Supplementary Information for:

Composition and Cr- and Fe-speciation of dust generated during ferrochrome production in a DC arc furnace

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SI Table 1. Bulk composition of feed materials to smelter

	Black Thor Chromite			**Reductant**	**Flux**	**Flux**	**Feed Compositions**				
	whole	coarse	fine	anthracite	limestone	silica			tests		
wt%	ore	fraction	fraction				1*	2	3	5	6,7,8
Cr_2O_3	45.06	47.40	47.60	0.02			28.60	30.90	30.80	30.90	29.80
MgO	13.85	13.90	13.60	0.12	0.54		9.50	8.90	9.10	9.60	9.30
Al_2O_3	12.90	13.80	13.40	3.83	0.07	0.10	9.30	9.30	9.50	9.40	9.10
SiO_2	6.00	5.60	5.60	5.29	0.39	99.56	12.20	12.20	12.20	11.20	11.40
CaO	0.97	0.30	0.50	1.16	55.07	0.08	6.50	7.60	7.50	6.40	7.70
FeO	18.86	18.80	19.00	0.40			12.50	12.40	12.30	13.00	12.50
TiO_2	0.37			0.22						0.30	0.30
MnO	0.21	0.20	0.20				0.10	0.10	0.10	0.10	0.10
C	0.14	0.04	0.08	86.60			12.50	12.40	12.40	13.20	12.70
CO_2					43.81		5.10	5.70	5.70	4.40	5.50
P	0.01			0.04							
S		0.01	0.20	0.61			0.20	0.20	0.10	0.10	0.10
Total	98.37	100.10	100.20	98.51	99.35	99.74	96.50	99.80	99.80	98.60	98.60

Particle sizes: <4.75 mm for the whole ore, 1.68-4.75 mm for the coarse size fraction and <1.68 mm for the fine fraction; Coarse size fraction forms 41 wt% of the whole ore whereas the remainder (59 wt%) is made by the fine size fraction; * measured feed composition, others calculated. Carbon in the chromite ore reflects the presence of carbonate minerals in the ore.

SI Table 2. Bulk chemical compositions (wt%) of the smelter dust samples

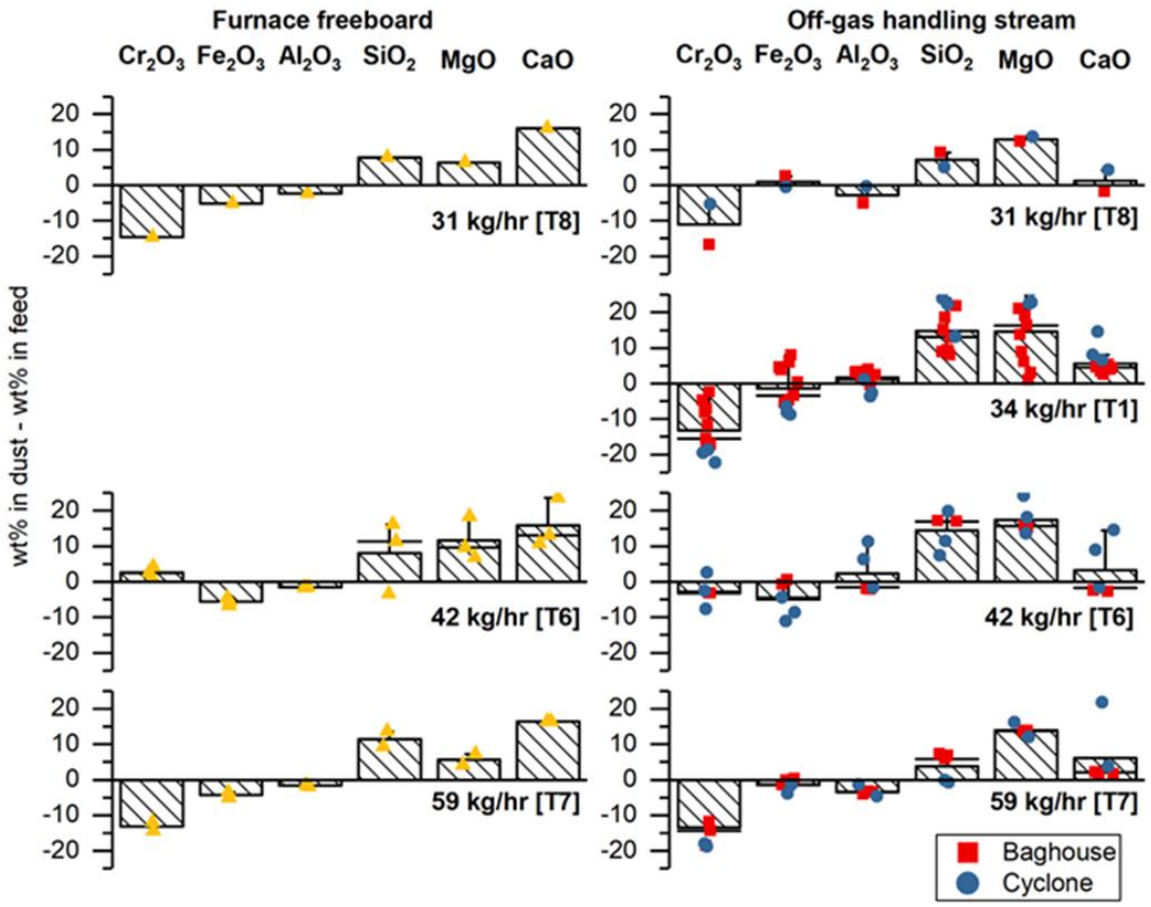
Test no	Location	Cr_2O_3	$Fe_2O_3^*$	Al_2O_3	SiO_2	MgO	CaO	K_2O	LOI	C	total
1	Cyclone	11.07	7.22	6.37	24.53	32.01	15.29	0.71	0.58	0.15	97.93
1	Cyclone	10.31	5.76	10.09	33.70	31.73	7.35	0.48	0.27	0.07	99.76
1	Cyclone	7.51	5.08	5.39	35.32	35.39	8.88	0.70	0.52	0.10	98.89
3	Cyclone	18.55	9.70	6.23	23.82	34.10	4.86	0.47	0.15	0.05	97.93
2	Cyclone	21.38	10.91	9.44	16.10	29.09	9.74	0.23	0.38	0.28	97.55
5	Cyclone	20.72	10.17	5.43	21.06	33.87	7.06	0.36	0.00	0.02	98.69
1	Baghouse	27.34	21.85	11.78	19.40	10.18	3.35	0.97	0.75	0.50	96.12
1	Baghouse	12.59	9.23	10.86	29.94	28.13	5.22	0.83	1.24	0.13	98.17
1	Baghouse	14.32	10.47	12.93	26.54	25.58	6.11	0.70	1.02	0.13	97.80
1	Baghouse	11.42	8.48	8.60	33.10	30.16	4.64	0.87	1.21	0.11	98.59
1	Baghouse	21.54	18.38	12.23	20.75	12.22	4.22	0.95	0.75	0.57	91.61
1	Baghouse	18.17	14.16	10.76	24.37	22.81	5.35	0.93	1.22	0.26	98.03
1	Baghouse	25.03	19.80	11.40	20.46	15.21	4.08	0.87	0.71	0.40	97.96
1	Baghouse	22.62	17.63	12.30	20.19	18.00	5.32	0.77	0.95	0.33	98.11
5	Baghouse	8.44	7.84	2.57	31.48	39.99	3.28	0.86	1.55	0.05	96.06
5	Baghouse	8.32	7.64	3.56	31.30	39.68	3.29	0.84	1.52	0.05	96.20
5	Baghouse	8.27	7.62	3.74	31.03	39.20	3.24	0.92	1.51	0.05	95.58
2	Baghouse	3.60	2.76	2.69	36.28	46.99	2.47	0.54	2.05	0.13	97.51
5	Baghouse	5.59	4.74	2.58	33.89	42.84	3.06	0.91	1.83	0.06	95.50
	Dropout box	17.86	10.68	8.60	18.30	24.88	14.65	0.57	1.05	1.70	98.29
6	Freeboard	13.65	7.28	7.44	22.74	27.59	18.47	0.96	0.25	0.98	99.36
6	Freeboard	16.72	9.25	7.57	7.97	16.04	31.40	0.37	7.69	3.76	100.77
6	Freeboard	14.95	8.31	7.52	27.54	18.90	20.85	1.07	-0.72	0.05	98.47
7	Freeboard	17.91	10.33	7.63	20.62	13.32	24.20	2.67	0.54	0.22	97.44
7	Freeboard	15.47	8.80	7.18	24.98	16.46	24.19	1.44	-0.21	0.73	99.04
8	Freeboard	15.25	8.84	6.69	15.52	15.50	23.78	2.12	3.86	1.35	92.91
6	Cyclone	4.78	2.75	20.42	31.18	33.41	6.04	0.56	-0.82	0.90	99.22
6	Cyclone	15.01	9.39	7.51	18.74	22.76	22.25	0.82	0.48	0.45	97.41
6	Cyclone	9.89	5.28	15.41	22.78	27.26	16.64	0.62	-0.32	0.61	98.17
7	Cyclone	15.85	10.07	7.68	10.59	21.22	29.58	0.31	-0.35	0.46	95.41
7	Cyclone	30.98	12.47	4.45	11.19	25.31	11.54	0.51	0.29	0.17	96.91
8	Cyclone	24.36	13.28	8.74	12.88	22.82	11.98	1.47	-0.04	0.27	95.76
6	Baghouse	9.24	14.33	7.02	28.44	24.45	4.90	1.99	2.30	0.49	93.16
6	Baghouse	9.24	13.05	6.96	28.40	24.97	5.28	2.17	1.73	0.49	92.29
7	Baghouse	11.25	13.73	5.69	18.15	22.77	9.45	4.09	1.92	0.32	87.37
7	Baghouse	10.95	12.49	5.60	18.63	23.01	9.32	4.25	1.98	0.29	86.52
7	Baghouse	11.72	14.21	5.02	17.17	22.91	9.84	4.32	1.80	0.34	87.33
8	Baghouse	13.03	16.34	3.96	16.88	21.41	5.92	4.90	2.28	0.40	85.12
	Dropout box	22.47	13.41	8.78	9.52	17.07	25.37	0.58	-1.26	0.99	96.93

