GeoArch

Report 2010/09

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Dr Tim Young
15th May 2010

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Dr T.P. Young

Abstract

Excavations as part of the A40 realignment project produced a small quantity of bloomery iron-smelting slag together with a possible truncated furnace.

The morphology of the majority of the slag fragments was indicative of an origin as slag tapped from an iron-smelting furnace. In one instance, the tapped slag flow had carried a small lump of unreacted ore. This study focussed on an investigation of the ore fragment, the slag flow containing the ore and on a second flow fragment.

The tapped slags showed a similar chemical signature to that of the ore, indicating the analysed slags had indeed been smelted from ore similar to that entrained in the flow.

The ore particle was remarkably unaltered, although cracked by dehydration. The microtexture of the particle indicated that much of the ore was a replacement after a carbonate precursor. Such replacement ores have been described previously from the Bristol Channel Orefield. The trace element chemistry of the ore bears very close comparison with similar ores from Brownslade (South Pembrokeshire) and also to some examples of ores from Gower (Swansea), both on the southern margin of the South Wales coalfield. An origin within the Carboniferous limestone on the northern side of the coalfield, closer to Robeston Wathen, is also possible given the known occurrence of ochres at Haverfordwest and ores of uncertain nature at Minwear.

Contents

Methods

All materials were examined visually with a low powered binocular microscope as part of the evaluation (Young 2010c). The evaluation identified this assemblage as being slags and associated residues produced in the processes of bloomery iron smelting. The catalogue of the material is presented again here in Table 1. A small programme of analysis was undertaken to provide evidence that might assist with the provenancing of the ore.

Two samples of slags (one containing an ore particle) and iron ore particle itself were selected for detailed analysis from sample Tr1 (B).

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 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.

Whole-specimen bulk chemical analyses are presented in Tables 2-4 and EDS microanalyses in Table 5, with their locations in Plates 1-4.

Results

Description of the ore particle

The ore particle almost entirely comprises iron oxide, predominantly haematite after goethite, with the dehydration reaction in the furnace having also produced significant volume change and cracking (e.g. Plate 1a, b, e, f, g, Plate 2 g, h and Plate 3b).

The microstructure varies from fine textures, with only very fine porosity (e.g. Plate 1e) to coarser textures with larger, angular pores (e.g. Plate 1h). Variations in the microstructure define a laminated texture, with an irregularly curved disposition in the plane of the section, but of unknown 3-dimensional form (e.g. Plate 1b, e).

The rhombic outlines (up to about 30µm across) present in much of the porous iron oxide (e.g. Plate 1h, Plate2a-f), indicate that the iron oxide is a replacement of a carbonate precursor. Such a precursor is likely to have been itself iron-rich, perhaps a ferroan dolomite or ankerite. The iron oxides have coated and/or replaced the outer parts of the carbonate mineral rhombs, with their interiors preserved as voids. Interstitial areas are either voids or finely porous iron oxides. These textures are reminiscent of, but not identical to, those recorded in both the “laminated facies” and the “replacement facies” of iron ore in the cargo of the Magor Pill ship (Young & Thomas 1998, 1999). Similar textures may also be seen in claystone ironstones, but in this instance the lack of a clay matrix (together with the low phosphorus content, see below), would argue against this origin.

Within the originally coarser-grained sections of material there are larger, probably tabular bodies of dense iron oxides with roundedly elongate internal porosity (Plate 1a, Plate 2e, f). The largest of these pieces is about 300 µm in length and they are up to about 50 µm in width. Interpretation of these fragments is uncertain, but they appear to have been inherited from the precursor rock and may be either a different morphology of replaced crystal, or perhaps more likely the pseudomorphs of fragments of calcareous fossils.

One area (300 µm by 200 µm) of the section shows (Plate 3b) bundles of sub-parallel iron oxide sheets, forming discretely oriented zones (up to 100 µm across) within the larger mass. This would appear to be the result of replacement of a cluster of larger carbonate crystals, with the iron oxides forming preferentially on particularly crystallographic planes, most likely along the mineral cleavage.

Description of the slags

The two slag samples are broadly similar, with iron oxide layers delimiting the chilled margins of the flow lobes of the tapped slag (Plate 3c, f and Plate 4b). Within the lobes the primary phase is wustite, forming dendrites of variable size and density (e.g. compare plates 3d and 4d).

The primary wustite is followed by elongate crystals of olivine. The olivine is close to end member fayalite, with 4-5% forsterite in the cores, decreasing to 1-2% on the crystal margins. Substitution of manganese is a fairly constant 2-2.5% and substitution by calcium ranges from about 1% in the cores to 2% on the margins.

The olivine crystals clearly exceed 2mm in length in places, are 20-50 µm in width, and often show complex morphology. Many olivine crystals forming radiating sheaves, nucleated on the chilled margins.

The investigated interstitial areas of RWT3 were glassy (e.g. Plate 4a, c), but those of RWT2 were locally more crystalline. Identification of the fine-grained late-stage minerals in the interstices was not possible by EDS, although a low electron-density mineral(s) is visible alongside a late generation of olivine. Bulk analyses hint that in some cases this might be leucite. Analyses of small crystallites of intermediate electron density and larger areas on the olivine margins (e.g. in the area seen in Plate 3d) suggest the presence hercynite, probably present as an intergrowth in the very margins of the olivine and as an overgrowth on the wustite dendrites were they are not covered by the main stage fayalite.

Chemical analyses

The chemical analyses show that the ore (RWT1) is a very pure iron oxide, with little major contamination. The phosphorus content is very low (at 0.12wt% P_2O_5), as is that of manganese (at 0.78 wt% MnO).

The trace elements in the ore are also in fairly low concentrations, although some elements are more abundant than they are in typical ores from the NE part of the Bristol Channel Orefield (Young & Thomas 1998). In particular, uranium (7ppm) is at a level above that typical for the eastern part of the orefield, but is typical of the concentration in low-U ores from the western part (although well below that for the high-U pres from the same area).

The upper-crust normalised rare earth element (REE) profile (Figure 1a; normalisation factors after Taylor & McLennan 1981) shows an inclined profile with increasing relative depletion towards the light rare earth elements (LREE).

