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Ironworking residues from Probus (ACD2489)

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Abstract

The assemblage from Probus indicates iron smelting in non-slag tapping furnaces that employed a basal packing of wood. These furnaces are large and constructed over pear-shaped cuts, so resembling other examples of MIA furnaces in the area.

The furnaces were constructed of a very aluminous clay, which may have caused the slags to be particularly viscous. The high degree of interaction between the furnace wall and the slag is demonstrated by the furnace superstructural debris in their backfill. This superstructural material comprises around 40% of the assemblage – an unusually high proportion and possibly suggesting that the furnaces were deliberately demolished rather than being allowed to decay.

The furnace material included evidence in both furnaces for their ventilation via rectangular-sectioned block tuyères.

Chemical analysis of the slags suggests that the smelting employed ore of at least two distinct types. Both types fall within the compositional Group 2 as recently described. This group is characterised by elevated contents of uranium, tin and phosphorus, but modest contents of manganese, compared with the Group 1 slags that are tentatively associated with smelting iron ores from the Great Perran Iron lode and associated deposits. The source of the Group 2 ores is less clear, but the vein system to the SW of St Stephen (6km NE of Probus) is contender.

Contents

Abstract 1

Contents 1

Methods 2
- Project rationale and history 2
- Analytical methods 2

Results 2
- General 2
- Iron-smelting residues 3
  - Furnace materials 3
  - Smelting slags 3
- Ironworking (smithing) residues 4
  - General 4
  - Elemental analysis 4

Interpretation 5
- Interpretation: the furnaces 5
- Interpretation: the ore source 5
- Interpretation: process models 6
- Summary 6

Discussion 6

Figure captions 7

References 8

Table 1: summary catalogue 10
Table 2: residue types by context 20

Table 3: major element analyses by XRF 22
Table 3: trace element analyses by ICP-MS 1 ... 23
Table 4: trace element analyses by ICP-MS 2 .. 24

Figures 25

Methods

Project rationale and history

An assessment of materials from Probus Phase II (ACD2489) was commissioned by Naomi Payne of AC Archaeology and was conducted in August 2023 (Young 2023). The materials derive from excavation work undertaken on a site in Probus, Cornwall, centred on NGR [SW 9035 4748] (See Figure 1 for the location and the locations of other key places mentioned in this report). The catalogue of materials is presented as Table 1.

The assessment resulted in the statement (Young 2023, 4):

> 'A programme of analysis is therefore suggested, with a representative suite of analyses of residues focussing on one furnace (to ensure coherency as far as is possible – to permit mass balance calculation of yield), plus analysis of a small number of equivalent residues from other contexts to look for any broader variation.'

The analysis phase of the work addressed this through the bulk elemental analysis of one sample taken from a fragment of a ceramic tuyère, one sample of furnace wall ceramic and five different slag samples, all taken from context (1237); one fragment of furnace ceramic and two slag samples from context (1081); two slag samples from context (1337); a single slag sample from context (1361) and a sample from a smithing hearth cake from context (1348). These source contexts include the lower fills (1237) and (1337) of the two main furnaces F1236 and F1334 respectively, a slag dump (1081), a small pit F1361, and a small pit F1346 adjacent to furnace F1334.

In addition, to facilitate interpretation of the results for ore provenancing, four further samples were analysed. Two were taken from a dump of large iron rich gossan boulders next to the beach at the north end of Perran Bay (just below the outcrop of the Great Perran Iron Lode where it has been exploited by the Gravel Hills Mine). Both these samples, PER1 and PER2, were diffusely laminated ores, with incipient boxstone textures and with limited developed on botryoidal coatings on void surfaces. Two samples were taken from Trevelgue Head, one, TRY1, from a low grade ore deposit on the N side of the chasm cutting off the headland and one, TRV2, from a surface find of iron smelting slag that had weathered out from the exposed fill of Ditch 7/4 on the cliff top on the southern side of the headland.

The site lies on solid geology of the Devonian Portscatho Formation (PORO) with local areas of head, and is situated 8km SW of the St Austell granite

The analysis was undertaken early in 2025, with reporting completed in March 2025.

Analytical methods

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

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

Samples for trace elemental analysis by ICP-MS were drawn from a second aliquot of the powdered material using the alkali fusion method (Jarvis & Jarvis 1992a and 1992b; Pearce *et al.* 1999). Once prepared, the samples were then all subjected to analysis using a Thermo Scientific XSERIES 2 ICP-MS. Data quality was strictly monitored in terms of precision and accuracy by five international rock standards of known concentration and varying compositions which are run after every 20 unknown samples. In addition, external monitoring of data quality is carried out four times a year via the GeoPt round robin proficiency testing program (*http://www.geoanalyst.org/ overview.html*).

The results of the elemental analyses are presented in Tables 3, 4 and 5 of this report.

The GeoArch site code used for the samples is PRB.

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

Results

General

The assemblage comprised approximately 104kg of picked fragments of residues and sieved samples from 50 discrete archaeological contexts (Table 1).

The distribution of the various classes of residue by context is presented in Table 2. The most important contexts are two furnaces, F1236 and F1334. These furnaces are apparently similar in structure. They were constructed over a pear-shaped cut, with a horseshoe-shaped footprint to the shaft, leaving a wide ramp facing onto an external ramp area. The internal diameter of the furnace chamber appears to have been approximately 0.7m to 0.8m (the precise size is unclear from the plans). The slag assemblage associated with the furnaces is typical of non-slag tapping furnaces with a wood-packed basal pit. The iron-smelting technology closely resembles that of a series of Middle Iron Age sites in the Truro area: Threemilestone (Young 2007, 2021), Tolgarrick Farm (Young 2016a, 2016d) and Tregurra (Young 2016c, 2022a).

The presence of wide, shallow burnt pits on the Probus site is also potentially similar to the occurrence of charcoal-making pits on other sides in the same area.

One key element of the residues associated with the furnaces, is the amount of fallen furnace superstructure preserved within the pits. In both furnaces this material included fragments of block

tuyères, the occurrence of which has only been documented in the region in similar furnaces at Nansledan (Young 2025a).

Smaller pits close to both furnaces (F1360 and F1346 respectively) produced evidence for smithing in the form of hammerscale and macroscopic smithing slags. Other negative features (pits and ditches) in the vicinity of Furnace F1236 produced smelting slag assemblages, but in at least some cases these are likely to be residual, probably indicating the former extent of slag disposal across this part of the area. An extant spread of residues (F1081) may represent the base of another slag dump to the west, comprising similar iron smelting residues.

Iron-smelting residues

General

The iron smelting residues (Table 2) comprised significant assemblages in each of the two furnaces (F1236 and F1334), plus debris from 'furnace bottoms' both in the slag spreads and as (probably residual) material in various cut features, including the 'fire pits' (likely to be Iron Age charcoal-making structures) and the ditches interpreted to be of Roman age (where they are presumably residual).

The evidence that there may have been multiple slag dumps is important, for often on typically truncated rural sites there is little evidence for these. This provides some indications of the likely relatively large scale of the smelting operation. If the relationship inferred at Tregurra between iron smelting and charcoal manufacture is also valid for Probus, then the presence of more than one furnace and dump may indicate reoccupation of the site for smelting following repeated woodland management operations (e.g. coppicing – but not limited to coppicing).

Furnace materials

The 'clays' employed for furnace construction appear consistent – a lithic- and grit- rich material, sometimes laminated.

Several pieces of block tuyère were recovered from contexts (1237) and (1337). These contexts are the lower fills of the furnaces, suggesting the tuyères were associated directly with the structures. Two fragments from (1337) provide the best evidence for the morphology of the block. The two pieces appear to form an upper corner of the front face of the block. The bore is incompletely preserved but appears to be approximately 27mm diameter. The centre of the bore lies at 80mm from one lateral margin and 95mm from the probable top. The face lies at approximately 70 degrees to the axis of the block. All the edges and corners are neatly rounded (suggesting little material has been lost from its front face). The front face is partially slagged, with slight impressions of fuel particles. The sides of the block show little significant high temperature alteration.

Elemental analysis of samples of furnace wall (PRB5) and tuyère (PRB3) from Furnace F1236 are remarkably similar across all elements (except zinc, which is susceptible to volatilisation). This strongly supports their derivation from the same clay source.

An analysed sample of wall ceramic (PRB12) from spread (1081) was also similar, but there was contamination from the iron slag in the furnace.

All of the ceramic samples were aluminous, with SiO_2:Al_2O_3 for samples PRB3, PRB5 and PRB12 of 2.36, 2.41 and 2.39 respectively.

Smelting slags

The basal (pit floor) residues from the furnace pits comprise small pieces of flow slags and rusty material with abundant very fine charcoal and tiny slag prills/droplets with an overall rough, granular or spiky surface texture. These indicate that the 'furnace bottom' did not reach the bottom of the pit, or that there was space forward of the FB, where small particles were able to descend to the pit floor.

The main slag mass in the basal pit of the furnace would have formed a 'furnace bottom' (FB). No intact furnace bottom was recovered. It is likely, based on the form of the furnaces, that the FBs would have been very large, approximately plano-convex slag cakes (for comparison the in-situ FB at Tolgarrick Farm was 80kg, more typical examples are around 20-30kg) but here the largest fragment was 3.4kg (from context (1260)) and the average weight of a slag particle identified as being from a FB was just 39g.

The components of the FBs include dense flow slags, often very dark in colour and where they were amalgamated they defined the moulds of large fragments of wood (mostly split wood, with a characteristic creviced surface), isolated flow slags, prilly slags containing moulds and clasts of the charcoal fuel and dense, massive, slags from towards the pit walls and probably forming the top of the FB.

Where the FB impinged on the pit wall, the dense slags are often contained within fragments of the wall, rather than as discrete FB pieces. The interaction with the wall ranges from dense lags simply abutting the wall ceramic (areas lateral to the blast) to deep interaction between the wall and the slag, often including the formation of a burr (a bulbous area of slag attached to indurated wall material) and/or areas in which the slag intrudes the wall material either as narrow complex veins or as sheets of flow-lobed tapslag-like material. Areas close to the wall may also generate slags with a 'coralline' texture – an open, porous structure with large equant, or rarely tabular, exposed olivine crystals.

The lateral attachment of the FB to the walls indicated a dense sheet approximately 30mm thick, but this increased markedly to 60-70mm on the blowing wall. The original FB would have been thicker than these estimates because of a large amount of flow slags below the dense sheet.

