

Supplementary material

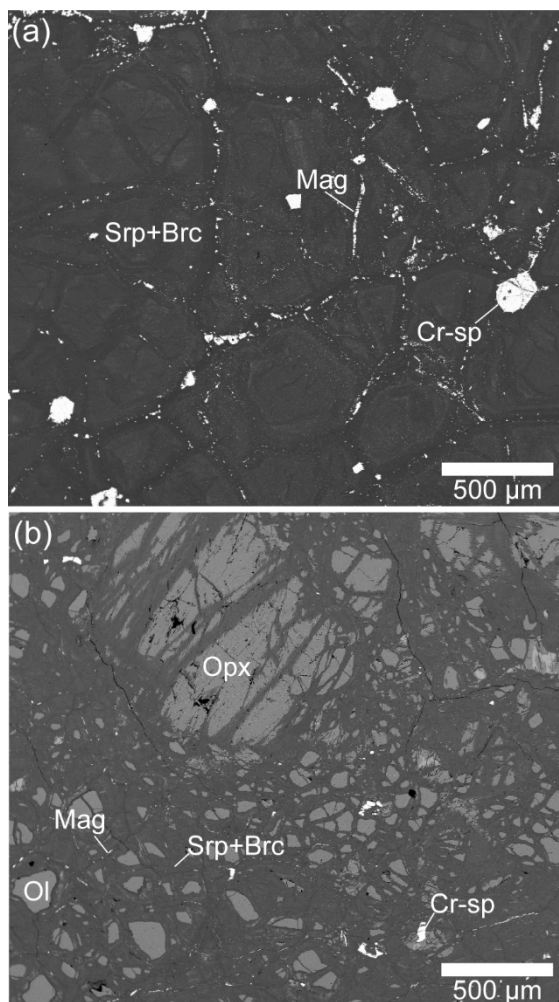


Figure S1. Backscattered electron images of (a) serpentinized dunite (CM2B-16Z2-30-35) and (b) partly serpentinized harzburgite (CM2B-106Z3-16-21). Srp: serpentine, Bruc: brucite, Mag: magnetite, Cr-sp: Cr-spinel, Ol: olivine, Opx: orthopyroxene.

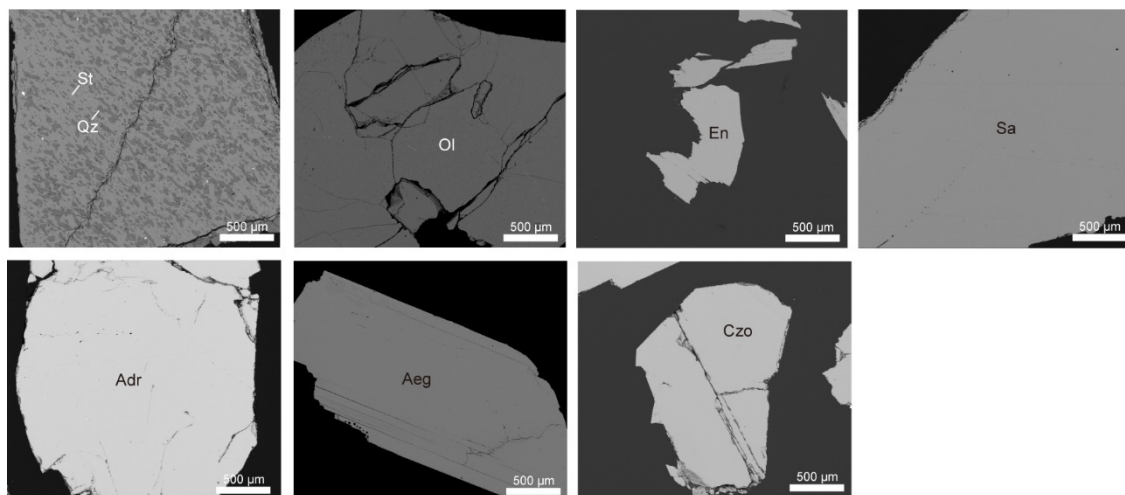


Figure S2. Backscattered electron images of mineral standards. Impurities (quartz) were only found in the staurolite. St: staurolite, Qz: quartz, Ol: olivine, En: enstatite, Sa: sanidine, Adr: andradite, Aeg: aegirine, Czo: clinozoisite.

