SUPPLEMENTAL ONLINE MATERIALS

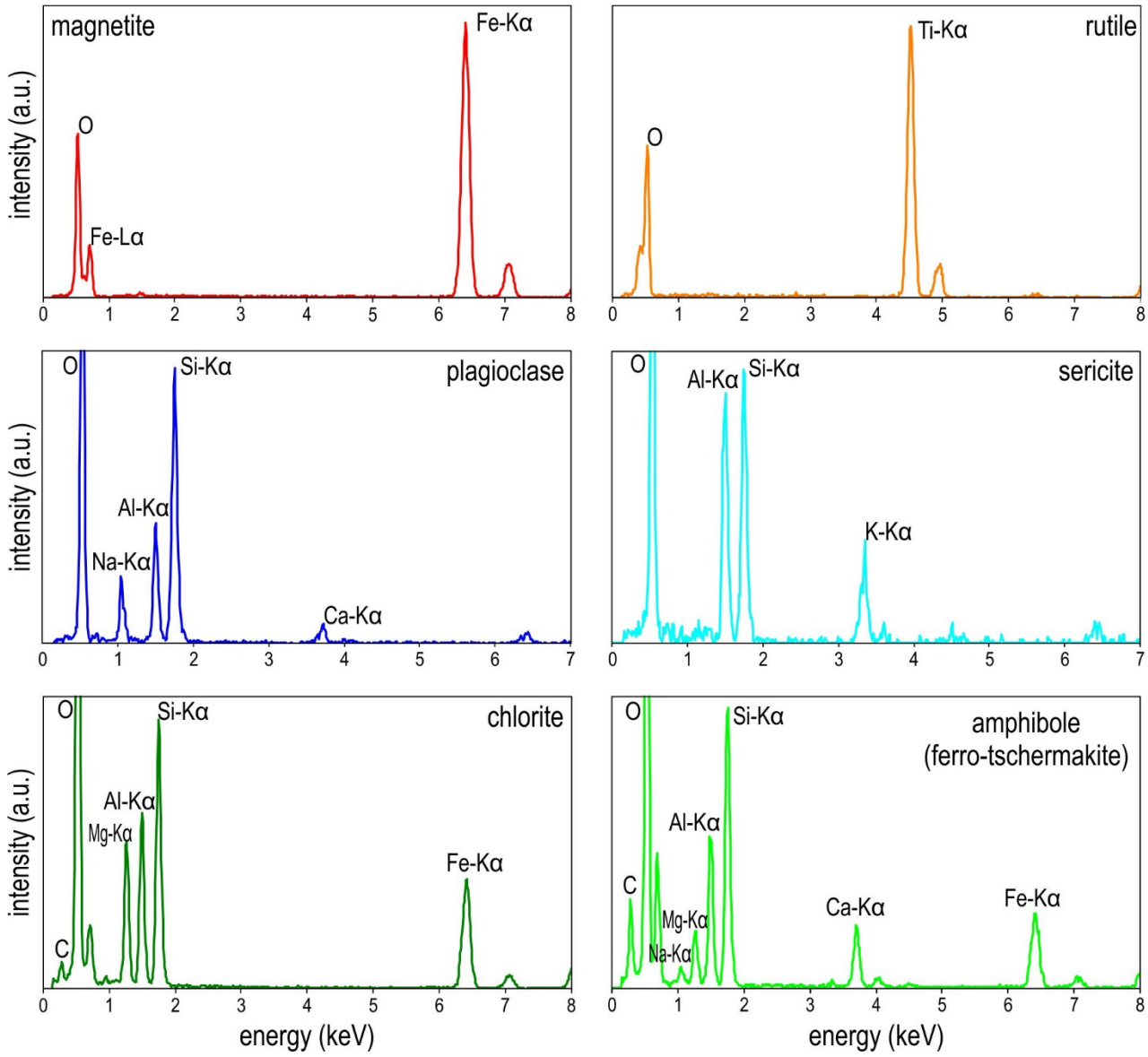

Figure A1. Representative EDX spectra for host magnetite and mineral inclusions identified as marked.