In the area close to the blast, the wall may form a smooth slag-coated embayment (above) or a complex mass of lining slags and spiky iron slags (below the blast). Several pieces of wall from this area show a groove eroded into wall; it is unclear if this represents erosion during the smelt exploiting a line of weakness associated with the construction, or if it is damage from tool use during extraction of the bloom and/or slag.

A horizontal division between oxidised- l and reduced-fired wall ceramic was very marked. It occurred at approximately the same level as the top of the FB. Although this may be associated with change in reducing conditions within a wall body, it is perhaps more likely that this line marks the approximate contemporary ground level, below which oxygen-rich

air could not be drawn into the ceramic from outside the structure.

Elemental analysis of the smelting slags showed that two groups were present, termed Suites A and B (Figures 2 and 4).

Samples taken from the fills (1237) and (1337) of furnaces F1236 and F1334 respectively, formed a closely coherent group of materials (Suite A). These slags are mostly very iron rich (except where directly associated with the furnace wall), they have a moderate content of MnO (mostly in the range 0.6% to 1.1% MnO), they have a very low content of alkali and alkaline earth elements, but have elevated phosphorus (1.4% to 2.6% P_2O_5). They show very slightly elevated levels of copper (148-280ppm), sometimes of zinc (up to 385ppm) and more distinctly of tin (up to 915ppm). The rare earth element (REE) upper-crust normalised profiles (Figure 2, upper right) show a humped profile, with a peak at europium accompanied by a moderately steep relative depletion down into the light REE (LREE) and a much less steep slope down in the heavy REE (HREE). Some of the analyses show a very slight positive cerium anomaly.

A second group (Suite B) includes flow slag samples from (1361) and (1081). These show elevated Mn (MnO of 2.86% and 1.82% for PRB10 and PRB13 respectively) but lower levels of phosphorus than for Group 1 (0.44% and 0.21% respectively).

REE profiles of samples from Suite B (Figure 2, lower right)show a slightly more marked europium peak that for those of Suite A, with a flat to slightly declined profile through the HREE and a moderately steep decline through the LREE, with a marked positive cerium anomaly.

One slag sample from (1081) has been distinguished as possibly representing a third suite, Suite C (although, it more likely is derived from Suite A by mixing). It shows a REE profile (Figure 2, lower left) very similar to that of the smithing hearth cake (SHC) described below (although not so diluted; Σ REE = 151ppm). It shows a low Mn content (MnO = 0.26%), but a phosphorus content similar to that of the smelting slag (P_2O_5 of 1.44%). It is aluminous (SiO_2/Al_2O_3 of 2.70). although this resembles the composition of a smithing slag, the morphology resembles that of other pieces of wall slag from a smelting furnace. The unusual composition may result from an atypical mixing of smelting slag with fresh furnace wall.

The major element chemistry of the slags is aluminous SiO_2/Al_2O3 is 3.1 to 3.8 for the flow slags, bust as low 2.5 for one furnace bottom fragment. On the FeO-SiO_2-Al_2O_3 ternary (Figure 3), the majority of the slags plot close to the join of the wustite, fayalite and hercynite fields, with only a very small number of flow slags showing more evolved compositions. The mixing of the aluminous wall ceramic with a rich ore, forces the slag evolution into a part of the phase diagram where slags are likely to be viscous.

The ironworking (smithing) residues

General

Iron smithing is represented by three classes of material: smithing hearth cakes, 'slag flats' and hammerscale. The occurrence of materials similar to the floor residues of the smelting furnaces in other might include examples of fines from the bases of smithing hearths (small scall flow-slags and prills may occur in both contexts).

Smithing hearth cakes (SHCs): there are no entirely morphologically unambiguous examples of SHCs because all the probable examples have a degree of irregularity of shape, but likely examples include a 400g slightly incomplete example from context (1070), a 658g example from context (1086), two small fragments from context (1112), a dubious 268g example from context (1201), a 188g fragment from context (1238), a possible 124g fragment from (1298), a 424g cake from context (1348) together with a smaller 66g fragment, The 424g example from context (1348) was selected for further detailed analysis and was confirmed as a product of bloomsmtihng (see below).The more convincing examples from amongst these are all formed of rather dense slag and have original weights in the range of 400g to 660g.

'Slag flats': these include examples from contexts (1337) and (1361). They comprise examples of slag with a flat, sometimes slightly striated, surface that is likely to have formed in contact with metal. That metal might have been the surface of a tool or the surface of a workpiece being fashioned by the smith (e.g a compacting bloom or bar).

Hammerscale: hammerscale forms from the superficial oxidation of the workpiece during heating. There are two forms (Young 2011): the flat scale that forms largely in the solid state on the surface of the iron, known as flake hammerscale (FHS), and chilled droplets formed from the same material that has melted, spheroidal hammerscale (SHS), mostly formed from molten oxide scale expelled during closure of a fire weld. Both forms are very rare in the present assemblage, with FHS recorded from contexts (1098), (1347) and (1361) (only context (1347) having FHS in larger quantities) and SHS recorded only from context (1361). A hearth floor assemblage from context (1098) includes a small proportion of FHS.

Elemental analysis

An SHC from context (1348) was analysed (as sample PRB11).

This showed an aluminous composition with SiO_2/Al_2O_3 of 2.74. Manganese is very low (MnO of 0.11) and phosphorus is also moderately low (P_2O_5 of 0.43%).

The REE profile (Figure 2, lower left) is broadly similar to the smelting slags of Suite A, but the REE are very diluted (Σ REE is just 45ppm, compared with an average of 250ppm for the smelting slags).

In Figure 5, the bulk composition (yellow dot) can be seen to lie close to the tie lie between the origin (in this case representing iron) and the composition of the furnace cermaic (orange dots), but with a slight offset in the direction of the smelting slags.

These parameters are compatible with the slag having formed as a reaction between iron bloom carrying a substantial proportion of entrained slag with hearth wall ceramic, implying this SHC was produced during bloom refining rather than blacksmithing.

Interpretation

Interpretation: the furnaces

The description of the furnaces (F1236 and F1334) suggests that they are among the larger members of spectrum of MIA furnaces (Young 2016c figure 11; Young & Anelay 2025 Figure 9), perhaps of approximately the same size as the furnace [2178] at Tolgarrick Farm (Young 2016a, d).

The Tolgarrick Farm produced a calibrated radiocarbon date of 370-100 cal. BC (SUERC-67876; Hughes & Farnell 2016). This long range is bimodal and so the furnace is likely to be either late 3rd to late 4th century BC or 2nd to early 3rd century. Thus, a Middle to early Late Iron Age date might be appropriate for the Probus furnaces too.

Since the penetration of the bellows blast through the charcoal fuel bed is limited (typically to around 400mm or so), large furnaces would develop dead zones in which fuel consumption was very slow. It is likely therefore that the furnaces were 'bottle-shaped' with the part of the furnace in which the reaction was taking place being narrower than the base. This shape means the area of slag attachment to the lining is reduced (so making for easier cleaning) and allows for a large furnace arch (for easier cleaning and bloom removal).

The basal chamber/pit of the furnace was packed with split wood prior to the smelt. The purpose of this technology has been much debated but it is likely that its major function was to introduce weaknesses into the FB, permitting its easier fracturing during extraction. The presence of an in-situ FB at Tolgarrick implies abandonment of the furnace; the normal situation would be the fracturing of the FB into smaller, manageable fragments, to permit extraction and disposal – as seen at Probus.

If the form of the furnace is recognisable elsewhere, the physical evidence for the furnace structure is unusual. The evidence for ceramic tuyères is unusual – and only paralleled in the region at Nansledan (Young 2025a). Middle to Late Iron Age rectangular sectioned block tuyères are better known from Iron Age and Roman contexts involving smithing (e.g. Gussage All Saints in Dorset, Spratling 1979, 129; Mucking in Essex, Dungworth and Bayley 1999), copper alloy working (Dainton Elm's Cross, Young 2025b, 216; Cloakham Lawn in Axminster, Devon, Young 2015, Hart & Sheldon 2017) and copper smelting (e.g. Llandysilio, Powys Young 2006, 2010, Havard *et a*l. 2016, illus. 17).

The presence of large quantities of lining slag and furnace ceramic (together comprising 44kg out of the site total of 104kg) is unusual. However, these large quantities were retrieved from the backfills of the furnaces themselves. This may, perhaps, imply deliberate demolition of the furnace structures rather than their gradual decay. Given the apparently high degree of slag adherence to the walls (probably a function of the highly aluminous system generating rather viscous slags), it raises the possibility that the furnaces were demolished because of the high degree of repair work required to reinstate them – although it is not possible to know whether this was after routine smelting, or after a particularly problematic smelt.

Interpretation: the ore source

Although no ore was retrieved from the site, the elemental composition of the smelting slags provides some useful provenancing information.

The bulk chemistry permits the recognition of two suites of analyses suggestive of different raw materials (Figures 2 and 4):

Suite A: moderate Mn, elevated phosphorus, very slightly elevated levels of copper, sometimes of zinc and more distinctly of tin. The REE profiles show a humped profile,

Suite B: elevated Mn, but lower levels of phosphorus than for Group 1. The REE profiles show a slightly more marked europium peak on a flat profile and a marked positive cerium anomaly.

These suites were included in the comparison of ore and slag compositions from central Cornwall presented by Young (2025a). The comparison diagrams are reproduced as Figure 3.

Figure 4a shows that Probus Suite A shows elevated phosphorus compared to other analysed groups of slags, but low Mn. Probus Group B slags show lower P and higher Mn, bring them into the same range of compositions as samples from Threemilestone and the Newquay area. Samples from Tregurra (both suites A and B of that site) show lower phosphorus contents, but a similar low Mn content as Probus Suite A.

Figure 4b shows that the shape of the REE profile for Probus Suite A is very similar to that of the Tregurra slags. Although not demonstrated by this plot, the REE profile for Probus Suite B differs from all others in its strong positive cerium anomaly.

Figure 4c shows that Probus Suite B, Probus Suite B, Tregurra Suite B and Tregurra Suite A form coherent groups with increasing U:Σ REE ratios, all quite distinct from the materials from Threemilestone and the Newquay area which all have low U contents.

Figure 4d shows that Tregurra Suite B, Probus Suite A and Probus Suite B form groups which not only show moderately elevated U, but also show increasingly elevated contents of Sn.

