Supplemental Material for “Mélange versus fluid and melt enrichment of the sub-arc mantle: a novel test using Barium isotopes in the Tonga-Kermadec arc”

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1. BARIUM ISOTOPE COMPOSITION OF MANTLE

Nielsen et al. (2018) investigates the Ba isotope variations in mid-ocean ridge basalt (MORB) and defines the $\delta^{138/134}\text{Ba}$ value of depleted upper mantle endmember (+0.14‰) from the MORB data, which is further suggested as the $\delta^{138/134}\text{Ba}$ of mantle source of arc lavas in Nielsen et al. (2020). However, we think that the DMM $\delta^{138/134}\text{Ba}$ value from Nielsen et al. (2018) should not be used as the canonical DMM reservoir and to be applied as mantle endmember for the Ba isotope studies for island arc magmatic rocks, because:

Barium isotope data for MORB glasses plotted against $^{87}\text{Sr}/^{86}\text{Sr}$, $^{143}\text{Nd}/^{144}\text{Nd}$ and Th/Ba ratios. All data is from Nielsen et al., (2018). The yellow and red areas are the $\delta^{138/134}\text{Ba}$ of DMM and EMM reservoirs suggested by Nielsen et al., (2018). The vertical dotted lines present the well-defined average $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ of D-MORB from Salters and Stracke (2004), and average Th/Ba ratios of D-MORB and E-MORB from Gale et al. (2013).

(1) The representativeness of samples for the estimation on DMM vs EMM reservoirs is limited by the current sampling size (21). Most of the MORB samples are from Mid-Atlantic Ridge and the defined EMM and DMM reservoirs by Nielsen et al. (2018) are actually estimated from the variations of these Mid-Atlantic Ridge samples. For comparison, the only three D-MORB samples from East Pacific rise, which likely share a similar mantle reservoir to that below Aleutians and Ryukyu arc in Nielsen et al. (2020) and Tonga-Kermadec arc in this work, all have $\delta^{138/134}\text{Ba}$ around +0.05‰. Thus, the DMM reservoirs given by Nielsen et al. (2018) could not be applied as the mantle endmember for the arc Ba isotope study in Nielsen et al. (2020) and this work, and probably need to be better estimated by further works.

(2) The way Nielsen et al. (2018) estimates the DMM reservoirs requires further verification. They define the $\delta^{138/134}\text{Ba}$ of DMM reservoir using the highest $\delta^{138/134}\text{Ba}$ value (+0.14‰) among their most depleted D-MORB samples from a radiogenic isotope perspective. However, the $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ of these samples are offset from the well-defined global average D-MORB values, thus do not represent the DMM reservoir. In addition, there is no correlation between $\delta^{138/134}\text{Ba}$ and Th/Ba (also Rb/Ba) ratio, which should keep a constant ratio during mantle melting and likely reflect the mantle heterogeneity and directly related to [Ba]. Thus, the way Nielsen et al. (2018) estimates the DMM reservoirs and their implicit assumptions (two endmember mixing) require further studies.

On the other hand, available Ba isotope data from mantle-derived rocks show that MORBs and igneous carbonatites have similar Ba isotope variations with average $\delta^{138/134}\text{Ba}$ values of $+0.06 \pm 0.06\text{‰}$ for MORBs (2SD, $n = 21$, Nielsen et al., 2018) and $+0.05 \pm 0.06\text{‰}$ for igneous carbonatites (2SD, $n = 16$, Li et al., 2020). Thus, we think the average $\delta^{138/134}\text{Ba}$ value of these

samples ($\sim +0.05\%$) could be taken to represent the likely Ba isotope composition of the mantle as suggested by Li et al. (2020).