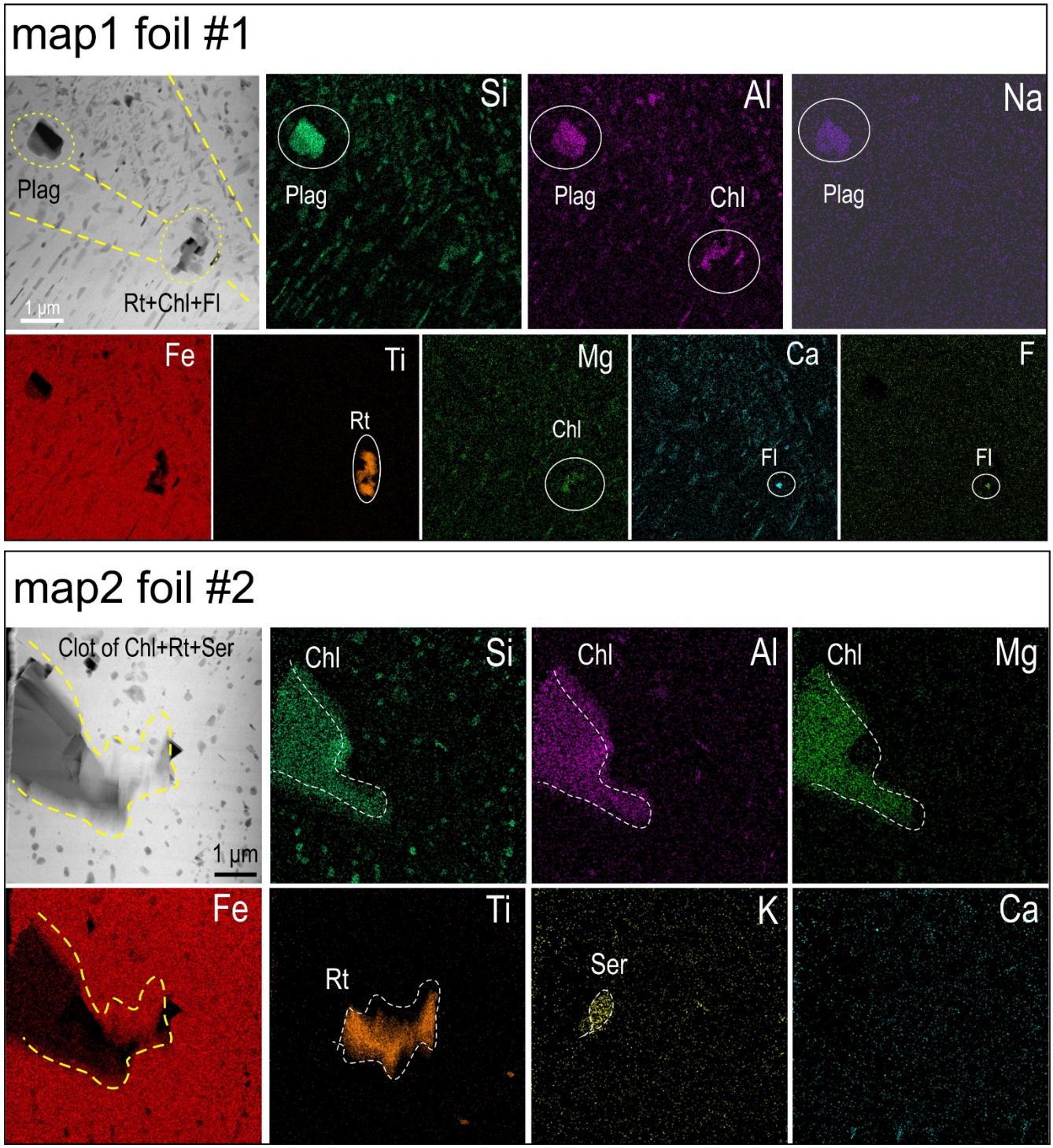

Figure A2. STEM EDX element maps of areas in magnetite showing the presence of coarser inclusions and clots. Abbreviations: Chl–chlorite, Fl–fluorite, Rt–rutile, Ser–sericite.