On this basis, Young (2025a) differentiated the smelting slags from Tregurra and Probus as 'Group 2' (Group 1, being slags and ores from Threemilestone, Trevelgue and Nansledan). The ore samples recovered from Tregurra were, however, a poor fit with the slags from the same site.

The four assemblages within Group 2 (Probus Suites A / B and Tregurra Suites A / B) show much in common, as well as being distinct from each other. The significance of elevated U, Sn and P to the identity of this group suggests that these materials may have an origin in gossan.

The shape of the REE profile of most members of Group 2 differs in detail from that of members of Group 1 (as demonstrated in Figure 3b), nonetheless they share a broadly humped shape. Thus, it is likely that all the materials share some factors in the genesis.

It is therefore postulated that Group 1 has an origin in the weathered cap (gossan) to the ores of the Perran Great Iron Lode and associated mineralisation near the N coast, whereas Group 2 potentially has its origin with the gossan of veins elsewhere.

There are no such mapped veins in the immediate vicinity of either Tregurra or Probus (which are just 6km apart).

One potential source area would that 6km NE of Probus and SW of St Stephen, where NW-SE iron lodes with N-S uranium-bearing crosscourses crop out. Old mines are known in this area (probably indicating points at which natural outcrop would have occurred) at Ladock ([SW 908512], [SW 904510), South Terra ([SW 929524] and Boddinick ([SW 946518]) (Dines 1956, 539-543; Brooks 2011, Chapter 12). These localities lie on the Trendean Mudstone Formation, which is also the host of the Perran Great Iron Lode which crops out just 8 or 9 km to the NW along the strike, and the iron resources may be the continuation of the Great Perran Iron Lode to the southeast.

Interpretation: process models

Figure 4 illustrates a series of binary plots that can be employed to interpret mass balance for a furnace (technique following Young 2016b).

The data plotted in Figure 4 include the analytical data from Probus (this report), plus the two ore samples retrieved from Tregurra (Young 2016c). These are included as being potentially relevant to the origin of the Group 2 smelting slags, despite showing a different REE profile to the Group 2 materials.

There are sufficient analyses from Probus Suite A to attempt to construct an approximate mass balance, but they are not drawn from the waste of a single smelt, so a full rigorous balance cannot be formed.

The plot of Al_2O_3 against SiO_2 (upper left) shows the slag analyses plotting below a line connecting the ceramic analyses to the origin. The ore composition must therefore lie to the right of the line connecting the origin to the slags, in order for the mixing line between the ore and furnace ceramic to be able be intersected by the enrichment trajectory from the origin to the slag compositions. Thus, the ore composition must have contained up to 3.5% silica.

The plots involving V, S REE, U, MnO and MgO show simpler geometries. The data are somewhat noisy, because of their disparate origins and it has not been possible to construct a mixing line between potential ore and ceramic that maintains all slag analyses to one side. A best fit solution has been constructed, which has enabled a model ore composition (the star on Figure 4) to be estimated. For an ore to be compatible with the slags as well as containing silica, the ore would have contained around 100ppm REE, 30ppm V, around 2ppm U, 0.6% MnO and perhaps 0.2% MgO.

The smelting model implied by the plots incorporates a smelting mixture of 11% lining, 89% ore. The enrichment factor for the slag over the smelting mixture is 192%.

The plot involving Sn is a little more difficult to interpret. It is possible for significant tin to be lost into the bloom, so the model composition here (500ppm) should be regarded as a minimum and the real tin content of the iron ore might have been considerably higher.

Summary

The iron smelting operation at Probus employed large, non-slag tapping furnaces, with a pre-smelt pit packing of wood. The furnaces were blown using rectangular-sectioned cermaic tuyères. The furnace clays and those employed to fabricate the tuyères appear to be identical. The clays were rather aluminous, which might have caused some problems with the slag viscosity.

The ore appears to have been drawn from a similar ore body to those used at Tregurra. The residues of both fall into the Group 2 of Young (2025a). The precise origin of the ores has not been identified, but it is provisionally interpreted to have been a gossan showing significant levels of both uranium and tin. One possible source of these ores would be an area to the SW of St Stephen, approximately 6km NE of Probus.

Smithing hearths near the furnaces produced examples both of hammerscale and of a smithing hearth cake which showed a component of its composition had been derived from iron melting slag entrained in the bloom. This provides some of the clearest evidence yet found in the area for the working of the raw blooms at the smelting sites.

Discussion

Recent work on Iron Age iron production in central Cornwall, particularly on the sourcing of the iron ores, has required some revision in the light of recent work at Nansledan (Young 2025a) and Probus (this report).

It has been proposed that, although the ores show great diversity, there were two dominant suites of slag compositions, representing two different types of ore source.

Group 1 is provisionally suggested to be associated with the Great Perran Iron Lode (and associated minor mineralisation, e.g. at Trevelgue Head). Exploitation of this resource is suggested for the EIA at Nansledan, the EIA to MIA at Trevelgue Head, and further afield at Threemilestone in the MIA to LIA.

Group 2 ores are of uncertain origin, but the vein system SW of St Stephen is a strong contender. These ores were smelted in the MIA at Tregurra and also at the Probus site described here.

This pattern shows that, of the known iron smelting sites, only Trevelgue Head is potentially directly associated with an ore source. The other sites occur in areas where contemporary charcoal production pits have been recorded (see compilation by Taylor (2022).

Such a dispersed pattern of iron smelting, where localised rich iron sources cannot be worked only at source because of insufficient charcoal supply, can be paralleled in the Roman and medieval exploitation of ores from the Forest of Dean which were carried up to 50km from source to areas with suitable woodland resources. A similar pattern may also be emerging in the early medieval exploitation of the iron resources of the Blackdown Hills.

Figure captions

Figure 1. locality map showing places mentioned in this report. Red = granites, yellow dots = ore localities, black star = Iron Age iron smelting site

Details of the iron smelting sites may be found as follows:

Threemilestone
Published report: Gossip 2021
Archaeometallugy report: Young 2007

Tolgarrick Farm
Published report: Hughes & Farnell 2016
Archaeometallugy report: Young 2016a

Tregurra
Published report: Taylor 2022
Archaeometallugy report: Young 2016c

Probus
Archaeometallugy report: this report

Trevelgue Head
Published report: Nowakokski & Quinnell 2011
Archaeometallugy report:

Nansledan
Archaeometallugy report: Young 2025a

Figure 2: upper crust-normalised rare earth element (REE) profiles (normalisation after Taylor & McLennan 1981) for samples from Probus.

Figure 3. Analyses of materials from Probus plotted within the ternary system SiO_2-Al_2O_3-FeO (fields after Schairer and Yagi 1952, fig 6). Analyses of ores from area are also shown.

Figure 4. Plots of selected chemical species and species ratios for analyses of both ores and slags from Iron Age sites in Cornwall. Comparative data taken from Young (2007, 2016c, 2025a). Figure from Young 2025a, Figure 6.

a. plot of P_2O_5 against MnO, both in wt%. The pale blue tone illustrates the approximate field of the average compositions for the various slag classes from Trevelgue Head (Dungworth 2011).

b. plot of Dy_N/Lu_N (where X_N is the upper crust normalised value for element X after Taylor & McLennan 1981; a measure of the slope of the heavy part of the upper crust normalised REE profile) against Eu_N/Ce_N (a measure of the slope of the light part of the profile).

c. plot of U against total REE (both in ppm).

d. plots of Sn against U (both in ppm). T

Figure 5. Plots of various species against silica for samples from Probus, to demonstrate the viability of a mass balance model samples of Probus Suite A.

The dashed orange line is the model tie line between the measured composition of a sample of furnace ceramic and a model ore composition. The red arrow show the trajectory of slag composition as iron is extracted from the smelting mixture.

For these diagrams, the smelting mixture is 11% lining, 89% ore. The enrichment factor for the slag over the smelting mixture is 192%.

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Table 1: summary catalogue, weights in g, assm = assemblage of small pieces.

context	sample	fraction	s wt	l wt	l no	notes
1046	<11>			18	15	slag scraps, larger pieces are flow slags
				<1	1	charcoal
1059			22	22	1	irregular nub of slightly prilly iron slag
1070			400	400	1	crudely plano-convex mass with one edge broken; red smooth slightly lobate top; base in several distanced rounded accumulations of slag, rough; this is probably a very crudely-formed SHC
1073	<12>			14	1	accretion-coated flow slag fragment
				0.36	1	bleb of lining slag
1076			8	8	3	vitrified oxidised fired lining
1076				466	2	dense slag from FB margin with wood parallel to edge, longest piece is 120x25mm
				26	1	completely encrusted small slag nub
1081			520	330	43	variably vitrified and slagged gravelly lining; mostly oxidised
				178	7	lining slag in massive to slightly lobate forms
				12	1	rusty prilly slag fragment
1081			1965	738	27	dense flow slags, many showing parts of wood moulds, many slightly brown on surface
				262	12	dense flow slags as above, but markedly brown/maroon on surface
				10	2	scraps of corroded iron
				798	45	dense slags with rather granular texture
				88	3	lining with vitrified surface, coarsely pebbly, slightly purple lining
				72	8	fragments of lining slags
1081			4345	1700	37	dense flow slags, many with wood moulds
				2276	55	dense slags without clear flow lobed structure
				52	4	lining slag
				40	2	slagged lining
				194	1	dense slag attached to grey wall, slag part of sheet c30mm thick with charcoal impressions on upper surface and fractured lower face

				64	1	weathered granular slag in sheet 20mm thick
1081			3115	1690	63	dense flow slags
				44	2	slagged lining
				20	5	lining slags
				1371	50	dense slag not in flow lobes, some massive, some charcoal bearing
1081			2905	1695	61	dense flow slags
				1085	53	dense slags without clear flow lobing
				102	6	intensely slagged ceramic
				16	1	glazed pebble
1083			44	44	3	vitrified oxidised fired lining
1083			675	675	3	(plus three crumbs) flow slags with wood moulds - all quite vesicular and porous
1086			658	658	1	SHC with slightly lobate margin, plano-convex, 110x120x55mm, heavily accreted, base very irregular
1088	<15>	magnetic		4.78	assm	stone
1088	<15>			8.53	60	fired clay
1094			22	22	1	flow slag
1096	<16>			596	247	furnace floor debris - rough slags, flow slags - all with slightly rough coating
1096	<16>	magnetic		8.68	assm	stone, fired clay, slag (some filmy slags, but very little true scale)
1096	<16>		110	47.53	25	oxidised fired clay
				24.63	8	oxidised fired clay with dark remnant vitrified surface
				20.73	9	slagged and accreted material
				13.83	10	grey fired clay
				1.53	1	slag with possible wood impression
1097				86	1	dense slag with wood moulds
				48	2	heavily accreted slag - probably with fuel moulds?

