# **Appendix DR1**

This file contains additional information accompanying the manuscript "Mid-Cretaceous Hawaiian tholeiites preserved in Kamchatka" by M. Portnyagin, D. Savelyev, K. Hoernle, F. Hauff and D. Garbe-Schönberg (Geology, 2008).

#### Analytical and experimental techniques

#### Major and trace elements in whole rocks

Rock chips were ground to flour in an agate mortar and agate mill. Major element analyses were obtained by X-ray fluorescence spectroscopy (XRF) on fused beads using Phillips X 'Unique PW1480 spectrometer at the IFM-Geomar (Kiel). International rock standards JB-3, JB-2 and JA-2 were analyzed with the sample series. Volatile contents ( $H_2O$  and  $CO_2$ ) were determined on a Rosemount infrared photometer.

Concentrations of trace elements were determined by ICP mass spectrometry after pressurized HF-aqua regia digestion of approximately 100 mg pulverized sample, made up to a solute on with < 0.1 % total dissolved solids in sub-boiled 2 % (v/v) nitric acid. Prior to analysis, sample digestion solutions were 10-fold diluted and spiked with 5 ng/ml indium (In) and rhenium (Re) for internal standardization. The instrument was calibrated using aqueous multi-element calibration standards without further matrix matching. All measurements were done using an Agilent 7500c ICP-MS instrument under standard operating conditions with plasma shield on, but no gas in the octopole reaction cell. Sample solution was introduced using a self-aspirating PFA micro-nebulizer (100 µl/min sample uptake) in combination with a standard Scott-type spray chamber maintained at 4 °C. The analytical results represent averages of 3 replicate measurements after subtraction of a laboratory reagent blank. For analytical quality control procedural blanks ("Blank") and international reference standards were prepared and analyzed along with the sample series. Results for the international rock standard BHVO-2 (Hawaiian Basalt, both from US Geol. Survey) are reported in the Table DR2. Standards were digested in duplicate, yielding differences in the results well below 1-3 % rel. for all elements. Instrument stability was monitored by re-analyzing one sample every 11 samples, and precision as calculated from 6 replicate analyses covering 27 hours was < 1-2 % RSD for all elements.

### Sr-Nd-Pb isotope ratios in whole rocks

Sample dissolution and element chromatography were carried out at the Leibniz Institute of Marine Sciences IFM-GEOMAR in Kiel (Germany) in Class 1000 clean rooms, equipped with Class 100 laminar flow hoods. All reagents used were either double distilled in a PicoTrace Teflon distillery (HCl and HNO<sub>3</sub>) or certified ultra pure HF and HBr acids from SEASTAR<sup>©</sup>. An ELGA<sup>©</sup> purifying system provided 18.2M $\Omega$  water. Sr-Nd-Pb isotope analyses were carried out on whole rock chips leached in 2N HCl at 70°C for 30 minutes and rinsed 3 times with 18.2M $\Omega$  water prior to dissolution. About 200mg of