2. MODELLING DETAILS

End-member compositions for the mixing calculations

	Ba ($\mu\text{g/g}$)	Pb ($\mu\text{g/g}$)	Sr ($\mu\text{g/g}$)	Nd ($\mu\text{g/g}$)
Mantle ^a	1.2	0.02	9.8	0.713
Sediment ^b	737	69	340	313
AOC ^c	15.6	0.44	109	11.3
		²⁰⁶ Pb/ ²⁰⁴ Pb	⁸⁷ Sr/ ⁸⁶ Sr	¹⁴³ Nd/ ¹⁴⁴ Nd
Mantle ^d		18.20	0.7031	0.51315
Sediment ^e		18.82	0.7095	0.51234
AOC ^f		18.52	0.7039	0.51275
	$\delta^{138/134}\text{Ba}$ (‰)			
Mantle ^g	0.05			
Sediment ^h	0.02			
AOC ⁱ	0.20			

Note:

a: depleted mantle average (Salters and Stracke, 2004);

b: represented value given by DSDP Sites 595 and 596b (Plank and Langmuir., 1998; Johnson and Plank, 2000);

c: AOC composite from ODP 801 (Kelley et al., 2003);

d: from the most depleted samples found in the Eastern Lau Spreading Center and the Valu Fa Ridge (Hergt and Woodhead, 2007);

e: weighted average Tonga sediment composition estimated from analyses of DSDP Site 204 and 595 sediment (Plank and Langmuir., 1998; Regelous et al., 2010);

f: ²⁰⁶Pb/²⁰⁴Pb is estimated based on the fluid addition trend (Turner et al., 1997), ⁸⁷Sr/⁸⁶Sr and ¹⁴³Nd/¹⁴⁴Nd: are estimated from ODP Site 801 (Hauff et al., 2003);

g: estimated from MORBs and mantle carbonatites average (Nielsen et al., 2018, Li et al., 2020);

h: estimated from pelagic sediments average (Bridgestock et al., 2018; Nielsen et al., 2018, 2020);

i: assumed to cover all the data for samples with high Ba/Th.

Mantle-sediment melt-AOC fluid mixing model

It is well established that the mantle wedge beneath the arc is highly depleted (Caulfield et al. 2008) and that the slab surface temperature (and thus potential sediment melting and AOC dehydration) is about 800 °C (Caulfield et al., 2012a). Thus, the sediment melt endmember is calculated from 20% partial melting of the sediment endmember with $D_{\text{Ba}}^{\text{melt/sediment}}$ of 0.61, $D_{\text{Pb}}^{\text{melt/sediment}}$ of 1.28, $D_{\text{Sr}}^{\text{melt/sediment}}$ of 1.49, and $D_{\text{Nd}}^{\text{melt/sediment}}$ of 0.23 based on melting experiments conducted on the down-going pelagic sediment from Tonga fore-arc at 800 °C (Johnson and Plank, 1999). The AOC fluid endmember is calculated from 20% dehydration of

the AOC endmember with $D_{\text{Ba}}^{\text{fluid/solid}}$ of 14.3, $D_{\text{Pb}}^{\text{fluid/solid}}$ of 19, $D_{\text{Sr}}^{\text{fluid/solid}}$ of 1.9, and $D_{\text{Nd}}^{\text{fluid/solid}}$ of 0.146 based on experiments conducted at 800 °C (Kessel et al., 2005). The mantle-sediment melt-AOC fluid mixing trend in $^{87}\text{Sr}/^{86}\text{Sr}$ - $\delta^{138/134}\text{Ba}$ (Figure 2C), $^{206}\text{Pb}/^{204}\text{Pb}$ - $\delta^{138/134}\text{Ba}$ (Figure 2D), $^{87}\text{Sr}/^{86}\text{Sr}$ - $^{143}\text{Nd}/^{144}\text{Nd}$ (Figure 2DR A), and $^{87}\text{Sr}/^{86}\text{Sr}$ -Nd/Sr (Figure 2DR B) is then calculated by binary mixing of these endmembers. Additional trends are calculated by mixing of AOC fluid with mantle-sediment melt mixture with sediment proportion of 0.05% to 0.2%, in order to show the effect of adding AOC fluid to mantle wedge metasomatized by sediment melt.

Mélange model

The Sr-Ba isotope (Figure 2C) and Nd-Ba isotope (Figure 2D) of hypothetical mélange component is calculated by the bulk mixing of AOC and sediment with plausible mixing ratios (ratio between the AOC and the sediment from 1:9 to 19:1). In the Sr-Nd isotope and Nd/Sr diagrams (Figure 2DR), we use the same approach by Nielsen and Marschall (2017) to calculate the hypothetical mélange mixing trend, by bulk mixing of mantle and sediment.