LOI: Loss on ignition. Negative values indicate mass gain during fusion (i.e. oxidation of metallic phases); * Fe_2O_3 as total Fe; Tests 1-5 were conducted during pilot smelting campaign 1 and Tests 6-8 during pilot smelting campaign 2.

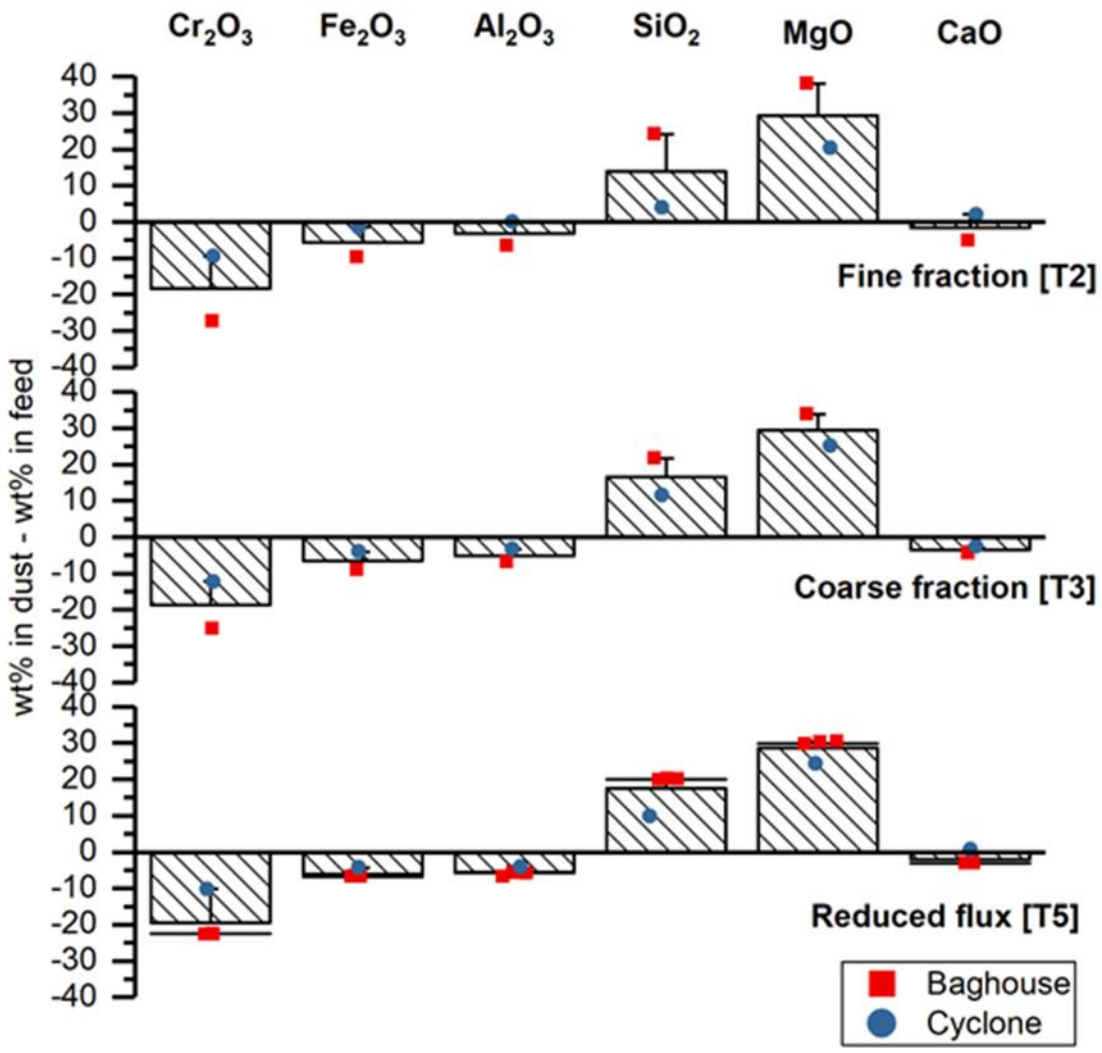
SI Table 3. Mineralogical composition of the dust samples from first pilot testing campaign