Such a profile is not usual amongst the ores of the Bristol Chanel Orefield, but has been observed in samples from Port Eynon, Gower (Figure 1b MUM3; Young 2000) and also in goethite crusts from Brownslade, South Pembrokeshire (Figure 1b BS3; Young 2010b). Similar profiles were also observed at Brownslade for iron smelting slags which had apparently utilised the goethitic ores there (Figure 1b BS1,2; Young 2010b).

The chemical analyses of the two associated smelting slags (RWT2 and RWT3) show a composition similar to that of the ore, with contamination by a siliceous furnace lining.

Trace element concentrations for those elements which are incompatible with significant incorporation within the iron bloom are generally low.

The upper-crust normalised REE profiles are very similar to that of the ore specimen (Figure 1a), with a relative concentration of 1.6 - 1.8 times that in the ore.

Although the lack of analysable furnace lining means that full mass balance (e.g. following the techniques of Thomas & Young 1999a and b) cannot be constructed, it is clear that the iron yield cannot have been particularly high given the low relative concentration of the REE, Th and U in the smelting slags: probably significantly less than 40% of the iron in the ore. However, it is not known how typical these slags would have been of the overall slag production during a smelt.

Interpretation

The microstructural evidence places the ore fragment from Robeston Wathen as a replacement ore. Such ores occur throughout the Bristol Channel Orefield (*sensu* Young & Thomas 1998, 1999; Young 2000), particularly in those areas where the ore-bodies are hosted by the Carboniferous limestone. The replacement ores, whether replacement of primary host rock (as in the Magor Pill cargo's "replacement facies") or of carbonate cements from a void fill (as in the "laminated facies" of the Magor Pill ship cargo; Young & Thomas1998, 1999), appear to underlies the void-filling stalactitic and botryoidal iron oxides in some examples. The two phases of replacement and neomorphic precipitation probably represent parts of a continuum of iron enrichment. An alternative origin as an iron enriched claystone ironstone seems chemically unlikely.

The REE profile of the ore is most closely matched by samples from Brownslade and Port Eynon, although somewhat similar profiles have also been observed for samples from the western Forest of Dean and Glamorgan (author's unpublished samples O39, FOD4, MIS O2, W12and, BQ3). The Port Eynon locality shows haematisation of a host mudrock, so is petrographically quite distinct from the Robeston Wathen sample.

The evidence thus points to the ore as probably being derived from mineralisation within the Carboniferous limestone. Although the similarity with the geochemistry of the Brownslade ore is strong, the origin of the ore is not necessarily to be sought to the south of the Pembrokeshire Coalfield, for mineralisation related to the Carboniferous limestone is also known from the north of the coalfield at Haverfordwest (near Cinnamon Grove Gate, Hamlet of St Thomas, and at Greenhill Ochre Mine, Haroldston St Issells; Claughton 1976). These two localities lie on a strongly faulted zone of the northern margin of the coalfield, which to the east passes close to Minwear, where another small iron ore deposit was worked in the 17th century. This deposit was apparently described by Raspe as bog ore. However, the ochre deposits of Haverfordwest were also manganiferous, so that it is possible the Minwear occurrence is a similar orebody. It would seem very likely that the operation was using a relatively local ore, although the smelting site is not, itself, on the Carboniferous limestone. Further fieldwork to clarify the nature of these, and other possible sources, would be desirable.

The ore utilised at Robeston Wathen is quite distinct from that employed at South Hook (Young 2010a).

The tapped slags examined have textures entirely typical of such slags (unlike the slightly unusual textures of the slags from Brownslade). As commented above, the trace element concentrations in the slag suggest that they are the result of a somewhat low degree of iron removal from the ore. Extraction of less than 40% of the iron from the ore may sound very inefficient by modern standards, but Thomas (2000) calculated similar efficiencies from several sites of Roman age. Only with apparently larger medieval furnaces did the efficiency of work the high-purity Bristol Channel ores increase.

The dating of the Robeston Wathen smelting operation remains uncertain. The use of slag-tapping furnaces in this area is unlikely to be pre-Roman, nor are such small, dense, extractionally inefficient, tap slags likely to be later than perhaps 14th century. The site might, therefore, lie anywhere between the Roman and medieval periods.

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Illustration Captions

Plate 1

RWT1
a. Area 1. Scalebar 200 µm
b. Area 3. Scalebar 1 mm
c. Area 4. Scalebar 70 µm
d. Area 5. Scalebar 70 µm
e. Area 6. Scalebar 800 µm
f. Area 7. Scalebar 100 µm
g. Area 8. Scalebar 600 µm
h. Area 9. Scalebar 60 µm

Plate 2

RWT1
a . Area 10. Scalebar 100 µm
b. Area 11. Scalebar 100 µm
c. Area 12. Scalebar 300 µm
d. Area 13. Scalebar 100 µm
e. Area 14. Scalebar 100 µm
f. Area 15. Scalebar 70 µm
g. Area 16. Scalebar 600 µm
h. Area 17. Scalebar 100 µm

Plate 3

RWT1
a Area 18. Scalebar 100 µm
b. Area 19. Scalebar 100 µm

RWT2
c, Area 1. Scalebar 600 µm
d. Area 2. Scalebar 60 µm
e. Area 3. Scalebar 100 µm
f. Area 4. Scalebar 2 mm

Plate 4

RWT3
a. Area 1. Scalebar 70 µm
b. Area 2. Scalebar 1mm
c. Area 3. Scalebar 1mm
d. Area 4. Scalebar 100 µm
e. Area 5. Scalebar 70 µm

Figure 1 Upper crust normalised REE profiles

a. For samples from Robeston Wathen (RWT1 ore, RWT2, 3 slags)
b. For comparative samples from Port Eynon (MUM3 ore) and Brownslade (BS1, 2 slags; BS 3 ore)

Normalisation factors after Taylor & McLennan 1981.