sample were weighed into a Teflon beaker and then dissolved for 2 days in a 5:1 mixture of HF and HNO<sub>3</sub> at 150°C. The ion chromatography followed established standard procedures. These include a two-pass Pb separation and clean-up using 100 µl Teflon micro-columns filled with BIORAD<sup>©</sup> AG 1x8 (100-200 mesh) resin that is equilibrated with 1M HBr for highest Pb retention and from which Pb is released with 1ml of 6N HCl. The sample matrix collected during Pb chromatography was then loaded in 2.5 NHCl onto 6ml quartz glass columns filled with BIORAD<sup>©</sup> AG50W-X8 (100-200 mesh) resin to separate Sr. The rare earth elements (REE's) are obtained in 6ml 6N HCl at the final washout of the Sr columns. The REE's are then loaded in 0.25N HCl onto 4ml quartz glass columns filled with EICHROM  $^{\odot}$  Ln-Spec resin (100-150  $\mu m$ ) to obtain the Nd fraction. Isotopic ratios were determined by thermal ionization mass spectrometry (TIMS) at IFM-GEOMAR on a TRITON (Nd) and MAT262 RPQ<sup>2+</sup> TIMS (Sr-Pb). Both instruments operate in static multi-collection mode. Sr and Nd isotopic ratios are normalized within each run to  ${}^{86}$ Sr/ ${}^{88}$ Sr = 0.1194 and  ${}^{146}$ Nd/ ${}^{144}$ Nd = 0.7219 respectively and all errors are reported as 2 sigma of the mean. Reference material measured along with the samples were normalized and gave  ${}^{87}$ Sr/ ${}^{86}$ Sr = 0.710250 ± 0.000010 (n=37) for NBS987 and  $^{143}$ Nd/ $^{144}$ Nd = 0.511850  $\pm$  0.000007 (N=32) for La Jolla. Sr-Nd replicate analyses of sample D542-3 were within the external errors of the reference material. The long-term reproducibility of NBS 981 (n = 197) is  $^{206}$ Pb/ $^{204}$ Pb =  $16.899 \pm 0.008$ ,  ${}^{207}\text{Pb}/{}^{204}\text{Pb} = 15.437 \pm 0.009$ ,  ${}^{208}\text{Pb}/{}^{204}\text{Pb} = 36.525 \pm 0.029$ . Pb isotope ratios are normalized to NBS 981 values of (Todt et al., 1996). Pb replicate analyses of sample D542-3 analyzed in one series with samples reported here is better than 0.02%/amu. Total chemistry blanks are <50 pg for Sr-Nd and Pb and thus are considered negligible. Measured present-day isotope ratios were back-corrected for 100 Ma radioactive decay using parent-daughter element ratios in whole rocks as analyzed by ICPMS (Table DR1 and DR2).

The main conclusions of the paper are based on Nd and Pb isotopes, for which mild acid leaching of rock chips (to remove possible surface contamination) is the method of choice as it does not remove or fractionate Pb in the sample. According to our experience with material of similar composition and age (Hauff et al 2000a, b, 2003), leaching of powders at higher temperature and stronger acids leads to Pb removal (up to 90%) and fractionation of ingrown and primary Pb isotopes, resulting in large uncertainty of age-corrected isotope ratios. This was the main reason why this study was carried on mildly leached chips rather than on strongly leached powders. Mild leaching did not eliminate the seawater signal in <sup>87</sup>Sr/<sup>86</sup>Sr ratios, and therefore Sr isotopes were excluded from discussion of the primary isotope characteristics of the rocks. Also our experience shows that strong acid leaching does not always remove the seawater signal in <sup>87</sup>Sr/<sup>86</sup>Sr ratios (Hauff et al. 2000a,b), resulting in misleading data. In any case, analysis of fresh rocks or mineral separates provides more robust results on initial Sr isotope composition than analysis of strongly leached samples, whereas analysis of mildy leached rock chips was shown to be appropriate technique to obtain primary Pb and Nd isotope ratios.

### Melt inclusion study

Compositions of melt inclusions were studied in accessory chromium spinel. Due to poor quenching upon eruption, the inclusions appear partly recrystallized and required experimental homogenization prior to analytical studies. The homogenization was carried out using a heating stage for microthermometrical studies operating at ambient pressure in the atmosphere of pure helium (Sobolev and Slutskii, 1984). In each of ten runs, five to seven grains of spinel separated from 0.25-0.5 mm fraction of crushed rock, were loaded on an olivine platelet inside a cylindrical heating element. The grains were heated to 1250°C within 5 minutes and then quenched by simultaneously switching off the power supply and opening gas flow through the chamber. Quenched spinel grains were mounted in epoxy and polished to expose melt inclusions in the inner parts of the crystals.