Test	Location	Mineralogical composition
1	Cyclone	chromite + lime + periclase + forsterite
1	Cyclone	periclase + chromite + forsterite + lime
1	Cyclone	chromite + forsterite + periclase + lime
3	Cyclone	chromite + periclase + forsterite + lime
2	Cyclone	chromite + periclase + forsterite + lime
5	Cyclone	chromite + periclase + forsterite + lime
1	Baghouse	chromite + chlorite + lime
1	Baghouse	chromite + forsterite + periclase
1	Baghouse	chromite + forsterite + periclase
1	Baghouse	chromite + forsterite +periclase
1	Baghouse	chromite + halite + lizardite + quartz + maghemite
1	Baghouse	chromite + forsterite + lizardite + lime + periclase + maghemite
1	Baghouse	chromite + forsterite + clay + lime + maghemite
1	Baghouse	chromite + forsterite + lizardite + lime + maghemite
5	Baghouse	forsterite + chromite + periclase + quartz
5	Baghouse	olivine + chromite + periclase + quartz
5	Baghouse	forsterite + chromite + periclase
2	Baghouse	forsterite + periclase + chromite + quartz
5	Baghouse	forsterite + periclase + chromite + quartz
	Dropout box	forsterite + chromite + periclase

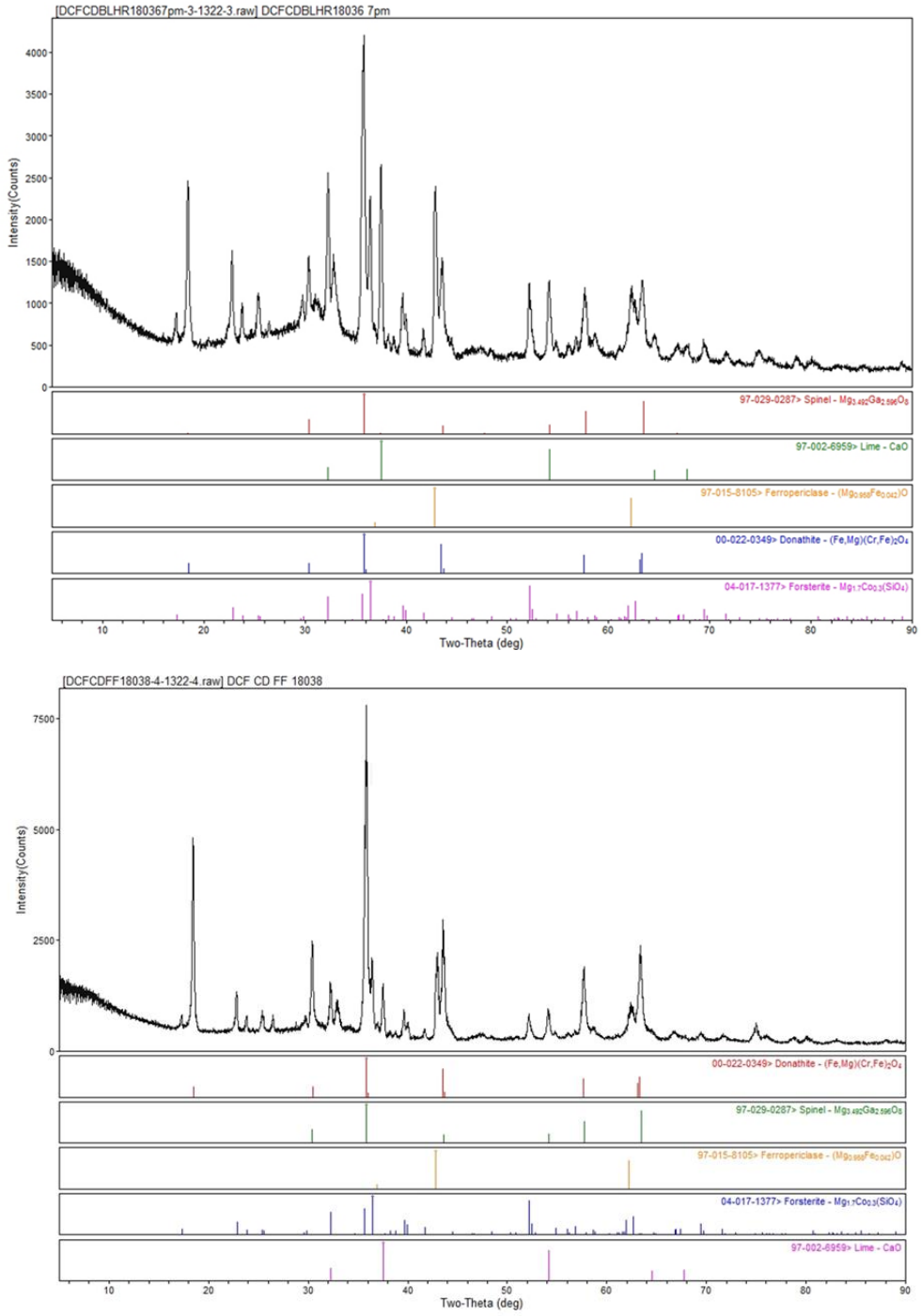
Mineralogical composition listed in order of abundance from high to low (qualitative), identified by powder-XRD; all the samples contain amorphous phase(s).