			weight (g)	no.	notes
TR1	TP1		340	24	tap slag fragments in small pieces
			3.3	1	weathered boxstone-like concretion fragment - doesn't appear particularly iron rich
			4.9	1	fuel ash slag fragment. Has smooth maroon upper surface, highly vesicular, variably white crystalline and black glassy
			5.9	1	pale ceramic with occasional large quartz grains, surface irregular and vitrified with black glass
			8.8	1	natural stone
			188	11	fragments of dense iron slag, variably vesicular. None shows characteristic textures of tap slag- they all could be, but lack appropriate preserved surfaces
TR1	(B)		13.5	1	naturally fractured flint
			416	21	tap slag fragments, mostly small, one larger fragment shows a clast of roasted ore of c20mm diameter
			190	3	larger slag blocks, all with a basal crust, with rather granular slag adhering - could be furnace slags but strictly indeterminate
			90	8	indeterminate vesicular iron slag fragments
			80	1	block with lobate base but rather irregular chaotic upper parts - rather similar to block from (018) but without definite dense tapslag top. Contains lots of small angular fragments of pale reduced fired clay
			8	1	dense dimpled slag surround part of a 25mm diameter cavity - possibly slag coating from a tool.
			2.7	1	coal
TR1	(C)		10.8	1	small tap slag fragment, dense
			13.3	1	flow lobed slag, probably tapped, porous, possibly etched but originally very vesicular, fayalitic and cindery
TR1	(D)		30	1	tap slag - small piece from flow c20mm thick
TR3	3001	e. end	26.1	2	rottenstone
			1.3	1	coal
			0.6	1	oxidised fired clay with vitrified surface
			2.8	1	natural rock
TR3	3002	w. end	22.3	1	piece of grey vesicular slag with dimpled base, probably lobate, top lost but shows large rounded vesicle suggestive of tap slag
	18	8	326	1	large block of slag with flow lobed dense upper part, lower part more chaotic with small lobes and moulds of c25mm charcoal, base dimpled, suggests tapped slag flow of c55mm thick

Table 1: Summary catalogue

	SiO_2	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**FeO**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**LOI**	**LOI**	**Total**	**Ba**	**Cr**	**S**
												as FeIII	as FeII		**ppm**	**ppm**	**%**
RWT2	19.65	0.253	3.77	78.44	70.60	0.947	0.59	0.59	0.19	0.61	0.266	-5.97	1.87	99.33	112	110	0.04
RWT3	21.86	0.308	4.83	73.29	65.96	0.931	0.75	1.40	0.22	1.21	0.269	-5.92	1.41	99.15	164	116	0.05

Table 2. Major element analyses by XRF. Iron expressed as Fe_2O_3 and alternatively as FeO (columns with grey tone). Selected trace elements also give,

	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Mo	Sn	Cs	Ba
RWT1	6.1	140.9	91.0	16.7	124.6	24.0	346.1	5.3	11.1	18.4	16.3	135.4	3.47	6.07	2.05	1.12	83.9
RWT2	5.9	112.6	86.6	4.9	16.5	15.5	100.2	6.0	18.8	48.8	37.0	170.0	5.15	6.32	2.13	1.56	168.9
RWT3	5.8	115.0	106.5	3.6	19.0	20.1	136.4	6.3	29.8	73.8	28.8	192.1	6.44	3.05	2.95	2.71	245.1

Table 3. Selected trace elements determined by ICP-MS. Expressed as ppm.

	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
RWT1	6.28	13.79	1.62	6.50	1.49	0.36	1.62	0.26	1.79	0.39	1.29	0.20	1.28	0.23	3.30	0.24	32.75	2.56	7.07
RWT2	12.23	20.70	2.96	11.58	2.51	0.57	2.83	0.46	3.28	0.74	2.48	0.38	2.49	0.40	4.24	0.38	5.46	3.61	8.59
RWT3	13.22	22.05	3.00	11.42	2.37	0.54	2.59	0.42	2.88	0.63	2.05	0.32	2.06	0.33	4.78	0.52	3.52	5.05	9.53

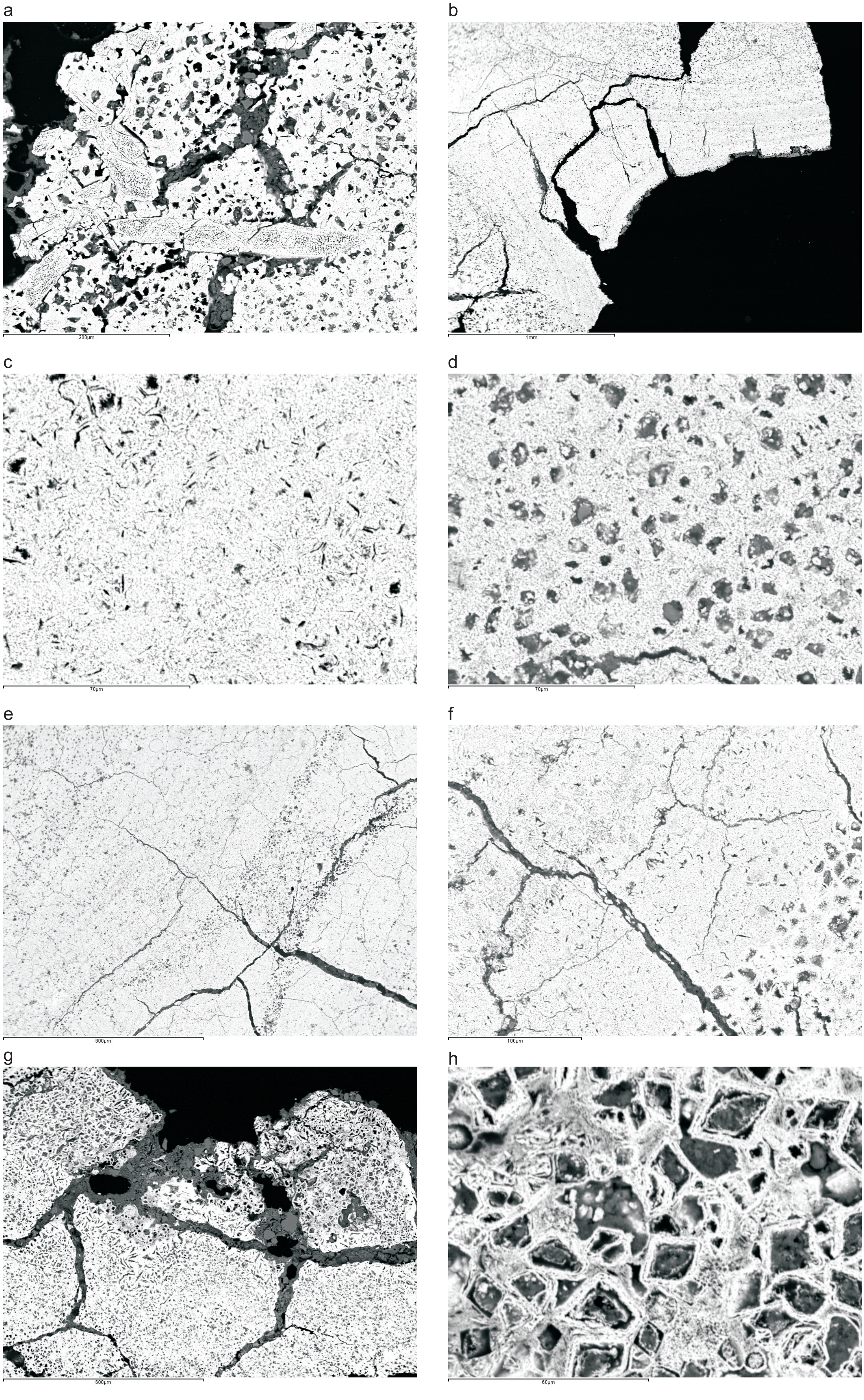
Table 4. Selected trace elements determined by ICP-MS. Expressed as ppm.

