	2.1	14.2	0.3		0.4	2.4		0.3	24.6		54.7	90.5	99	8.8	1.0
TCF2	7	14	analysed		0.3	1.1	14.6	0.3		0.2	2.1	0.1	0.3	26.4		54.6	91.4	99	7.3	1.0
TCF2	7	9	analysed		1.1	0.2	14.8				0.8		0.4	28.5		54.1	97.8	96	2.7	1.4
TCF2	8	1	analysed			1.4	14.3	0.2		0.2	2.1		0.3	25.8		55.8	94.0	100	7.5	1.1
TCF2	8	2	analysed		0.3	1.1	14.3	0.3			2.0		0.3	27.2		54.6	93.9	99	6.7	1.0
TCF2	8	3	analysed			0.6	14.4	0.3		0.2	3.2		0.2	25.9		55.1	93.3	100	11.0	0.8
RLS7	2	1	stoich		0.2	1.9	11.6	0.2	0.6		0.1			28.4		57.0	83.0	99	0.2	0.0
RLS7	2	2	stoich		0.0	2.5	14.1	0.0	0.4		0.1			24.7		58.1	82.4	100	0.3	0.0
RLS7	2	3	stoich		0.5	0.4	14.8	0.1	0.0		0.2			26.3		57.7	95.6	98	0.6	0.0

Table 6. Olivine compositions determined by EDS. (continued)

Glass

Sample	Site	Point	Oxygen by	Atom % Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	Br	Ba	O	total wt%	notes
RLS11	2	4	stoich	1.2	0.8	8.2	21.6	0.1			3.4	1.2	0.2	0.1	1.4			61.8	95.7	
RLS11	2	5	stoich	1.3	0.6	8.7	21.2	0.1			3.4	1.4	0.1	0.1	1.4			61.7	96.0	
RLS11	2	6	stoich	1.1	0.3	12.2	17.6	0.2			1.0	5.0	0.2	0.0	0.9			61.5	99.1	
RLS11	3	1	stoich	1.2	0.2	6.9	18.8	0.2			2.6		0.0		9.7			60.3	81.8	
RLS11	3	2	stoich	0.8	0.3	15.8	17.3	0.0			2.5		0.4		1.0			62.0	86.7	
RLS11	3	3	stoich	0.6	0.4	16.3	17.3	0.0			2.1		0.2		0.9			62.2	91.0	
RLS11	3	4	stoich	0.8	0.3	15.0	17.1	0.1			2.5		0.5		1.9			61.8	98.8	
RLS11	3	5	stoich	0.8	0.4	15.5	17.2	0.1			2.7		0.4		1.1			61.8	86.4	
RLS2b	1	4	stoich	0.4	0.3	7.1	18.9	0.2			1.6	0.4	0.2	0.5	9.4			61.0	97.4	
RLS2b	1	5	stoich	0.7	0.2	6.7	23.9	0.0			3.5	0.2	0.2	0.1	1.7			62.7	94.3	
RLS2b	2	1	stoich	0.4	0.8	6.1	17.2	0.3			1.5	0.3	0.3	0.6	12.6			60.0	89.2	
RLS2b	2	2	stoich	0.4	0.7	6.9	18.8	0.2			1.4	0.3	0.2	0.5	9.6			60.9	95.9	
RLS2b	2	3	stoich	0.4	0.8	6.6	18.9	0.2			1.5	0.2	0.2	0.5	9.9			60.9	96.7	
RLS2b	2	4	stoich	0.3	0.1	3.9	11.7	0.2			0.5	0.3	0.1	0.1	25.9			56.9	73.9	
RLS2b	2	5	stoich	0.5	0.6	6.6	24.1	0.0			3.1	0.0	0.3	0.2	1.6			63.0	95.3	
RLS2b	2	6	stoich	0.6	0.7	6.9	21.8	0.1			2.7	0.2	0.3	0.3	4.5			62.0	96.7	
RLS3	3	6	stoich	1.0	0.1	8.3	14.3	3.6			5.3	1.4	0.0	0.7	4.2		0.2	60.5	93.6	
RLS4	4	3	stoich	1.3	0.0	7.9	13.9	2.1	0.1	0.0	5.3	1.7	0.0	0.6	7.5	0.8	0.1	58.6	99.7	
RLS4	4	4	stoich	0.2	0.0	5.6	5.9	1.6	1.4	0.6	0.0	0.1	0.0	0.2	27.8	0.3	0.0	56.4	77.6	
RLS4	4	7	stoich	0.2	0.2	4.1	22.6	1.5	0.8	0.1	0.5	0.6	0.0	0.6	4.5	0.5	0.0	63.7	74.9	
TCF1	2	10	analysed	1.3		18.1	6.0		0.2	0.5	0.3	1.5		1.7	31.5			38.9	66.4	
TCF1	2	9	analysed	2.1		7.5	16.6	1.6	0.4		5.5	2.9		0.6	8.4			54.6	89.0	
TCF1	4	16	analysed	0.6		2.7	22.3	0.7	0.2		4.3	1.3	0.1	0.6	8.5			58.6	87.5	
TCF2	6	14	analysed			9.0	22.1	0.5				1.1	0.2		3.7			63.4	80.7	altered between late dendrites
TCF2	8	6	analysed	2.1		9.1	14.0	0.6	0.1		1.5	6.6	0.3		8.5			57.1	92.4	between late dendrite
TCF2	8	7	analysed	2.2		9.2	14.2	0.5	0.2		1.5	6.6	0.2		8.4			57.0	92.4	between late dendrite
TCF2	8	8	analysed	1.9		8.8	14.2	0.5			1.3	7.2	0.3		8.2			57.4	94.1	between late dendrite
TCF2	4	4	analysed	1.9		8.5	13.1	0.6			0.7	7.0	0.1		9.2			58.9	101.7	
TCF2	4	5	analysed	2.1		7.5	13.5	0.7			1.0	5.8	0.2		11.8			57.5	100.7	
TCF2	5	10	analysed			7.2	6.0	0.2	0.3			0.2			23.9			62.3	98.6	within leucite
TCF2	5	8	analysed			9.1	10.5	0.4				1.3	0.1	0.1	24.1			54.3	98.3	within leucite
TCF2	5	9	analysed		0.3	8.0	11.4	0.3				0.9		0.2	21.7			57.1	110.1	within leucite
TCF2	7	15	analysed	2.0		8.4	14.4	0.6	0.1		1.0	7.1	0.2	0.1	9.4			56.6	84.3	between late dendrite
TCF2	7	16	analysed	2.0		8.4	14.0	0.5			1.1	7.1	0.3		9.0			57.5	85.7	between late dendrite
TCF2	7	3	analysed	2.1		8.6	15.1	0.6	0.1		1.3	6.6	0.2	0.1	8.7			56.6	97.0	
TCF2	7	4	analysed	1.8		7.1	14.9	0.6	0.2		0.7	7.2	0.1	0.2	10.7			56.6	94.1	
TCF2	7	5	analysed	1.9		8.0	14.1	0.6			0.8	7.4	0.2		9.8			57.2	93.7	
TCF2	7	8	analysed	1.7		7.6	15.0	0.6	0.1		0.7	7.1	0.1	0.1	10.5			56.4	99.0	between late dendrite

Table 7. Glass compositions determined by EDS.

Sample	Site	Point	Oxygen by	Atom%													total wt%		atoms where N=24					
				Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	O			Fe	Mn	Mg	Al	Si	Ti
Magnetite																								
RLS12	4	1	analysed							0.6					53.6	45.8	68.6		24.0	0.0	0.0	0.0	0.0	0.0
TCF1	4	1	analysed			1.4								0.5	46.0	52.1	90.1		23.0	0.3	0.0	0.7	0.0	0.0
TCF1	4	2	analysed			1.4								0.5	46.0	52.1	90.5		23.1	0.2	0.0	0.7	0.0	0.0
TCF1	4	3	analysed			1.4	0.2							0.4	46.0	52.0	91.3		23.0	0.2	0.0	0.7	0.1	0.0
TCF1	4	4	analysed			1.3								0.4	46.0	52.4	90.6		23.2	0.2	0.0	0.6	0.0	0.0
TCF1	5	1	analysed				0.2							0.5	45.2	53.0	92.8	bleb	23.7	0.2	0.0	0.0	0.1	0.0
TCF1	5	10	analysed			0.6	5.8							0.9	41.6	51.1	88.6	blade	20.4	0.4	0.0	0.3	2.9	0.0
TCF1	5	3	analysed			1.0	0.3							0.4	46.0	52.1	91.1		23.2	0.2	0.0	0.5	0.1	0.0
TCF1	5	5	analysed			1.0	0.5							0.4	45.9	52.2	89.0		23.1	0.2	0.0	0.5	0.3	0.0
TCF1	5	6	analysed			1.6	0.6							0.5	45.0	52.4	88.7	bleb	22.7	0.2	0.0	0.8	0.3	0.0
TCF1	5	7	analysed			0.8	0.6							0.4	46.6	51.6	87.8		23.1	0.2	0.0	0.4	0.3	0.0
TCF1	5	8	analysed			0.6	1.0				0.2			0.4	45.5	52.3	87.9		23.0	0.2	0.0	0.3	0.5	0.0
TCF1	5	9	analysed			0.7	5.4					0.1		0.9	42.3	50.6	89.4	blade	20.6	0.4	0.0	0.3	2.6	0.0
TCF1	7	1	analysed			1.2								0.8	45.4	52.5	87.5	carious bleb	22.9	0.4	0.0	0.6	0.0	0.0
TCF1	7	2	analysed											0.9	47.1	52.0	88.9	crust	23.6	0.4	0.0	0.0	0.0	0.0
TCF1	7	3	analysed			0.5								0.7	46.3	52.5	90.3	o/g	23.4	0.3	0.0	0.3	0.0	0.0
TCF1	7	4	analysed			0.5								0.8	46.0	52.8	88.8	o/g	23.4	0.4	0.0	0.2	0.0	0.0
TCF1	7	5	analysed			0.7								1.0	48.9	49.4	88.0	o/g	23.2	0.5	0.0	0.3	0.0	0.0
TCF2	5	14	analysed				0.5								44.6	54.9	107.3	altered?	23.7	0.0	0.0	0.0	0.3	0.0
TCF2	5	15	analysed				0.3								44.9	54.8	103.0	altered?	23.8	0.0	0.0	0.0	0.2	0.0
Hercynite																								
RLS1	7	8	stoich	0.1	0.1	23.5	0.3	0.1			0.1	0.1	1.0	0.6	17.8	56.5	102.1		9.9	0.4	0.0	13.0	0.2	0.5
RLS1	7	9	stoich	0.1	0.1	23.5	0.2	0.1			0.0	0.0	1.0	0.6	18.0	56.5	102.0		10.0	0.3	0.1	13.0	0.1	0.6
RLS1	8	1	stoich		0.2	23.6	0.2	0.0				0.0	0.8	0.6	18.0	56.5	99.9		10.0	0.3	0.1	13.0	0.1	0.5
RLS1	8	6	stoich		0.1	23.1	0.2	0.0				0.0	1.0	0.6	18.5	56.4	100.4		10.2	0.3	0.1	12.8	0.1	0.6
RLS1	8	7	stoich		0.2	24.2	0.2	0.0				0.0	0.6	0.6	17.5	56.5	99.9		9.7	0.3	0.1	13.4	0.1	0.4
RLS3	3	3	stoich	0.1	0.1	24.0	0.2	0.0			0.0	0.0	0.6	0.5	18.0	56.4	94.8		9.9	0.3	0.0	13.3	0.1	0.3
RLS3	4	5	stoich	-0.1	0.2	23.6	0.2	0.1			0.0	0.0	0.7	0.5	18.4	56.4	100.0		10.2	0.3	0.1	13.0	0.1	0.4
RLS4	3	12	stoich	0.4	0.1	21.3	2.3	0.6		0.0	0.7	0.2	0.3	0.7	16.2	56.3	98.7		9.5	0.4	0.0	12.5	1.4	0.2
RLS4	3	3	stoich	0.4	0.1	23.0	0.5	0.3		0.0	0.1	0.1	0.4	0.6	17.7	55.5	100.7		10.1	0.3	0.0	13.1	0.3	0.2
RLS4	3	4	stoich	0.1	0.1	24.3	0.3	0.1		0.0	0.0	0.1	0.3	0.6	17.0	55.7	100.3		9.6	0.3	0.0	13.7	0.2	0.2
RLS11	2	2	stoich	0.5	8.2	13.4	5.7	0.1			0.9	0.3	0.3	0.4	13.9	56.1	96.8		8.0	0.3	4.7	7.7	3.3	0.2
TCF2	4	1	analysed			25.6	0.2						0.4		18.7	55.1	101.0		10.0	0.0	0.0	13.7	0.1	0.2
TCF2	4	13	analysed			26.2							0.4		18.1	55.3	95.4		9.7	0.0	0.0	14.1	0.0	0.2
TCF2	4	2	analysed			26.2	0.3						0.3		18.4	54.8	98.3		9.8	0.0	0.0	13.9	0.2	0.1
TCF2	4	3	analysed			26.2							0.4		18.5	55.0	97.3		9.9	0.0	0.0	13.9	0.0	0.2
TCF2	5	12	analysed			25.0	0.4						0.5		19.0	55.1	98.0		10.1	0.0	0.0	13.4	0.2	0.3
TCF2	6	1	analysed			26.0	0.3						0.4		18.5	54.8	100.8		9.8	0.0	0.0	13.8	0.1	0.2
TCF2	6	6	analysed			26.6	0.2						0.3		18.3	54.5	97.9		9.7	0.0	0.0	14.0	0.1	0.2
TCF2	7	1	analysed		0.3	25.9	0.2						0.5	0.1	18.9	54.1	98.4		9.9	0.1	0.2	13.6	0.1	0.3
TCF2	7	2	analysed		0.3	28.9	0.3						0.7		22.6	47.3	85.3		10.3	0.0	0.1	13.1	0.1	0.3
TCF2	2	8	analysed			11.7	4.2	1.1	1.1			0.4			14.8	66.7	97.6		11.6	0.0	0.0	9.1	3.3	0.0

Table 8 Composition of spinels determined by EDS.