After experimental reheating, inclusions were completely homogenized and consisted of glass, which was analyzed for major elements by electron probe. A subset of inclusions of suitably large size (>30 micron) was analyzed by ion probe for a wide range of trace elements. Major elements in glasses of melt inclusions and in host spinel were analyzed by Cameca SX50 electron microprobe at the Leibniz Institute of Marine Sciences IFM-GEOMAR in Kiel (Germany) at 15 kV. Glasses were analyzed at 10 nA in scanning mode over 5 to 10  $\mu$ m areas. Presented analyses are averaged from 3 to 5 measurements for every inclusion. Host spinel was analyzed at 30 nA with focused beam in 3 points around inclusion. Synthetic standards from Cameca and natural minerals and glasses (Jarosewich et al., 1980) were used for calibration. Counting time was 20/10 s (peak/background) for major elements, 60/30 s for K, S, Cl and P. Basaltic glass USNM 111240/52 VG-2 and Chromite USNM 117075 were used as monitor samples in routine measurements of glasses and spinel, respectively. Concentrations of trace elements in melt inclusions were determined by secondary ion mass-spectrometry (SIMS) using a CAMECA ims4f at the Institute of Microelectronics and Informatics of the Russian Academy of Sciences in Yaroslavl' (Russia). Details of the analytical procedure are given in (Portnyagin et al., 2007; Sobolev et al., 2000). Accuracy and precision were estimated to be better than 10 % for all elements with concentrations above 1 ppm and 10 to 30% for concentrations 0.1-1 ppm. Detection limit for most trace elements is estimated at 0.01-0.005 ppm. Detection limit for Nb was estimated to be ~0.5 ppm due mass superposition of <sup>93</sup>Nb<sup>+</sup> with HCaCr<sup>+</sup> (?) molecule, which was not resolved at operating mass resolution of spectrometer ( $M/\Delta M = 300$ ). Glass KL-2G (Jochum, 2006) and NIST-610 (Rocholl et al., 1997) were used as daily monitors for trace element analyses. Reported concentrations (Table DR3) were corrected for possible trapping of host spinel during SIMS analyses, which was difficult to avoid for inclusions  $\leq 40$ microns in size. Correction was done assuming negligible concentrations of incompatible elements in spinel (except V and Ti).

It was shown in several studies that compositions of melt inclusions in spinel can be significantly compromised by later processes of cation exchange with host spinel (e.g., Zlobin et al., 1991; Shimizu et al., 2001). The signs of this process are also evident from the compositions of melt inclusions studied here as is suggested by strong correlations between MgO and FeO (positive) and MgO and Al<sub>2</sub>O<sub>3</sub> (negative) in the melt inclusions trapped in spinel with a narrow compositional range (Table DR3). The reequilibration primarily affected elements which are major constituents of the host spinel (Mg, Fe, Al, Cr), causing MgO and FeO content in melt to decrease and Al<sub>2</sub>O<sub>3</sub> content to increase with increasing extent of re-equilibration. Major and trace elements incompatible in host spinel were not affected by the re-equilibration process and do not correlate with MgO, FeO and Al<sub>2</sub>O<sub>3</sub>. Although complete reconstruction of the initial compositions of the partially re-equilibrated melt inclusions is presently impossible, inclusions with the highest Mg#>0.6 are considered to correspond most closely to the compositions of initially trapped melts.

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## **Supplementary figures**



**Figure DR1.** Variations of incompatible element ratios in spinel-hosted melt inclusions from the Kamchatsky Mys ophiolites are explained by melting of compositionally heterogeneous mantle source, which consisted of recycled Hawaiian-type material with low Th/Ba and high Nb/La ratios compared to typical oceanic magmas from hotspot and mid-ocean ridge settings. No correlation between Th/Ba and Sr/Ce ratios in the melt inclusions suggests that the low Th/Ba ratios in melt inclusions reflect source composition and could not result from assimilation of plagioclase-rich oceanic gabbros. The latter was shown to be the reason of low Th/Ba in some oceanic magmas (e.g., Saal et al., 2007) Subscript n denotes primitive-mantle-normalized concentrations. Average compositions of N-MORB, E-MORB and OIB are shown for reference (Sun and McDonough, 1989).