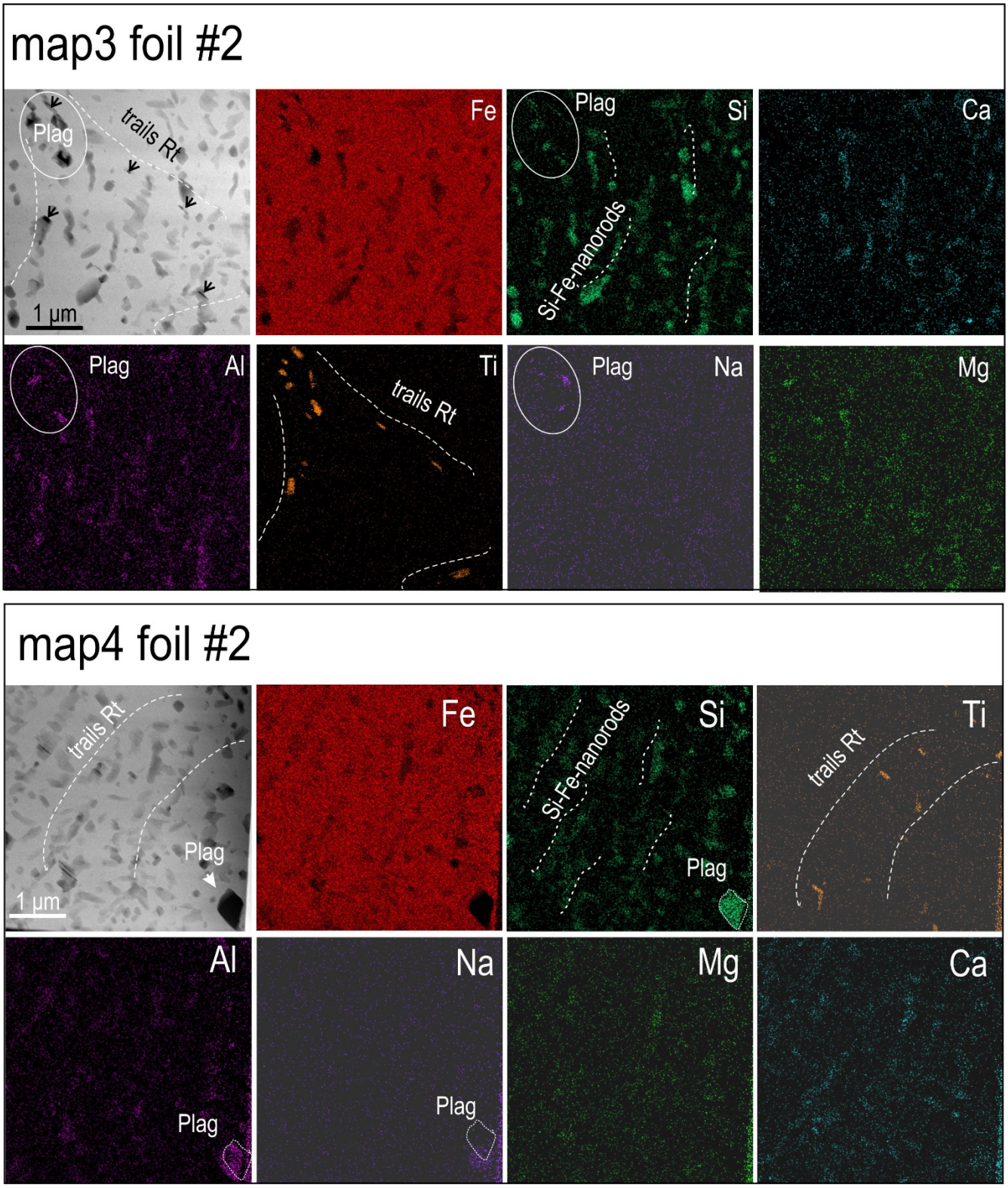

Figure A3. STEM EDX element maps of domains in magnetite containing Si-Fe-nanorods and trails of rutile. Abbreviations: Plag–plagioclase, Rt–rutile.

