

Supplemental Material File for: **The oxidation behavior of a selection of South African chromites**

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Table S-1: Average spinel grain compositions from EDS analysis (mass %)

	Ore A		Ore B		Ore C		Ore D		Ore E		Ore F		Ore G	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Cr ₂ O ₃	46.00	1.05	45.69	1.35	46.48	1.01	46.20	0.71	46.82	0.74	47.17	0.65	44.13	0.83
Al ₂ O ₃	16.01	0.65	16.12	0.90	16.11	1.18	16.15	0.38	15.91	0.50	15.85	0.59	17.47	0.83
Fe ₂ O ₃	7.50	0.34	7.67	0.22	7.33	0.70	7.58	0.24	8.31	0.24	8.79	0.51	8.11	0.49
FeO	20.26	0.91	20.71	0.60	20.12	1.93	19.43	0.62	17.12	0.49	18.10	1.05	20.06	1.21
MgO	9.62	0.21	9.41	0.21	9.55	0.21	10.05	0.21	11.29	0.21	10.25	0.21	9.77	0.21
TiO ₂	0.56	0.60	0.60	0.53	0.29	0.52	0.40	0.56	0.09	0.29	0.00	0.00	0.37	0.48
Sum	99.94		100.20		99.88		99.81		99.53		99.53		99.91	
n	12		10		11		13		11		11		10	
	Ore H		Ore I		Ore J		Ore K		Ore L		Ore N		Ore O	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Cr ₂ O ₃	43.47	2.05	47.43	1.86	43.83	1.23	47.15	0.67	44.25	1.22	47.74	0.51	47.40	1.98
Al ₂ O ₃	17.48	1.25	17.11	1.50	17.55	0.72	14.74	1.00	18.54	0.80	15.41	0.40	15.99	0.30
Fe ₂ O ₃	8.06	0.26	5.79	0.56	7.80	0.14	7.83	1.32	7.07	0.19	7.76	0.22	7.82	0.19
FeO	20.25	0.65	19.79	1.91	20.06	0.36	19.23	3.24	20.25	0.53	17.72	0.51	17.85	0.43
MgO	9.71	0.21	9.79	0.21	10.20	0.21	9.67	0.21	9.73	0.21	10.86	0.21	10.94	0.21
TiO ₂	0.59	0.66	0.09	0.28	0.92	0.50	0.15	0.32	0.24	0.54	0.09	0.28	0.08	0.25
Sum	99.56		100.00		100.36		98.76		100.08		99.57		100.08	
n	10		10		10		10		10		10		9	

n = number of EDS analyses performed

Table S-II: Molar cation proportions for raw ores derived from SEM-EDS analyses, normalised to 4 oxygens

	Ore A		Ore B		Ore C		Ore D		Ore E		Ore F		Ore G	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Cr	1.178	0.027	1.169	0.035	1.191	0.026	1.181	0.018	1.191	0.019	1.203	0.017	1.123	0.021
Σ Fe	0.732	0.033	0.747	0.022	0.725	0.070	0.710	0.023	0.662	0.019	0.702	0.041	0.736	0.044
Al	0.612	0.025	0.615	0.034	0.615	0.045	0.615	0.014	0.604	0.019	0.603	0.022	0.663	0.031
Mg	0.464	0.021	0.454	0.023	0.461	0.043	0.484	0.021	0.541	0.015	0.493	0.026	0.469	0.037
Ti	0.014	0.015	0.015	0.013	0.007	0.013	0.010	0.014	0.002	0.007	0.000	0.000	0.009	0.012
Sum	2.99		3.02		2.99		2.98		2.96		3.01		2.99	
N	12		10		11		13		11		11		10	
$X_{\text{Fe}^{2+}} = n_{\text{Fe}^{2+}} / \Sigma n_{\text{Fe}}$	0.75		0.75		0.75		0.74		0.70		0.72		0.73	
$n_{\text{Cr}} : n_{\text{Al}}$	1.93	0.097	1.90	0.079	1.94	0.190	1.92	0.068	1.97	0.064	2.00	0.120	1.69	0.107
$n_{\text{Mg}^{2+}} + n_{\text{Fe}^{2+}}$	1.01	0.057	1.01	0.055	1.01	0.119	1.01	0.049	1.00	0.034	1.00	0.068	1.01	0.091
	Ore H		Ore I		Ore J		Ore K		Ore L		Ore N		Ore O	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Cr	1.110	0.052	1.207	0.047	1.107	0.031	1.227	0.017	1.119	0.031	1.220	0.013	1.203	0.050
Σ Fe	0.743	0.024	0.673	0.065	0.724	0.013	0.723	0.122	0.712	0.019	0.668	0.019	0.668	0.016
Al	0.665	0.048	0.649	0.057	0.661	0.027	0.572	0.039	0.699	0.030	0.587	0.015	0.605	0.011
Mg	0.467	0.012	0.470	0.056	0.486	0.014	0.474	0.087	0.464	0.037	0.523	0.019	0.523	0.021
Ti	0.014	0.016	0.002	0.007	0.022	0.012	0.004	0.008	0.006	0.013	0.002	0.007	0.002	0.006
Sum	2.96		3.03		3.03		2.89		3.01		2.96		3.01	
N	10		10		10		10		10		10		9	
$X_{\text{Fe}^{2+}} = n_{\text{Fe}^{2+}} / \Sigma n_{\text{Fe}}$	0.74		0.79		0.74		0.73		0.76		0.72		0.72	
$n_{\text{Cr}} : n_{\text{Al}}$	1.67	0.095	1.86	0.194	1.68	0.056	2.15	0.363	1.60	0.061	2.08	0.064	1.99	0.096
$n_{\text{Mg}^{2+}} + n_{\text{Fe}^{2+}}$	1.01	0.036	1.00	0.141	1.02	0.032	1.00	0.222	1.01	0.082	1.00	0.042	1.00	0.043