Figure DR2. Variations of <sup>208</sup>Pb\*/<sup>206</sup>Pb\* in Emperor Seamount Chain lavas and enriched tholeiites from the Kamchatsky Mys ophiolites compared to recent Hawaiian lavas (<5 m.y. old). Compositions of the Emperor lavas are from Keller et al. (2000), Regelous et al. (2003) and Huang et al. (2005). The range of recent Hawaiian tholeiites is from compilation by Abouchami et al. (2005). The <sup>208</sup>Pb\*/<sup>206</sup>Pb\* boundary between marks the dashed line bold Loa (<sup>208</sup>Pb\*/<sup>206</sup>Pb\*>0.95) and Kea components (<sup>208</sup>Pb\*/<sup>206</sup>Pb\*<0.95) (Abouchami et al., 2005). Compositions of the Emperor lavas and enriched tholeiites from the Kamchatsky Mys ophiolites indicate prevailing contribution from Kea component. The least altered Emperor Ridge lavas are shown, whose Pb isotope compositions required relatively small correction for the radiogenic ingrowth and (<sup>206</sup>Pb/<sup>204</sup>Pb)-(<sup>206</sup>Pb/<sup>204</sup>Pb)<sub>t</sub><0.5, selected following criteria were where (<sup>206</sup>Pb/<sup>204</sup>Pb) is measured ratio, (<sup>206</sup>Pb/<sup>204</sup>Pb)<sub>t</sub> is age corrected ratio.