Sample	Site	Point	Oxygen by	Atom%													total wt%						
				Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	O							
Goethite																							
RLS5	9	10	stoich	0.1	-0.1	0.2	0.6	0.2			0.0	0.0		0.1	50.4	52.8	71.8						
RLS5	9	4	stoich	0.2	0.0	0.1	0.3	0.1			0.0	0.0		0.6	49.9	51.8	74.9						
RLS5	9	5	stoich	0.3	0.0	0.2	0.2	0.1			0.0	0.0		0.6	49.9	52.1	75.2						
RLS5	9	9	stoich	0.2	0.0	0.3	0.8	0.2			0.0	0.0		0.2	50.1	53.0	72.6						
RLS6	8	1	stoich	0.2	0.2		2.3	0.1			0.0	0.0		0.0	45.9	51.2	56.9						
RLS6	8	2	stoich	0.5	0.1		2.1	0.3			0.0	0.1		0.4	45.5	51.1	61.6						
RLS6	8	3	stoich	0.1	0.2		1.3	0.7			0.0	0.0		0.9	45.6	51.1	60.8						
RLS6	8	6	stoich	0.4	0.2		1.4	0.9			0.0	0.1		0.9	44.9	51.3	65.6						
RLS6	8	7	stoich	0.3	0.1		2.0	0.3			-0.1	0.1		0.2	46.0	51.2	73.7						
RLS6	9	1	stoich	0.4		0.1	2.9	0.7	0.1			0.2		0.3	43.3	52.0	77.3						
RLS6	9	10	stoich	0.3		0.1	2.3	0.8	0.3			0.2		0.3	43.8	52.0	75.2						
RLS6	9	2	stoich	0.3		0.1	3.1	0.7	0.0			0.1		0.4	43.3	52.0	77.0						
RLS6	9	3	stoich	0.5		0.1	2.9	0.6	0.0			0.1		0.4	43.3	51.9	76.3						
RLS6	9	4	stoich	0.5		0.1	3.2	0.6	0.0			0.1		0.4	43.2	51.9	75.9						
RLS6	9	5	stoich	0.1		0.1	1.4	0.7	0.0			0.0		0.5	46.0	51.2	75.3						
RLS6	9	6	stoich	0.2		0.0	1.4	0.7	0.0			0.1		0.6	45.7	51.2	75.6						
RLS6	9	7	stoich	0.7		0.2	1.4	0.6	0.1			0.1		0.5	45.2	51.1	74.4						
RLS6	9	8	stoich	0.4		0.2	1.5	0.6	0.0			0.1		0.7	45.4	51.1	74.6						
RLS6	9	9	stoich	0.6		0.9	2.2	0.7	0.1			0.2		0.3	43.1	51.8	77.3						
Wustite																		Fe	Mn	Ti	Mg	Al	Si
RLS3	3	10	stoich	0.0	0.1	0.5	0.2	0.0			0.1	0.1	0.4	0.6	47.5	50.5	93.3	96.2%	1.3%	0.9%	0.2%	1.0%	0.4%
RLS4	4	6	stoich	0.1	0.1	0.5	0.2	-0.1	0.0	0.1	0.0	0.0	0.2	1.0	47.6	50.2	99.1	96.1%	2.0%	0.3%	0.1%	1.0%	0.4%
TCF1	2	1	analysed			0.6								1.0	51.6	46.8	91.9	97.0%	1.9%	0.0%	0.0%	1.1%	0.0%
TCF1	2	2	analysed			0.6	0.3							1.0	51.7	46.4	92.7	96.5%	1.9%	0.0%	0.0%	1.0%	0.5%
TCF1	2	3	analysed			0.6								1.0	51.9	46.5	90.7	97.0%	1.9%	0.0%	0.0%	1.1%	0.0%
TCF1	4	5	analysed			0.4	0.3							0.7	50.5	48.0	88.3	97.3%	1.4%	0.0%	0.0%	0.7%	0.6%
TCF1	4	6	analysed			0.3	0.3							0.8	51.1	47.5	89.1	97.5%	1.5%	0.0%	0.0%	0.5%	0.5%
TCF1	4	7	analysed				0.4							0.8	51.1	47.8	90.1	97.9%	1.5%	0.0%	0.0%	0.0%	0.7%
TCF1	4	8	analysed			0.4	0.3							0.7	51.0	47.6	89.7	97.3%	1.4%	0.0%	0.0%	0.7%	0.6%
TCF2	2	4	analysed			1.7	0.5					0.4			51.5	45.9	93.2	95.9%	0.0%	0.0%	0.0%	3.1%	1.0%
TCF2	2	5	analysed			1.0									51.5	47.5	95.3	98.2%	0.0%	0.0%	0.0%	1.8%	0.0%
TCF2	4	14	analysed			0.8							0.3		49.9	49.0	103.3	97.9%	0.0%	0.6%	0.0%	1.6%	0.0%
TCF2	4	15	analysed			0.8							0.3		50.2	48.6	97.2	97.8%	0.0%	0.6%	0.0%	1.6%	0.0%
TCF2	4	16	analysed			0.8							0.2		50.0	49.0	97.2	97.9%	0.0%	0.4%	0.0%	1.6%	0.0%
TCF2	6	12	analysed			1.9	2.4				0.4	0.1	0.2		42.2	52.7	92.1	90.3%	0.0%	0.5%	0.0%	4.1%	5.1%
TCF2	6	9	analysed			1.0	0.3						0.3		50.2	48.3	100.0	97.0%	0.0%	0.6%	0.0%	1.9%	0.5%
TCF2	6	8	analysed			0.9	0.4				0.2		0.4	0.1	49.4	48.6	97.4	96.5%	0.3%	0.7%	0.0%	1.8%	0.7%

Table 9 Composition of other iron oxides determined by EDS.

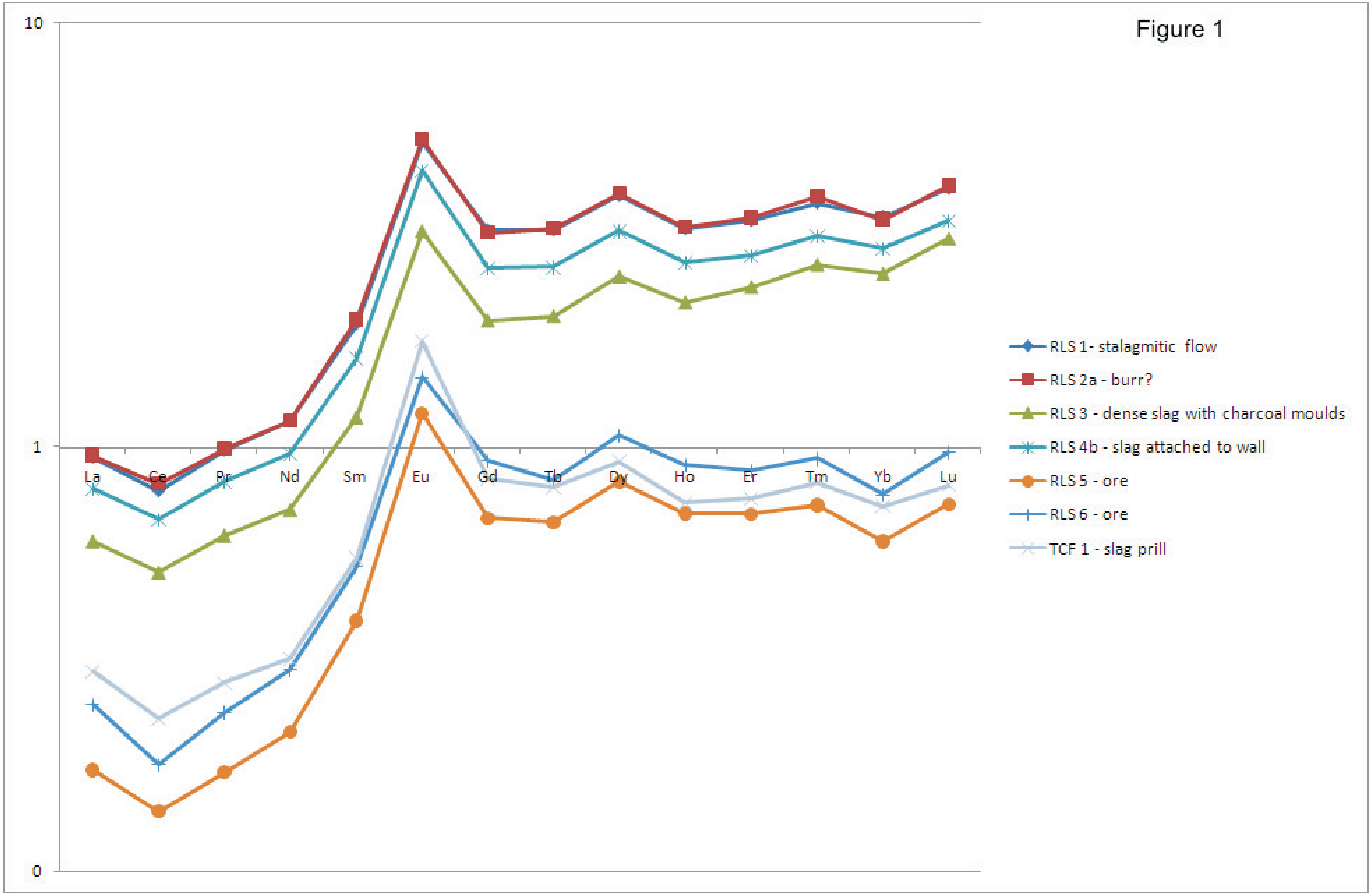
Sample	Site	Point	Oxygen by	Atom% Na	Mg	Al	Si	P	K	Ca	Ti	Mn	Fe	Ba	O	total wt%						
Rhönite																	modelled rhönite with O=20					
																	Ca	Fe	Ti	Al	Si	Al
TCF2	10	10	analysed	0.3		9.4	11.0	0.3		5.0	0.7		14.9		58.5	97.2	1.72	5.08	0.23	0.97	3.75	2.25
TCF2	10	8	analysed	0.4		9.3	10.6	0.2		5.0	0.9		13.2		60.3	103.3	1.66	4.39	0.30	0.60	3.53	2.47
TCF2	10	9	analysed	0.3		8.5	11.4	0.2		5.3	1.0		14.7		58.6	98.2	1.81	5.00	0.33	0.79	3.88	2.12
TCF2	8	4	analysed	1.1		9.6	12.3	0.5	1.0	5.5	0.4		10.0		59.4	99.5	1.86	3.37	0.14	1.38	4.15	1.85
TCF2	8	5	analysed	1.5		9.3	13.5	0.5	1.2	5.7	0.4		10.5		57.4	95.7	1.98	3.65	0.13	1.97	4.72	1.28
Apatite																	modelled apatite with P=6					
																	P	Ca	Na	Fe	Mn	K
RLS3	3	4	stoich	1.8	0.0	0.7	0.8	14.0	0.7	18.0	-0.1	0.2	2.7	0.0	60.7	95.7	6	7.73	0.78	1.14	0.09	0.28
RLS3	3	9	stoich	2.0	0.1	0.2	0.3	14.3	0.5	18.7	0.0	0.2	2.6	0.0	60.6	94.4	6	7.84	0.83	1.08	0.08	0.22
RLS3	4	3	stoich	1.9	0.0	0.1	0.1	14.8	0.3	19.3	0.0	0.2	2.6	0.0	60.6	94.6	6	7.84	0.78	1.05	0.09	0.11
RLS3	4	4	stoich	2.0	0.1	0.0	0.1	14.7	0.3	19.4	0.0	0.2	2.6	0.0	60.5	93.7	6	7.91	0.80	1.07	0.08	0.12
RLS3	4	6	stoich	2.1	0.1	0.2	0.4	14.3	0.5	19.0	0.0	0.2	2.8	0.1	60.4	92.2	6	7.95	0.87	1.16	0.09	0.19
RLS3	4	7	stoich	8.8	0.2	0.0	0.2	13.4	0.9	6.0	0.0	2.1	10.3	0.2	57.8	96.8	6	2.66	3.91	4.62	0.94	0.39
RLS4	3	10	stoich	2.4	0.0	3.0	2.3	11.7	0.5	14.1	0.0	0.4	5.3	0.0	59.7	97.0	6	7.25	1.24	2.72	0.23	0.28
Leucite																	Na/(Na+K)					
RLS1	7	10	stoich	0.6		10.2	19.3	0.2	9.3	0.0	0.1	0.0	0.4		59.9	100.8	7%					
RLS1	7	11	stoich	0.7		9.6	18.7	0.7	8.8	1.0	0.0	0.0	0.6		59.9	99.2	8%					
RLS3	3	5	stoich	0.2		10.1	19.3	0.2	9.4	0.0	0.0	0.0	0.9	0.0	59.9	91.8	2%					
RLS3	4	9	stoich	0.1		9.9	19.4	0.1	10.1	0.0	0.0	0.0	0.6	0.0	59.7	96.7	1%					
RLS4	3	2	stoich	0.4		9.0	19.7	0.4	9.5	0.1	0.0	0.0	0.5	0.1	59.5	100.2	4%					
RLS4	3	9	stoich	0.3		9.3	19.3	0.4	8.1	0.1	0.0	0.1	1.8	0.1	59.8	97.7	4%					
TCF2	2	1	analysed	0.4		10.5	20.4		10.2				0.4		58.1	93.5	3%					
TCF2	2	2	analysed	0.4		10.5	20.5		10.0				0.4		58.1	93.5	4%					
TCF2	2	3	analysed	0.3		9.3	19.1		9.6	0.3			0.9		60.5	91.9	3%					
TCF2	4	6	analysed	0.4		10.3	19.8		9.3				1.9		58.3	96.5	4%					
TCF2	5	11	analysed	0.6		10.5	20.2		9.7				0.3		58.7	100.2	6%					
TCF2	5	6	analysed	0.7		11.7	19.7		9.4				0.4		58.1	99.4	6%					
TCF2	5	7	analysed	0.6		10.3	20.3		9.7				0.3		58.8	106.5	5%					
TCF2	6	13	analysed	0.6		10.6	20.1		9.8				0.4		58.5	94.4	6%					
TCF2	6	15	analysed	0.6		10.6	20.6		9.9				0.3		58.0	89.1	5%					
TCF2	6	16	analysed	0.9		10.3	20.4		9.6				0.3		58.6	97.3	9%					
TCF2	6	18	analysed	0.6		10.6	19.7		9.4				0.4		59.4	97.7	6%					
TCF2	7	6	analysed	0.4		10.2	20.7		10.1				0.3		58.3	92.8	4%					
TCF2	7	7	analysed	0.3		10.4	20.4		10.0				0.3		58.6	96.8	3%					

Table 10 Composition of rhönite, apatite and leucite determined by EDS.