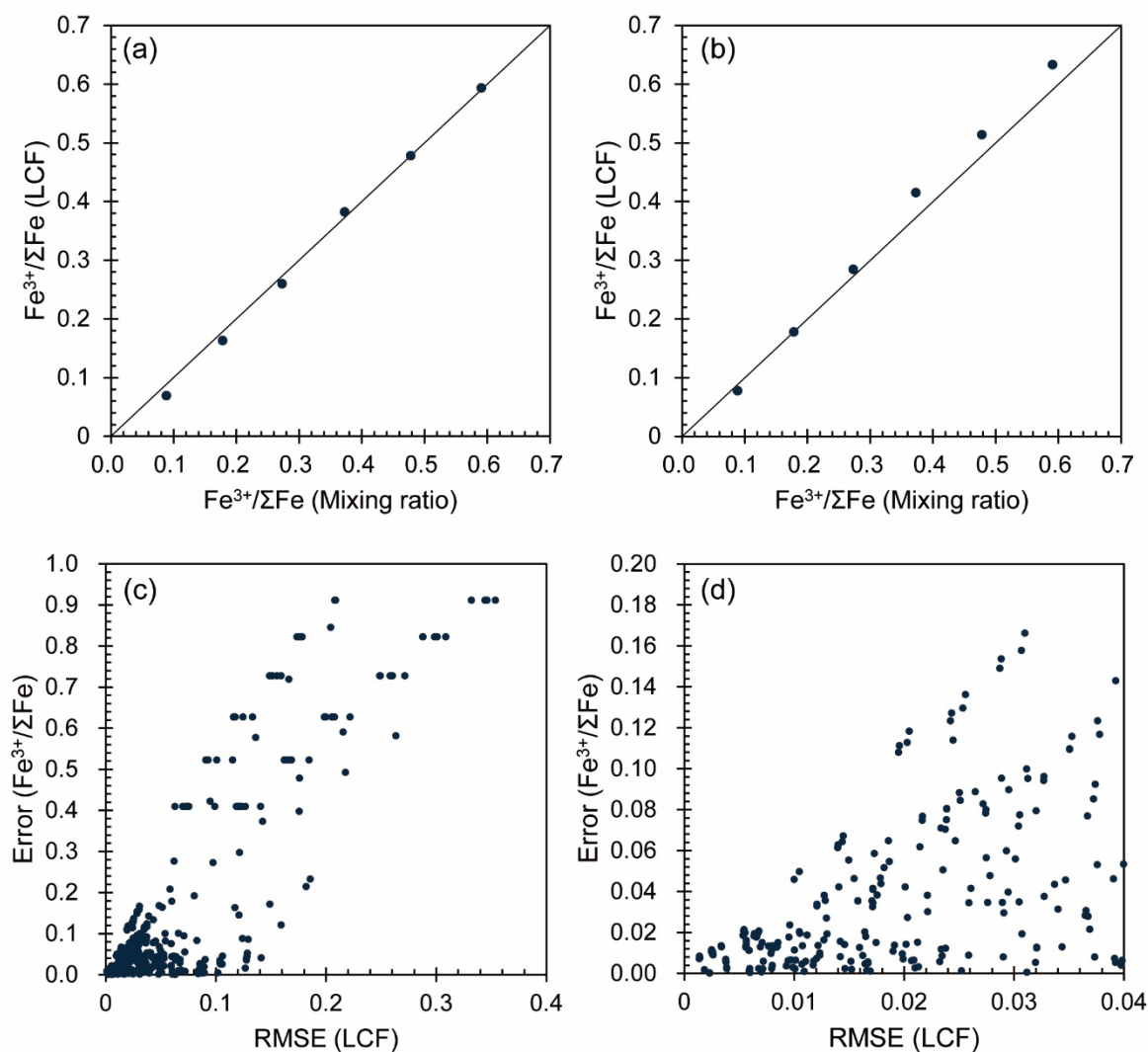


Figure S3. $\text{Fe}^{3+}/\Sigma\text{Fe}$ ratios of olivine–magnetite mixtures estimated using linear combination fitting using olivine and magnetite (a), and olivine, enstatite, aegirine, andradite, and sanidine standards (b). The expected $\text{Fe}^{3+}/\Sigma\text{Fe}$ ratios are calculated from the mixing ratio between olivine and magnetite. (c) Root mean squared error (RMSE) of the linear combination fitting and estimation error for the $\text{Fe}^{3+}/\Sigma\text{Fe}$ ratios. (d) Magnified view of (c) for data with an RMSE of 0–0.04 and error of 0–0.2.