75
 76 **Figure S1.** Barium isotope plotted against SiO₂ concentrations for magmas from the Tonga-
 77 Kermadec arc lavas. It is evident that fractional crystallization and assimilation processes that
 78 occur as SiO₂ increases do not cause a discernible change in Ba isotopes.

Figure S2. Plots of (A) $^{143}\text{Nd}/^{144}\text{Nd}$ and (B) Nd/Sr versus $^{87}\text{Sr}/^{86}\text{Sr}$ comparing Tonga-Kermadec lava data (Turner et al., 1997) with modelled mixing curves for addition of bulk sediment (mélange model) and with a model in which a depleted mantle wedge is successively enriched by addition of a sediment melt and then a fluid derived from the altered oceanic crust. Allowing for a range in the amounts and/or composition of the sediment melt and fluid components can easily allow the full range in the data to be described. The modelling details are provided in the text of Data Repository.

88 **4. TABLES**

89 Table S1 Barium isotope compositions of reference materials.

	$\delta^{138/134}\text{Ba}$	2SD	Analyses	Splits	Reference
<i>BCR-2</i>	0.07	0.04	9	3	This study
	0.07*		13	3	Nan et al., 2018
	0.06	0.06	6	2	An et al., 2019
<i>BHVO-2</i>	0.04	0.04	12	4	This study
	0.04	0.04	4	n.g.	Zuilen et al., 2016
	0.06*		22	3	Nan et al., 2018
	0.04	0.03	9	2	Nielsen et al., 2018
	0.02	0.03	6	1	An et al., 2019
<i>USTC-Ba</i>	0.09	0.04	82		This study
	0.09*		210		Nan et al., 2018
	0.08	0.05	81		An et al., 2019
<i>ICPUS-Ba</i>	-0.03	0.04	73		This study
	-0.03*		184		Nan et al., 2018
	-0.03	0.04	89		An et al., 2019

90 n.g. – information not provided.

91 Analyses refer to the number of individual mass spectrometric analyses performed.

92 Splits refer to number of separate dissolved splits of sample processed through the entire ion
93 exchange column procedure.

94 * The published $\delta^{137/134}\text{Ba}$ values have been recalculated here to $\delta^{138/134}\text{Ba}$ values,

95 i.e. $\delta^{138/134}\text{Ba} = 1.33 \times \delta^{137/134}\text{Ba}$.

96 Table S2. Barium isotopic and selected element data for Tonga-Kermadec lavas

Sample	Location		SiO ₂ ^a (wt.%)	MgO ^a (wt.%)	LOI ^a (wt.%)	Sr ^a (µg/g)	Ba ^a (µg/g)	Th ^a (µg/g)	Yb ^a (µg/g)	⁸⁷ Sr/ ⁸⁶ Sr ^a	206Pb/204Pb ^b	δ ^{138/134} Ba (‰)	2SD	n
	Lat	Long												
	(°S)	(°E)												
Back-Arc Lau Basin														
Niuafo'ou											18.42 ± 0.04			
31461	15°36′	175°39′	49.43	6.71	-0.41	184	31.8	0.256	3.074	0.70429		0.03	0.03	3
31461-Re												0.02	0.04	3
31462	15°36′	175°39′	49.85	6.80	-0.44	180	32.8	0.260	3.107	0.70428		0.03	0.04	2
31463	15°36′	175°39′	49.91	6.99	-0.33	172	33.2	0.305	3.219	0.70427		0.03	0.02	2
31477	15°36′	175°39′	50.11	7.16	-0.51	170	38.2	0.309	3.398	0.70432		0.03	0.04	2
Tonga														
Tafahi											19.18 ± 0.08			
T116	15°52′	173°55′	52.81	6.07	0.55	155	41.4	0.131	0.918	0.70399		-0.01	0.02	4
TAF18/10	15°52′	173°55′	52.35	7.14	0.19	137	38.7	0.097	1.012	0.70387		-0.06	0.03	2
TAF43/6	15°52′	173°55′	51.82	7.47	0.08	137	38.7	0.096	0.947	0.70388		-0.02	0.03	3
Niuatoputapu											19.10 ± 0.06			
NTT25/4	15°57′	173°58′	58.84	3.31	0.21	291	174.4	0.399	1.926	0.70397		0.00	0.02	3
NTT29/3	15°57′	173°58′	60.13	2.90	0.07	294	176.8	0.390	2.148	0.70397		-0.02	0.04	2
NTT29/3-Re												-0.01	0.03	2
Fonualei											18.58 ± 0.01			
FON31	17°42′	174°20′	60.29	2.59	0.28	406	245.3	0.321	2.649	0.70381	18.593	0.08	0.03	3
FON39	17°42′	174°20′	65.34	1.54	0.15	317	245.0	0.487	2.407	0.70376	18.576	0.07	0.02	3
Late											18.58 ± 0.01			
Late 2	18°49′	174°40′	53.66	6.29	-0.26	212	80.3	0.134	1.311	0.70355	18.575	0.16	0.01	3
Late2-Re												0.14	0.01	2
Late 7	18°49′	174°40′	53.19	5.02	0.10	230	91.5	0.136	1.373	0.70361	18.558	0.16	0.02	2
Late 13	18°49′	174°40′	57.57	3.29	0.26	229	133.6	0.217	2.085	0.70369	18.566	0.07	0.02	2
Kao											18.61 ± 0.02			
T103c	19°03′	175°01′	53.93	5.56	0.13	244	123	0.188	1.89	0.70328		0.10	0.04	2
Tofua											18.59 ± 0.03			
26833	19°45′	175°05′	54.56	3.70	-0.22	240	131.5	0.13	1.63	0.70346	18.454	0.10	0.02	3
26835	19°45′	175°05′	53.94	6.39	-0.21	206	107.9	0.13	1.42	0.70345		0.12	0.01	2