Sample	Site	Point	Oxygen by	Atom%																total wt%	
				Na	Mg	Al	Si	P	S	K	Ca	Ti	Mn	Fe	Cu	Zn	Pb	Sn	O		
Amorphous																					
TCF2	6	17	analysed			9.6	20.5	0.5	0.2	0.1	1.0	0.2		5.7					62.2	83.9	leucite margin
TCF2	5	13	analysed			1.0	3.2		0.1					34.4					61.3	91.5	vesicle rim
Cassiterite																					
RLS13	1	1	analysed			0.3								0.3				26.5	72.9	84.0	
Clay																					
RLS5	9	1	stoich	0.2	3.2	10.2	10.2	0.1		0.1	0.1		0.2	18.9					58.6	70.4	
RLS5	9	2	stoich	0.2	3.7	11.1	11.3	0.1		0.2	0.1		0.2	16.0					59.8	85.2	
RLS5	9	3	stoich	0.2	3.6	11.1	11.2	0.1		0.1	0.1		0.1	16.2					59.7	85.2	
Cu-Zn																					
RLS6	8	10	stoich	2.5	0.0		0.1	0.1		0.0	0.0		0.2	0.3	28.6	17.0	1.8		49.4	127.7	
RLS6	8	11	stoich	2.4	0.0		0.1	0.0		0.0	0.0		0.3	1.1	28.4	16.4	1.8		49.4	125.8	
RLS6	8	9	stoich	3.1	0.1		0.0	0.0		0.0	0.0		0.1	1.3	28.5	16.8	0.9		49.2	125.7	
Fe-ox																					
RLS11	2	1	stoich	0.1	0.5	1.4	0.5	0.0		0.5	0.3	1.0	0.1	44.7					50.9	41.0	
Quartz																					
RLS11	2	3	stoich	0.0	0.0	0.1	33.2	0.0		0.0	0.0	0.0	0.0	0.0					66.6	99.9	
RLS13	1	2	analysed			0.3	34.4												65.3	80.2	
Mixed olivine																					
TCF2	6	10	analysed			6.4	15.6	0.7	0.1		0.9	0.1		12.0					64.2	94.4	
TCF2	6	11	analysed			9.9	8.7	0.4	0.2		0.4	0.1		19.2					61.0	95.4	
TCF2	6	5	analysed			6.1	15.0	0.5			0.9	0.1		12.7					64.5	97.9	
Iron																					
RLS12	4	2	analysed											100.0						89.3	
Mn-oxide																					
RLS5	9	6	stoich	1.0	1.0	3.3	-0.1	0.0		1.6	1.2		39.0	1.3					49.0	79.3	
RLS5	9	7	stoich	0.4	0.1	0.6	0.0	0.0		4.9	0.2		42.5	1.4					47.9	81.8	
RLS5	9	8	stoich	0.5	0.1	0.6	0.0	0.0		5.1	0.1		42.0	1.0					47.2	83.1	
RLS6	8	4	stoich	1.3	2.2		0.0	0.0		1.9	1.3		43.8	0.4					49.2	58.8	
RLS6	8	5	stoich	0.8	2.5		0.1	0.0		1.8	1.1		43.9	0.4					49.4	61.5	
RLS6	8	8	stoich	1.2	2.6		0.1	0.1		1.5	1.3		43.3	0.4					49.4	68.2	

Table 11 Composition of other phases determined by EDS

Figure 1



10
1
0
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
RLS 1- stalagmitic flow
RLS 2a - burr?
RLS 3 - dense slag with charcoal moulds
RLS 4b - slag attached to wall
RLS 5 - ore
RLS 6 - ore
TCF 1 - slag prill

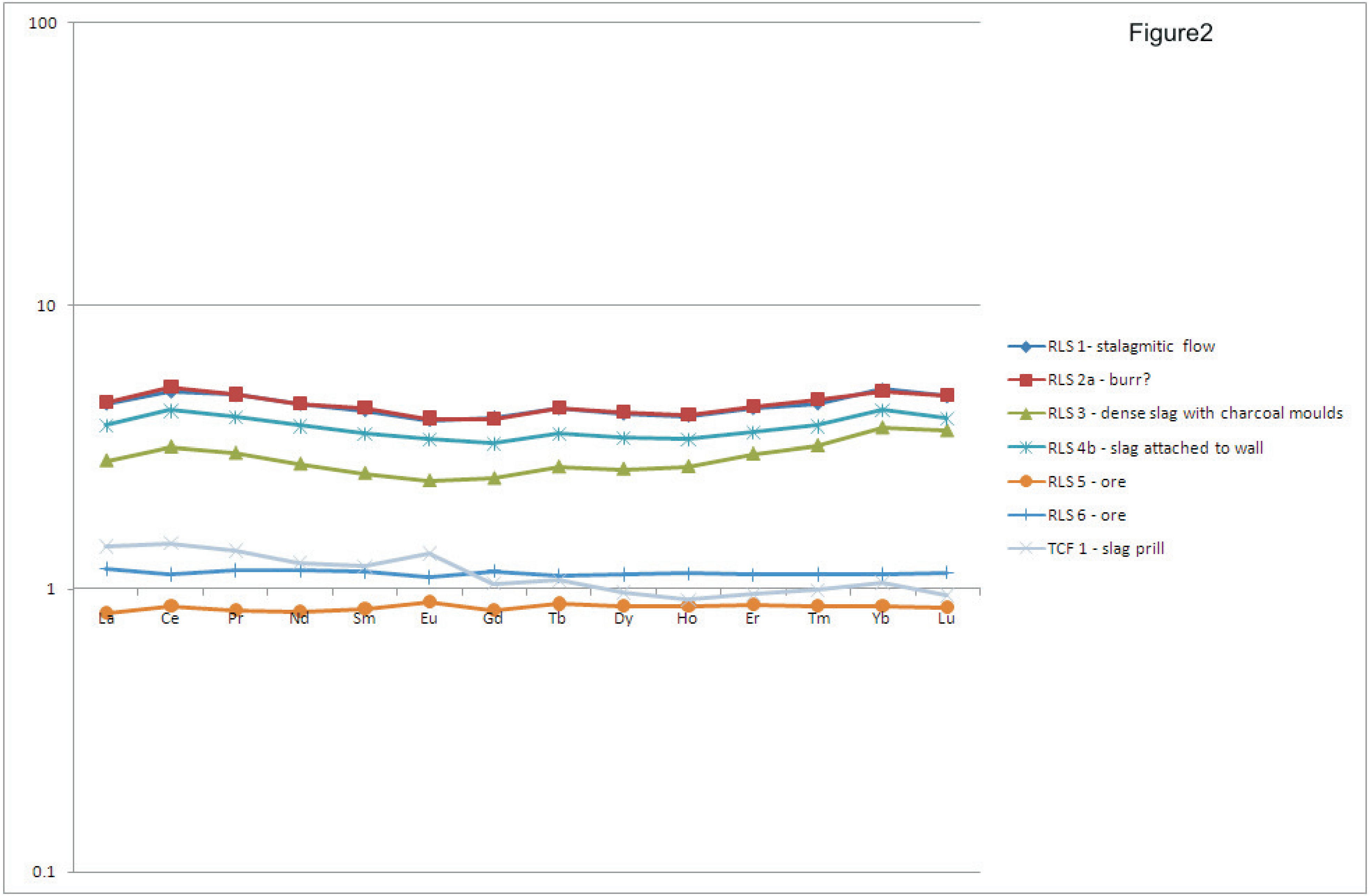


Figure2
100
10
1
0.1
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
RLS 1- stalagmitic flow
RLS 2a - burr?
RLS 3 - dense slag with charcoal moulds
RLS 4b - slag attached to wall
RLS 5 - ore
RLS 6 - ore
TCF 1 - slag prill

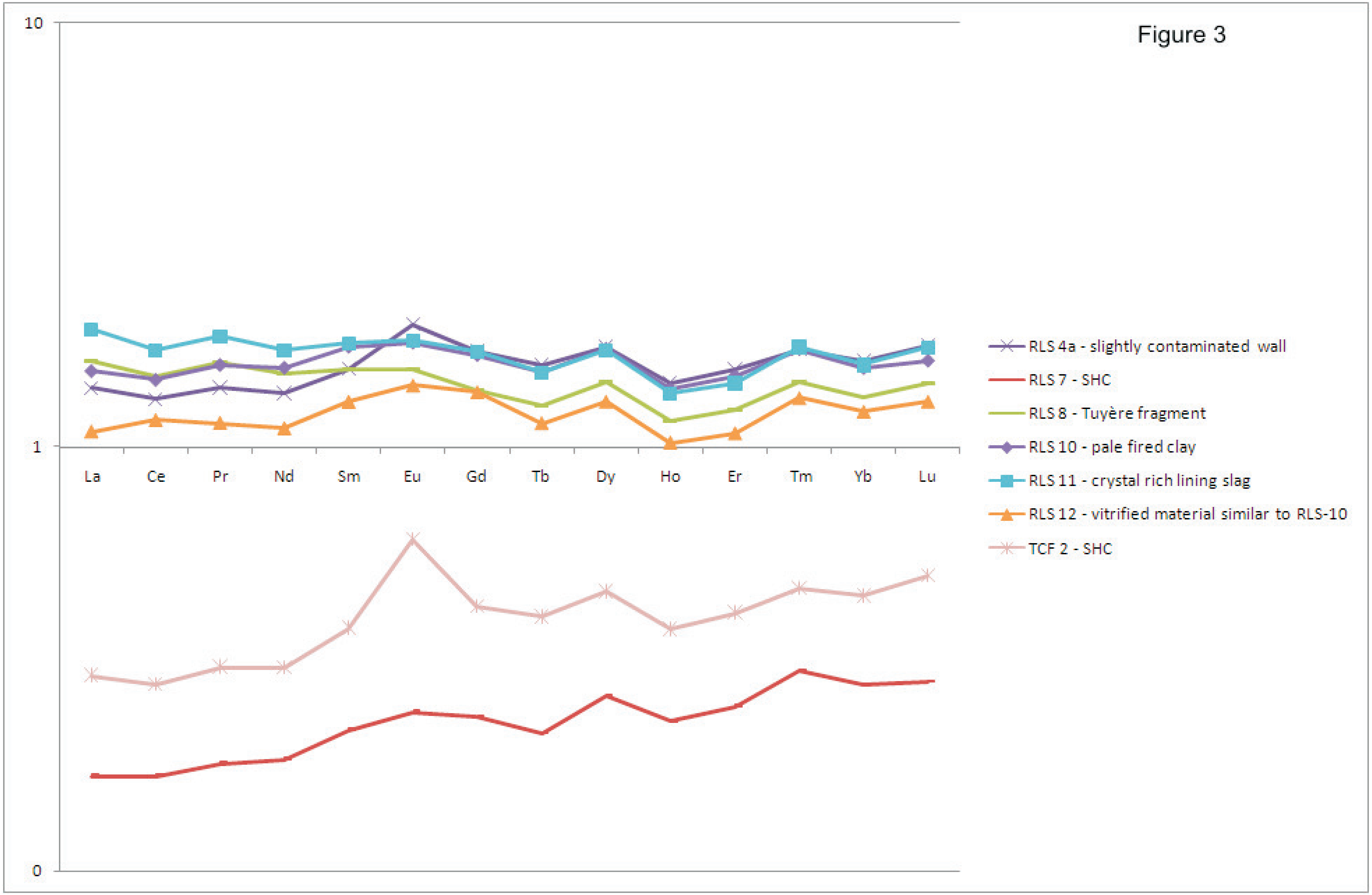
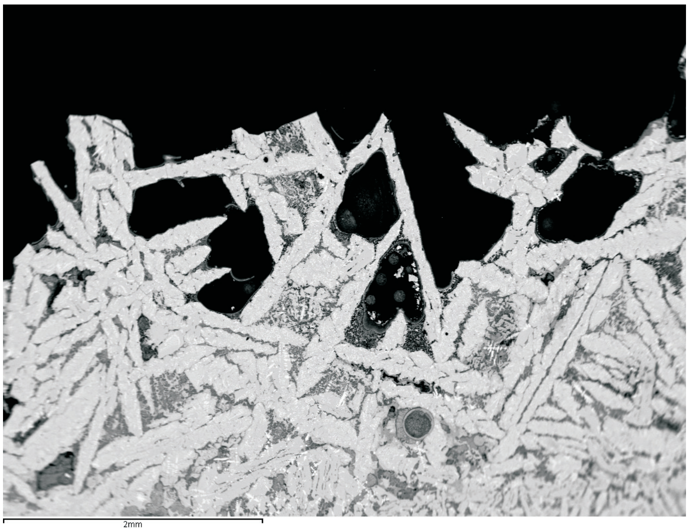
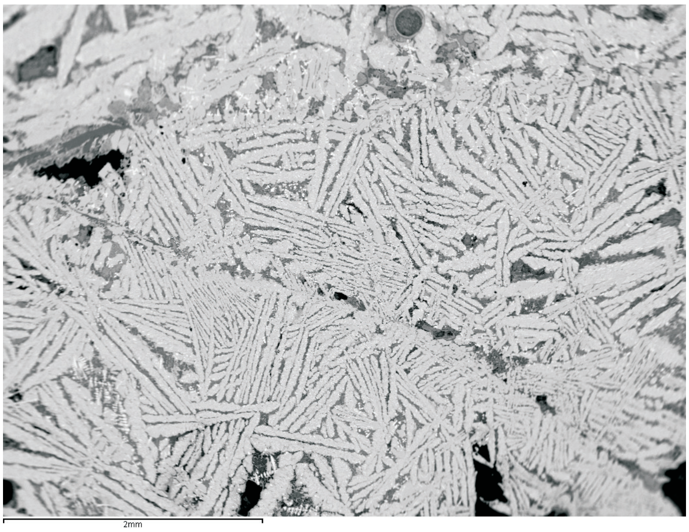


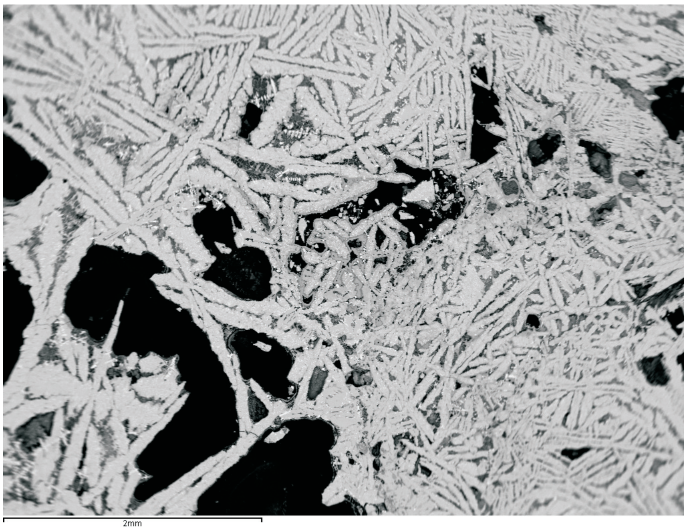
Figure 3
10
1
0
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
RLS 4a - slightly contaminated wall
RLS 7 - SHC
RLS 8 - Tuyère fragment
RLS 10 - pale fired clay
RLS 11 - crystal rich lining slag
RLS 12 - vitrified material similar to RLS-10
TCF 2 - SHC