Table S-III: VII Lattice parameters for the chromite spinel and sesquioxide phases from Rietveld refinement after roasting at 1200°C for 5min. Estimated errors are smaller than the decimal precision reported for lattice parameters.

	Rexp(%)	Rwp(%)	Spinel Lattice parameter a(Å)			Sesquioxide Lattice Parameters(Å)		Sesquioxide Mass%		
			Before	After	%Change	a	c	XRD ¹	SEM ²	FactSage ³
Ore A	2.33	4.06	8.304	8.284	-0.20%	4.960	13.510	45%	54%	52%
Ore B	2.35	3.90	8.304	8.284	-0.20%	4.960	13.508	43%	48%	53%
Ore C	2.32	3.81	8.303	8.285	-0.20%	4.958	13.504	42%	50%	52%
Ore D	2.34	3.95	8.305	8.281	-0.30%	4.961	13.511	47%	45%	49%
Ore E	2.36	3.72	8.303	8.290	-0.20%	4.960	13.512	32%	35%	43%
Ore F	2.32	3.67	8.304	8.287	-0.20%	4.959	13.508	41%	39%	43%
Ore G	2.32	3.80	8.298	8.282	-0.20%	4.957	13.499	43%	49%	51%
Ore H	2.32	3.91	8.298	8.280	-0.20%	4.956	13.500	42%	51%	51%
Ore I	2.32	3.74	8.299	8.288	-0.10%	4.951	13.490	41%	38%	51%
Ore J	2.31	3.87	8.302	8.277	-0.30%	4.961	13.508	46%	46%	49%
Ore K	2.35	3.66	8.303	8.293	-0.10%	4.958	13.507	35%	48%	50%
Ore L	2.32	3.91	8.290	8.275	-0.20%	4.951	13.487	44%	43%	52%
Ore N	2.36	3.69	8.294	8.293	0.00%	4.960	13.512	32%	36%	45%
Ore O	2.33	3.68	8.301	8.292	-0.10%	4.959	13.510	28%	36%	45%
Al ₂ O ₃ (JPCDS PDF 10-173) Lattice Parameters						4.758	12.991			
Fe ₂ O ₃ (JCPDS PDF 33-664) Lattice Parameters						5.036	13.749			
Cr ₂ O ₃ (JCPDS PDF 38-1479) Lattice Parameters						4.958	13.593			

¹ Normalised weight fraction between sesquioxide and spinel phase, excluding gangue phases

² Average area occupied by sesquioxide phase determined with ImageJ from SEM imaging, average of 5 measurements. Average EDS composition used in conjunction with XRD lattice parameters to calculate theoretical densities and convert the area percentage occupied by sesquioxide to mass percentage

³Equilibrium phase composition calculated in air at 1200°C with FactSage 8.0

Table S-IV: Molar cation proportions for oxidised spinel phase derived from SEM-EDS analyses, normalised to 4 oxygen atoms