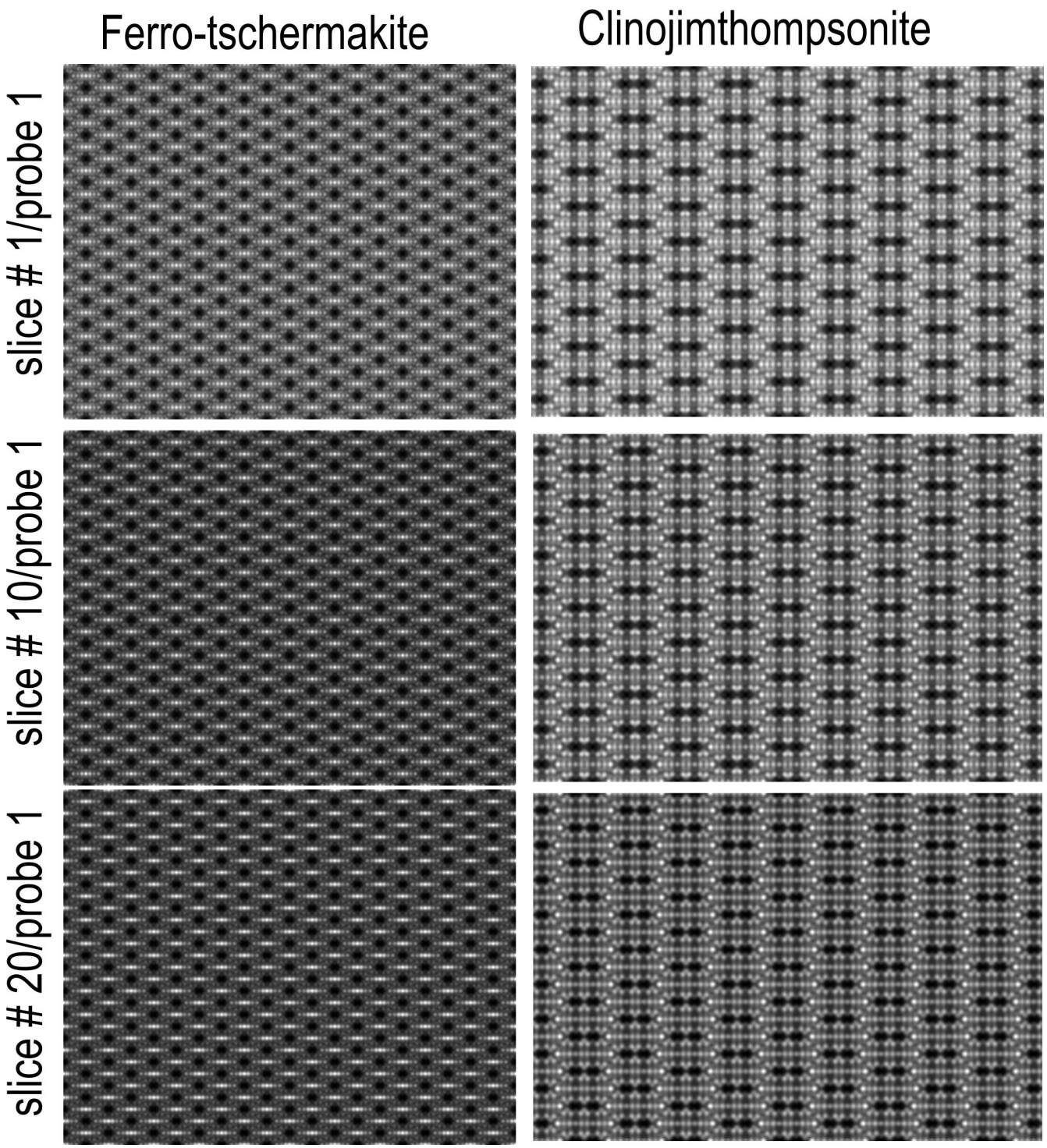

Figure A4. HAADF STEM simulations using WHREM software with default setting from the STEM module. Unlike in conventional BF TEM imaging, the STEM simulations do not change significantly with parameters such as thickness (slice number) and defocus. A nominal value for probe size at 1 nm is used here, but the models do not change significantly with probe size, except for a smearing effect. A good fit between simulations and images is obtained if the specimen is perfectly tilted on a zone axis of interest and the no/little stigmatism is present (so the image is formed by dots rather than lines or fringes).

Supplementary Material Table A1. EPMA data for magnetite

Concentration	Transect#1								Transect#2					
wt%	*Mt1-1	*Mt1-2	*Mt1-3	*Mt1-4	*Mt1-5	*Mt1-6	Mt1-7	Mt1-8	Mt2-1	Mt2-2	*Mt2-3	*Mt2-4	*Mt2-5	*Mt2-6
MgO	0.34	0.23	0.57	0.47	0.55	0.28	<mdl	0.01	<mdl	<mdl	0.25	0.44	0.36	0.54
CaO	0.33	0.30	0.33	0.38	0.70	0.56	<mdl	<mdl	0.02	0.02	0.26	0.41	0.38	0.42
MnO	<mdl	0.04	<mdl	<mdl	0.05	<mdl	0.04	<mdl	<mdl	<mdl	<mdl	0.05	<mdl	0.05
CoO	0.05	0.04	0.05	0.05	0.03	0.04	0.04	0.05	0.03	<mdl	0.03	0.04	0.04	0.06
NiO	<mdl	<mdl	<mdl	0.02	0.02	<mdl	0.02	<mdl	<mdl	0.02	0.03	<mdl	0.02	0.02
ZnO	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	0.03	<mdl	<mdl	0.02	<mdl	<mdl
PbO	<mdl	<mdl	0.02	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	0.03	<mdl
Al_2O_3	1.65	0.81	1.33	1.27	2.33	1.95	0.06	0.11	0.11	0.09	0.88	1.11	0.91	1.66
V_2O_3	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05
FeO_{total}	88.84	90.33	88.92	88.91	85.61	86.10	93.61	92.84	92.87	93.44	90.26	89.04	88.40	87.21
SiO_2	2.57	1.90	2.48	2.52	4.39	3.67	<mdl	0.08	0.16	0.10	2.36	2.44	2.35	3.99
TiO_2	0.11	0.11	0.40	0.14	0.16	0.19	0.04	0.07	0.24	0.07	0.08	0.18	1.24	0.13