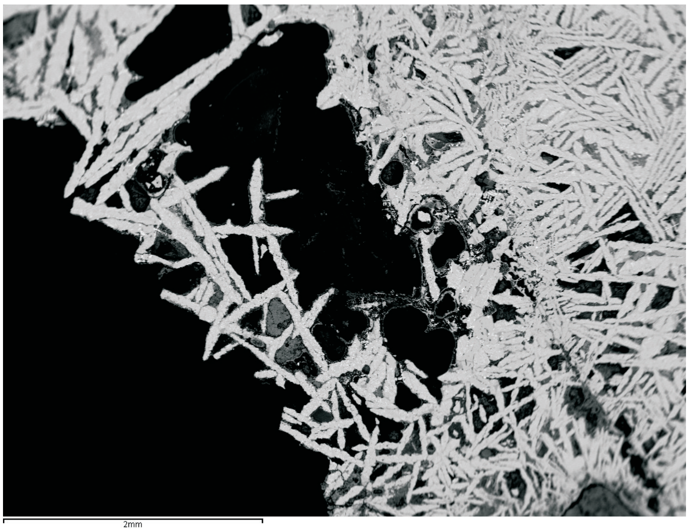
RLS1

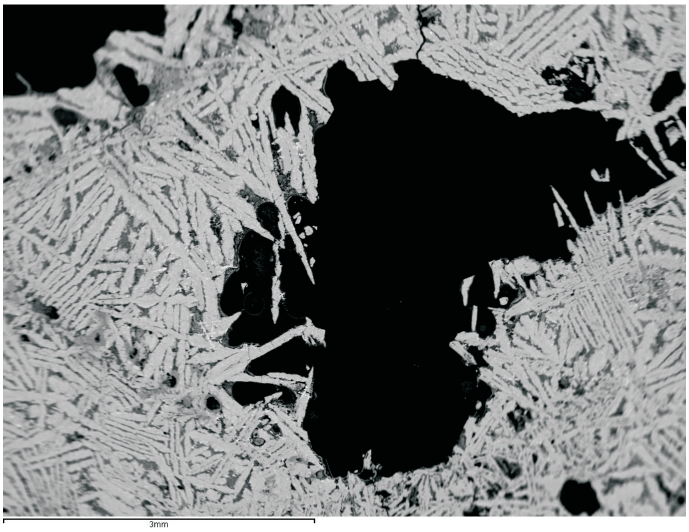
Plate 1

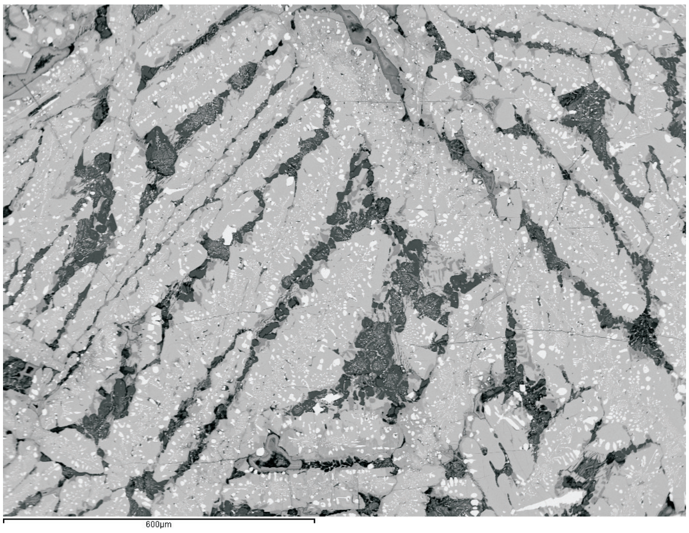
1


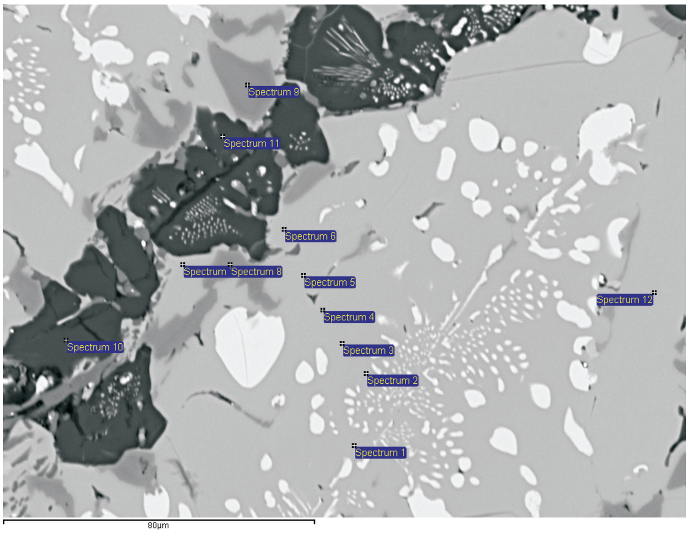
2


3


4


5


6


7


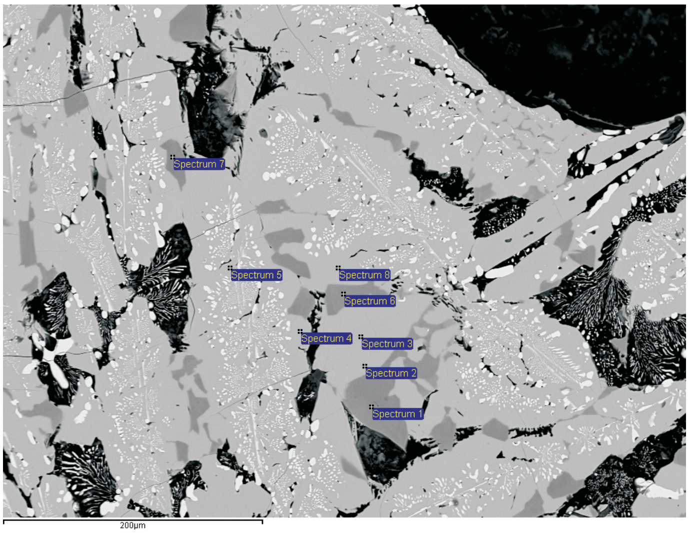
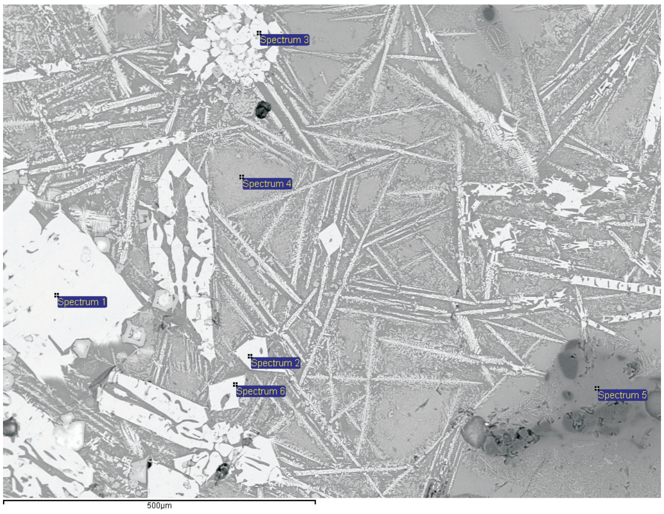
8