Table DR1a. Sample	e locations and whole i	rock major (in wt%	b) and trace element (	in p	pm) compositions
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Elements	Method	D533-6	D533-8	D536	D538	D533-7	D533-9	BHVO-2 <u>Ref.</u>	BHVO-2 this study	STD
Latitude		N56° 09.895'	N56° 09.895'	N56° 09.877'	N56° 09.800'	N56° 09.895'	N56° 09.895'			
Longitude		E162° 46.228'	E162º 46.228'	E162° 51.645'	E162° 51.942'	E162° 46.228'	E162° 46.228'			
Major elemen	nts in wt %									
SiO <sub>2</sub>	XRF	34.40	39.85	39.3	44.63	39.74	39.82			
TiO <sub>2</sub>	XRF	1.05	1.21	1.22	1.36	1.14	1.24			
$AL_2O_3$	XRF	11.88	14.09	13.6	14.75	13.01	13.68			
Fe <sub>2</sub> O <sub>3</sub>	XRF	11.53	11.84	10.99	10.53	10.26	11.84			
MnO	XRF	0.16	0.17	0.14	0.2	0.16	0.16			
MgO	XRF	5.28	4.98	4.92	5.99	5.62	5.28			
CaO	XRF	20.17	14.96	17.67	14.12	18.05	16.07			
Na <sub>2</sub> O	XRF	2.44	3.33	2.76	2.96	2.37	3.04			
K <sub>2</sub> O	XRF	0.35	0.48	0.17	0.13	0.25	0.4			
$P_2O_5$	XRF	0.19	0.38	0.21	0.16	0.17	0.34			
$H_2O$	IR	3.00	2.91	2.08	2.18	2.87	2.66			
CO <sub>2</sub>	IR	9.45	5.86	6.77	3.34	6.78	5.87			
Total		99.90	100.06	99.83	100.35	100.42	100.40			
Calcite, wt%		21.5	13.3	15.4	7.6	15.4	13.3			
Trace elemen	te in nom									
Trace element	ICPMS	15.5	16.7	10.7	14.1			48	47	0.1
Sc	ICPMS	27	31	30	33			32	31	0.1
V	ICPMS	232	274	244	256			317	317	2.8
v	XRF	209	257	218	230	229	229	517	517	2.0
Cr	ICPMS	1187	1041	829	575			280	287	2.1
Cr	XRF	1328	1103	898	580	878	1088			
Co	ICPMS	67	58	48	45			45	45	0.3
Со	XRF	70	56	49	49	61	51			
Ni	ICPMS	408	244	285	184			119	119	0.5
Ni	XRF	363	212	263	189	325	215			
Cu	ICPMS	26	31	101	80			127	124	1.0
Zn	<b>ICPMS</b>	109	130	116	91			103	103	0.9
Zn	XRF	110	131	119	93	95	123			
Ga	<b>ICPMS</b>	12	14	13	15			22	21	0.2
Ga	XRF	10	13	13	14	11	13			
Rb	ICPMS	2.8	4.4	1.9	0.8			9.11	9.0	0.1
Sr	ICPMS	224	245	221	242	210		396	393	5
Sr	XRF	215	236	210	234	219	218	26	26	0.2
Y	<u>ICPMS</u>	18	25	20	22	22	25	26	20	0.2
Y Zr	ICPMS	20	29	23	24	22	25	172	166	1.2
Zr	YPE	85	87	00	100	01	101	1/2	100	1.2
Nb	ICPMS	4.4	53	55	5 7	91	101	18.1	16.7	0.14
Mo	ICPMS	0.68	0.77	0.77	0.88			4	167	0.14
Sn	ICPMS	0.41	0.51	0.36	0.22			1.7	0.10	0.01
Cs	ICPMS	0.12	0.25	0.06	0.03			0.1	0.10	0.002
Ba	ICPMS	155	108	123	245			131	135	2
Ba	XRF	112	106	99	187	87	67			
La	ICPMS	4.45	6.21	5.72	5.57			15.2	14.71	0.07
Ce	ICPMS	11.77	14.39	14.07	14.82			37.5	36.15	0.22
Pr	ICPMS	1.89	2.34	2.25	2.34			5.35	5.23	0.03
Nd	ICPMS	9.17	11.41	10.80	11.12			24.5	24.11	0.09
Sm	ICPMS	2.47	3.09	2.90	3.11			6.07	6.00	0.03
Eu	ICPMS	0.88	1.12	1.03	1.11			2.07	2.02	0.01
Gd	ICPMS	2.81	3.63	3.31	3.59			6.24	6.10	0.04
Tb	ICPMS	0.47	0.61	0.56	0.61			0.92	0.93	0.01
Dy	ICPMS	2.94	3.80	3.41	3.84			5.31	5.22	0.03
Но	ICPMS	0.60	0.80	0.70	0.78			0.98	0.96	0.01
Er	ICPMS	1.63	2.17	1.88	2.11			2.54	2.38	0.01
1m Vi	ICPMS	0.24	0.32	0.27	0.31			0.33	0.32	0.00
YD Lu	ICPMS	1.55	2.05	1.77	1.98			2.00	1.94	0.01
	ICPMS	0.23	0.31	0.26	0.30			0.274	0.27	0.002
пі То	ICPMS	1.8/	2.13	2.16	2.36			4.56	4.51	0.018
ra W	ICPMS	0.270	0.334	0.340	0.357			1.14	1.044	0.004
vv T1	ICPMS	0.140	0.1/8	0.14/	0.152			0.21	0.400	0.014
Ph	ICPMS	0.040	1 49	1 47	0.008			1.6	1 570	0.131
Th	ICPMS	0.005	0 280	0.282	0.335			1.0	1 172	0.008
U	ICPMS	0.159	0.163	0.150	0.121			0.403	0.419	0.004

**Notes.** Total Fe is reported in Fe<sub>2</sub>O<sub>3</sub> equivalent. Concentrations of some trace elements were determined by XRF and ICPMS. Underlined is method providing the most reliable results for these elements. Reference values for BHVO-2 are from GeoReM data base (http://georem.mpch-mainz.gwdg.de/). Amount of secondary calcite in rocks (in wt%) is calculated from bulk CO<sub>2</sub> concentrations.