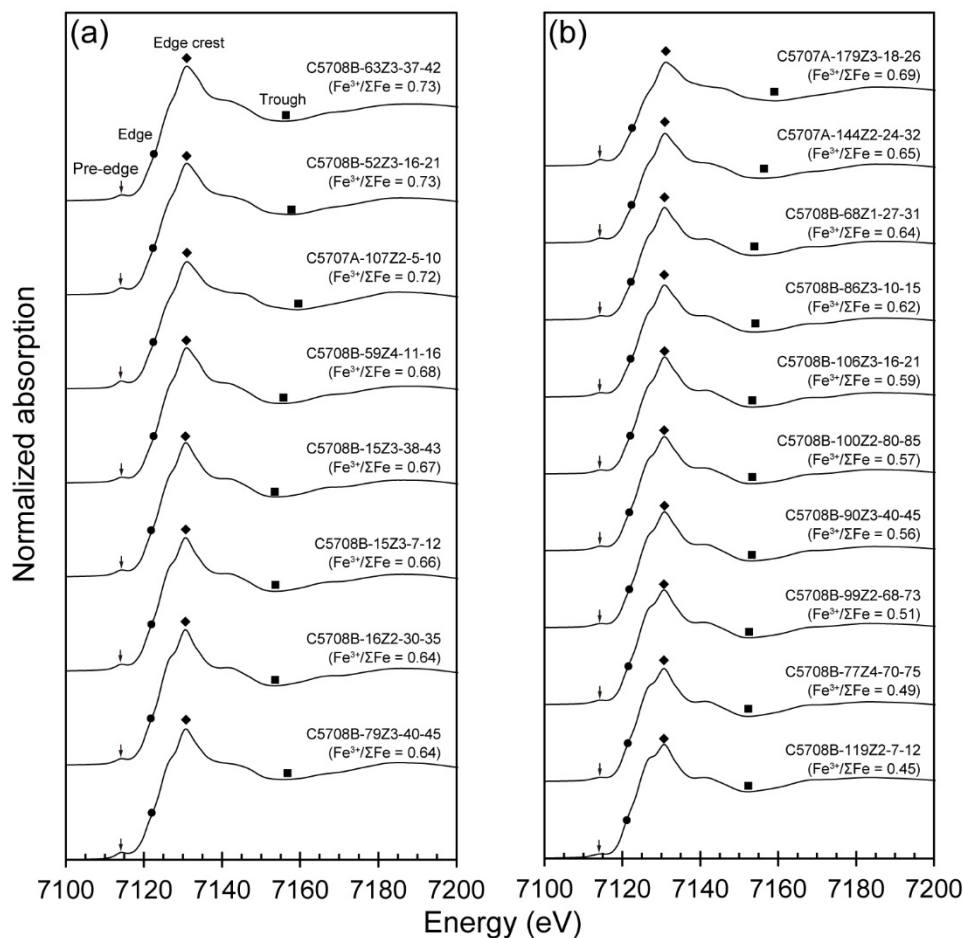


Figure S4. XANES spectra from (a) serpentinized dunites and (b) serpentinized harzburgites. $\text{Fe}^{3+}/\Sigma\text{Fe}$ ratios were determined by titration. Arrows indicate the pre-edge peaks, circles indicate the edges, diamonds represent the edge crests, and squares represent the troughs.