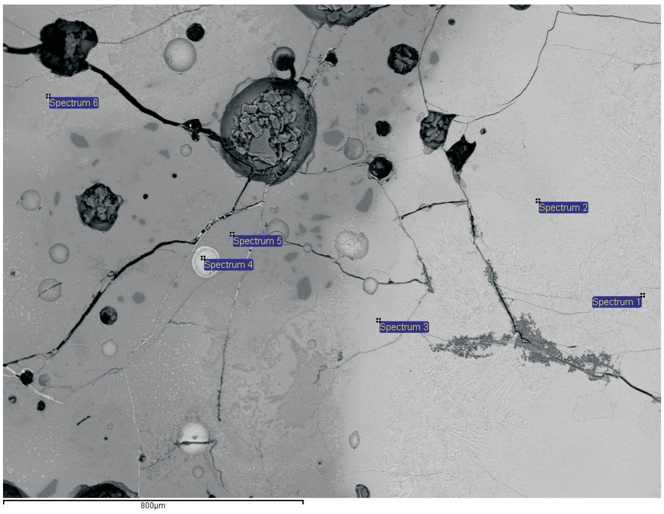
Plate 2

RLS2b

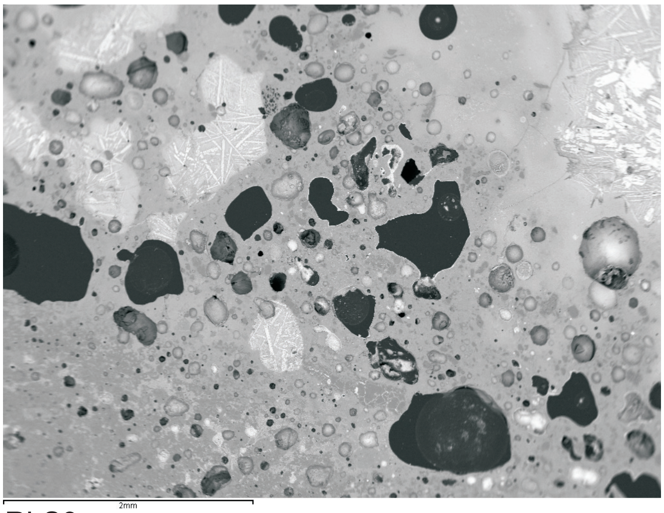
1



2



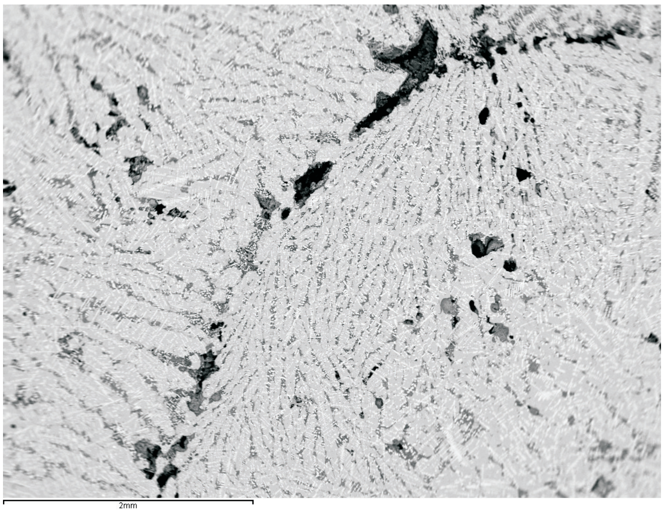
3



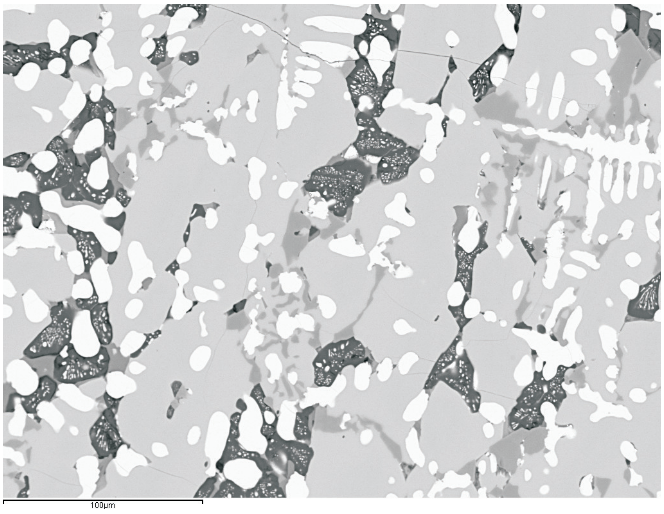
4

RLS3

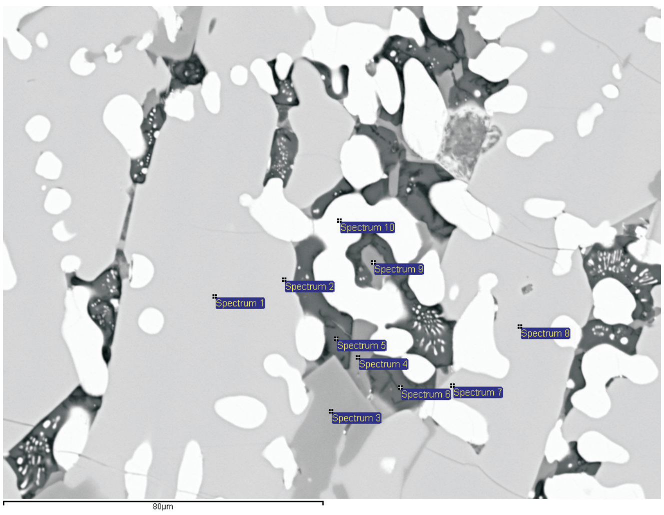
1



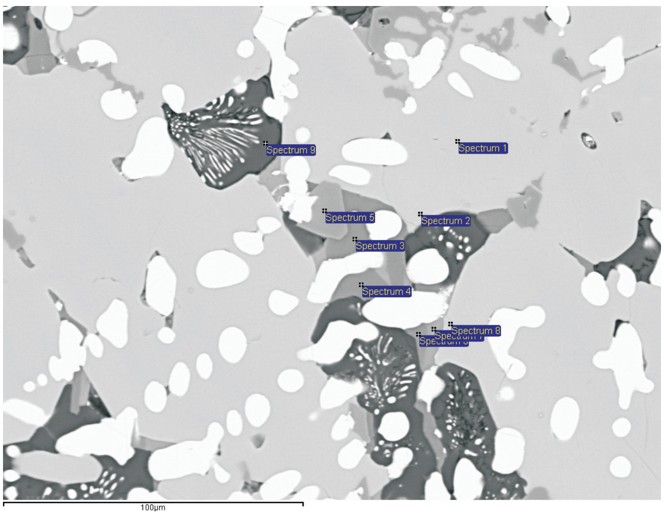
2



3



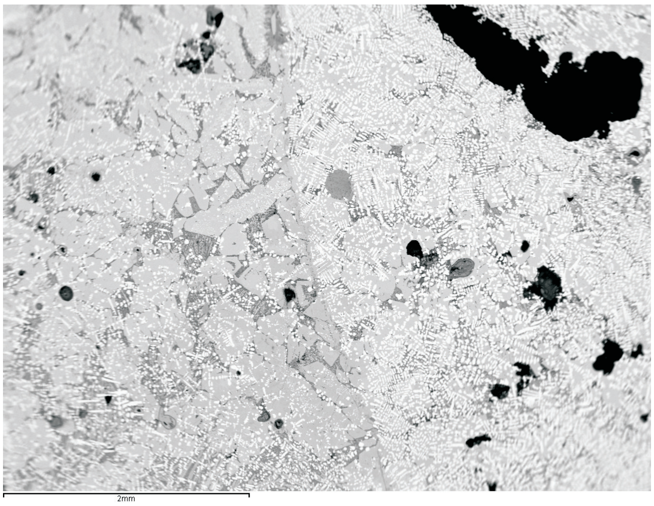
4



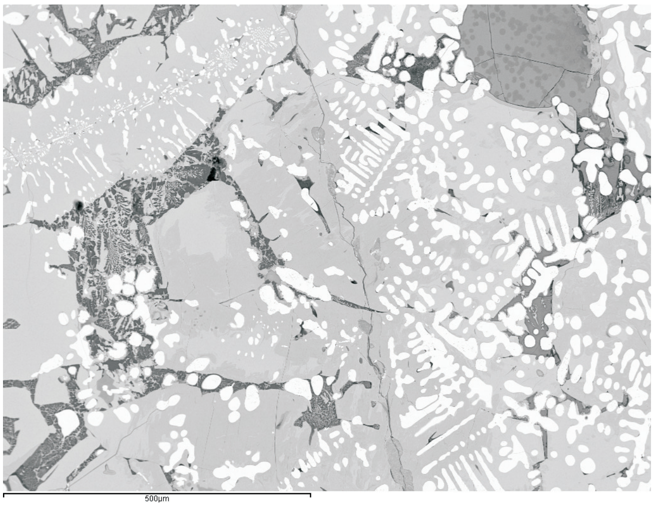
RLS4

Plate 3

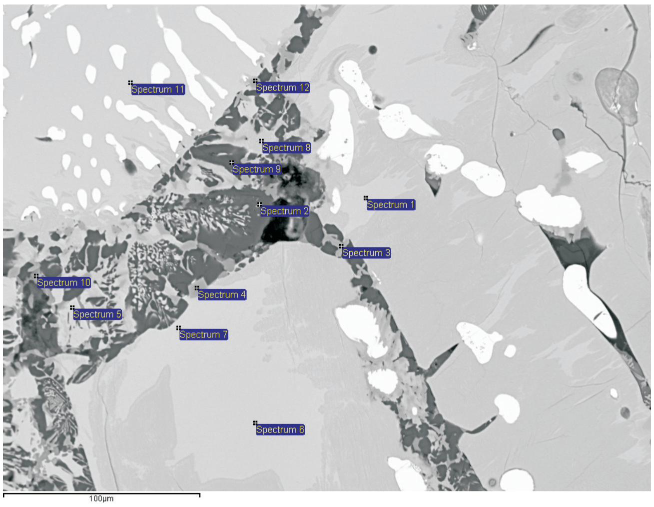
1



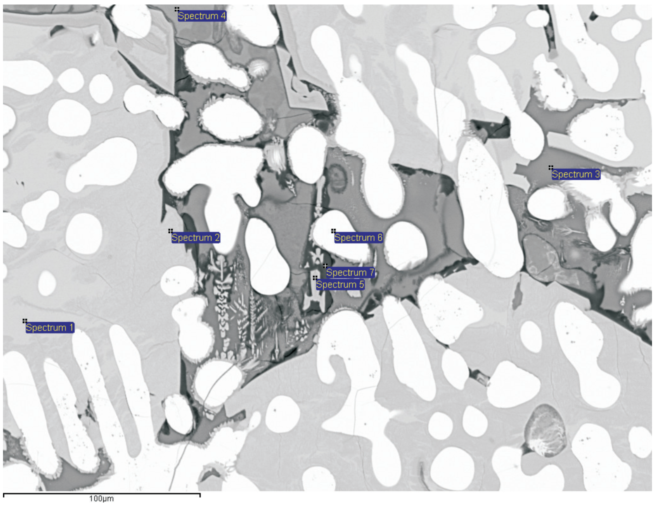
2



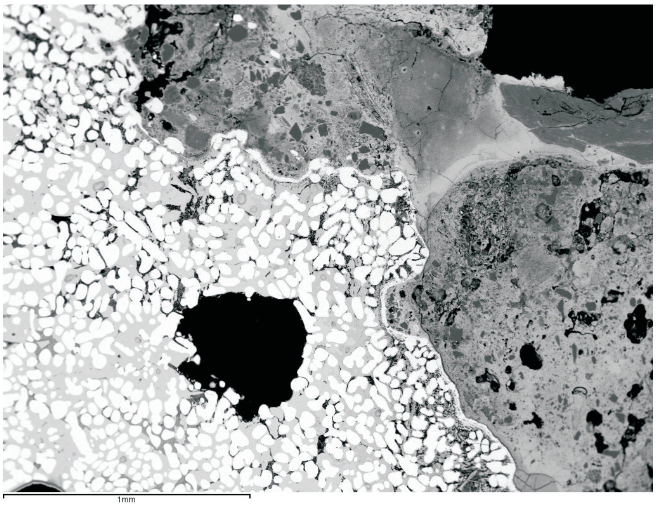
3



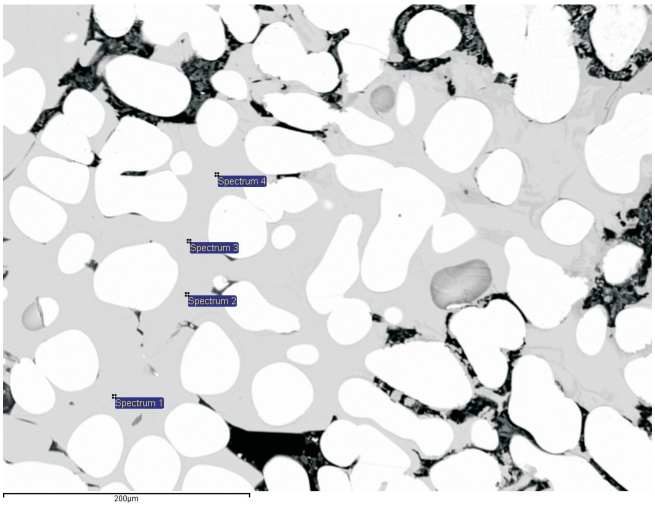
4



5

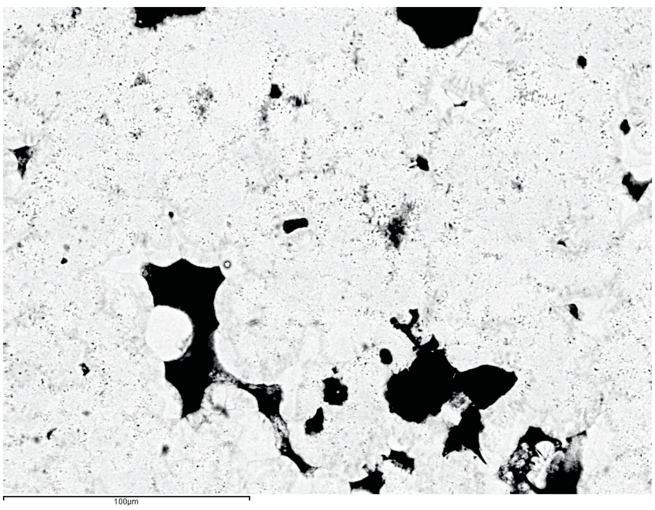


6

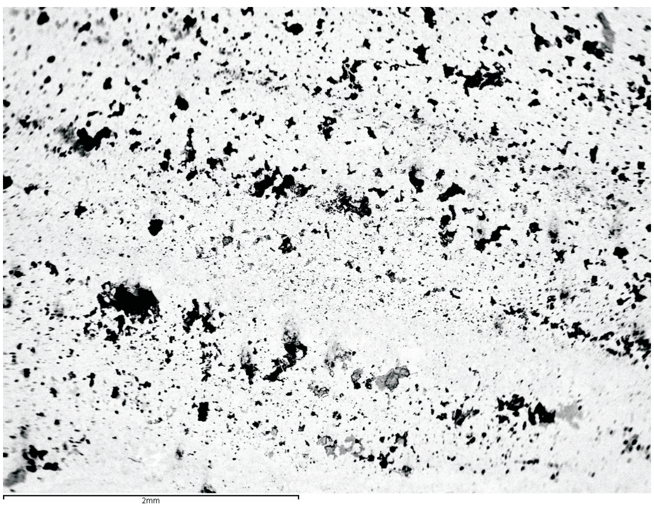


RLS5

1

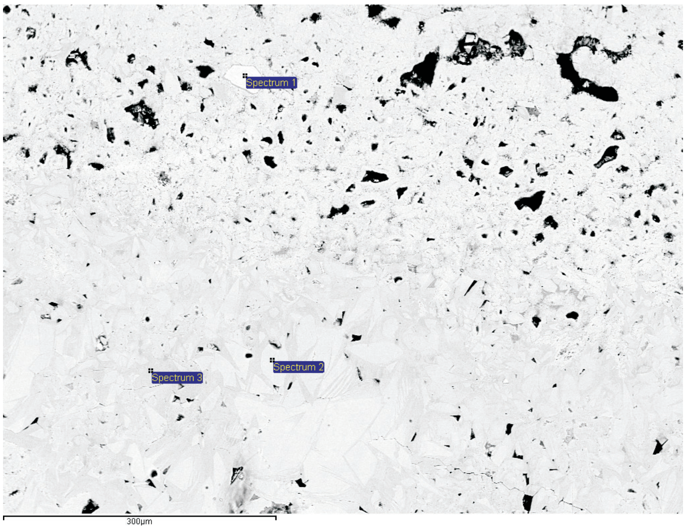


2

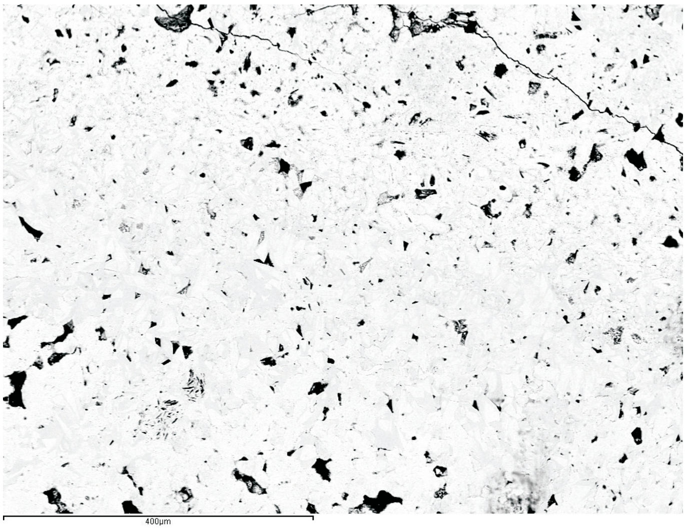


RLS5

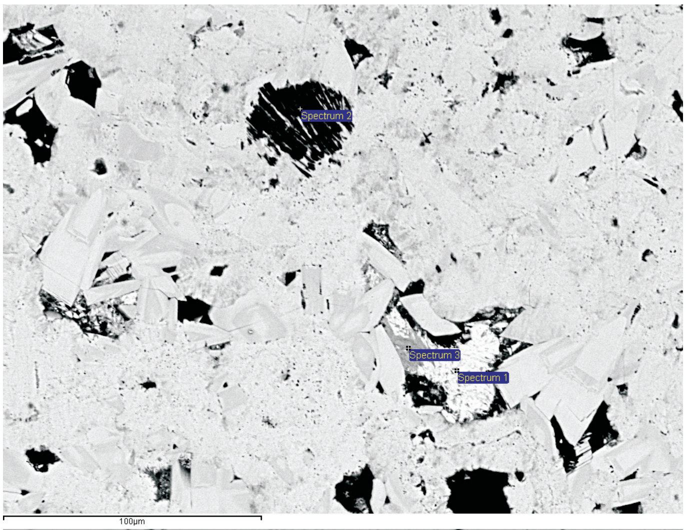
3