Sample	D533-6	D533-8	D536	D538
Measured ratios				
<sup>87</sup> Sr/ <sup>86</sup> Sr	0.704082(5)	0.704217(4)	0.703373(5)	0.703432(5)
<sup>143</sup> Nd/ <sup>144</sup> Nd	0.513050(3)	0.513040(3)	0.513040(3)	0.513048(2)
<sup>206</sup> Pb/ <sup>204</sup> Pb	18.492(1)	18.450(2)	18.444(2)	18.389(3)
<sup>207</sup> Pb/ <sup>204</sup> Pb	15.471(1)	15.484(2)	15.486(2)	15.467(2)
<sup>208</sup> Pb/ <sup>204</sup> Pb	37.866(3)	37.919(5)	37.949(4)	37.892(6)
Parent/daughter rat	tios			
<sup>87</sup> Rb/ <sup>86</sup> Sr	0.036	0.052	0.024	0.010
147Sm/144Nd	0.162	0.163	0.162	0.169
$^{238}U/^{204}Pb$	21.3	17.9	16.8	12.8
<sup>232</sup> Th/ <sup>204</sup> Pb	31.3	31.6	32.6	36.7
Initial isotope ratios	s 100Ma			
( <sup>87</sup> Sr/ <sup>86</sup> Sr) <sub>i</sub>	0.704031	0.704143	0.703338	0.703418
$(^{143}Nd/^{144}Nd)_i$	0.512944	0.512933	0.512934	0.512938
( <sup>206</sup> Pb/ <sup>204</sup> Pb) <sub>i</sub>	18.160	18.170	18.181	18.189
$(^{207}\text{Pb}/^{204}\text{Pb})_{i}$	15.455	15.471	15.473	15.457
$(^{208}\text{Pb}/^{204}\text{Pb})_i$	37.711	37.762	37.787	37.710
<sup>208</sup> Pb*/ <sup>206</sup> Pb*	0.930	0.935	0.937	0.927

Table DR2.	(a)	Whole	rock	isotope	com	positions
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Note: Values in parentheses refer to 2 standard deviations of the last digit of measured value. Mild acid leaching applied during sample preparation for isotope analyses did not eliminate the seawater signal in <sup>87</sup>Sr/<sup>86</sup>Sr ratios, and therefore Sr isotopes were excluded from discussion of the primary isotope characteristics of the rocks. See details in the Appendix DR1.

Table DR2.	(b)	Parent/daughter	<ul> <li>ratios used</li> </ul>	to calculate is	sotope com	positions a	at 100 Ma
	·~ /						

	Pacific MORB	Garrett FZ	Mauna Kea	Koolau	Detroit
Sm/Nd	0.36	0.39	0.27	0.26	0.29
Th/Pb	0.40	0.22	0.97	0.52	0.90
U/Pb	0.16	0.15	0.31	0.15	0.27

Note: Parent/daughter ratios are given after or calculated (Detroit Seamount) from data of Huang et al. (2005)