Table 5: EDS microanalyses from slags RWT2 and RWT3.

			O	*Na*	*Mg*	*Al*	*Si*	*P*	*S*	*K*	*Ca*	*Ti*	*Mn*	*Fe*		*olivine*				
																Fe	*Mg*	*Ca*	*Mn*	*Fo*
RWT2	Area 2	1	53.89	0.00	1.14	0.41	15.00	0.00	0.00	0.00	0.18	0.00	0.75	28.62	olivine inner	1.87	0.07	0.01	0.05	0.04
RWT2	Area 2	2	53.81	0.00	0.85	0.24	15.27	0.00	0.00	0.00	0.11	0.00	0.71	29.01	olivine outer	1.89	0.06	0.01	0.05	0.03
RWT2	Area 2	3	55.41	0.00	0.42	0.73	15.56	0.11	0.00	0.07	0.24	0.00	0.62	26.84	olivine margin	1.91	0.03	0.02	0.04	0.02
RWT2	Area 2	4	57.36	1.48	0.00	8.72	17.18	0.74	0.22	5.28	3.01	0.00	0.10	5.91	glass with crystallites					
RWT2	Area 2	5	56.91	0.28	0.00	6.23	13.08	0.30	0.07	2.02	1.21	0.00	0.36	19.53	late olivine core					
RWT2	Area 2	6	55.95	0.37	0.00	12.08	9.40	0.28	0.09	1.53	0.86	0.13	0.30	19.01	late olivine margin					
RWT2	Area 2	7	54.04	0.75	0.00	14.41	10.35	0.33	0.09	1.71	0.87	0.10	0.25	17.10	late olivine margin					
RWT2	Area 2	8	53.20	0.25	0.18	9.08	9.16	0.23	0.00	0.21	0.57	0.20	0.44	26.50	olivine on wustite					
RWT2	Area 2	9	48.48	0.00	0.00	0.52	0.40	0.00	0.00	0.00	0.00	0.23	0.15	50.22	wustite					
RWT2	Area 2	10	53.70	0.00	1.17	0.25	15.17	0.10	0.00	0.06	0.15	0.00	0.73	28.68	olivine inner	1.87	0.08	0.01	0.05	0.04
RWT2	Area 2	11	54.27	0.00	0.61	0.28	15.11	0.00	0.00	0.00	0.16	0.00	0.71	28.86	olivine outer	1.90	0.04	0.01	0.05	0.02
RWT2	Area 2	12	53.78	0.00	0.38	0.40	15.12	0.00	0.00	0.00	0.28	0.00	0.75	29.29	olivine margin	1.91	0.02	0.02	0.05	0.01
RWT2	Area 2	13	55.77	1.50	0.00	10.30	16.63	0.55	0.17	4.83	3.07	0.07	0.10	7.02	olivine/hercynite					
RWT2	Area 2	14	54.63	0.97	0.00	16.12	11.48	0.23	0.00	2.93	0.96	0.12	0.17	12.40	olivine/hercynite					
RWT2	Area 2	15	53.57	0.00	0.00	12.12	8.31	0.12	0.00	0.07	0.37	0.18	0.49	24.77	olivine/hercynite					
RWT2	Area 2	16	53.29	0.93	0.15	18.22	9.97	0.31	0.12	2.60	0.84	0.09	0.12	13.35	olivine/hercynite					
RWT2	Area 2	17	52.12	0.96	0.00	6.06	8.56	0.20	0.10	1.83	1.02	0.13	0.14	28.88	wustite in glass?					
RWT2	Area 2	18	53.53	0.00	0.00	15.57	5.31	0.09	0.00	0.12	0.37	0.18	0.35	24.47	olivine/hercynite					
RWT2	Area 2	19	54.04	0.00	0.00	19.03	3.05	0.10	0.00	0.23	0.21	0.33	0.24	22.78	olivine/hercynite					
RWT2	Area 3	1	54.83	0.00	1.30	0.25	14.76	0.00		0.00	0.13	0.00	0.70	28.04	olivine core	1.86	0.09	0.01	0.05	0.04
RWT2	Area 3	2	57.16	0.00	0.34	0.24	14.36	0.20		0.00	0.22	0.00	0.60	26.87	olivine margin	1.92	0.02	0.02	0.04	0.01
RWT2	Area 3	3	57.48	0.00	0.00	0.30	14.71	0.15		0.00	0.27	0.00	0.58	26.50	olivine margin	1.94	0.00	0.02	0.04	0.00
RWT2	Area 3	4	59.30	0.32	0.00	2.24	15.07	0.27		0.27	0.59	0.00	0.54	21.41	late olivine					
RWT2	Area 3	5	57.54	0.00	1.13	0.34	14.82	0.10		0.00	0.10	0.00	0.68	25.29	olivine core	1.86	0.08	0.01	0.05	0.04
RWT2	Area 3	6	57.82	0.00	0.31	0.34	14.57	0.10		0.00	0.17	0.00	0.61	26.08	olivine margin	1.92	0.02	0.01	0.04	0.01
RWT2	Area 3	7	56.02	0.00	0.00	23.25	2.01	0.14		0.80	0.21	0.26	0.17	17.14	hercynite					
RWT3	Area 1	1	57.76	1.15	0.00	10.97	15.09	0.32		4.42	3.33	0.07	0.16	6.73	glass					
RWT3	Area 1	2	49.94	0.00	0.00	0.61	0.38	0.00		0.08	0.08	0.32	0.16	48.44	wustite					
RWT3	Area 1	3	54.49	0.28	1.39	0.84	14.95	0.00		0.14	0.32	0.00	0.66	26.95	olivine core	1.84	0.09	0.02	0.04	0.05
RWT3	Area 1	4	54.92	0.00	0.52	0.25	14.97	0.00		0.00	0.40	0.00	0.62	28.32	olivine margin	1.90	0.03	0.03	0.04	0.02
RWT3	Area 1	5	55.60	0.00	1.19	0.31	14.69	0.00		0.00	0.29	0.00	0.63	27.29	olivine inner	1.86	0.08	0.02	0.04	0.04