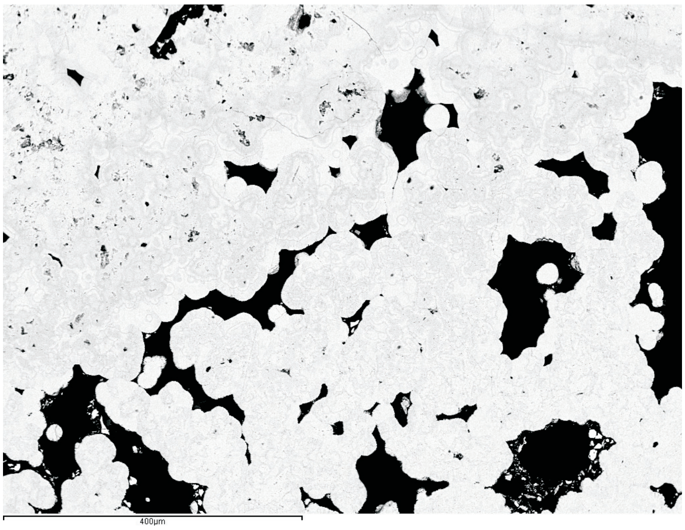
4



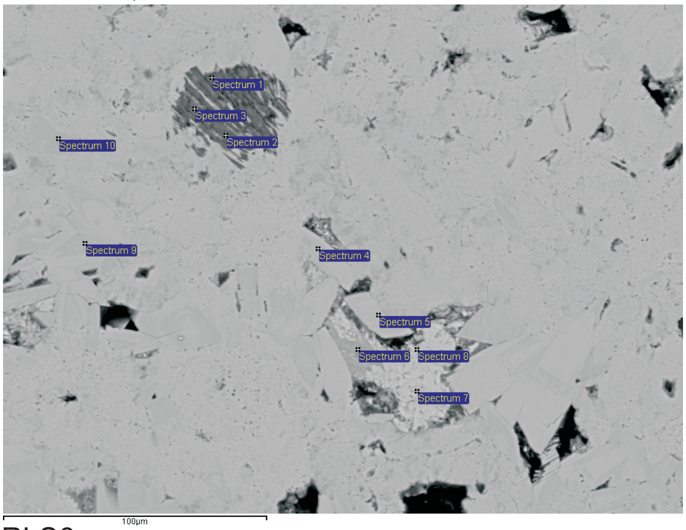
5



6



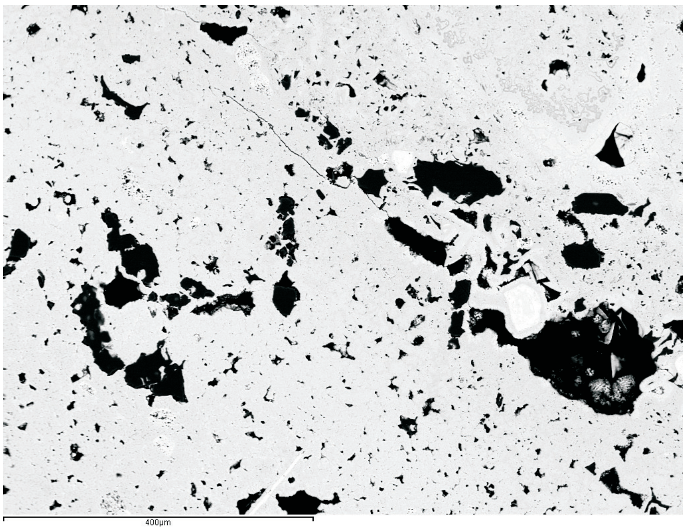
9



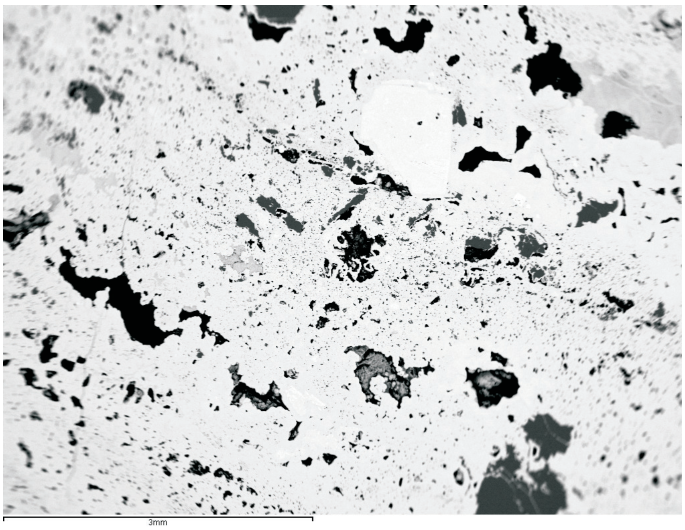
6

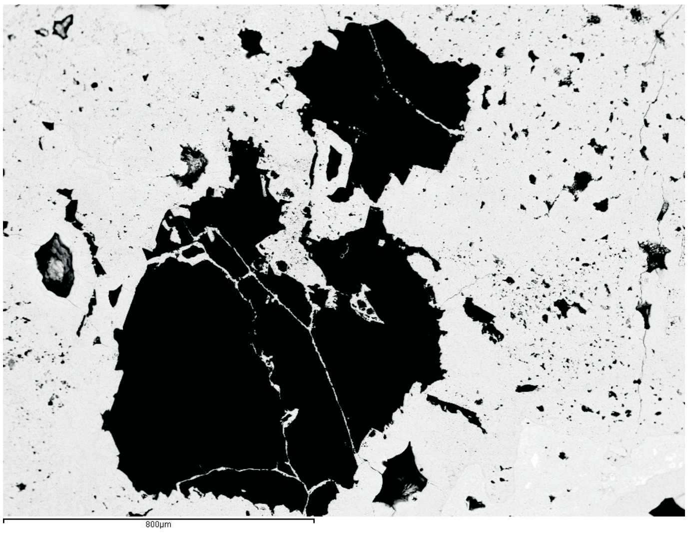
RLS6

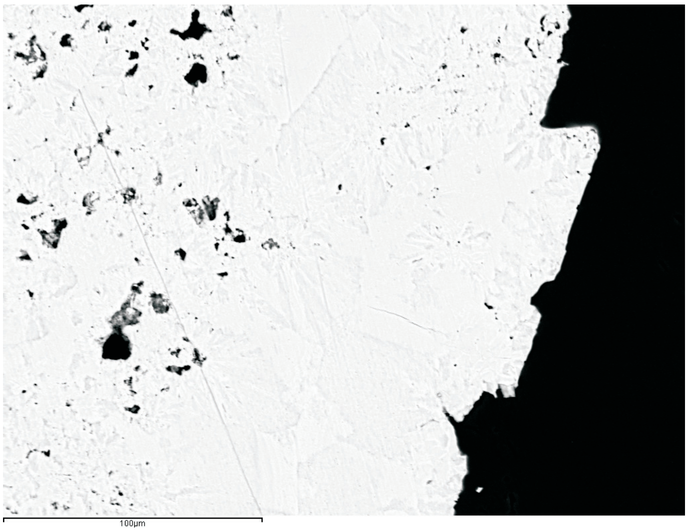
1

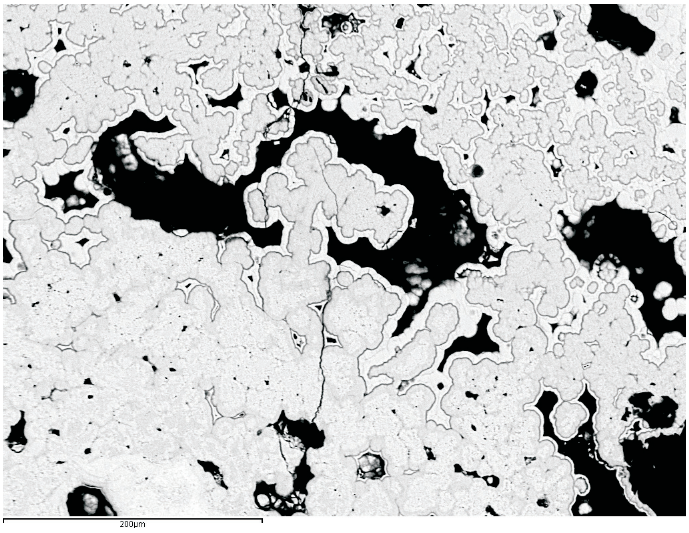


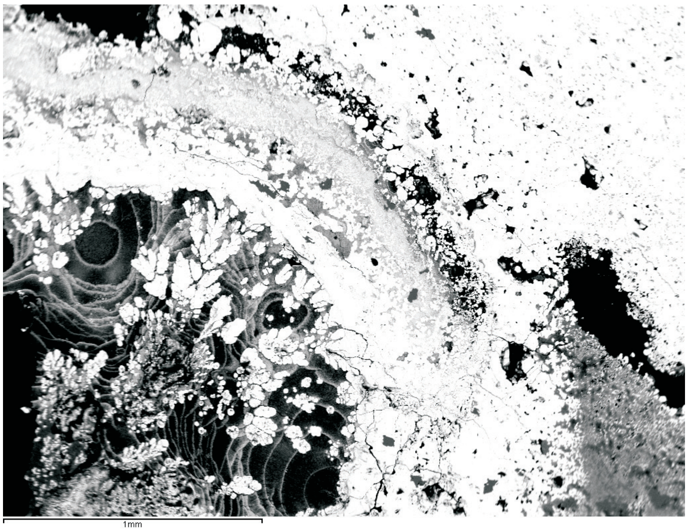
2

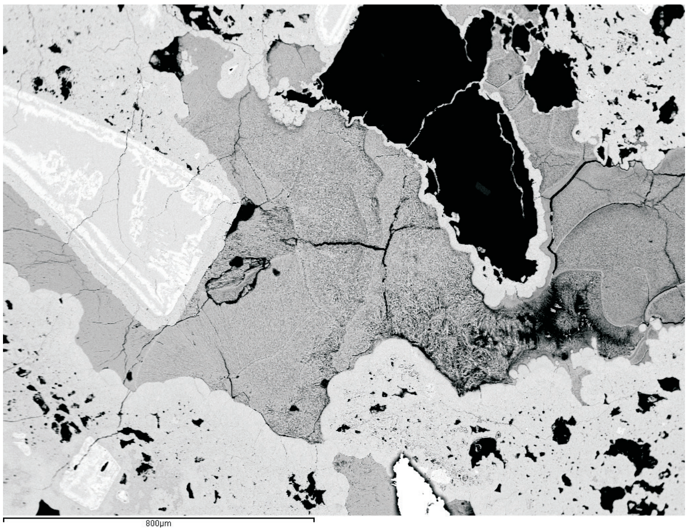


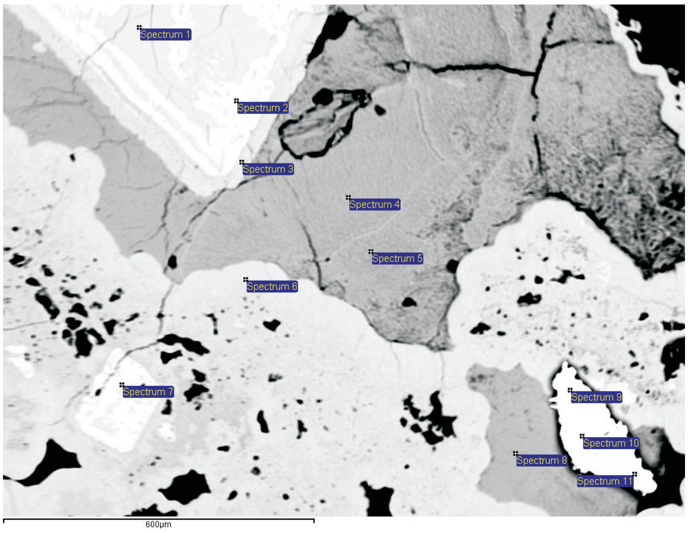
3

800µm

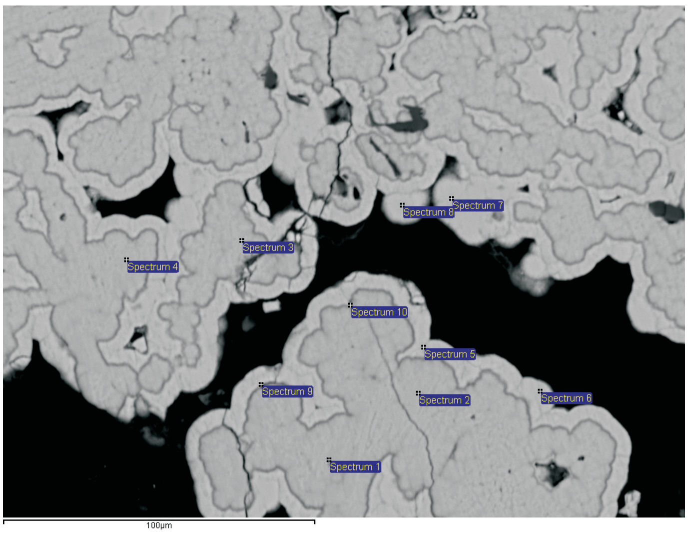
4

100µm

5

200µm

6

1mm

7

800µm

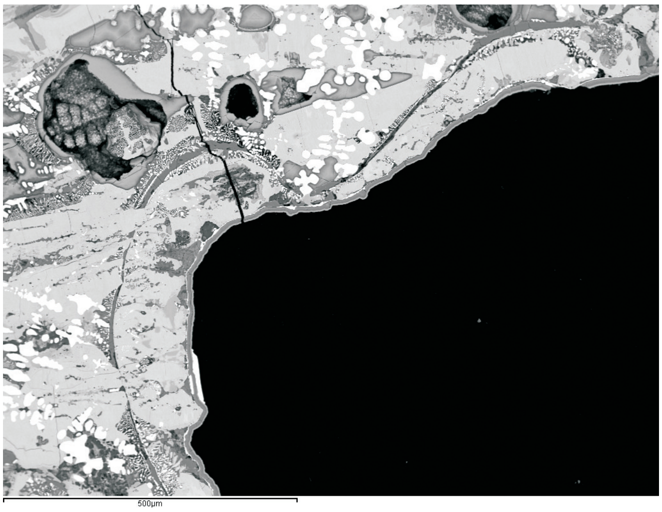
8

Spectrum 1
Spectrum 2
Spectrum 3
Spectrum 4
Spectrum 5
Spectrum 6
Spectrum 7
Spectrum 9
Spectrum 10
Spectrum 8
Spectrum 11
600µm

9

Spectrum 7
Spectrum 8
Spectrum 3
Spectrum 4
Spectrum 10
Spectrum 5
Spectrum 9
Spectrum 2
Spectrum 6
Spectrum 1
100µm