1099			118	118	1	crudely lobate vesicular slag with wood mould
1101			8	8	1	flow slag prill
1107			24	24	5	buff and orange, pale fired clay
1108	<19>	magnetic		2.07	assm	stone
1108	<19>			26	35	slag scraps, probably all FB material
1108	<19>			14	38	reduced fired clay
1112			158	158	2	slag fragments with rounded dimpled bases - could be dense, but small, SHC fragments
1114			10	10	2	Iron slag chips - one with ?wood mould surface, the other very weathered
1116			42	42	1	brown banded cherty rock with dark iron mineralised layers
1119	<21>			64	183	oxidised fired clay
1125	<23>		3.77	3.77	2	bog ore mottles
1125	<23>			2.3	3	fired clay, oxidised
1132			18	18	1	prilly slag
1134			28	28	9	highly fragmented weathered low density vesicular slags
1141			12	12	3	vitrified oxidised fired lining
1141			1845	116	1	accreted and total mineralised iron fragment
				820	22	dark flow slags, some with slightly reddened surfaces
				6.23	1	iron; 5mm wide tang expanding into 17mm wide blade? Small mineralised iron fragment in concretion
				4.43	1	iron; 5x7mm rectangular shaft and 17mm or more head- probably a nail
				332	1	dense slag block, forming small burr attachment

			554	11	porous dense slag, mainly charcoal rich
			1	2	lining slag fragments
			10	1	slagged fragment of oxidised lining
1145		96	96	1	fractured rounded nub of vesicular slag
1157	<26>		9.69	9	grey fired clay
1164	<28>		6.87	22	grey fired clay, many pieces have pale and dark halves
1165		18	18	1	small nub of vesicular slag
1190			482	2	dense slag with wood moulds
			230	1	dense slag lump, probably from near burr on FB margin
			86	2	lining slag
1198		110	60	1	mixture of fresh flow slag lobes with lining slag - burr region top of cake
			52	1	porous iron slag, vesicular, saccharoidal
1200		2	2	1	oxidised fired lining
1200		2565	1125	6	dense slag with wood moulds, some pieces show secondary reddening
			874	3	dense , more massive slag
			178	3	coralline type slag, granular vesicular
			158	8	dense blebby/prilly slags in small pieces
			68	8	lining slag fragments
			104	3	grey ceramic with slagged surface, convex surface - possible tuyère
			52	1	dense slag in vesicular slag with smooth undulating upper surface, base rough
1201		1365	858	7	dense slag with wood moulds and flow lobes
			268	1	dense slag in small crudely plano-convex form; probably just a fragment of FB, but could be SHC; top has charcoal impressions, bottom lobate surface roughened
			62	3	lining slag
			182	1	dense irregular slightly reddened slag lump

1237	2475	2475	1	chord 210mm, depth 130mm, bowl moves in 50mm; main slag 65mm thick rests with oxidised wall behind, below less slag on bowl and reduced, probable multiple wall repairs within indurated wall attached to slag; in plan wall only curves slightly
1237		200	1	vitrified and thickly slagged oxidised fired lining
		2135	2	friable and prilly slag around large wood moulds, mostly not typical very dense flow slags
		386	1	thick and complex angular block of lining slag
		606	1	tapslag like flow slag extending away from oxidised and vitrified lining - possibly a tuyère tip
1237		686	7	vitrified and thickly slagged oxidised fired lining, with similar internal material
		182	1	thick angular block of lining slag
		398	3	rusted slag fragments, some slightly prilly, some granular
		2250	1	large block from side of pit, 150mm tall, oxidised wall going grey to base; heavily indurated wall, mass of slag at (?) foot of wall, shows some wood mould surfaces
1237		6060	1	chord 290mm, dense slag cake 100mm tick overlain by 60mm of complex lining slag, extends 120mm into hearth (but starts behind wall?)
1237		840	25	approximate number of fragmented brown material - probably equivalent to sinter faces - includes small prills
		392	6	vitrified and thickly slagged oxidised fired lining
		46	1	lining slag piece with slightly dished surface
		1200	6	dense massive slag fragments
		48	3	simple clean flow slags
		636	9	flow slags involved with messy rusty slags
1237		1535	74	flow slags involved with messy rusty slags
		108	5	dark friable gravelly sinter?
		24	2	vitrified stones
1237	1762	328	1	dense large flow slags surrounding wood moulds
		178	3	oxidised fired gravelly pinkish fired clay
		278	3	dense flow slags in tapslag like flows, one has fired clay on upper face, two show fuel moulds
		164	1	messy block of porous material - probably slag intruded into fired clay
		814	1	large block from burr region of furnace, tapslag like flows cut wall and overlain by fired clay, overlain by dense sheets down wall
1237	2795	1255	72	rusty prilly slags, lots of fine charcoal debris
		674	1	dense irregular block from burr region, slag probably old fracture on front, slightly prilly below and flattish top, wall red above, grey below; gravelly

			358	29	furnace wall fragments, variable vitrified/slagged, mostly oxidised fired
			60	1	dense dark sandy indurated material
			122	2	dense rusty slag lumps
			14	1	quartz pebble
1237		6775	6775	1	chord 330mm, height 150mm, extends 120mm into furnace. 90mm below redux line, 60-70mm above, one end shows big slag build up at wall foot, the other more fluid with multiple tapslag like intrusions into wall, appears to be fractured 40mm thick sheet with slightly prilly base extending forward of pit wall
1237		1370	298	3	marginal sherds of a tuyère
			56	5	probable additional fragments from the tuyère
			440	1	slagged ceramic, just possibly tuyère tip, face with deep incision or eroded cleft, below cleft slag is thick, above cleft slag has cleaved off
			392	4	dense slags with wood moulds
			6	1	fragment of lining slag
			206	6	granular slag/sinter
1238			1685	112	vitrified and thickly slagged oxidised fired lining
			214	1	dense slag adhering to oxidised fired clay - lateral margin of FB?
			342	34	prilly slags and 'messy' charcoal bearing slags
			56	5	lining slag fragments
1238	2 of	1489	1365	20	hearth ceramic, mostly laminated clay with angular grit; one piece shows an abrupt undercut in the vitrified surface; mostly oxidised fired
			124	1	prilly slag fragment with fuel/wood contact surfaces
1238	3 of	2300	1430	38	variably vitrified and slagged gravelly lining; mostly oxidised; one piece shows curious rounded indent in glassy slag surface
			480	17	lining slag in massive to slightly lobate forms
			200	8	rusty prilly slags, lots of fine charcoal debris
			188	1	fragment of SHC, dense lower crust to 25mm, vesicular, overlain by grey slag with abundant gravel debris
1238		416	416	18	flow slags, from dense material with wood moulds to finer flows with much lining input
1238		2000	1273	51	vitrified and slagged oxidised fired lining, gravelly, slagged surface varies up to 30mm.
			384	10	lining slag fragments, gravelly
			134	11	rusted slag with charcoal
			144	2	dense flow slags

				80	1	dense slag with somewhat granular texture
1243			74	74	1	vitrified oxidised fired lining
1260				1435	1	150x130mm large piece of furnace wall gently concave, slagging up to 40mm thick, presumably near blowhole
				812	1	rusty mass of prilly charcoal baring slag - could be upper part of FB or much less likely a very irregular SHC; rust suggests this had a high metal content originally
				260	1	dense slag with wood moulds
				66	1	slag with large charcoal or wood
				18	1	fragment of rusty slag, spalled from another larger piece
1260				3390	1	large piece of FB with wood moulds, 210x190x100mm
1265			256	256	3	crudely lobate dense slags, one with wood impression
1270			42	42	1	vesicular slag with fuel moulds
1298				124	1	heavily encrusted small puck with fuel dimples on top, dense; could just possibly be SHC fragment
				106	1	heavily encrusted porous slag
1298			58	40	1	vitrified oxidised fired lining
				18	1	vitrified and slagged stone
1333	<33>			4	38	fired clay, oxidised
1335	<34>			168	9	small dense slag fragments, mostly or entirely from FBs
1335	<34>		398	194	77	fired clay, oxidised
				204	285	slag, mostly in very small pieces of highly vesicular pale material
1335	<34>	>10mm	2020	2020	assm	mostly oxidised fired clay, thin veneer reduced below slightly slagged surface, rare pieces of lining slag, ceramic fine, rarely white/orange laminated, grit present but not dominant
1335	<34>	magnetic		4.74	assm	stone, fired clay, slag
1336			36	36	6	pale grey vitrified fired lining

1336			504	216	1	dense slag, mixture of flow lobes and coarse crystals, in contact with grey ceramic wall
				24	1	small lobe of flow slag with wood impression
				24	1	green glazed ceramic and stones
				128	1	dense lining slag apparently below curved grey ceramic - probably a tuyère base
				54	1	slagged surface on grey ceramic - has one very smooth face - if original could be tuyère
				50	8	lining slag
				12	1	granular slag, only slightly lobate
1337	<35>	2 of	378	92	1	corner of tuyère (presumably from back, since no high-temperature alteration?
				120	10	lining slag and slagged lining
				162	80	fired clay
1337	<35>	magnetic		8.33	assm	stone, fired clay, slag
1337	<35>		2410	226	8	flow slags
				42	2	indurated sediment
				58	1	vesicular lining slag
				2086	1500	(approximate number) small fragments of rough slag, flow slag, some lining-related material
1337	1 of 6		4145	3325	1	290mm chord, 180mm high, large piece of wall with step - ?shaft/pit junction or level of top of FB; main vitrified face overlies earlier similar one, has lots of sloughed lining slag on ?lower edge,
				286	1	dense slag with some charcoal
				448	1	angular block of burr type slag
				56	6	small pieces probably fractured from large block
1337	2 of 6			1701	12	slagged lining and lining ceramic
				338	1	block of ceramic with 95 degree angle between slightly dished face with maroon surface slag veneer and almost planar face fired grey; internally oxidised fired; from side of tuyère block; conjoins 456g block below
				608	1	contact of slag sheet, c. 30mm, with reduced fired wall; presumably lateral to furnace
				1300	7	porous FB material, lots of wood moulds, charcoal and some prilly sections
				125	1	dense flow slags around wood moulds
				55	1	thin fragment of slag from mass with dimpled base
				65	2	two pieces of slag with planar but gently lineated surfaces; one thick one just a film; detached from a bloom surface or a tool??
1337	3 of 6		4035	404	13	fragments of lining slag