			O	*Na*	*Mg*	*Al*	*Si*	*P*	*S*	*K*	*Ca*	*Ti*	*Mn*	*Fe*		*olivine*				
																Fe	*Mg*	*Ca*	*Mn*	*Fo*
RWT3	Area 1	6	55.12	0.00	1.47	0.51	14.76	0.11		0.10	0.29	0.00	0.64	27.02	olivine inner	1.84	0.10	0.02	0.04	0.05
RWT3	Area 1	7	55.42	0.00	1.16	0.43	14.51	0.00		0.00	0.28	0.00	0.71	27.48	olivine inner	1.85	0.08	0.02	0.05	0.04
RWT3	Area 1	8	59.33	0.33	0.34	2.63	15.62	0.08		0.23	0.53	0.00	0.47	20.44	olivine margin					
RWT3	Area 1	9	57.85	1.16	0.00	10.40	15.75	0.38		4.48	3.60	0.05	0.08	6.24	glass					
RWT3	Area 5	1	53.74	0.00	1.48	0.60	15.31	0.09	0.00	0.13	0.29	0.00	0.69	27.67	olivine inner	1.84	0.10	0.02	0.05	0.05
RWT3	Area 5	2	54.68	0.00	1.40	0.42	14.90	0.11	0.00	0.09	0.40	0.00	0.64	27.37	olivine inner	1.84	0.09	0.03	0.04	0.05
RWT3	Area 5	3	54.03	0.00	1.18	0.31	15.18	0.00	0.00	0.00	0.31	0.00	0.68	28.31	olivine inner	1.86	0.08	0.02	0.04	0.04
RWT3	Area 5	4	53.81	0.26	0.74	1.05	15.75	0.12	0.00	0.21	0.41	0.00	0.64	27.01	olivine margin	1.88	0.05	0.03	0.04	0.03
RWT3	Area 5	5	54.61	0.00	0.56	0.63	15.15	0.00	0.00	0.38	0.52	0.00	0.63	27.51	olivine margin	1.88	0.04	0.04	0.04	0.02
RWT3	Area 5	6	48.12	0.00	0.00	0.52	0.28	0.00	0.00	0.10	0.09	0.32	0.28	50.30	wustite					
RWT3	Area 5	7	56.69	1.11	0.00	11.00	15.35	0.36	0.09	4.39	3.45	0.11	0.12	7.31	glass					
RWT3	Area 5	8	56.66	1.23	0.00	10.65	16.11	0.37	0.10	4.69	3.31	0.07	0.13	6.69	glass					
RWT3	Area 5	9	52.74	0.62	0.00	4.78	14.83	0.26	0.00	1.09	0.69	0.08	0.46	24.44	olivine layer on wustite?	1.91	0.00	0.05	0.04	0.00
RWT3	Area 5	10	53.28	0.00	0.20	9.14	8.99	0.12	0.00	0.15	0.38	0.28	0.45	27.01	olivine layer on wustite?					

Plate 1



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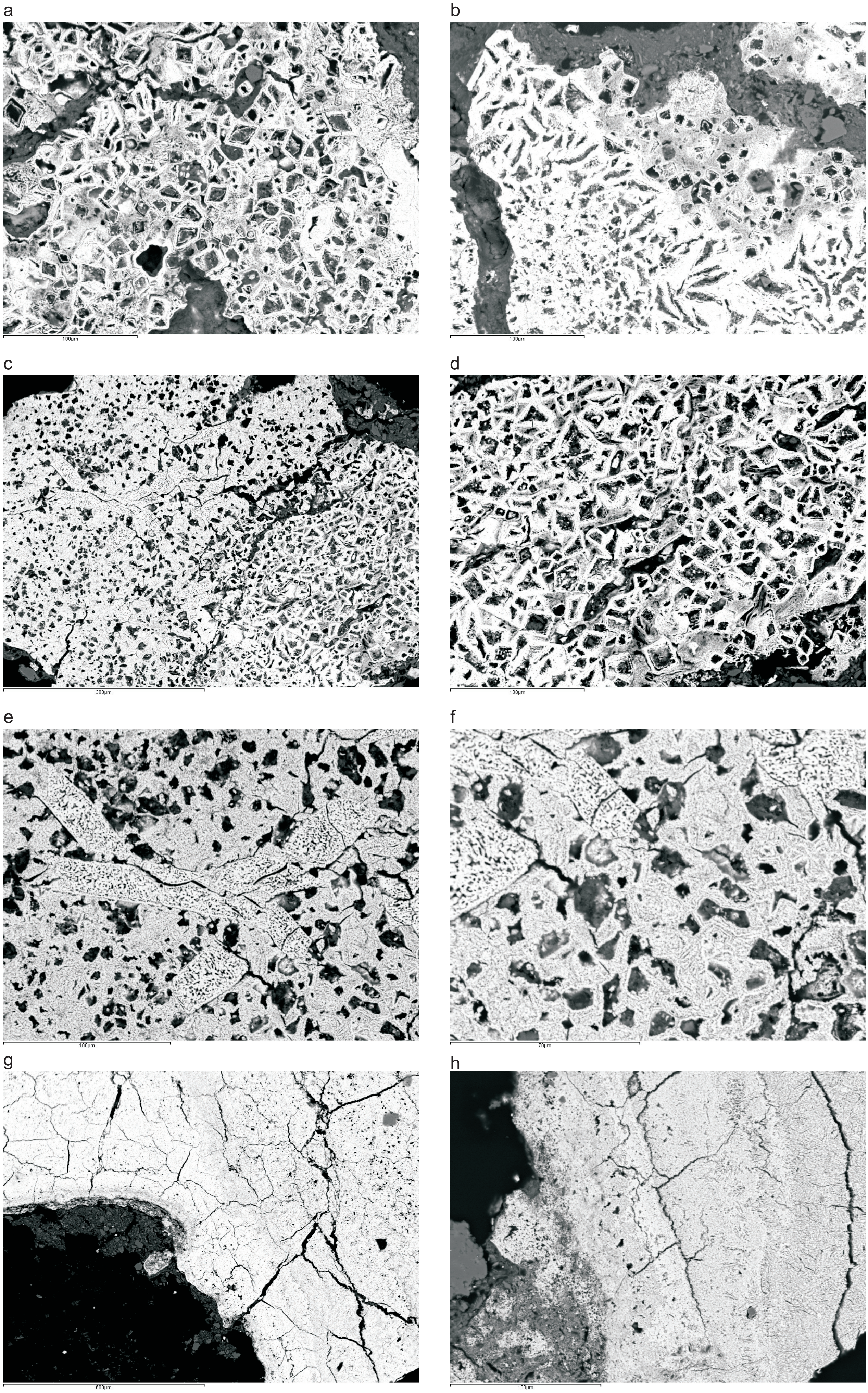