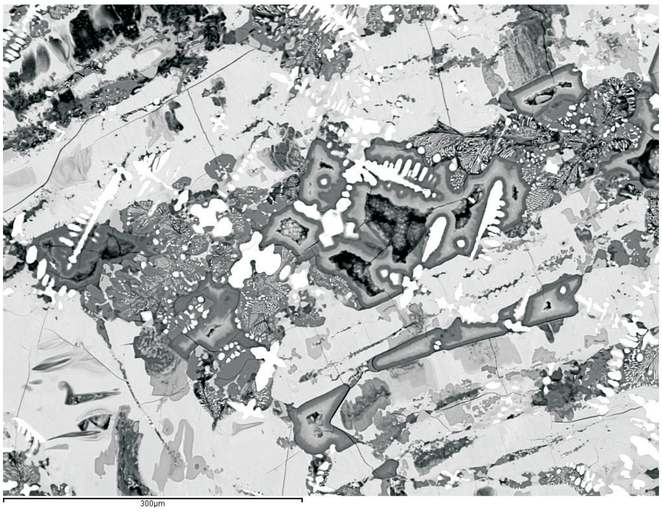
RLS7

Plate 6

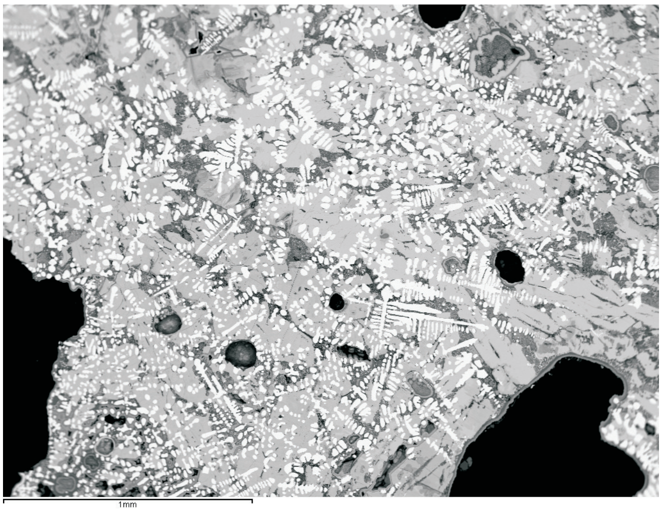
1



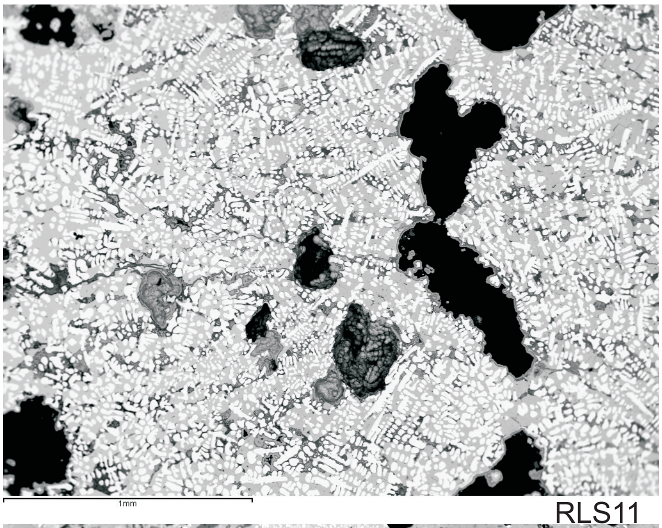
2



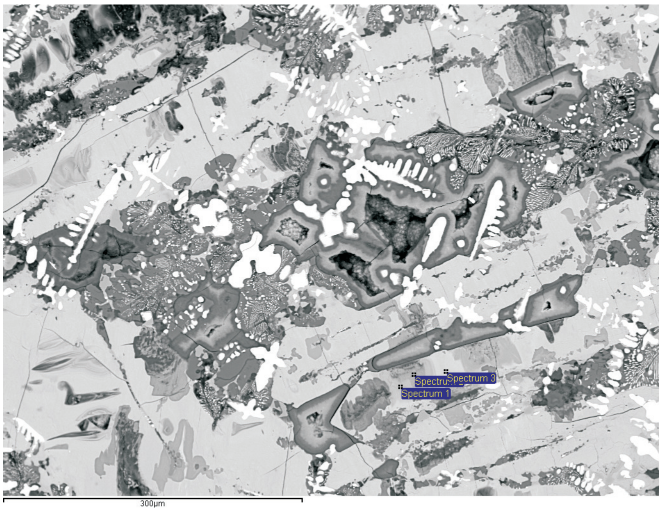
3



4

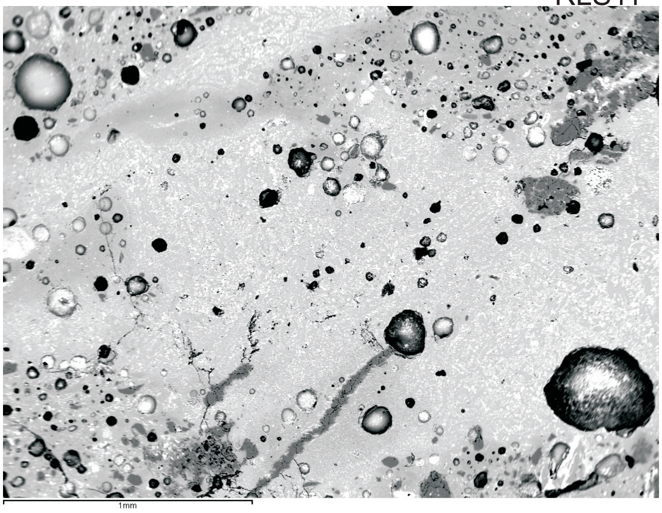


9

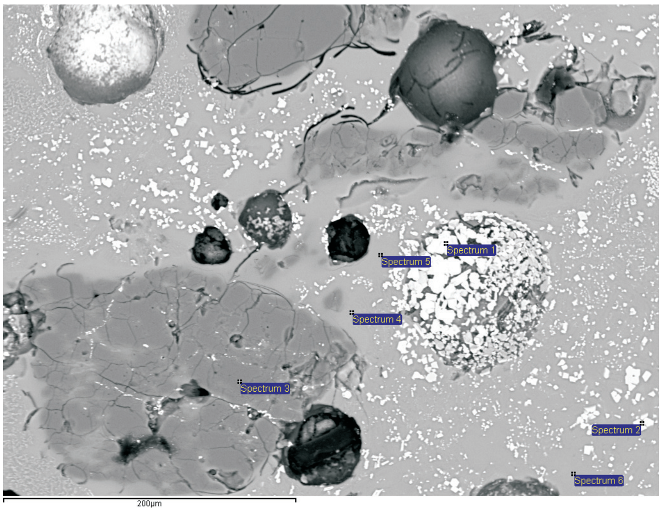


RLS11

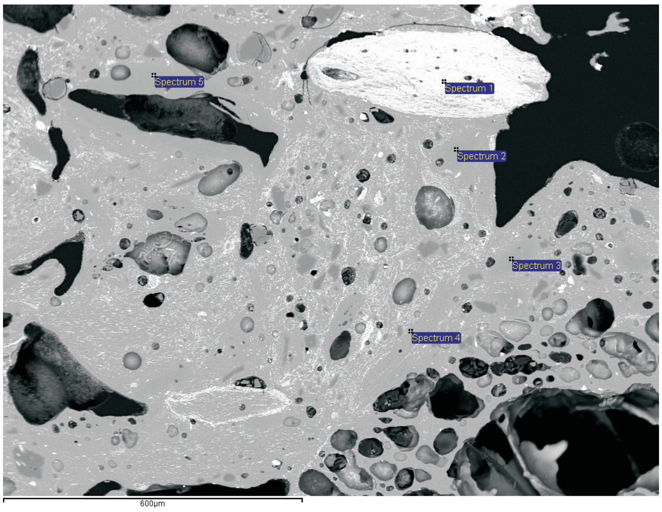
1



2



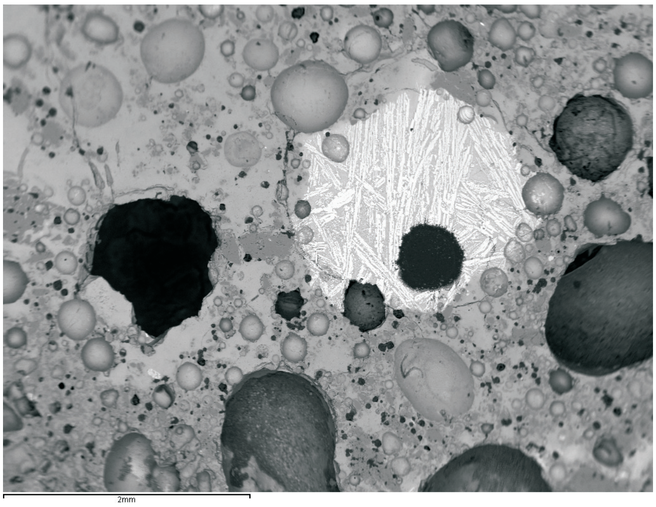
3



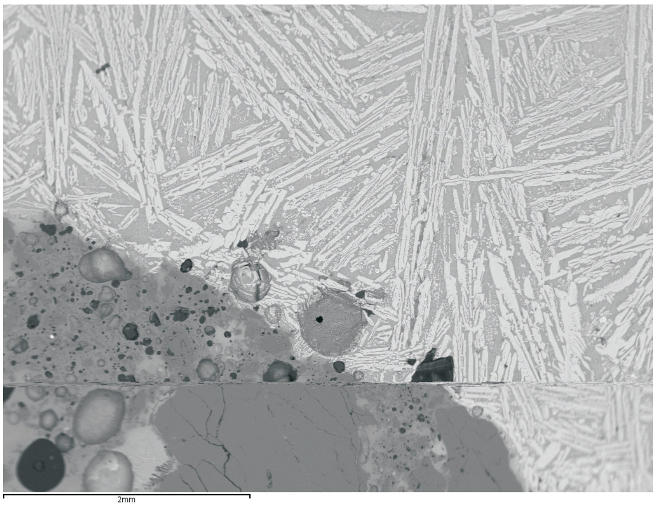
RLS12

Plate 7

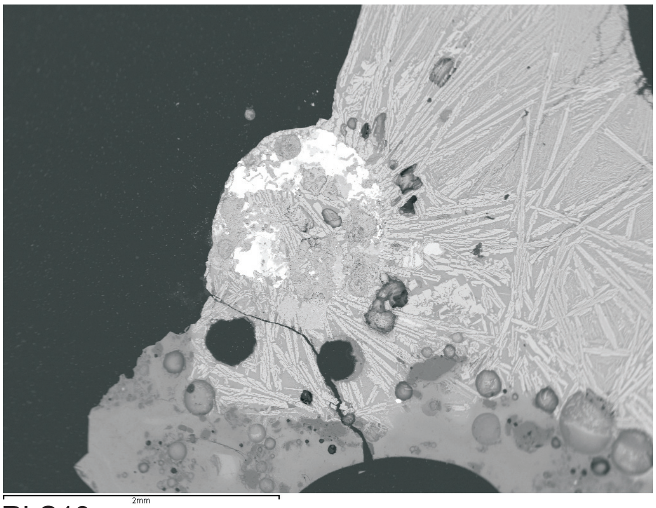
1



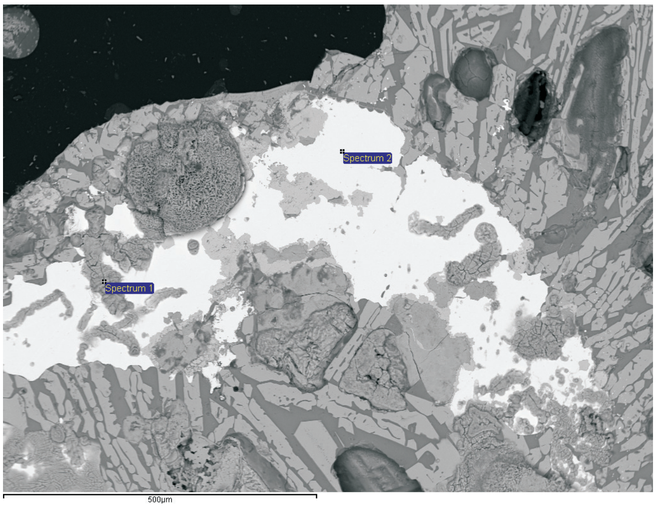
2



3

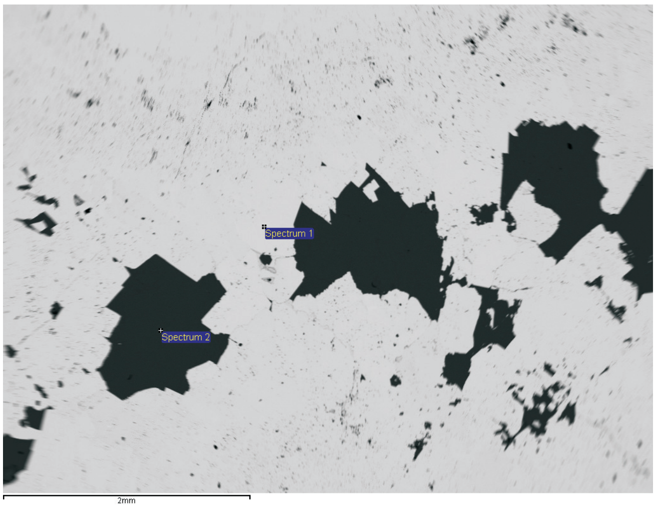


4



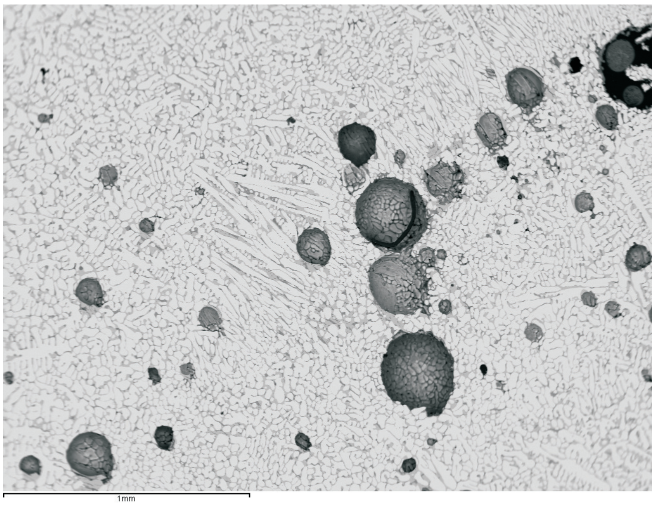
RLS13

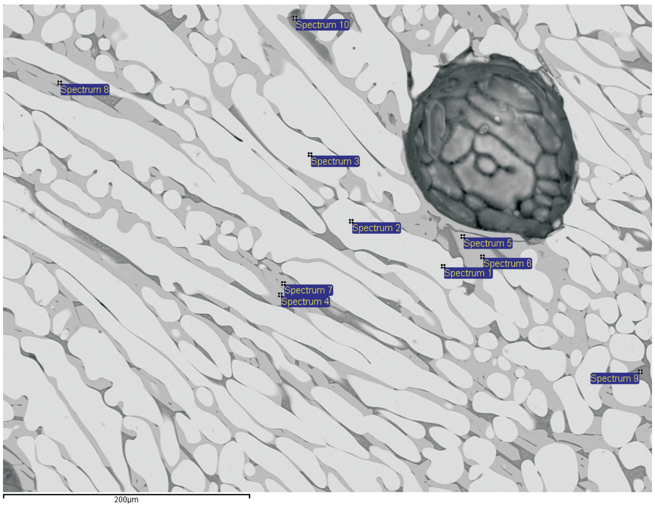
1

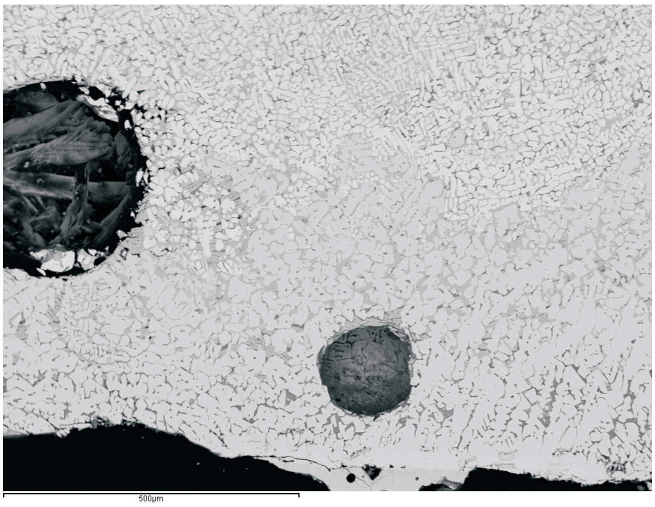


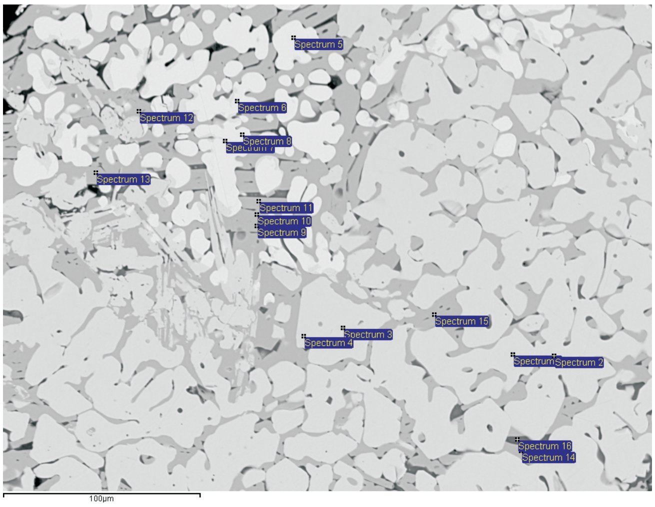
TCF1

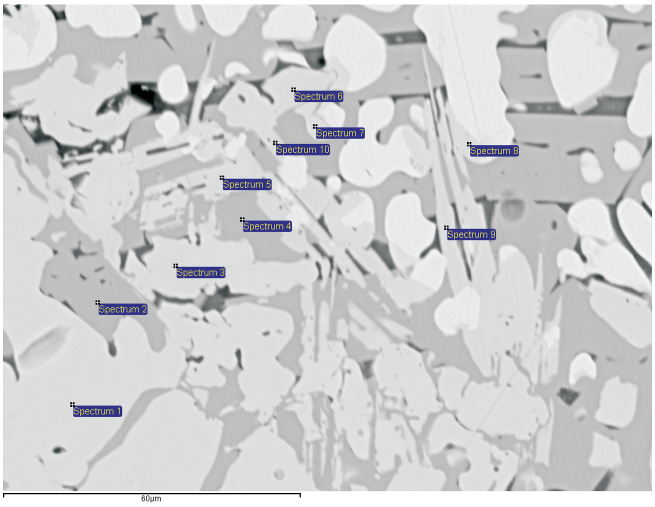
Plate 8

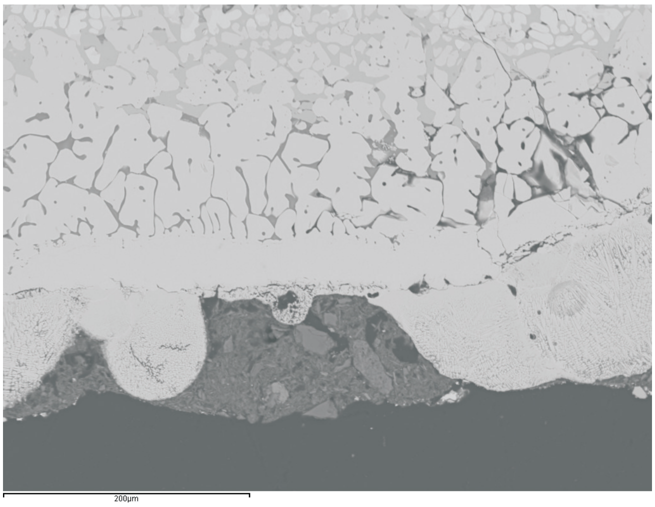