				1420	42	slagged lining and lining ceramic
				106	1	granular or fragmental slag/clinker
				116	1	slag with moulds of fuel attached to reduced fired lining
				190	6	small dense irregular slag pieces
				794	2	FB fragments with well-preserved wood moulds
				74	2	dense flow slags
				624	1	irregular block - slag veining into wall at burr?
				276	2	dense slags against wall, one possibly burr
1237	4 of 6		4425	304	6	vitrified and thickly slagged oxidised fired lining
1337?				366	11	angular fragments of lining slag
				1085	8	charcoal/wood bearing FB fragments
				1935	3	contact between FB margins and wall - hot contact but probably lateral to blast
				714	1	large block from wall - well slagged and deeply vitrified to purple in hollowed shape, orange fired clay behind - from just above tuyère?
1337	5 of 6			456	1	further part of the tuyère block, centre of bore 80mm from margin and 95mm from top; face at 70 degrees of so to axis of tuyère; conjoins 338g block above
				236	1	gravelly ceramic, grey on one side of the slab, reddish on the other - no real surface, but could just be part of tuyère
				1045	1	large block of wall, with slag-surface embayment; appear to be multiple generations of clay involved
				1360	1	rusty lump of charcoal bearing slag, 130x150x60mm, plano-convex lump with upper mass of obscured slag
				738	16	deep lining slag layer on furnace ceramic
				198	2	lumps of crudely lobate slag with remnants of wood(?) moulds
1337	6 of 6		2620	2605	1	accumulation of granular/prilly slags against slightly vitrified wall
1347	<36>			7.33	24	slag debris
1347	<36>			27.5	165	grey fired clay
1347	<36>	magnetic		2.82	assm	stone, slag, moderate amount of FHS
1348			944	314	6	dense slags with wood moulds and or flow lobes
				138	6	porous iron slags with charcoal moulds
				424	1	slightly incomplete very dense plano-convex cake, 95x75x49mm, base rough, top with deeply impressed moulds, slightly two layer, but both upper and lower parts very dense
				66	1	elongate dense slag - possibly spall from similar dense plano-convex cake

F1353	no context		108	62	2	irregular dense slags
				42	2	flow slags
				4	1	lining slag
1361	<37>	magnetic		4.98	assm	stone, clay, slag, small proportion of FHS and some SHS
1361	<37>			46	8	fired clay
				36	1	slag with minor burr like interaction with oxidised fired wall
				10	1	highly accreted slag fragment
1361	<37>	slag		86	3	vitrified lining
				1996	442	flow slags, slags with charcoal and other FB component debris, from moderately large pieces down to fine debris; heavily accreted, and coated in clay, much is rusty
				4.4	1	slag flats
1364				22	1	vitrified lining slag
				4	1	very worn tapslag-like sliver with a maroon surface
1376			186	184	1	very dense slag with large, rounded vesicles and fuel moulds
				2	1	burnt stone
1391	<39>			46	141	reduced fired clay
1443			332	332	1	dense tapslag-like mass, very wide flow lobes (>50mm) forming dense mass, flow surfaces reddened, one side appears to curve around obstacle - but it isn't entirely certain this obstacle was wood

Table 2: residue types by context (excluding material in processed samples, except where indicated by 'y' = present in sieved sample) Orange fill = smelting furnaces, blue tone = potential smithing-related features, green = 'hearth' F1095, with its ancillary features in pale green.

context	'furnace bottom'	pit floor	lining slag	lining	SHC	scale	slag flat	iron	tuyère	total	Context notes
1046	18									***18***	Lower fill fire pit F1045
1059	22									***22***	Same as 1056 (upper fill ditch 1055, probably a continuation of F1042)
1070					400					***400***	Lower fill ditch 1069
1073	14		0.4							***14.4***	Lower fill pit F1072
1076	472			8						***480***	Upper fill ditch 1075
1081	11885		322	620				10		***12827***	Spread of slag and charcoal
1083	675			44						***719***	Single fill ditch 1082
1086					657					***657***	Third fill fire pit F1084
1088				9						***9***	Lower fill fire pit F1084
1094	22									***22***	Single fill pit F1093
1096	23	605		87		y				***715***	Fill of hearth F1095
1097	134									***134***	Upper fill hearth F1095
1099	118									***118***	Single fill posthole F1098
1101	8									***8***	Single fill posthole F1100
1107				24						***24***	Fill/lining pit F1106
1108	26			14						***40***	Lower fill pit F1108
1112					158					***158***	Fill curvilinear ditch terminus 1111
1114	10									***10***	Fill curvilinear ditch terminus 1113
1116										***0***	Single fill pit F1115
1119				64						***64***	Charcoal-rich lower fill pit F1117
1125				2						***2***	Lower fill fire pit F1124
1132	18									***18***	Single fill tree throw F1131
1134			28							***28***	Lower fill fire pit 1133
1141	1706		1	22				127		***1729***	Upper fill ditch F1138
1145	96									***96***	Upper fill ditch F1143
1157				9						***9***	Lower fill firepit F1156
1164				7						***7***	Upper fill fire pit F1163
1165	18									***18***	Upper fill fire pit F1163
1190	712		86							***798***	Lower fill ditch F1188
1198	112									***112***	Lower fill ditch seg 1197
1200	2335		120	106						***2561***	3rd fill ditch seg 1197

1201	1040			62	258					***1360***	Upper fill ditch seg 1197
1237	7287	6823	774	17741					y	***32625***	Lower fill furnace pit F1236
1238	1654		920	5753	188					***8515***	Upper fill furnace pit F1236
1243				74						***74***	Middle fill pit F1241
1260	4546			1435						***5981***	Middle fill pit F1258
1265	256									***256***	Single fill ditch seg 1264
1270	42									***42***	Fill gully F1269
1298	106			58	124					***288***	Fill curvilinear ditch terminus 1297
1333				4						***4***	Single fill oval pit F1332
1335	168		204	2214						***2586***	Upper fill furnace F1334
1336	252		50	242						***544***	Fill furnace F1334
1337	9714	2234	2248	10463	1415		65		y	***26139***	Fill furnace F1334
1347	24			28		y				***52***	Fill burnt pit F1346
1348 (6?)	452				490					***942***	
F1353	104		4							***108***	Cut no. for gully
1361	2042			132		y	4			***2178***	Single fill posthole/pit 1360
1364	4			22						***26***	Single fill gully F1363
1376	184			2						***186***	Single fill ditch F1375
1443	332									***332***	Single fill ditch seg 1442
totals	*46631*	*9662*	*4757*	*39246*	*3690*		*69*			***104192***	

Table 3: major element analyses by XRF expressed as wt% for macroscopic materials. Raw measured values, except for calculated columns for FeO (as an alternative to Fe_2O_3). < = below detection. Analyses ordered by group of material.

Sample				SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	SO_3	LOI	total
PRB3	Tuyère	ceramic	1237	58.11	24.62	6.97	6.27	0.05	0.62	0.26	0.69	3.71	1.16	0.06	<0.15	4.07	100.32
PRB5	Wall	ceramic	1237	58.32	24.24	8.46	7.61	0.06	0.73	0.18	0.75	3.69	1.17	0.07	<0.15	2.32	99.99
PRB2	Sinter?	Suite A	1237	15.43	4.99	78.63	70.75	0.84	0.48	0.26	<0.1	0.48	0.63	1.44	<0.15	-2.81	100.36
PRB1	Flow slag	Suite A	1237	15.46	4.84	80.04	72.02	0.89	<0.2	0.3	0.45	0.44	0.62	1.51	<0.15	-6.20	98.35
PRB4	Flow slag	Suite A	1237	18.94	5.72	77.23	69.49	0.57	0.45	<0.1	0.11	0.76	0.53	1.44	0.41	-3.80	102.35
PRB6	Flow slag	Suite A	1237	18.62	5.62	78.46	70.60	0.98	0.49	<0.1	<0.1	0.81	0.63	1.59	<0.15	-6.45	100.76
PRB7	Dense wall slag	Suite A	1237	26.16	8.50	65.02	58.51	0.36	0.35	<0.1	0.11	0.77	0.59	1.30	0.36	-3.61	99.925
PRB8	FB	Suite A	1337	8.52	3.39	91.59	82.41	0.34	0.49	0.49	<0.1	0.40	0.12	2.36	<0.15	-6.94	100.75
PRB9	Flow slag	Suite A	1337	17.57	4.97	79.73	71.74	1.11	0.46	0.33	0.17	0.62	0.69	1.93	<0.15	-6.52	101.06
PRB12	Wall	ceramic	1081	53.43	22.38	19.29	17.36	0.14	0.57	0.27	0.95	3.61	1.10	0.19	<0.15	-0.10	101.83
PRB10	Flow slag	Suite B	1361	22.50	5.91	71.62	64.44	2.86	<0.2	0.32	0.28	0.45	1.52	0.44	0.20	-4.99	101.11
PRB13	Flow slag	Suite B	1081	22.64	7.27	72.85	65.55	1.82	0.26	0.11	0.26	0.86	0.71	0.21	<0.15	-6.63	100.37
PRB14	Dense wall slag	Suite C	1081	16.64	6.17	81.11	72.98	0.26	<0.2	<0.1	0.40	0.81	0.30	1.44	<0.15	-4.56	102.57
PRB11	SHC	SHC	1348	13.14	4.79	86.29	77.64	0.11	0.46	0.22	0.13	0.16	0.26	0.43	0.39	-5.13	101.27
PER1	Perran Lode ore			6.34	<0.1	82.23	73.99	1.236	<0.2	0.16	0.554	<0.05	<0.05	1.766	<0.15	11.67	103.956
PER2	Perran Lode ore			3.28	<0.1	80.87	72.77	9.282	<0.2	<0.1	0.327	0.303	<0.05	0.612	<0.15	6.25	100.924
TRV1	Iron-rich rock			0.42	0.23	10.13	9.12	2.862	0.8	45.78	0.106	<0.05	<0.05	<0.05	0.251	37.24	97.819
TRV2	Flow slag			17.65	2.9	82.73	74.44	2.638	0.92	0.48	<0.1	0.477	0.153	0.61	0.171	-6.41	102.319