Plate 3

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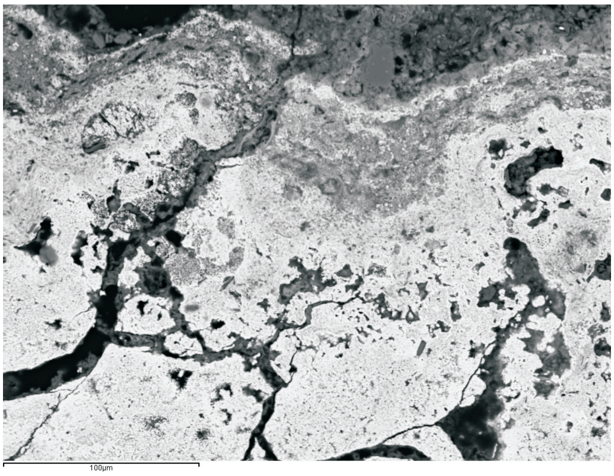

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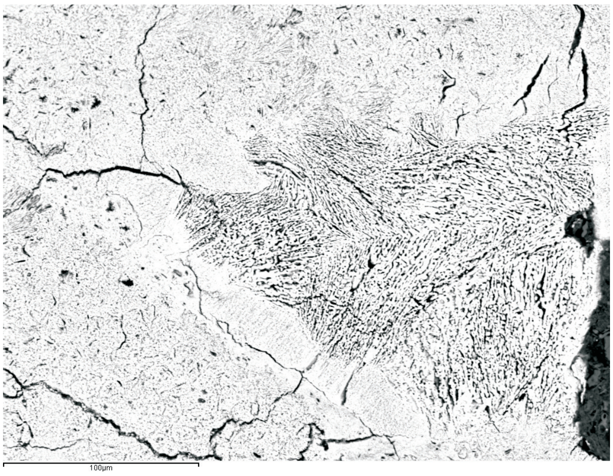

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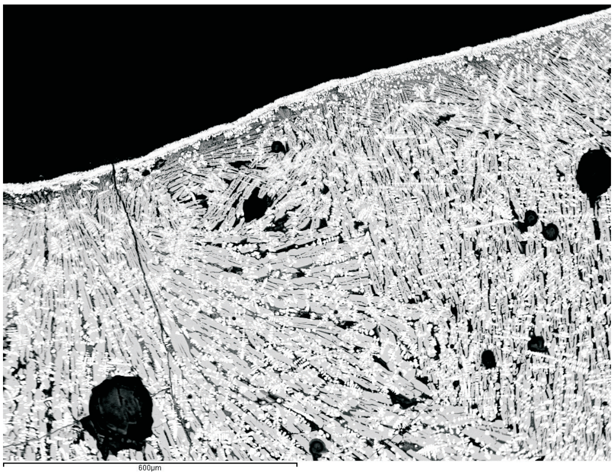

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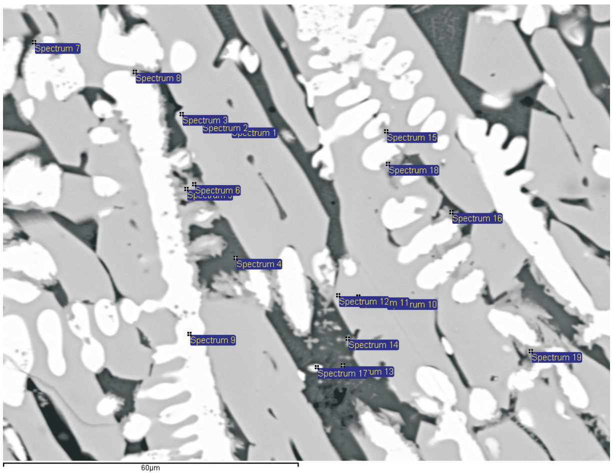

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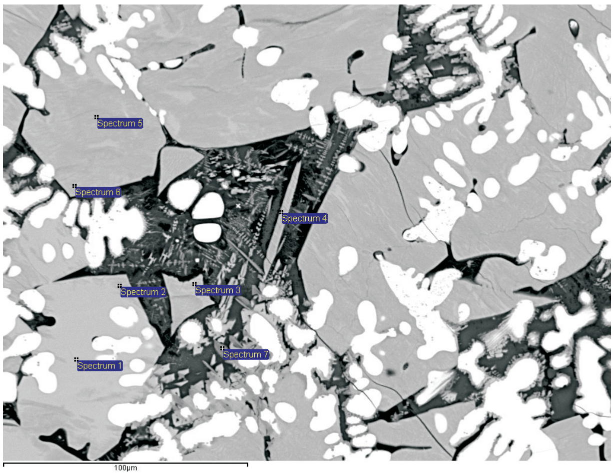