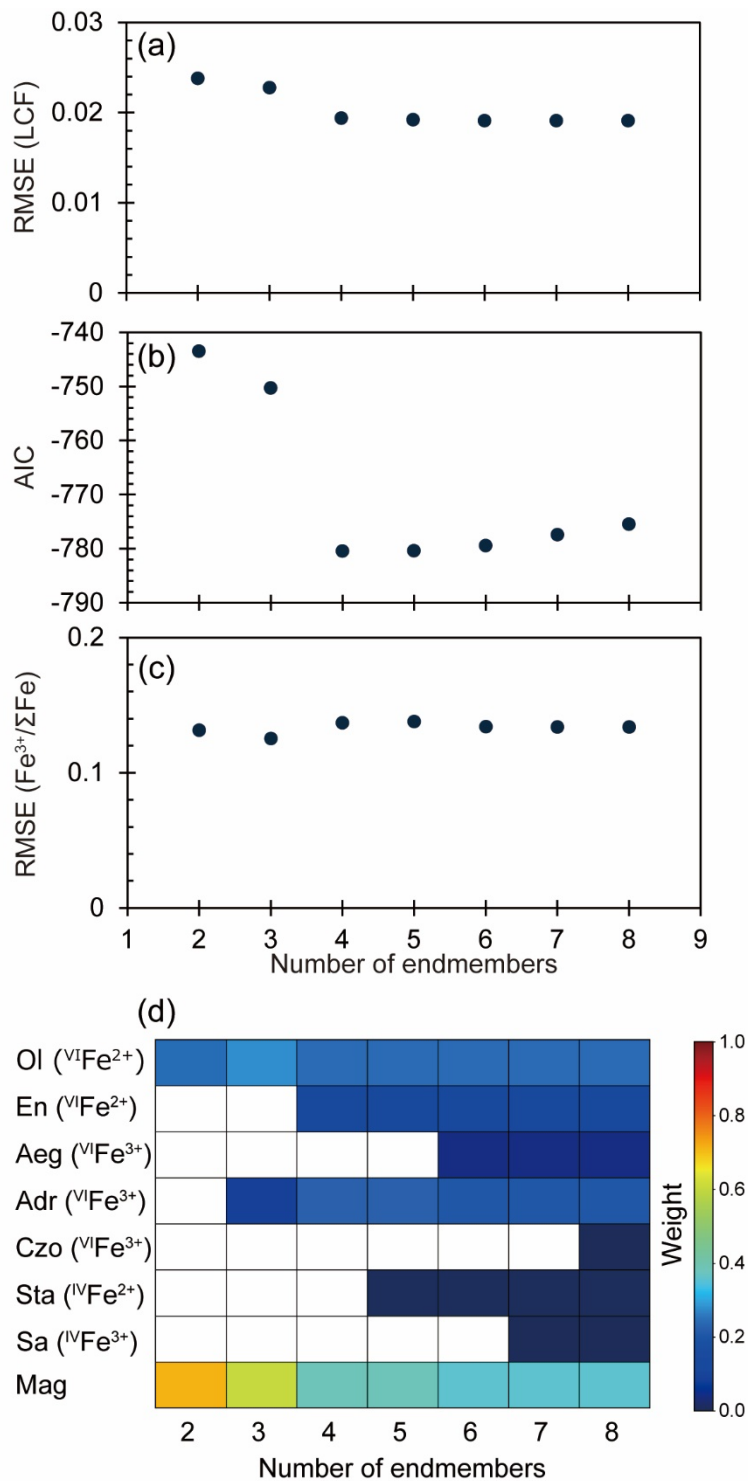


Figure S5. Number of endmembers vs. (a) the root mean squared error (RMSE), (b)

Akaike's information criterion (AIC), and (c) the RMSE of the $\text{Fe}^{3+}/\Sigma\text{Fe}$ ratio of serpentinites estimated using linear combination fitting, and (d) the weight of endmembers used in linear combination fitting. The color in (d) indicates the weight of each standard sample used. Ol: olivine, En: enstatite, Aeg: aegirine, Adr: andradite, Czo: clinozoisite, St: staurolite, Sa: sanidine, Mag: magnetite.

Table S1. List of the mineral standards.

Mineral	Origin	CN	Fe ³⁺ /ΣFe
Olivine	China, unknown locality	6	0
Enstatite	Tanzania, unknown locality	6	0
Andradite	Tenkawa-mura, Yoshino-gun, Nara, Japan	6	1
Aegirine	Mt. Malosa, Zomba, Malawi	6	1
Clinozoisite	Tormiq Valley, Haramosh Mts., Roundu District, Gilgit-Baltistan, Pakistan	6	1
Staurolite	Madagascar, unknown locality	4	0
Sanidine	Itongay, Mahasoia East Commune, Betroka District, Anosy Region, Tulear Province, Madagascar	4	1
Magnetite	FUJIFILM Wako Pure Chemical Corporation	4, 6	0.67

CN: coordination number.

Table S2. Mean major-element compositions determined by electron microprobe

analysis (wt%), 1 σ uncertainties, and the calculated structural formula of each mineral.