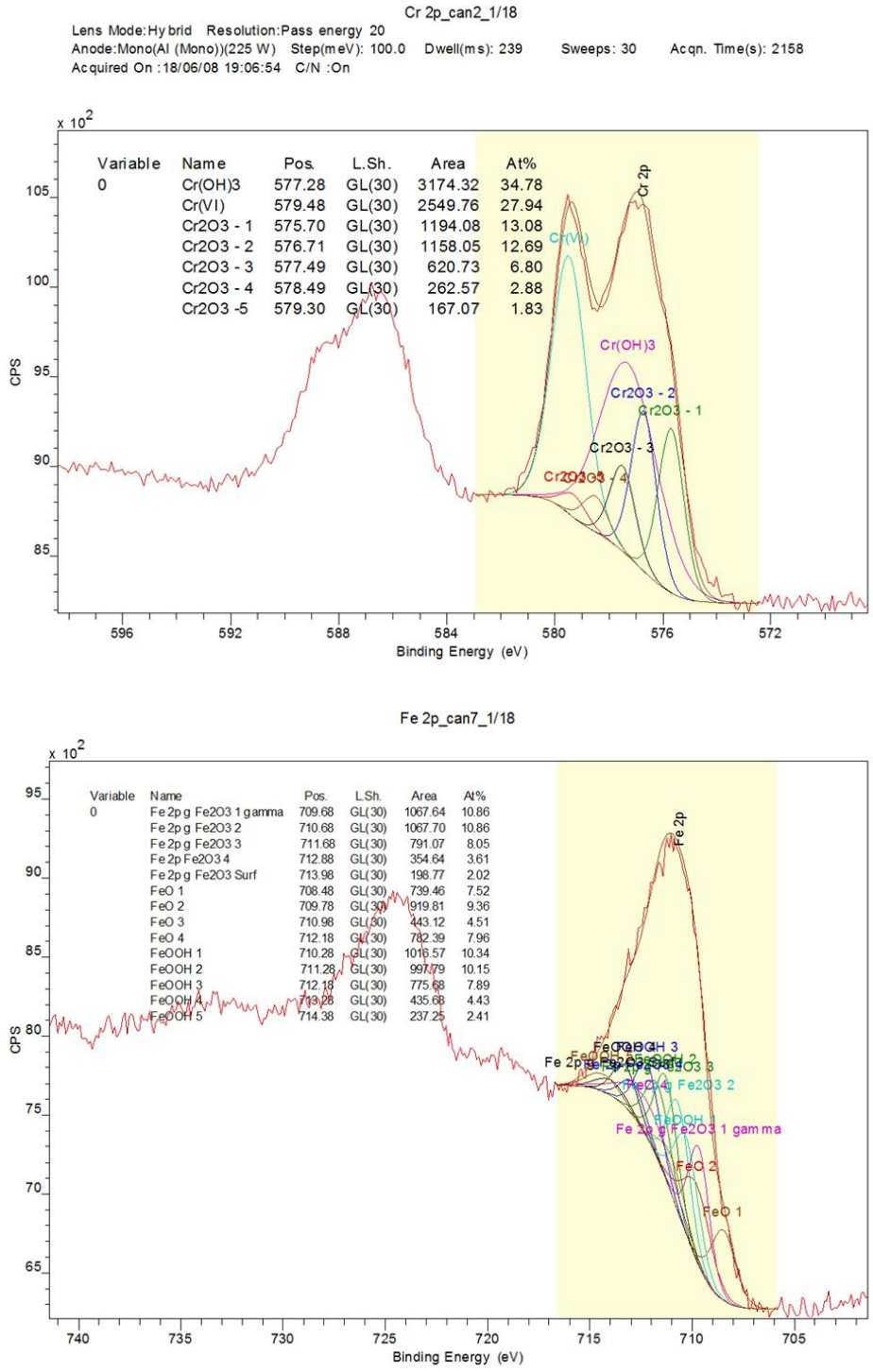
SI Figure 1. Major element bulk composition of dust samples collected from the baghouse, the cyclone, and the furnace freeboard relative to the feed composition. Data presented is for tests using whole ore with variable ore feed rates. Data points represent individual samples; columns indicate average values; and bars median values



SI Figure 2. Major element bulk composition of dust samples collected from the baghouse and the cyclone, relative to the feed composition. Data presented is for tests using variable size fractions of ore and comparable feed rates. T5 used whole ore and a reduced amount of flux (see Table 1 for details). Data points represent individual samples; columns indicate average values; and bars median values



SI Figure 3. XRD patterns of the cyclone dust samples produced during Test 1 (top) and Test 2 involving fine-grained feed (bottom)