	Ore A		Ore B		Ore C		Ore D		Ore E		Ore F		Ore G	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Cr	1.088	0.074	1.109	0.062	1.195	0.048	1.130	0.027	1.159	0.013	1.146	0.036	1.028	0.088
Σ Fe	0.578	0.112	0.511	0.095	0.501	0.099	0.420	0.021	0.384	0.015	0.542	0.060	0.506	0.065
Al	0.549	0.037	0.630	0.019	0.578	0.014	0.602	0.027	0.585	0.011	0.642	0.021	0.698	0.028
Mg	0.660	0.151	0.652	0.190	0.651	0.179	0.841	0.031	0.839	0.020	0.635	0.122	0.729	0.118
Ti	0.000	0.000	0.003	0.010	0.003	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum	2.874		2.905		2.929		2.993		2.967		2.965		2.961	
N	10		10		10		10		10		10		10	
$X_{\text{Fe}^{2+}=\text{n}_{\text{Fe}^{2+}}/\Sigma\text{n}_{\text{Fe}}}$	0.52		0.63		0.65		0.37		0.39		0.65		0.51	
Cr:Al	1.98	0.409	1.76	0.342	2.07	0.415	1.88	0.106	1.98	0.081	1.79	0.206	1.47	0.228
$\text{n}_{\text{Mg}^{2+}} + \text{n}_{\text{Fe}^{2+}}$	0.96	0.239	0.97	0.305	0.98	0.297	1.00	0.041	0.99	0.028	0.99	0.203	0.99	0.172
	Ore H		Ore I		Ore J		Ore K		Ore L		Ore N		Ore O	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Cr	1.092	0.064	1.179	0.012	1.134	0.108	1.170	0.017	1.047	0.024	1.175	0.066	1.107	0.020
Σ Fe	0.534	0.100	0.399	0.033	0.651	0.290	0.414	0.022	0.434	0.069	0.459	0.078	0.428	0.015
Al	0.656	0.042	0.604	0.016	0.586	0.063	0.581	0.015	0.681	0.012	0.581	0.013	0.595	0.016
Mg	0.679	0.181	0.868	0.032	0.647	0.241	0.802	0.028	0.797	0.081	0.703	0.166	0.832	0.016
Ti	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum	2.962		3.049		3.018		2.967		2.959		2.918		2.963	
N	10		10		10		10		10		10		10	
$X_{\text{Fe}^{2+}=\text{n}_{\text{Fe}^{2+}}/\Sigma\text{n}_{\text{Fe}}}$	0.58		0.37		0.55		0.45		0.44		0.59		0.36	
Cr:Al	1.66	0.326	1.95	0.161	1.93	0.881	2.01	0.112	1.54	0.248	2.02	0.360	1.86	0.073
$\text{n}_{\text{Mg}^{2+}} + \text{n}_{\text{Fe}^{2+}}$	0.99	0.283	1.02	0.049	1.01	0.449	0.99	0.042	0.99	0.121	0.97	0.249	0.99	0.023

Table S-V: Cation proportions for sesquioxide phase derived from SEM-EDS analyses, normalised to 3 oxygens

	Ore A		Ore B		Ore C		Ore D		Ore E		Ore F		Ore G	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Cr	0.903	0.007	0.884	0.016	0.903	0.012	0.928	0.016	0.919	0.010	0.876	0.021	0.829	0.014
Al	0.471	0.018	0.467	0.027	0.450	0.009	0.477	0.009	0.466	0.015	0.491	0.026	0.525	0.014
Fe	0.584	0.019	0.620	0.034	0.615	0.046	0.607	0.015	0.609	0.023	0.632	0.022	0.622	0.019
Ti			0.002	0.008										
Mg			0.026	0.034	0.031	0.081	0.006	0.013	0.003	0.008	0.028	0.042	0.009	0.016
Sum	1.957		2.000		1.999		2.018		1.997		2.027		1.986	
N	10		10		10		10		10		10		10	
Cr:Al	1.92	0.076	1.89	0.113	2.00	0.048	1.94	0.049	1.97	0.065	1.79	0.104	1.58	0.051
	Ore H		Ore I		Ore J		Ore K		Ore L		Ore N		Ore O	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Cr	0.860	0.020	0.954	0.008	0.864	0.043	0.961	0.022	0.839	0.007	0.935	0.053	0.928	0.032
Al	0.460	0.040	0.542	0.021	0.445	0.033	0.454	0.016	0.551	0.009	0.454	0.036	0.475	0.024
Fe	0.649	0.054	0.563	0.023	0.585	0.088	0.612	0.034	0.640	0.011	0.470	0.068	0.568	0.032
Ti					0.006	0.013					0.007	0.011	0.004	0.013
Mg	0.049	0.079			0.120	0.142	0.020	0.056			0.162	0.196		
Sum	2.017		2.059		2.020		2.047		2.031		2.029		1.975	
N	10		10		10		10		10		10		10	
Cr:Al	1.87	0.170	1.76	0.071	1.94	0.174	2.12	0.088	1.52	0.029	2.06	0.201	1.96	0.120