Rock sample	D533-9	D533-8	D536	D533-6	D536	D536	D533-6	D536	D536	D536	D536
SiO antly	50.25	50 55	50.22	50.1C	52.59	SP16B	SP18A	SP /	52.1C	SP18	51.99A
$SIO_2$ wt%	50.25	50.55	50.22	1 26	52.58	51.51	49.44	52.73	52.16	53.62	51.88
1102	1.59	1.50	1.45	1.20	1.91	1.55	1.47	1.02	1.29	1.11	1.95
$AI_2O_3$	18.69	16.39	15.14	17.05	20.36	17.72	16.74	20.32	19.14	19.42	17.97
FeO	7.42	8.32	8.62	7.76	5.42	7.27	7.91	5.35	6.49	6.03	7.48
MnO	0.10	0.12	0.15	0.11	0.10	0.07	0.10	0.03	0.07	0.05	0.07
MgO	3.90	7.56	8.16	7.60	3.14	3.84	6.55	2.67	3.84	3.31	3.78
CaO	12.56	12.61	11.66	12.72	12.02	12.45	11.44	11.53	12.31	12.70	12.37
Na <sub>2</sub> O	2.93	2.21	2.43	2.62	2.97	2.82	3.08	3.32	2.86	2.89	2.89
K <sub>2</sub> O	0.27	0.23	0.28	0.20	0.36	0.28	0.49	0.59	0.37	0.18	0.21
$P_2O_5$	0.12	0.16	0.10	0.13	0.14	0.14	0.24	0.28	0.22	0.10	0.12
S	0.105	0.069	0.149	0.102	0.111	0.081	0.125	0.122	0.113	0.111	0.107
Cl	0.021	0.011	0.017	0.020	0.007	0.000	0.037	0.011	0.011	0.016	0.025
$Cr_2O_3$	0.81	0.32	0.56	0.43	0.69	0.86	0.65	0.68	0.68	0.73	0.63
Total	98.76	99.86	98.94	100.16	99.81	98.59	98.27	98.64	99.54	100.27	99.45
Li, ppm	3.63	3.53	2.03	3.57	1.34	5.12	3.95	3.38	2.98	1.81	1.50
Be	0.57	0.50	0.33	0.41	0.39	0.59	0.48	0.49	0.56	0.50	0.46
В	0.89	1.05	1.01	0.81	0.95	1.00	1.19	1.84	1.19	1.16	1.17
K	3321	2264	2656	2291	3920	3182	5575	7643	4662	1706	1804
Ti	13280	8089	9326	9787	12147	12583	11198	10386	14085	10600	12936
Cr*	60730	108	8754	14507	33592	72855	15040	123815	141484	59412	11623
V**	<1223	258	351	<436	<1068	<1209	524	<1527	<1845	<1004	538
Sr	307	217	241	262	273	240	354	553	484	274	248
Ŷ	26.1	23.0	25.7	25.3	26.1	30.4	28.7	22.2	30.6	23.4	27.5
Zr	111	69	99	98	128	135	105	94	135	93	153
Nb	7.9	9.3	8.6	6.0	11.0	10.4	13.0	17.4	15.1	11.8	14.4
Ba	/9.3	63.9	55.2	55.0 5.05	88.5	/1.2	122.5	208.9	11/.4	46.9	40.5
La	10.0	4.60	17.4	5.95	0.91	0.55	18.0	22.0	22.8	0.45	0.10
Nd	13.0	9.2	17.4	12.5	11.2	19.0	13.9	26.9	32.8 20.7	23.7	19.8
Sm	3.60	2 57	3.97	4 37	4 68	4 64	4.06	7.09	7 18	4 87	5 31
Fu	1.55	1.04	1 38	1.21	1.00	1 72	1.00	1.89	1.86	1.56	1 75
Gd	5.93	3.17	3 79	4 47	5 76	7 35	4 95	5 53	5 38	4 91	5.66
Dv	5.19	3.73	4.39	4.76	5.49	6.21	4.67	4.41	5.84	4.49	4.97
Er	2.61	2.38	2.97	2.55	2.52	3.17	2.47	2.06	3.61	2.43	3.03
Yb	2.36	2.26	2.94	2.41	1.91	2.20	1.71	2.50	3.09	2.23	2.81
Hf	3.49	1.84	2.82	2.62	3.82	4.06	2.63	2.93	3.92	2.73	3.93
Pb	1.13	0.59	1.15	0.71	0.94	1.63	1.34	1.18	1.90	0.73	0.61
Th	0.43	0.29	0.41	0.29	0.44	0.40	0.67	1.58	0.68	0.25	0.25
U	0.12	0.13	0.15	0.14	0.15	0.12	0.18	0.42	0.31	0.18	0.15
X sp ***	0.25	0.00	0.03	0.07	0.12	0.29	0.06	0.49	0.55	0.23	0.05
SDINEL HOST											
SI INEL HOST	0.10	0.09	0.00	0.09	0.07	0.10	0.00	0.11	0.07	0.05	0.07
SIO <sub>2</sub>	0.10	0.08	0.08	0.08	0.07	0.10	0.08	0.11	0.07	0.03	0.07
1102	0.75	0.61	0.58	0.56	0.79	0.63	0.74	0.45	0.55	0.62	1.02
Al <sub>2</sub> O <sub>3</sub>	28.03	29.38	29.15	35.02	26.76	28.02	28.82	29.13	28.84	28.27	27.06
$Cr_2O_3$	35.64	36.47	37.63	31.12	39.65	37.27	36.80	37.07	37.50	37.78	36.78
FeO	19.80	18.04	15.87	16.79	17.24	17.64	17.16	16.81	16.52	17.37	19.97
MnO	0.21	0.19	0.18	0.18	0.19	0.18	0.18	0.16	0.16	0.20	0.21
MgO	14.61	15.68	16.58	17.13	15.95	15.36	15.79	15.69	16.42	15.55	15.04
NiO	0.15	0.19	0.23	0.22	0.19	0.21	0.21	0.19	0.22	0.18	0.17
ZnO	0.06	0.05	0.11	0.06	0.09	0.05	0.04	0.10	0.10	0.01	0.02
Total	99.35	100.69	100.40	101.14	100.94	99.46	99.81	99.70	100.38	100.04	100.34