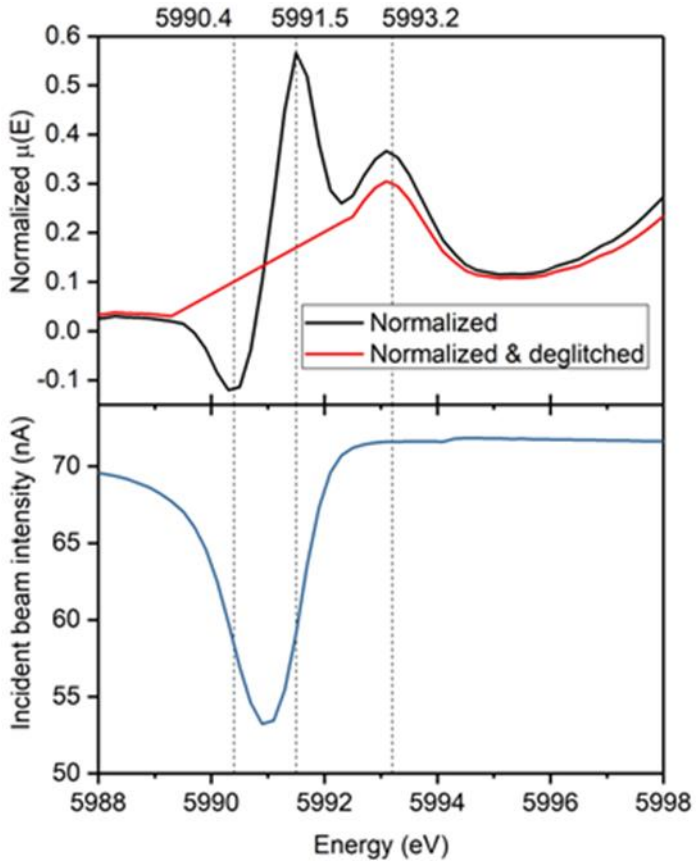


SI Figure 4. XPS spectrum of a dust sample showing the Cr species and their relative abundances (top) and Fe species and their relative proportions (bottom). Concentrations (at%) were determined through deconvolution of reference spectra. Measured spectra are shown in red and the fits in black. The yellow background in both shows the energy range used in fitting.

SI Table 4. Distribution of Cr and Fe species on particle surfaces (at%) as determined by XPS

Pilot	Test	Location	Cr(0)	Cr_2O_3	$Cr(OH)_3$	Cr(VI)	Fe(0)	FeO	Fe_2O_3	FeOOH
1	1	Cyclone	0.4	47.7	28.0	23.9		6.1	13.3	80.6
	1	Cyclone	0.3	37.0	35.1	27.6				100.0
	1	Cyclone	0.2	45.7	44.6	9.6		14.1		85.9
	3	Cyclone	0.3	47.9	30.6	21.1				100.0
	2	Cyclone	1.2	76.3	12.1	10.4		26.3	9.7	64.0
	5	Cyclone	1.3	85.0	8.7	5.1		16.6	11.3	72.1
	1	Baghouse	0.2	92.1	7.7	0.1		29.4	35.4	35.2
	1	Baghouse	0.4	44.3	46.0	9.2		30.6	5.8	63.6
	1	Baghouse	0.3	63.1	32.1	4.5		35.8	18.4	45.8
	1	Baghouse	0.3	46.8	45.2	7.8		41.0	0.2	58.9
	1	Baghouse	0.3	91.5	8.1	0.1		29.5	34.2	36.3
	1	Baghouse	0.3	79.0	17.4	3.3		34.0	23.4	42.6
	1	Baghouse	0.3	86.2	13.5	0.1		34.8	34.8	30.4
	1	Baghouse	0.3	90.9	8.8	0.1		33.3	36.3	30.4
	5	Baghouse	0.4	48.0	38.2	13.4		7.3		92.7
	5	Baghouse	0.7	43.5	43.3	12.5		26.9	3.8	69.2
	5	Baghouse	0.2	38.8	44.7	16.4		9.9	9.0	81.1
	2	Baghouse	0.5	24.8	57.2	17.5		21.3		78.7
	5	Baghouse	0.3	27.1	53.6	19.1		12.2		87.8
		Dropoutbox	0.6	84.6	12.0	2.8		23.5	19.4	57.1
2	6	Freeboard	1.5	49.4	2.3	46.8	14.1	43.5		42.3
	6	Freeboard		5.3	33.5	50.6	15.3	47.3	37.5	
	6	Freeboard		11.3	33.8	54.9	17.3	51.3	13.6	17.8
	6	Freeboard	0.6	52.5	12.9	34.1	22.0	48.1		30.0
	6	Freeboard	4.2	82.5	5.3	8.0				
	6	Freeboard	0.8	55.0	33.0	11.2		82.4		17.6
	7	Freeboard	4.2	43.9	40.1	11.8				
	7	Freeboard		29.2	47.4	23.4		42.5	12.1	45.4
	7	Freeboard	0.7	27.7	54.2	17.5		71.0		29.0
	6	Cyclone		44.2	45.1	10.7				
	6	Cyclone	0.5	35.0	38.9	25.6		37.2		62.8
	6	Cyclone	1.0	48.5	27.8	12.8		10.2		89.8
	7	Cyclone		38.2	39.4	22.4				
	7	Cyclone		29.2	50.1	20.7		31.4		68.7
	8	Cyclone	0.9	37.5	41.2	20.5		43.8	10.4	45.9
	6	Baghouse	0.9	45.2	37.4	16.6		44.7		55.3
	6	Baghouse	1.2	46.1	39.1	13.7		78.8		21.2
	7	Baghouse	1.5	42.1	35.0	21.3		58.4		41.6
	7	Baghouse	1.4	38.9	42.1	17.6		76.8		23.2
	7	Baghouse	1.3	49.0	22.1	27.7		76.7		23.4
	8	Baghouse	0.5	25.1	26.3	48.1	20.6	69.4		10.0
	6	PAB	1.1	4.6	54.8	39.6		46.4		53.6
	7	PAB	0.6	28.5	45.7	25.3				
	8	PAB	0.9	32.7	36.6	29.9				