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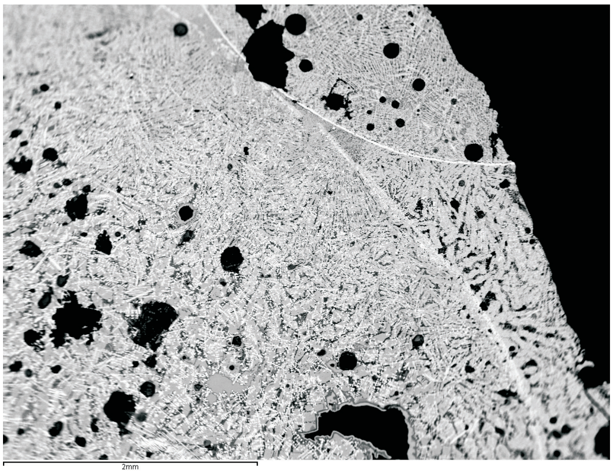

Plate 4

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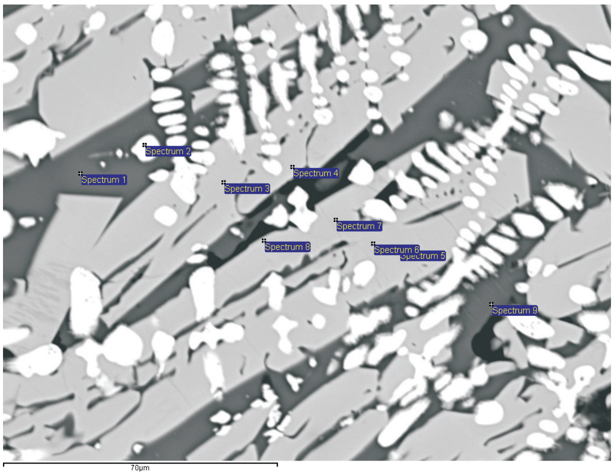

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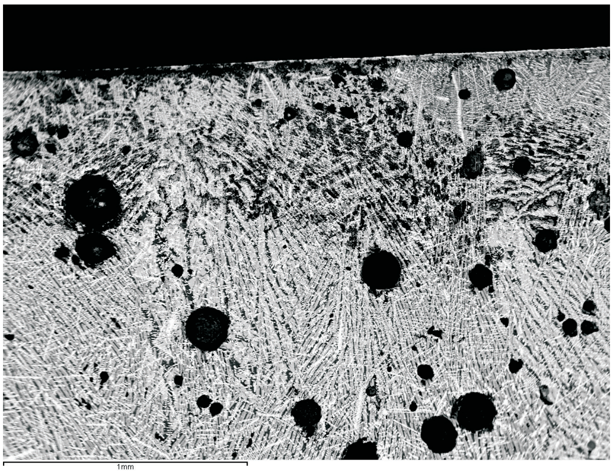

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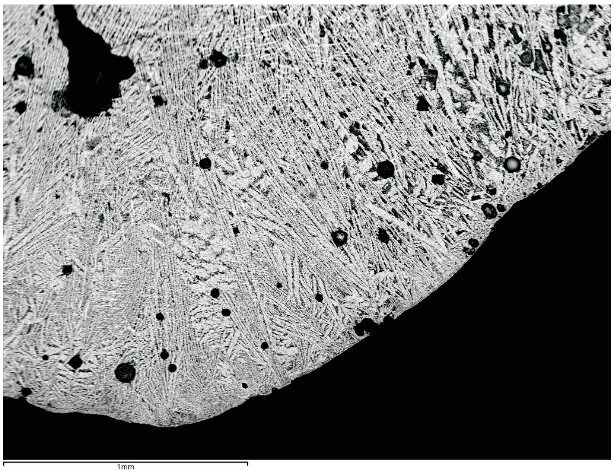

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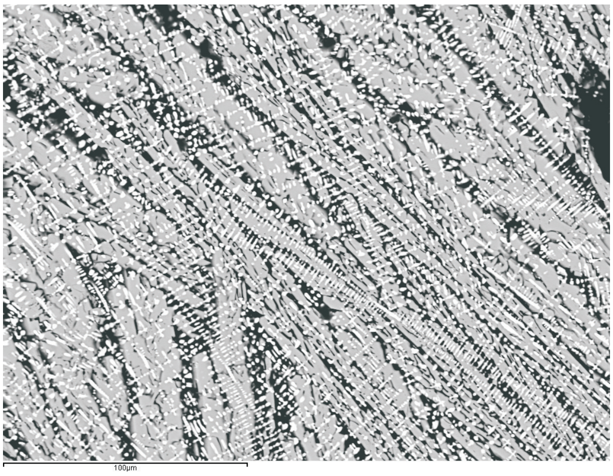