<i>N</i>	Staurolite 20		Olivine 12		Enstatite 14		Sanidine 15		Andradite 12		Aegirine 6		Clinzoisite 40	
	Av	1 σ	Av	1 σ	Av	1 σ	Av	1 σ	Av	1 σ	Av	1 σ	Av	1 σ
wt%														
SiO ₂	27.42	0.28	40.60	0.23	57.36	0.45	64.54	0.29	35.13	0.29	52.67	0.41	38.60	0.25
TiO ₂	0.64	0.05	0.01	0.02	0.05	0.03	0.02	0.02	0.03	0.02	1.43	0.03	0.14	0.06
Al ₂ O ₃	54.35	0.33	0.02	0.03	0.12	0.08	17.35	0.26	0.03	0.04	0.29	0.07	28.00	0.39
Fe ₂ O ₃ *	-		-		-		1.22	0.12	31.20	0.40	31.44	0.72	7.51	0.48
FeO*	14.16	0.43	9.70	0.23	7.64	1.50	-		-		-		-	
MnO	0.10	0.06	0.12	0.07	0.24	0.05	0.03	0.04	0.35	0.06	0.48	0.07	0.13	0.05
MgO	1.88	0.08	49.64	0.18	34.15	1.15	0.04	0.04	0.10	0.08	0.02	0.02	0.08	0.05
CaO	0.02	0.01	0.07	0.01	0.21	0.06	0.00	0.00	33.04	0.15	0.21	0.04	23.81	0.13
Na ₂ O	0.03	0.05	0.02	0.03	0.07	0.07	0.16	0.08	0.07	0.07	14.45	0.38	0.05	0.06
K ₂ O	0.00	0.01	0.00	0.01	0.01	0.01	16.94	0.35	0.00	0.00	0.00	0.01	0.01	0.01
Cr ₂ O ₃	0.02	0.02	0.02	0.03	0.04	0.03	0.01	0.02	0.02	0.04	0.02	0.03	0.01	0.02
Total	98.61	0.60	100.20	0.21	99.89	0.44	100.31	0.36	99.97	0.33	101.01	0.31	98.35	0.49
Oxygen	23.50		4.00		6.00		32.00		12.00		6.00		12.50	
Si	3.87		0.99		1.99		11.99		2.98		2.00		2.99	
Ti	0.07		0.00		0.00		0.00		0.00		0.04		0.01	
Al	9.03		0.00		0.01		3.80		0.00		0.01		2.56	
Fe ³⁺	-		-		-		0.17		1.99		0.90		0.44	
Fe ²⁺	1.67		0.20		0.22		-		-		-		-	
Mn	0.01		0.00		0.01		0.01		0.03		0.02		0.01	
Mg	0.39		1.81		1.77		0.01		0.01		0.00		0.01	
Ca	0.00		0.00		0.01		0.00		3.00		0.01		1.98	
Na	0.01		0.00		0.00		0.06		0.01		1.06		0.01	
K	0.00		0.00		0.00		4.02		0.00		0.00		0.00	
Cr	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
Total	15.05		3.01		4.01		20.06		8.03		4.04		8.00	

*Fe is calculated as FeO for staurolite, olivine, and enstatite, and Fe₂O₃ for sanidine,

andradite, aegirine, and epidote.

Table S3. Pre-edge characteristics (centroid energy and integrated pre-edge intensity)

for standard minerals for pre-edge method and olivine-magnetite mixtures.

Sample	Centroid energy (eV)	Integrated pre-edge intensity
Ol	7112.9	0.08
Adr	7114.4	0.08
Sa	7114.3	0.33
Ol-Mag (0.09)	7113.1	0.09
Ol-Mag (0.18)	7113.3	0.10
Ol-Mag (0.27)	7113.7	0.14
Ol-Mag (0.37)	7113.9	0.14
Ol-Mag (0.48)	7114.1	0.17
Ol-Mag (0.59)	7114.1	0.18
Mag	7114.2	0.18

Ol = olivine, Adr = andradite, Sa = sanidine, Mag = magnetite, Ol-Mag = olivine-magnetite mixture (the number indicates $\text{Fe}^{3+}/\Sigma \text{Fe}$ ratio).

Table S4. Total Fe and FeO content (wt%), and $\text{Fe}^{3+}/\Sigma\text{Fe}$ ratios of olivine and magnetite determined by titration.

Sample name	Fe_2O_3^*	FeO	$\text{Fe}^{3+}/\Sigma\text{Fe}$
Olivine	10.8 **	8.2	0.15
Magnetite	103.7 ***	20.5	0.78

*Total Fe calculated as Fe_2O_3 . **From EPMA data. ***From theoretical structural formula of magnetite (Fe_3O_4).