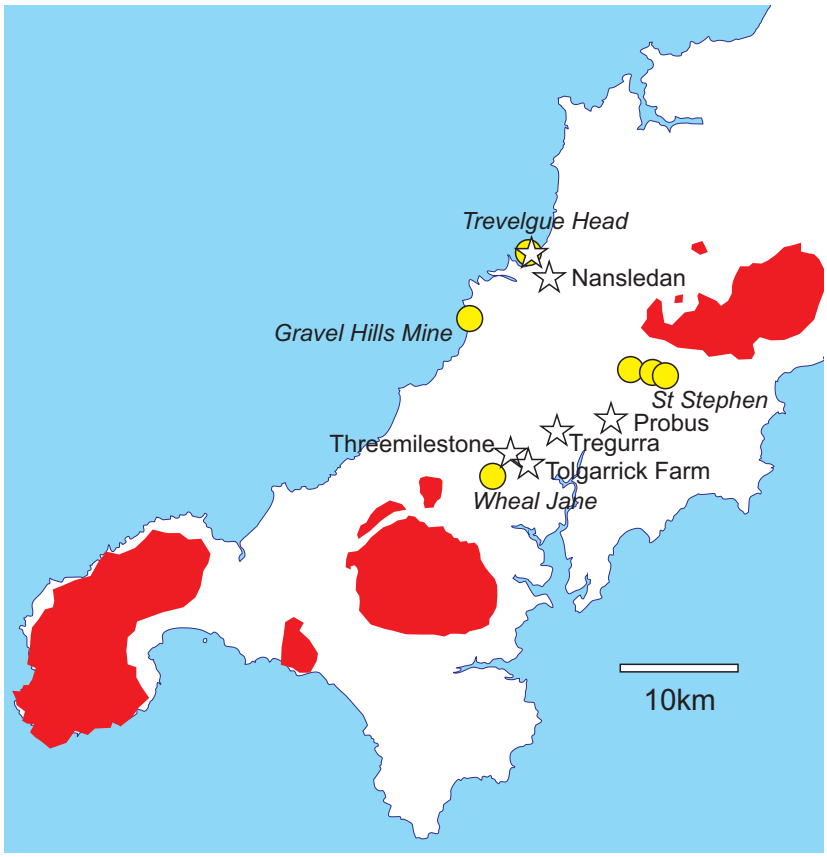
Table 4: trace element analyses by ICP-MS for macroscopic materials (part 1). Raw numerical values in ppm. < = below detection. Analyses ordered by group of material.

Sample	Be	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Mo	Sn	Cs	Ba
PRB3	3.63	129.47	119.20	18.60	28.59	240.23	71.44	29.41	163.92	127.98	33.17	206.05	18.13	0.24	10.07	8.02	615.61
PRB5	3.62	144.41	126.23	17.02	33.96	222.26	129.59	29.55	167.22	101.25	32.29	214.83	19.08	0.22	22.43	8.59	678.85
PRB2	20.59	87.48	71.46	9.46	17.39	248.70	300.72	11.08	19.00	78.51	68.82	83.61	9.92	0.57	726.43	4.33	146.95
PRB1	21.13	85.16	71.32	9.05	21.21	279.06	389.66	11.03	13.68	73.09	67.49	79.46	10.17	0.89	844.25	3.60	120.68
PRB4	14.06	73.85	56.05	4.83	9.27	224.89	168.15	10.87	28.03	76.62	50.05	92.21	8.79	0.70	535.10	3.17	204.72
PRB6	24.22	71.47	55.30	3.96	6.34	190.85	172.26	11.76	26.62	93.41	79.45	101.86	11.69	0.60	914.98	5.06	212.55
PRB7	13.46	73.33	46.88	12.33	21.88	229.53	384.61	13.05	55.43	79.45	37.60	90.42	8.89	0.91	419.44	5.12	252.33
PRB8	22.55	24.37	18.12	0.72	7.54	158.02	48.65	6.56	4.42	94.58	79.09	61.79	2.53	0.89	53.11	0.12	130.46
PRB9	25.28	85.08	59.95	0.61	4.67	147.80	43.63	11.05	17.14	101.90	93.39	100.05	11.86	0.40	692.14	3.84	204.99
PRB12	4.76	134.08	107.30	14.42	34.53	162.08	105.91	28.43	155.99	140.12	33.31	165.51	17.16	0.72	103.01	9.73	568.51
PRB10	19.46	65.62	19.34	1.05	8.69	145.47	103.94	21.34	20.68	56.76	159.70	150.57	36.41	0.12	2754.39	13.60	261.36
PRB13	8.67	118.89	66.64	6.46	9.37	161.33	92.22	17.69	36.22	116.23	15.93	86.88	9.77	0.48	501.04	3.39	278.73
PRB14	13.54	55.96	37.94	3.72	9.66	166.72	95.70	8.23	22.38	78.53	43.50	72.70	4.71	0.83	22.57	0.80	141.50
PRB11	3.07	34.29	33.43	11.95	59.92	351.64	4.41	6.11	5.69	25.53	10.38	79.18	3.66	2.58	48.31	0.36	94.50
PER1	27.52	7.6	6.8	9.9	42.3	327.3	3278.7	1.98	3.16	20.9	33.28	45.7	0.45	1.94	25.02	0.25	11.5
PER2	23.04	2.6	1.5	17.7	53.3	219.3	2885.0	0.94	2.75	98.3	17.65	41.2	0.06	4.56	1.68	<	14.2
TRV1	1.05	0.8	0.6	2.2	6.1	209.2	10.9	3.93	0.22	191.2	99.81	53.3	0.05	0.38	0.48	<	<
TRV2	8.56	17.5	20.5	3.0	6.0	210.2	49.2	5.56	10.92	54.6	62.08	65.3	2.04	0.59	2.16	0.41	66.4

Table 5: trace element analyses by ICP-MS for macroscopic materials (part 2). Raw numerical values in ppm. < = below detection.

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Pb	Th	U
PRB3	41.39	88.43	9.69	34.71	7.02	1.53	6.21	1.01	6.33	1.26	3.66	0.53	3.52	0.55	5.33	1.33	1.82	28.07	16.29	3.19
PRB5	40.82	85.78	9.85	35.66	6.97	1.60	6.08	0.95	6.09	1.23	3.59	0.53	3.43	0.52	5.73	1.44	2.01	22.63	16.60	2.95
PRB2	29.72	79.76	9.57	46.84	12.52	4.83	13.29	2.06	13.05	2.62	7.23	1.00	6.08	0.89	2.19	0.61	4.73	9.87	3.43	4.47
PRB1	28.62	78.43	9.40	46.58	12.27	4.81	13.14	2.08	12.88	2.53	7.19	0.98	6.11	0.90	2.11	0.71	4.84	13.00	3.31	4.46
PRB4	26.24	66.20	8.36	40.06	10.33	3.75	10.50	1.61	9.83	1.95	5.53	0.76	4.75	0.70	2.39	0.54	5.25	2.34	3.82	4.22
PRB6	32.55	89.97	10.59	51.51	13.87	5.29	14.98	2.41	15.11	3.04	8.51	1.19	7.04	1.02	2.62	0.80	5.39	2.85	3.89	4.99
PRB7	25.34	58.94	7.31	33.05	7.98	2.82	7.71	1.19	7.53	1.48	4.30	0.62	3.97	0.60	2.45	0.59	4.23	6.17	5.20	3.57
PRB8	45.02	105.27	15.01	74.98	20.40	7.09	19.75	3.00	18.06	3.41	9.36	1.28	8.12	1.11	1.57	0.18	5.33	3.00	2.09	8.49
PRB9	36.87	101.12	12.42	64.34	17.12	6.60	18.16	2.85	17.94	3.58	10.09	1.36	8.35	1.18	2.45	0.80	6.96	3.63	3.26	5.90
PRB12	48.81	102.69	11.58	43.61	8.75	1.99	7.26	1.08	6.77	1.30	3.78	0.54	3.54	0.53	5.08	1.28	2.12	34.65	14.53	3.09
PRB10	41.98	155.75	12.18	54.07	13.68	9.32	18.21	2.90	20.04	4.54	13.48	1.78	10.14	1.56	3.72	2.15	3.91	2.82	5.70	4.01
PRB13	25.47	96.27	5.67	22.38	4.69	1.98	4.16	0.59	3.56	0.68	1.85	0.25	1.65	0.25	2.31	0.60	1.91	3.90	4.98	2.85
PRB14	20.42	47.52	6.82	32.36	8.47	2.83	8.90	1.47	9.33	1.85	5.23	0.72	4.73	0.66	1.89	0.46	3.13	3.22	3.23	4.66
PRB11	7.35	16.54	2.13	8.78	2.14	0.67	2.12	0.35	2.10	0.43	1.23	0.19	1.22	0.18	1.91	0.23	1.94	1.96	2.62	1.19
PER1	20.77	41.10	4.98	20.09	6.31	4.03	7.78	1.28	7.53	1.34	3.40	0.41	2.20	0.28	1.15	<	6.61	9.35	0.35	1.06
PER2	8.86	11.71	1.67	6.63	1.96	1.12	2.66	0.50	3.16	0.63	1.75	0.23	1.33	0.17	1.05	<	3.34	2.78	0.11	0.64
TRV1	51.49	104.85	13.20	54.60	18.73	17.15	25.56	3.86	20.68	3.39	8.03	0.96	5.33	0.66	1.23	<	<	1.27	0.09	1.06
TRV2	40.93	80.00	10.70	45.19	15.04	11.13	17.80	2.84	16.02	2.69	6.94	0.90	5.54	0.76	1.77	0.15	5.09	1.50	1.77	0.83