UO_2	<mdl	0.02	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	<mdl	0.04
Sum	100.05	100.21	100.29	99.96	99.47	98.54	100.82	100.09	100.35	100.69	100.49	99.98	99.78	99.95
Atoms per formula unit (a.p.f.u.) based on 32 oxygen														
Mg	0.153	0.105	0.253	0.209	0.246	0.125	0.000	0.005	0.000	0.000	0.114	0.197	0.163	0.241
Ca	0.106	0.098	0.107	0.123	0.223	0.183	0.000	0.000	0.006	0.006	0.084	0.132	0.123	0.135
Mn	0.000	0.011	0.000	0.000	0.013	0.000	0.012	0.000	0.000	0.000	0.000	0.014	0.000	0.012
Fe^{2+}	8.000	8.000	8.000	8.000	8.000	8.000	7.983	8.025	8.082	8.035	8.000	8.000	8.000	8.000
Co	0.011	0.010	0.011	0.013	0.008	0.009	0.010	0.012	0.008	0.000	0.008	0.009	0.009	0.013
Ni	0.000	0.000	0.000	0.004	0.004	0.000	0.006	0.000	0.000	0.005	0.006	0.000	0.004	0.004
Zn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.006	0.000	0.000
Pb	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000
$\sum Me^{2+}$	8.270	8.224	8.373	8.349	8.494	8.317	8.011	8.042	8.103	8.046	8.212	8.358	8.302	8.405
Al	0.585	0.288	0.472	0.452	0.818	0.698	0.023	0.040	0.040	0.031	0.311	0.394	0.324	0.585
V	0.012	0.013	0.012	0.011	0.011	0.013	0.013	0.012	0.012	0.012	0.013	0.012	0.010	0.012
Fe^{3+}	14.394	14.915	14.359	14.448	13.427	13.909	15.944	15.863	15.739	15.865	14.792	14.507	14.447	13.862
$\sum Me^{3+}$	14.991	15.216	14.843	14.911	14.256	14.620	15.980	15.915	15.791	15.908	15.116	14.913	14.781	14.459
Si	0.773	0.576	0.744	0.758	1.307	1.113	0.000	0.026	0.048	0.031	0.710	0.735	0.711	1.192
Ti	0.024	0.024	0.091	0.031	0.037	0.042	0.010	0.017	0.056	0.015	0.019	0.041	0.282	0.030
U	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
$\sum Me^{4+}$	0.797	0.601	0.835	0.789	1.344	1.156	0.010	0.042	0.104	0.046	0.729	0.776	0.993	1.224
$\sum$ Me	24.06	24.04	24.05	24.05	24.09	24.09	24.00	24.00	24.00	24.00	24.06	24.05	24.08	24.09