Table DR3. Compositions of melt inclusions and host spinel

**Notes.** Cr=measured Cr concentrations; \*\*V = V concentrations represent maximum values because of high V concentration in host spinel; \*\*\*Xsp = maximum amount of host spinel (in mass fraction of melt) trapped during SIMS analysis as calculated from measured Cr concentration in melt, concentration of Cr in host spinel and assuming true Cr concentration in melt to be 0 wt%.

Table DR3. Continued

Rock sample	D536	D533-7	D533-6	D536	D536
Inclusion	SP13A	SP2	SP9A	SP6A	SP12A
SiO <sub>2</sub> wt%	50.75	50.62	51.55	51.16	52.41
TiO <sub>2</sub>	1.39	1.33	1.53	2.88	1.60
$Al_2O_3$	16.71	16.13	17.56	18.61	20.36
FeO	8.31	7.63	7.40	6.61	5.89
MnO	0.11	0.15	0.12	0.08	0.08
MgO	6.03	6.74	5.12	3.25	3.00
CaO	12.52	12.72	12.01	12.36	12.66
Na <sub>2</sub> O	2.87	2.70	3.18	2.94	2.61
K <sub>2</sub> O	0.09	0.13	0.13	0.18	0.18
$P_2O_5$	0.15	0.05	0.04	0.12	0.07
S	0.157	0.085	0.094	0.104	0.120
Cl	0.000	0.018	0.004	0.005	0.011
$Cr_2O_2$	0.47	0.69	0.81	0.88	0.79
Total	99.55	98 98	99 55	99.16	99 77
Lippm	2.94	5.03	2.90	2.50	3.78
Be	0.39	0.59	0.54	0.52	0.52
В	0.22	0.93	0.62	1.32	0.65
K	932	1654	1329	2211	1656
Ti	9035	13515	13749	27807	13950
Cr*	10899	78050	66094	94761	77438
V**	412	<1298	<1012	<1790	<1395
Sr	88	267	132	316	214
Y	24.5	31.3	31.1	29.0	26.2
Zr	113	127	125	173	105
Nb	12.2	12.6	16.5	15.2	9.2
Ba	21.8	36.1	40.4	63.8	32.3
La	2.57	4.80	4.32	6.45	4.36
Ce	8.4	14.9	18.8	23.6	13.1
Nd	11.5	18.8	22.6	25.9	14.3
Sm	4.69	6.54	6.73	7.57	4.30
Eu	1.46	2.22	2.10	2.10	1.32
Gd	4.33	5.60	7.33	6.08	5.52
Dy	4.12	5.48	6.22	5.50	5.13
Er	2.62	3.26	3.04	3.55	3.00
Yb	2.19	3.09	2.87	3.09	2.50
Hf	2.56	3.52	3.70	4.86	3.01
Pb	0.99	1.16	0.55	2.23	0.56
Th	0.14	0.19	0.19	0.30	0.23
U	nd	0.12	0.15	0.14	0.06
X sp ***	0.04	0.35	0.25	0.36	0.31
SPINEL HOST					
SiO2	0.08	0.08	0.09	0.06	0.08
TiO2	0.69	0.53	0.75	1.34	0.73
Al2O3	27.99	33.53	27.35	26.22	29.05
Cr2O3	37.79	32.31	38.31	38.62	36.88
FeO	17.69	16.74	17.77	17.99	17.57
MnO	0.18	0.18	0.17	0.18	0.17
MgO	15.68	16.58	15.52	15.31	15.77
NiO	0.19	0.21	0.19	0.19	0.20
ZnO	0.07	0.05	0.06	0.10	0.10
Total	100.37	100.20	100.21	100.00	100.56