1


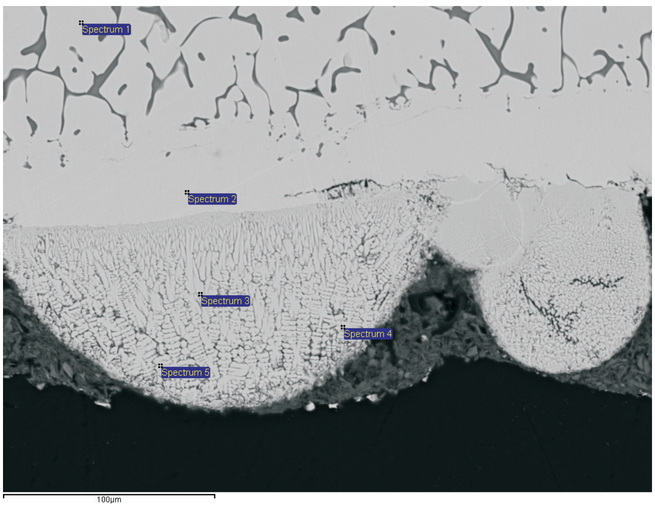
2


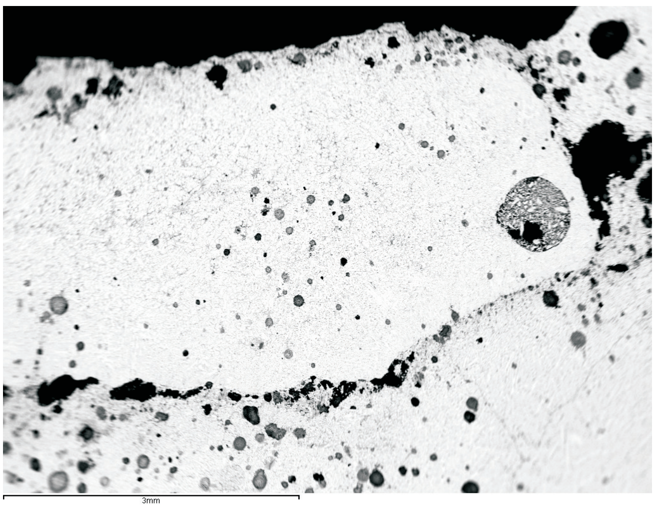
3


4


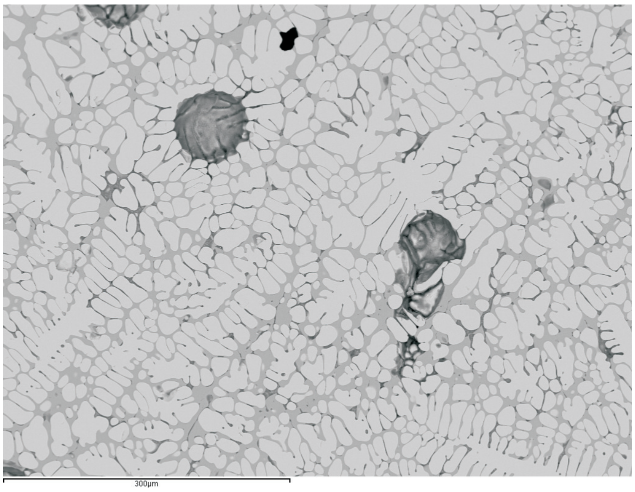
5


6


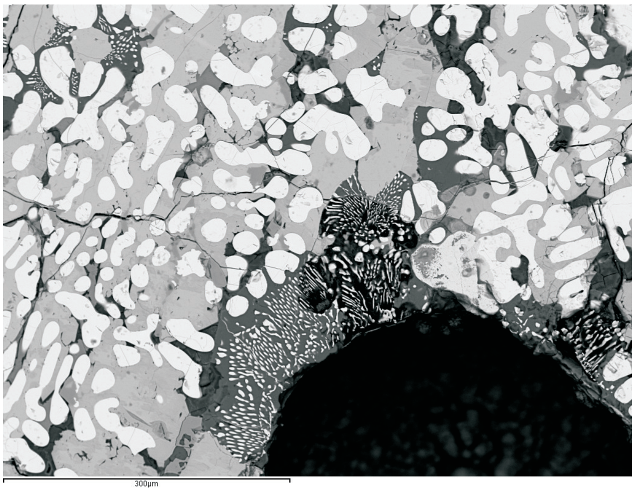
7


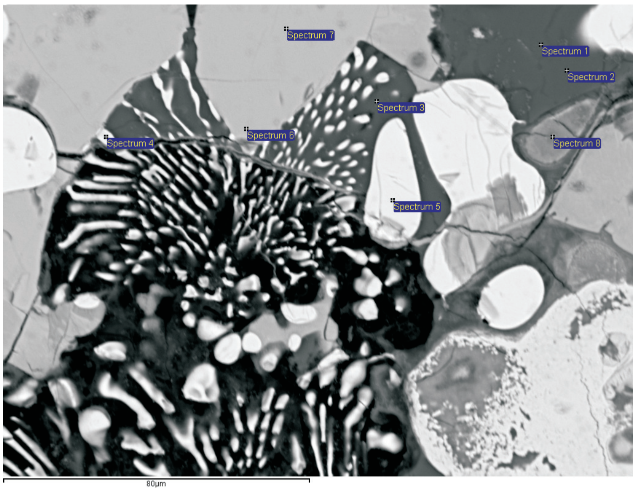
8


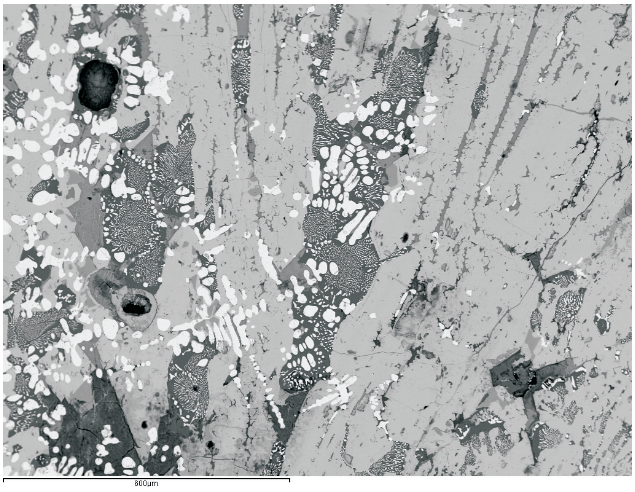
TCF1

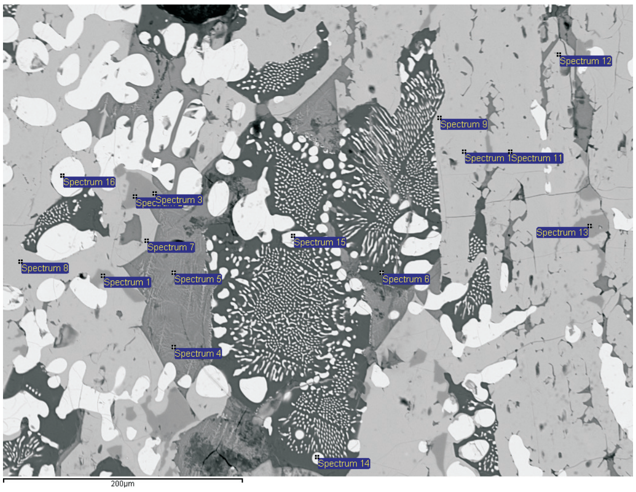
9


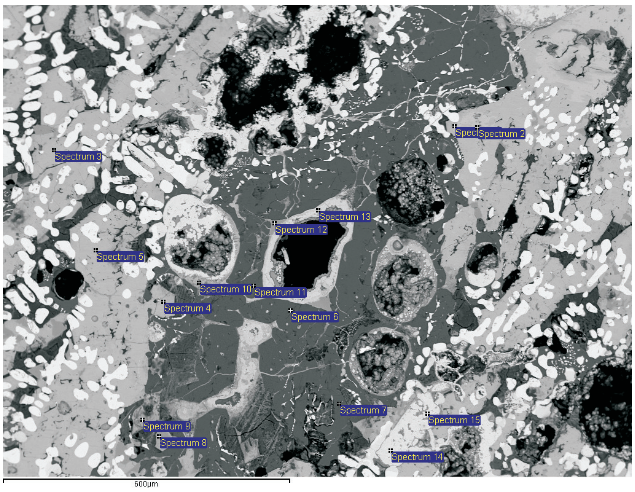
TCF2

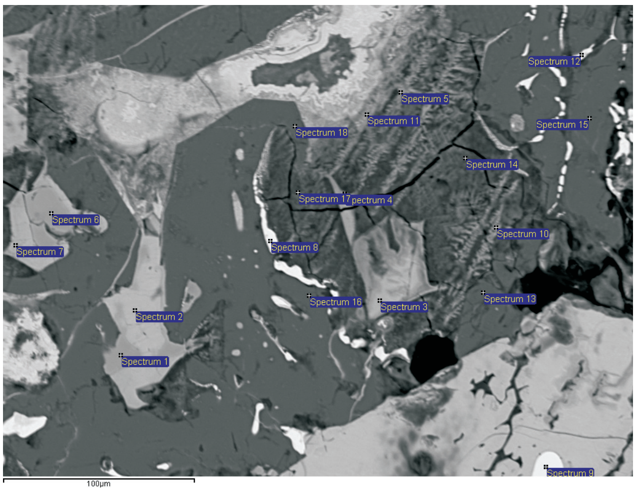
1


2


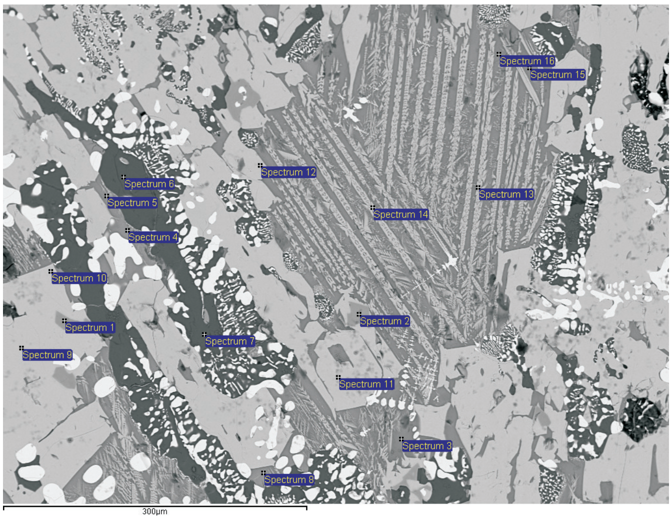
3


4


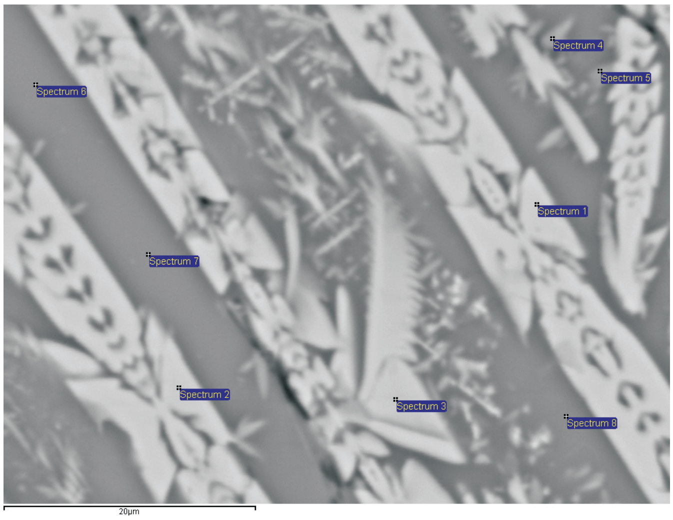
5


6


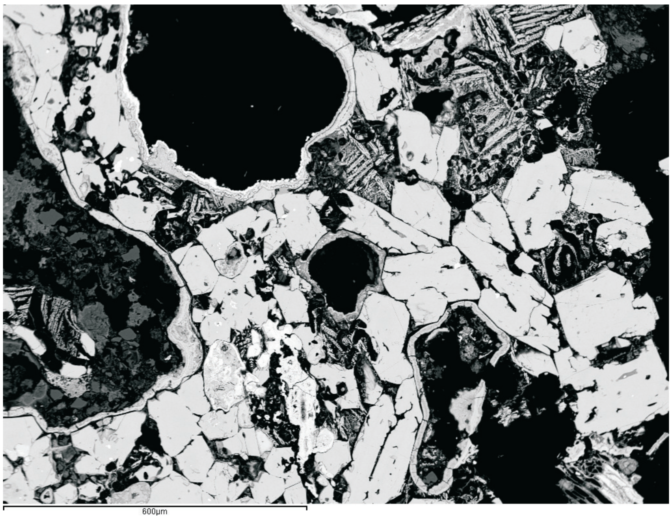
7



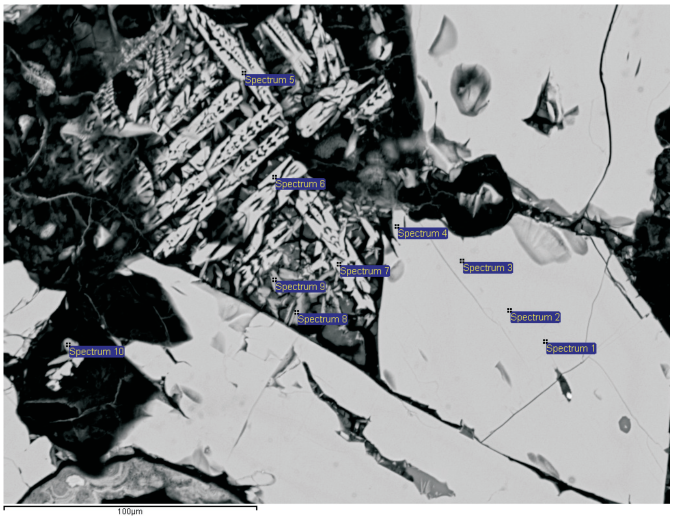
8



9



10



GeoArch

geoarchaeological, archaeometallurgical & geophysical investigations

54 Heol y Cadno,
Thornhill,
Cardiff,
CF14 9DY.

Mobile: 07802 413704
Fax: 08700 547366
E-Mail: Tim.Young@GeoArch.co.uk
Web: www.GeoArch.co.uk