Figure 1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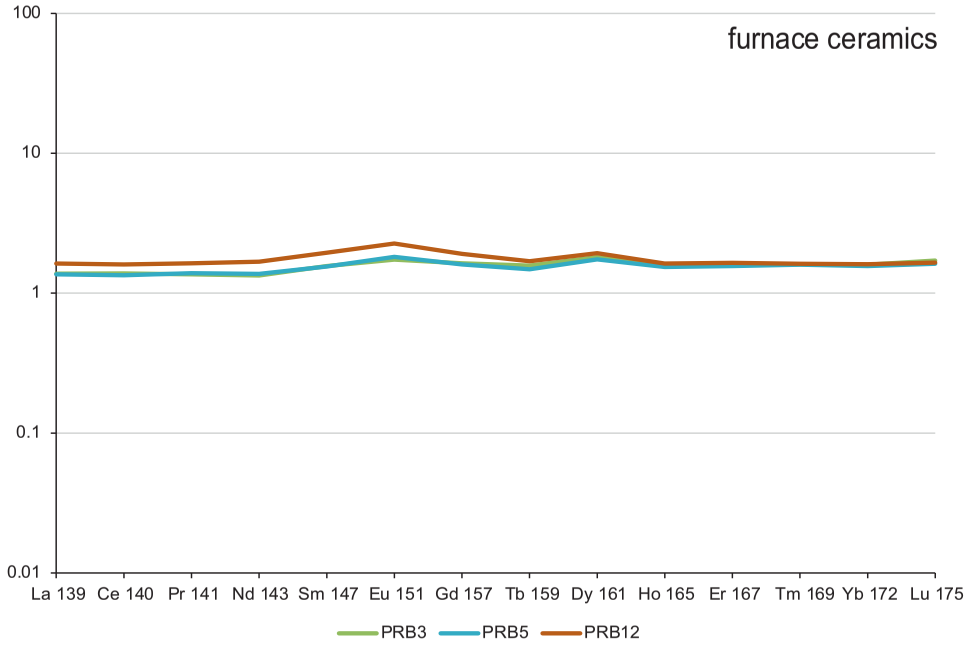
Nansledan
Gravel Hills Mine
St Stephen
Probus
Tregurra
Threemilestone
Tolgarrick Farm
Wheal Jane
10km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100
10
1
0.1
0.01
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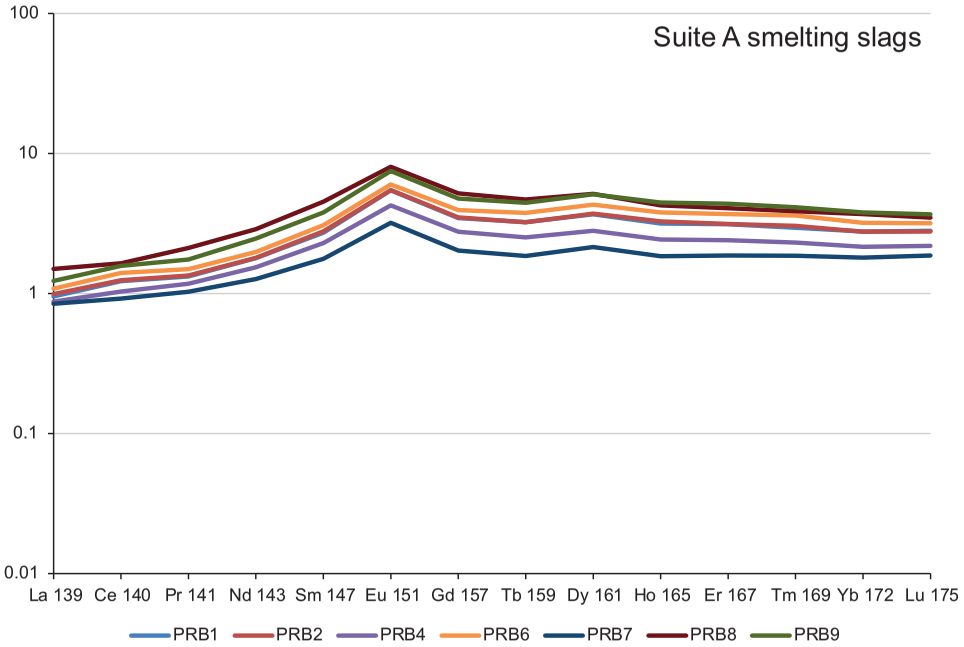
PRB3
PRB5
PRB12


Suite A smelting slags
100
10
1
0.1
0.01
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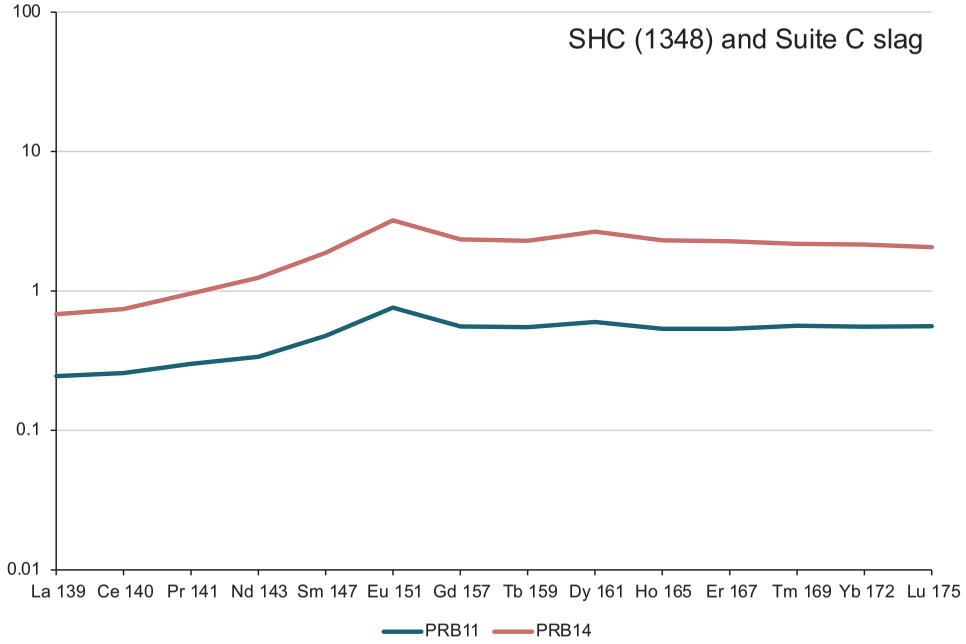
PRB1
PRB2
PRB4
PRB6
PRB7
PRB8
PRB9


SHC (1348) and Suite C slag
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1
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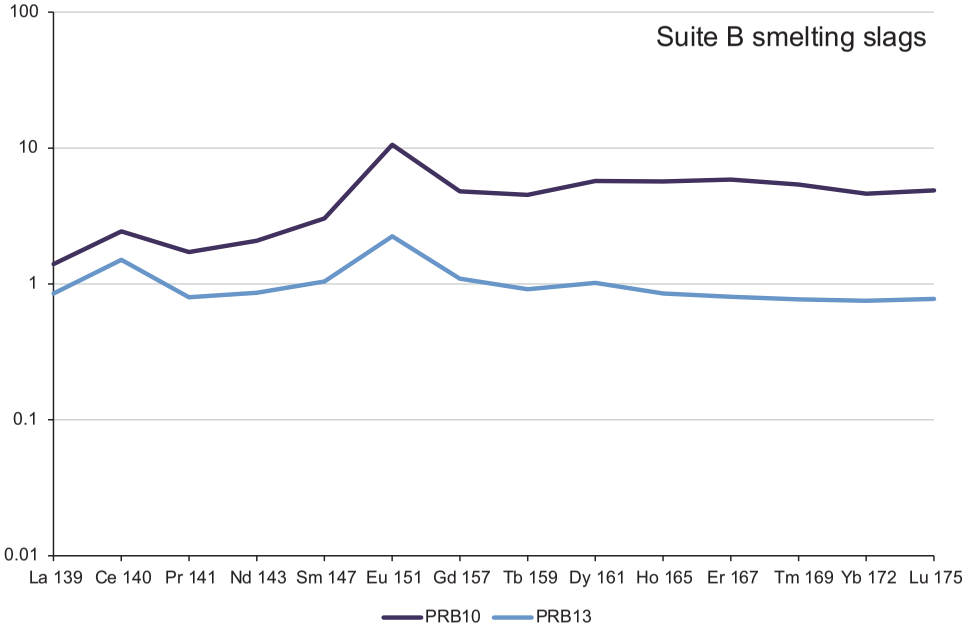
PRB11
PRB14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10
1
0.1
0.01
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PRB10
PRB13