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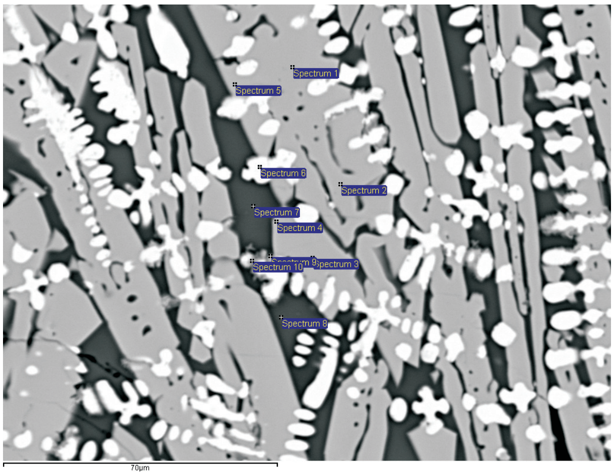
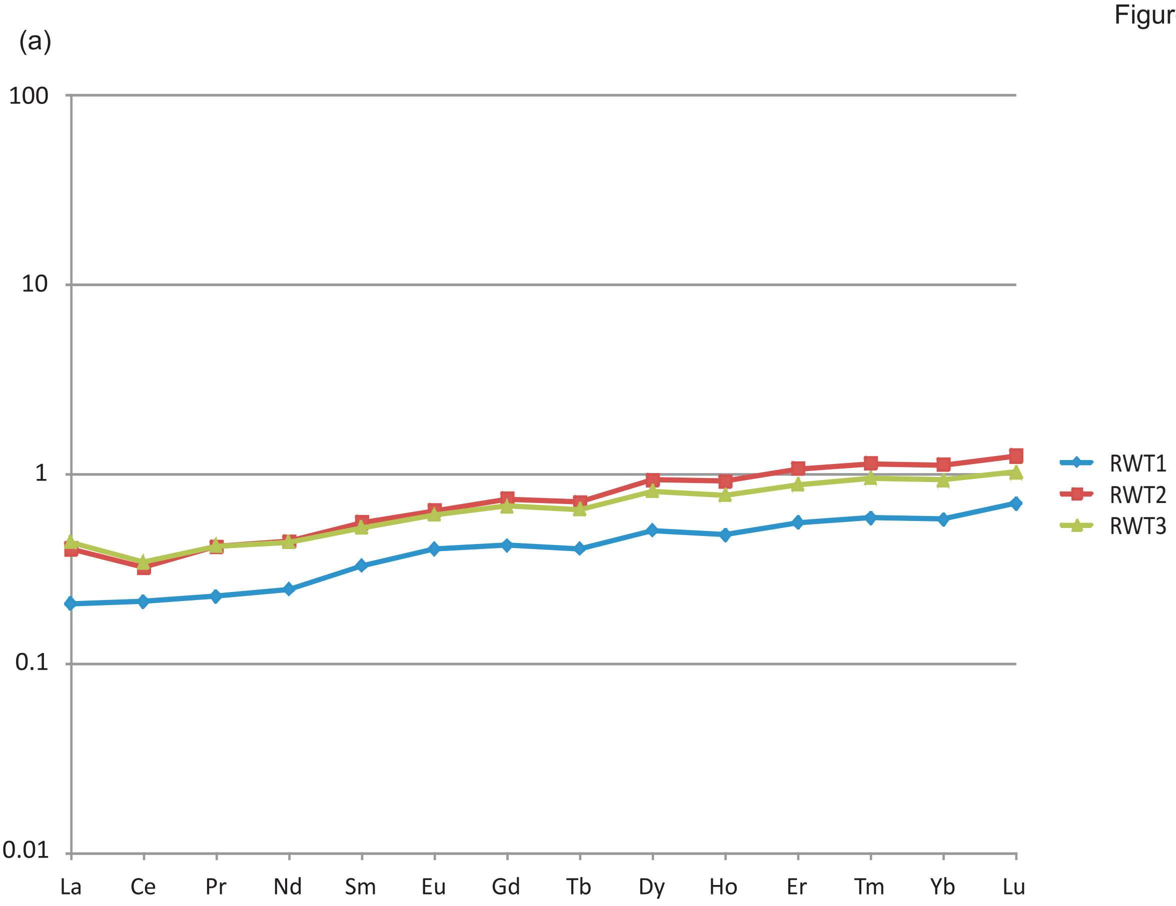


Figure 1



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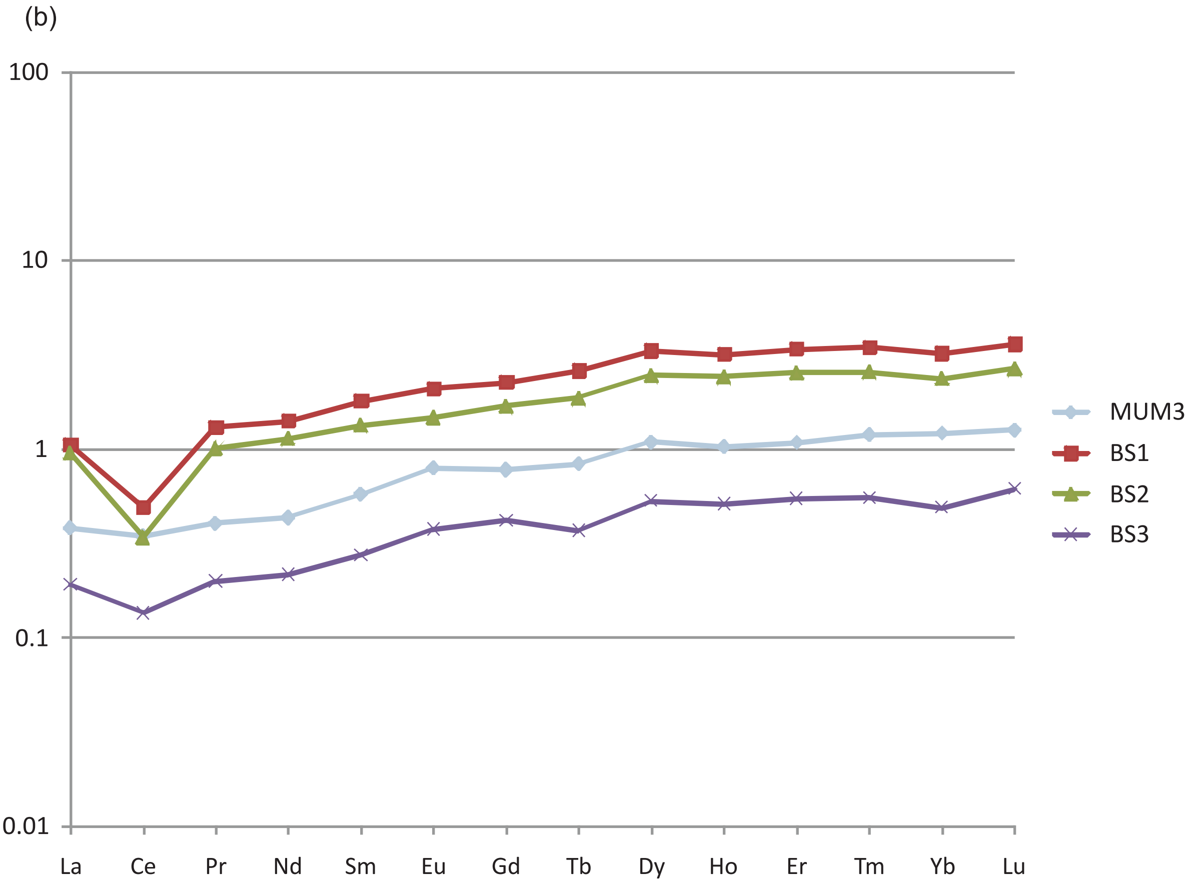

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BS2
BS3

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