PAB: post after-burner

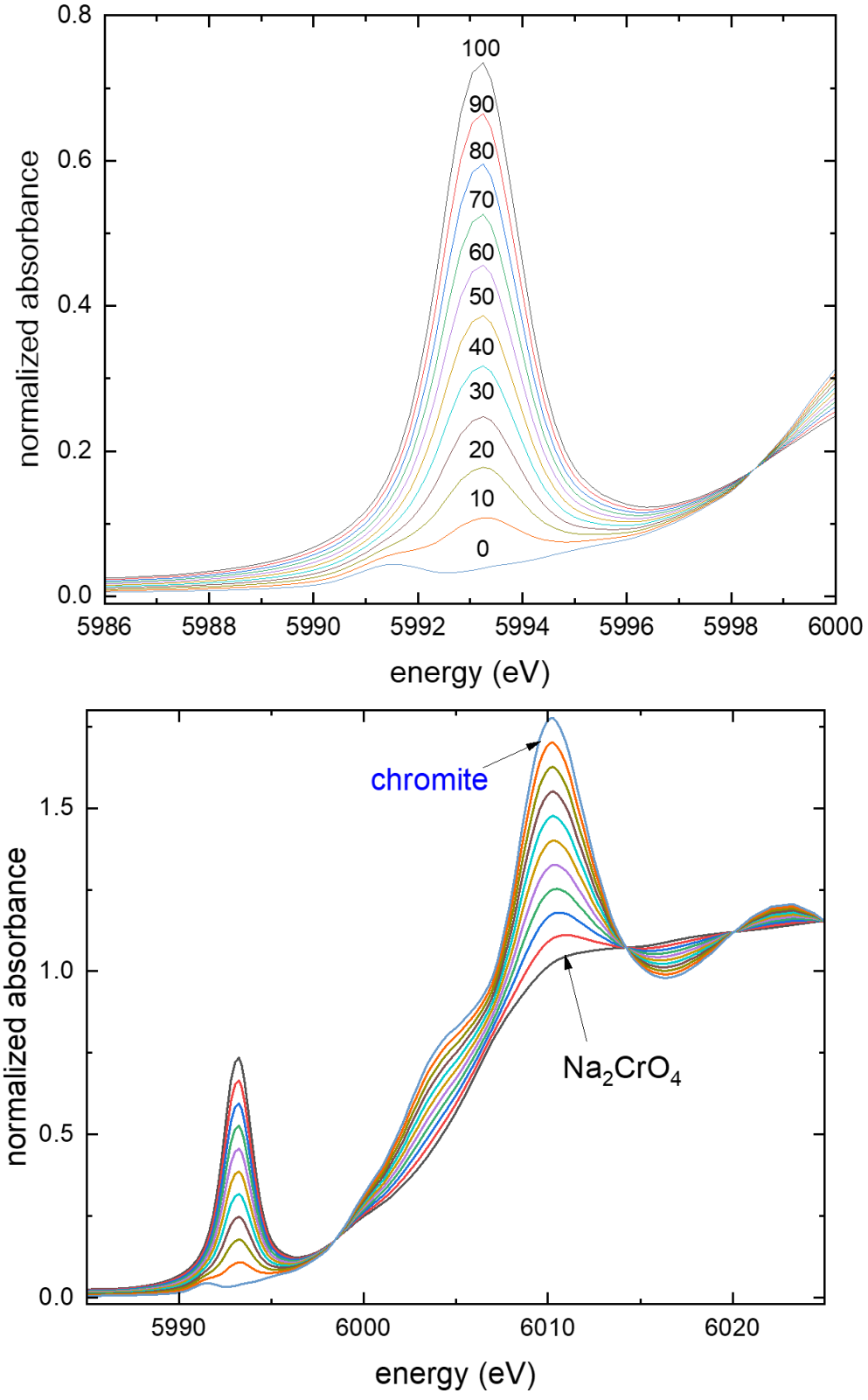


SI Figure 5. Example of the effect of the monochromator glitch on the normalized XANES spectrum in the pre-edge region of the Cr K-edge spectra. The incident beam intensity drops across 5989.3-5992.5 eV (bottom panel). The most drastic artefact in the normalized spectra resulting from the glitch is shown in the upper panel (sample T7PAB). The sinusoidal glitch corresponds closely with the monochromator glitch. Data from the glitched region has been removed in the deglitched spectrum. It should be noted that the pre-edge peak at 5993.2 eV is not affected by the monochromator glitch.

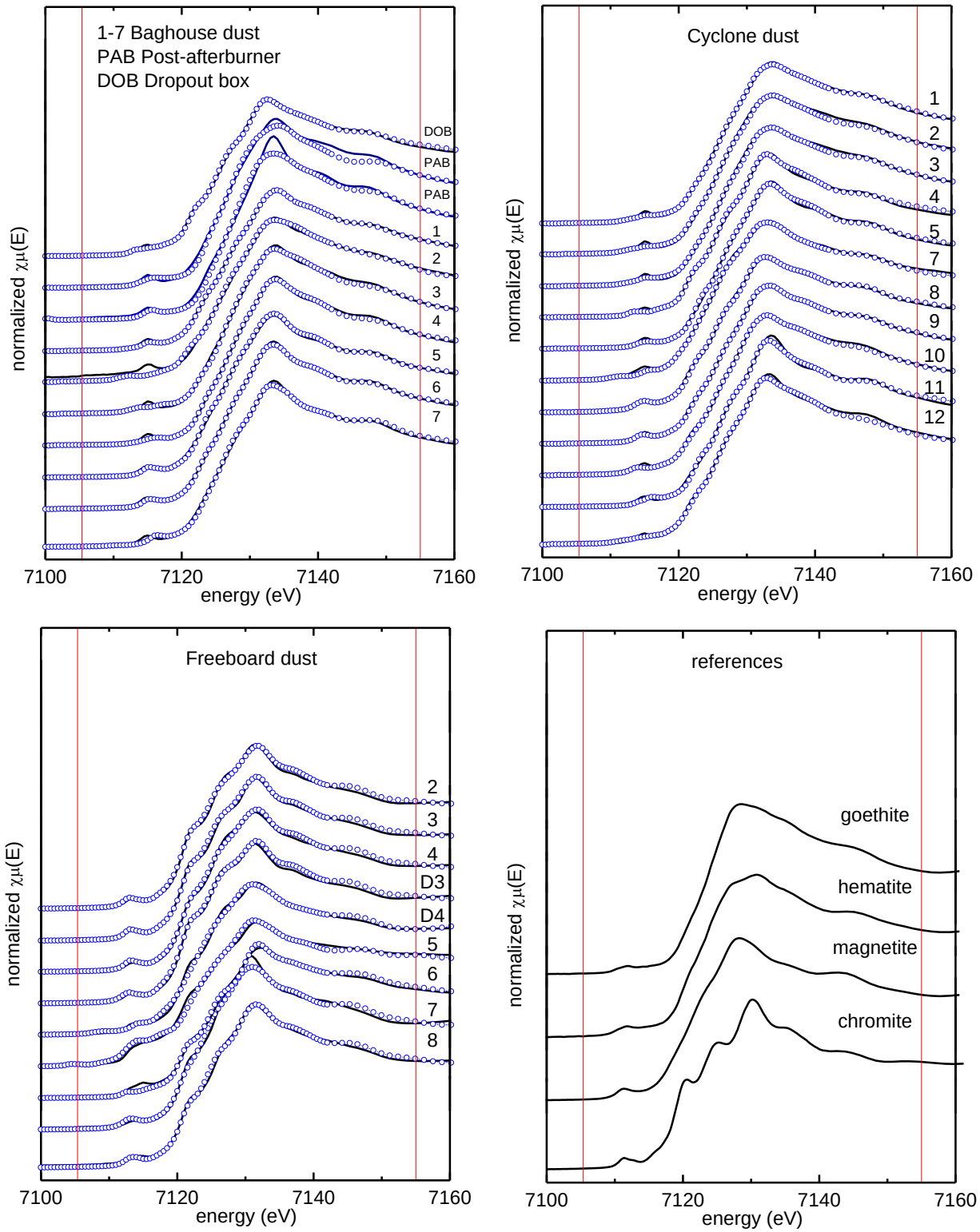
SI Table 5. Fe species in bulk dust samples based on LCA of XANES spectra