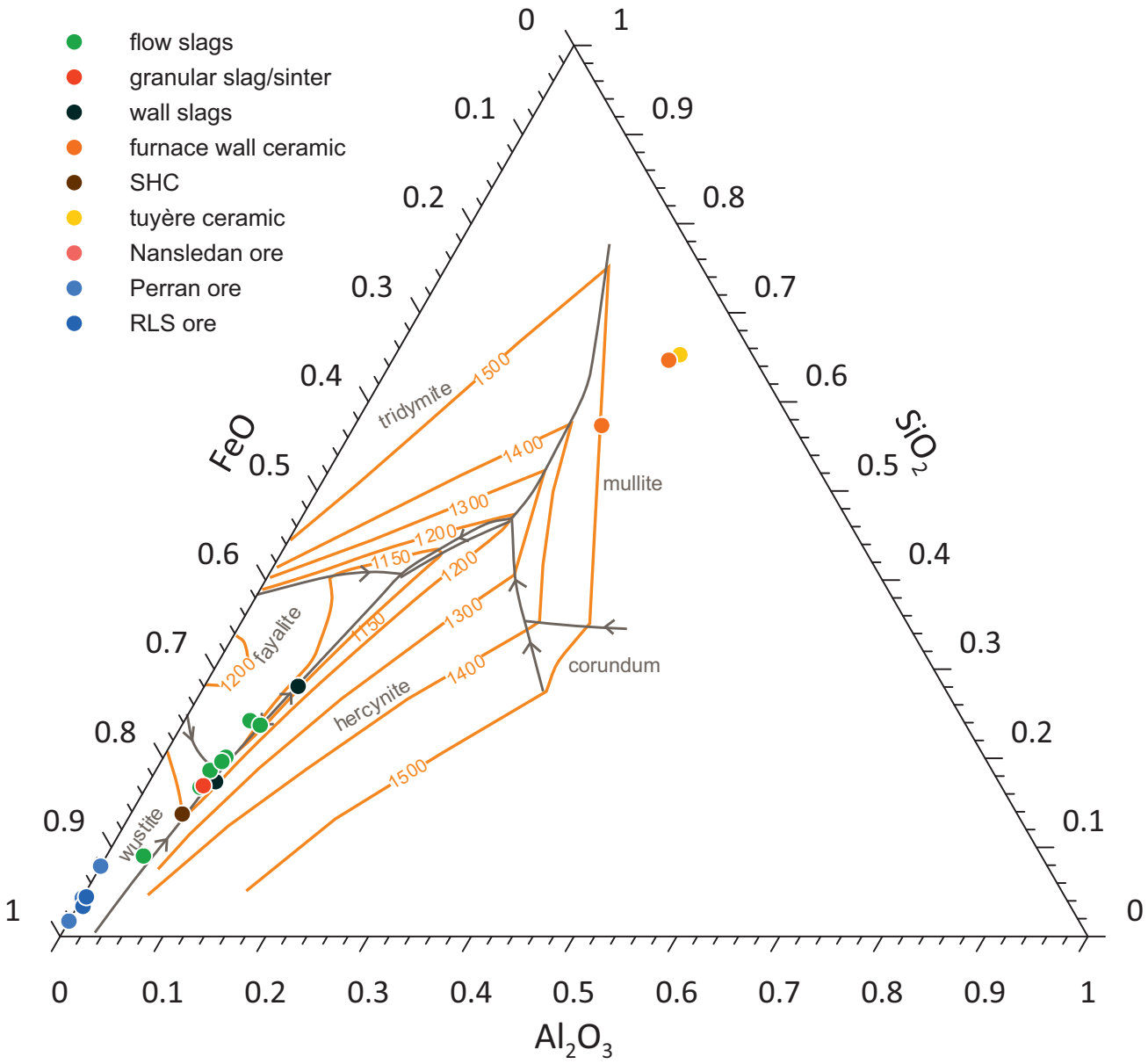

flow slags
granular slag/sinter
wall slags
furnace wall ceramic
SHC
tuyère ceramic
Nansledan ore
Perran ore
RLS ore
FeO
SiO2
Al2O3
tridymite
1500
1400
1300
1200
1150
mullite
corundum
fayalite
hercynite
wüstite

Figure 4

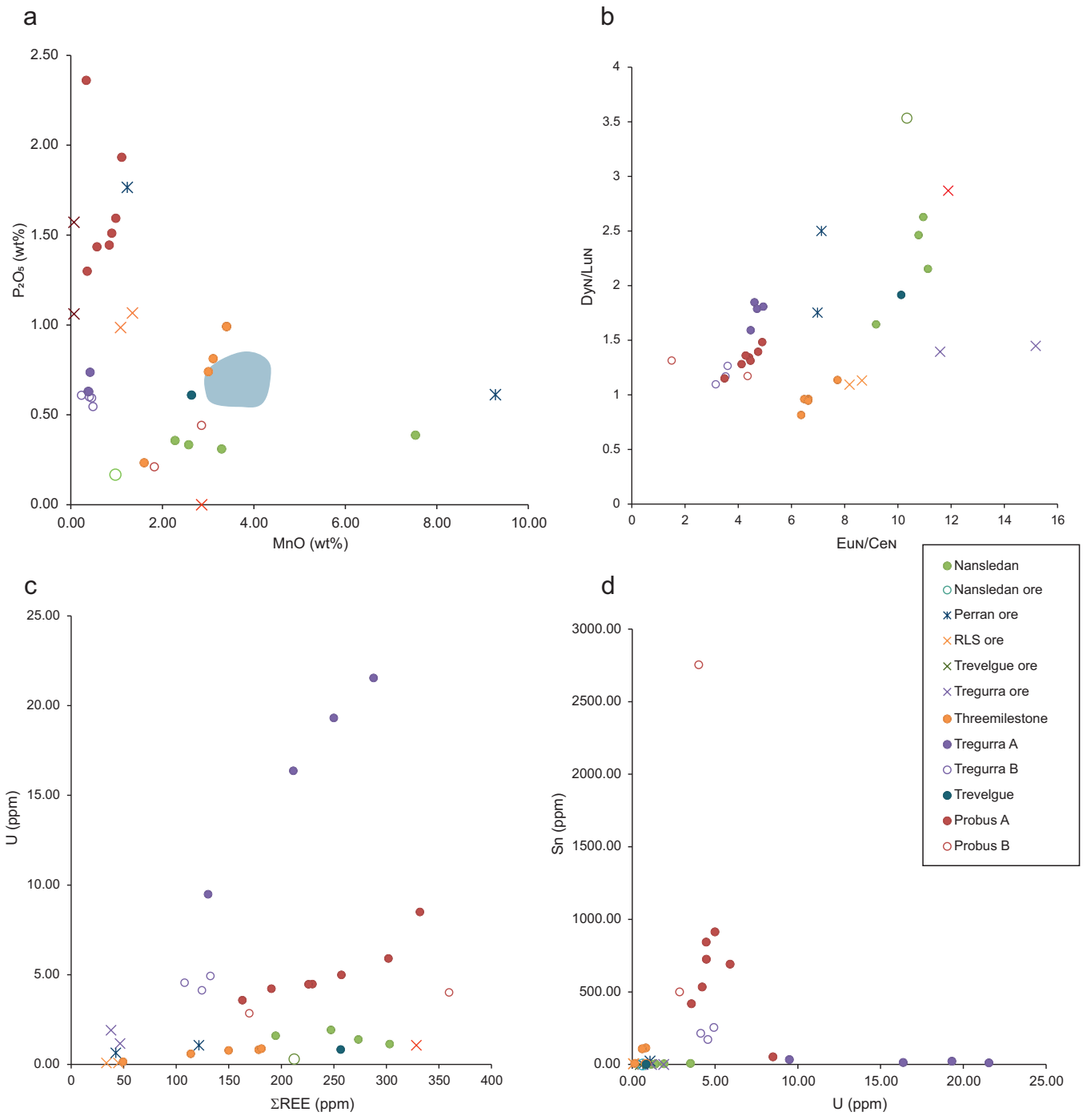
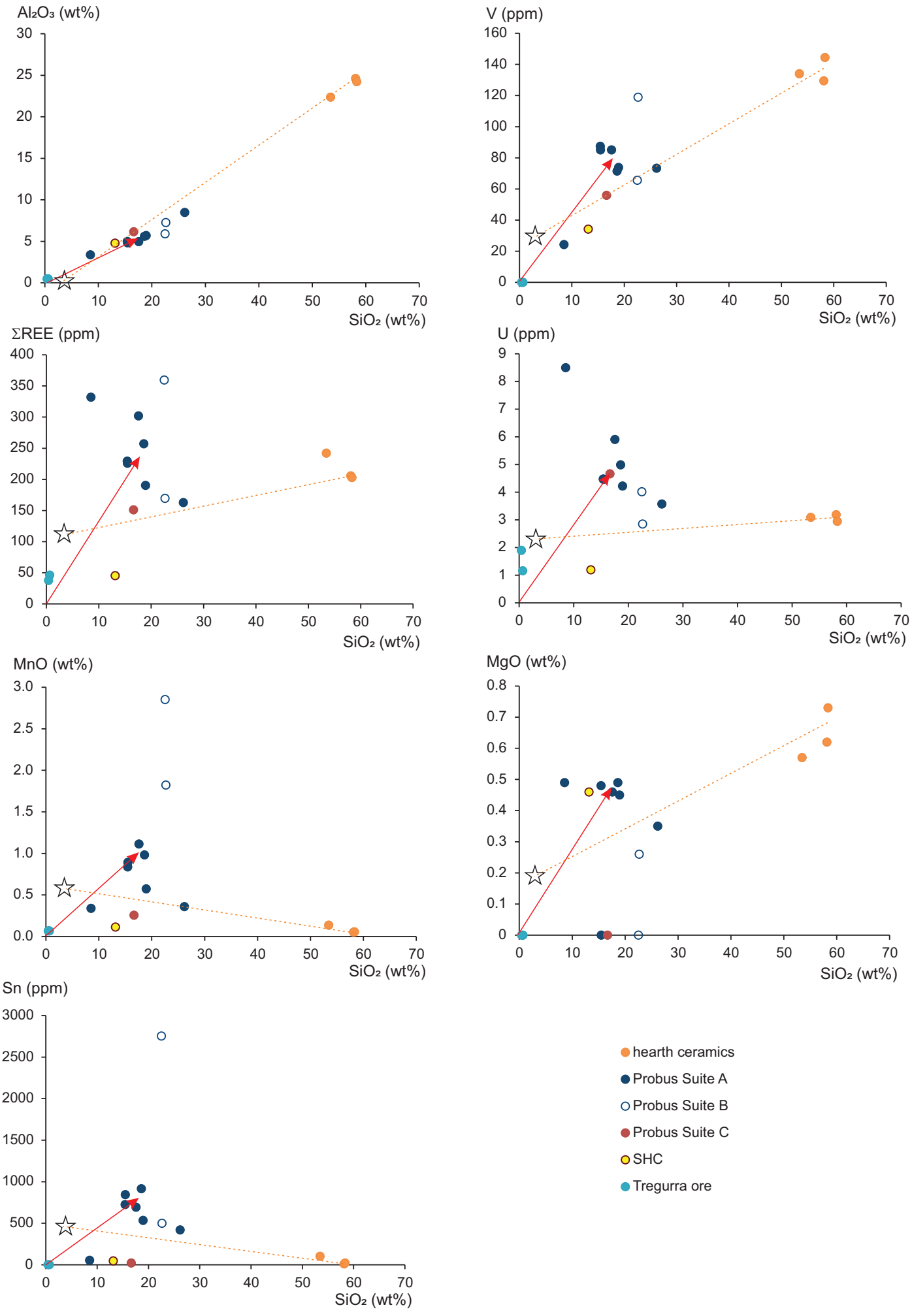

a
2.50
2.00
1.50
1.00
0.50
0.00
P2O5 (wt%)
0.00
2.00
4.00
6.00
8.00
10.00
MnO (wt%)
b
4
3.5
3
2.5
2
1.5
1
0.5
0
DyN/LuN
0
2
4
6
8
10
12
14
16
EuN/CeN
c
25.00
20.00
15.00
10.00
5.00
0.00
U (ppm)
0
50
100
150
200
250
300
350
400
ΣREE (ppm)
d
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
Sn (ppm)
0.00
5.00
10.00
15.00
20.00
25.00
U (ppm)
Nansledan
Nansledan ore
Perran ore
RLS ore
Trevelgue ore
Tregurra ore
Threemilestone
Tregurra A
Tregurra B
Trevelgue
Probus A
Probus B

Figure 5


Al₂O₃ (wt%)
V (ppm)
ΣREE (ppm)
U (ppm)
MnO (wt%)
MgO (wt%)
Sn (ppm)
SiO₂ (wt%)
hearth ceramics
Probus Suite A
Probus Suite B
Probus Suite C
SHC
Tregurra ore

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