*Excess Fe^{2+} over 8 a.p.f.u in the range 0.379-0.85 a.p.f.u was added to Fe^{3+} following conversion. <mdl: less than minimum limit of detection.

Quantitative EPMA were obtained using a CAMECA SX-Five Electron Probe Microanalyzer (EPMA), equipped with 5 wavelength-dispersive spectrometers (WDS) (Adelaide Microscopy, The University of Adelaide). The instrument was operated at a constant accelerating voltage of 15 keV and variable beam current (see below). A constant beam spot-size of ~1 µm was utilized for the measurements. Individual analytical conditions for each analyzed element are listed below. Calibration and data reduction were conducted using the software package 'Probe for EPMA' (Donovan et al. 2016).

Element	Line	Current (nA)	Crystal	Standard	Peak count (s)	Bkgd count (s)	Ave. mdl (wt%)
Al	Kα	20	TAP	Astimex Plagioclase An65	20	10	0.012
Ca	Kα	20	LPET	Titanite	20	10	0.011
Co	Kα	100	LLIF	Cobaltite	50	25	0.012
Fe	Kα	20	LLIF	P&H Specularite	20	10	0.03
Mg	Kα	100	TAP	Astimex Almandine	50	25	0.004
Mn	Kα	20	LLIF	P&H Rhodonite	20	10	0.028
Ni	Kα	100	LLIF	Astimex Pentlandite	35	15	0.013
Pb	Mα	100	LPET	K227 Pb glass	20	30/40	0.011
Si	Kα	20	TAP	Astimex Plagioclase An65	20	10	0.013
Ti	Kα	20	LPET	Titanite	50	25	0.008
U	Mβ	100	LPET	DAS UO2	20	30/40	0.017
V	Kα	100	LLIF	Astimex Vanadium metal	35	20	0.007
Zn	Kα	100	LLIF	Astimex Willemite	50	25	0.019

Donovan JJ, Singer JW, Armstrong JT (2016) A new EPMA method for fast trace element analysis in simple matrices. Am Mineral 101, 1839–1853. doi: 10.2138/am-2016-5628