Location	test	label	chromite	magnetite*	goethite	hematite	R-factor	Chi^2
Freeboard	6	FBD2	57.9	42.1			0.0007	0.0409
	6	FBD3	51.6	48.4			0.0006	0.0373
	6	FBD-D3	55.3	44.7			0.0009	0.0543
	6	FBD4	42.1	57.9			0.0007	0.0421
	6	FBD-D4		67.5	5.4	27.1	0.0007	0.0388
	7	FBD5	20.2	74.0	5.8		0.0011	0.0568
	7	FBD6	47.1	45.9		7.0	0.0007	0.0384
	7	FBD7	20.3	63.9	15.8		0.0013	0.0770
	8	FBD8	38.8	56.7	4.5		0.0005	0.0305
Dropout box	6-8	DOB	39.7	27.8	4.3	28.2	0.0002	0.0093
Postafterburner	6	PAB		27.3		72.7	0.0014	0.0808
	7	PAB		27.5		72.5	0.0020	0.1195
Cyclone	1	CD1		43.8	28.0	28.2	0.0002	0.0093
	1	CD2		35.4	28.5	36.0	0.0004	0.0219
	1	CD3		51.9	24.9	23.1	0.0003	0.0160
	2	CD4	38.2	25.4	18.1	18.2	0.0002	0.0141
	3	CD5	26.0	20.6	28.8	24.6	0.0003	0.0169
	6	CD7	3.8	49.6	12.4	34.2	0.0003	0.0165
	6	CD8	18.3	69.9	10.6	1.2	0.0001	0.0087
	6	CD9	13.7	66.2	20.2		0.0001	0.0041
	7	CD10	10.3	51.2	34.3	4.2	0.0002	0.0110
	7	CD11	26.4	59.4	15.0		0.0004	0.0233
	8	CD12	24.2		47.5	28.4	0.0004	0.0251
Baghouse	1	BHD1	20.5	43.7	23.5	12.3	0.0001	0.0042
	1	BHD2			49.9	50.1	0.0015	0.0905
	3	BHD3			44.4	55.6	0.0005	0.0280
	5	BHD4	21.2	15.2	41.7	21.8	0.0002	0.0140
	6	BHD5	31.7	49.2	19.1		0.0003	0.0165
	7	BHD6	22.9	57.9	19.7		0.0001	0.0063
	8	BHD7		91.1	8.9		0.0004	0.0223

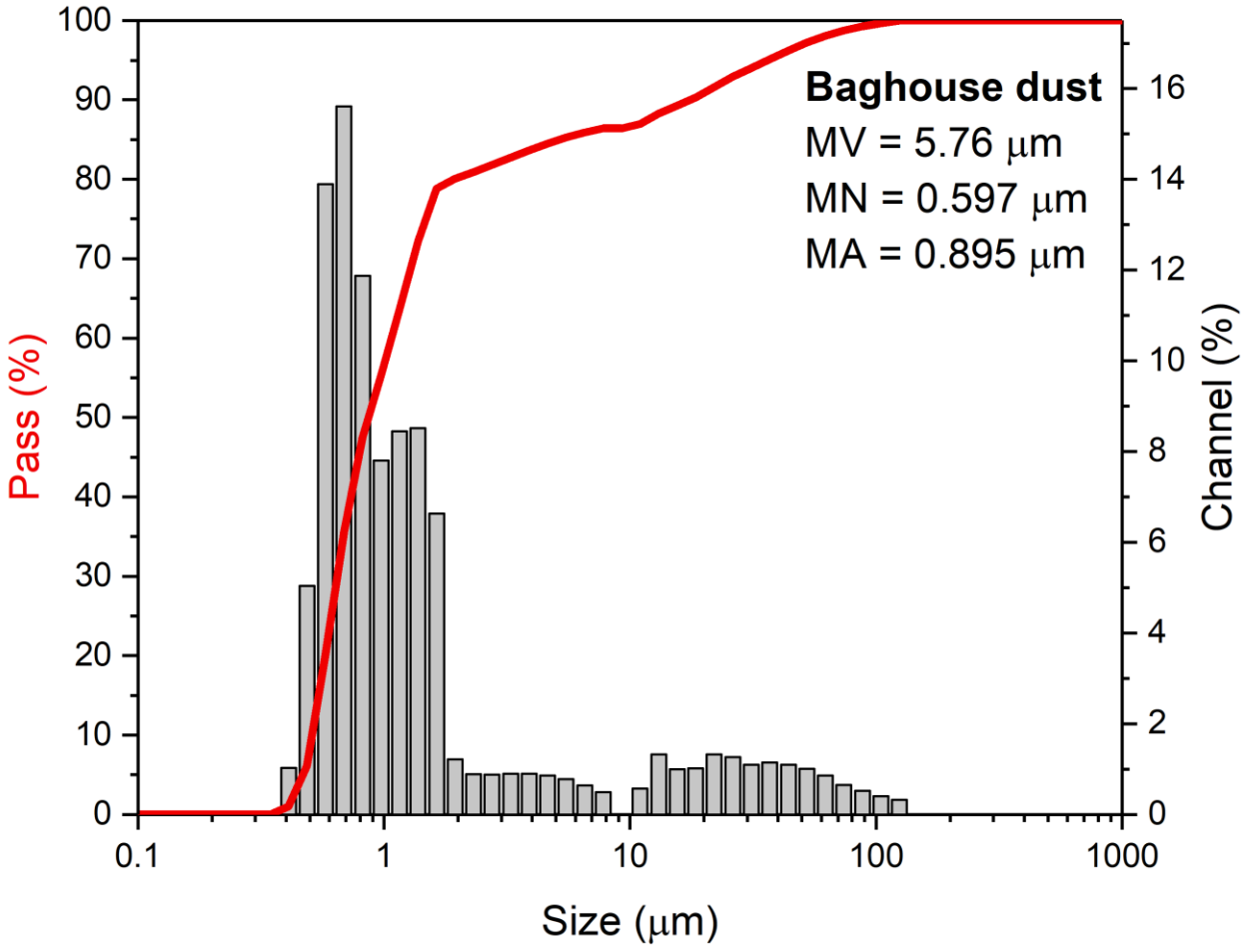
R-factor and Chi-square (Chi^2) values represent uncertainties in fitting; Percent values that are less than about 5 are probably insignificant; *can include maghemite (γFe_2O_3) as well as magnetite (Fe_3O_4)



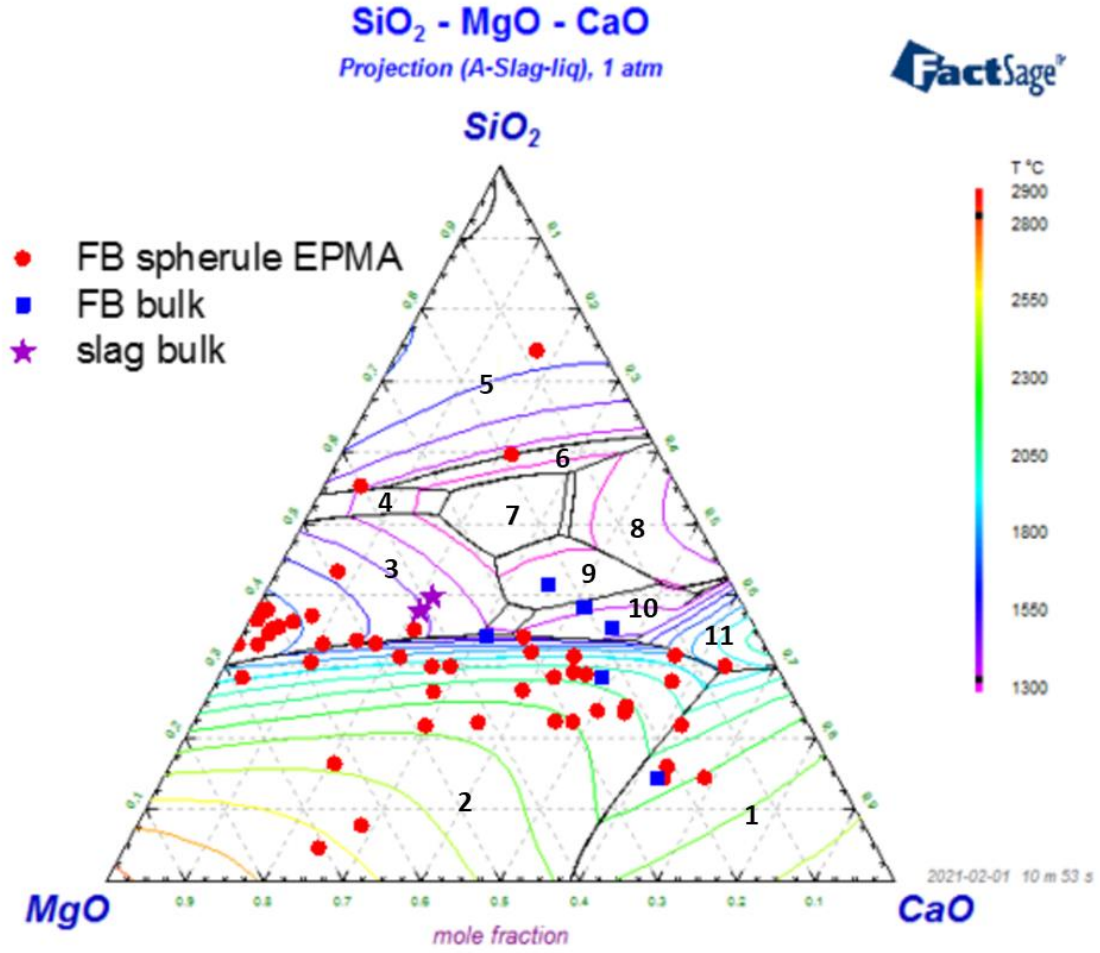
SI Figure 6. Binary mixtures of Cr K-edge XANES spectra of Na_2CrO_4 and chromite showing the pre-edge peak (top) and the pre-edge and edge regions (bottom). Numbers next to spectra signify the proportion of chromate (at%) in the mixtures. Chromite: 0%; Na_2CrO_4: 100%.



SI Figure 7. Linear combination fitting of Fe K-edge XANES spectra with reference compounds, chromite, magnetite, hematite and goethite. Measured spectra shown in solid black lines whereas fits shown in blue circles. Fitting range is marked by red vertical lines.



SI Figure 8. Particle size distribution of baghouse dust (BHD2) determined by laser diffraction. The sample was ultrasonicated in distilled water for 300 seconds before being poured into the Microtrac particle size analyzer. The sample was run for 60 seconds with ultrasonication turned on. The data was analyzed using a refractive index of 1.46 (silica glass), transparent particles, spherical in shape. MV, MN, and MA refer to the mean calculated based on the volume, number, and area distribution, respectively.



SI Figure 9. Compositions of bulk freeboard dust, individual freeboard spherules as determined by electron microprobe (EPMA) (Berryman and Paktunc 2021) and bulk slag as shown on SiO_2-MgO-CaO phase diagram calculated from FactSage 8.0; 1: monoxide CaO; 2: monoxide MgO; 3: forsterite; 4: protopyroxene; 5: slag-liquid; 6: quartz; 7: $CaMgSi_2O_4$; 8: $CaSiO_3$; 9: $Ca_2MgSi_2O_7$; 10: $Ca_2MgSi_2O_7$; 11: Ca_2SiO_4; Isotherms are color-coded as per the temperature (T °C) bar on the right