26877	19°45'	175°05'	55.63	4.56	-0.11	231	148.2	0.19	1.94	0.70342		0.10	0.01	3
26907	19°45'	175°05'	53.83	5.48	-0.28	250	119.2	0.130	1.648	0.70340	18.608	0.11	0.04	3
<u>Hunga Ha'apai</u>											18.64 ± 0.02			
HHHTOP	20°33'	175°25'	55.35	4.80	0.84	179	126.9	0.164	1.724	0.70368		0.11	0.02	2
HHBTM	20°33'	175°25'	54.44	4.16	0.22	185	108.1	0.121	1.416	0.70371		0.09	0.00	3
<u>Ata</u>											18.73 ± 0.02			
482-8-11	20°20'	176°12'	50.40	7.43	0.42	242	127.3	0.318	1.389	0.70337	18.726	0.04	0.01	2
482-8-1	20°20'	176°12'	51.90	5.54	0.28	271	151.0	0.365	1.480	0.70342	18.714	0.04	0.03	3
482-8-8	20°20'	176°12'	51.40	5.53	0.37	269	147.4	0.37	1.62	0.70336		0.01	0.04	3
Kermadec														
<u>Raoul</u>											18.66 ± 0.03			
T16	29°15'	177°52'	56.77	3.29	-0.31	168	87.0	0.133	2.599	0.70352		0.06	0.02	3
7090	29°15'	177°52'	53.26	4.60	-0.40	171	108.4	0.252	2.363	0.70345		0.05	0.03	4
T5	29°15'	177°52'	56.50	3.55	-0.46	184	144.6	0.439	2.809	0.70349		0.07	0.03	2
R4	29°15'	177°52'	66.28	1.56	1.30	162	172.8	0.333	3.672	0.70350		0.05	0.04	3
R29	29°15'	177°52'	68.47	1.22	0.49	168	194.2	0.424	4.216	0.70355		0.07	0.03	3
I20 xen	29°15'	177°52'	44.69	14.75	-0.26	89	7	0.032	0.34	0.70353		0.08	0.01	2
<u>Macauley</u>											18.68 ± 0.02			
45657	30°13'	178°33'	49.22	7.06	-0.25	237	119.2	0.510	1.653	0.70345		0.02	0.02	3
45657-Re												0.04	0.03	3
45658	30°13'	178°33'	48.30	5.72	0.09	278	100.8	0.467	1.241	0.70346		0.02	0.02	2
<u>Curtis</u>											18.71 ± 0.03			
14868	30°35'	178°36'	70.50	0.93	1.30	181	327.7	0.855	3.902	0.70444		0.04	0.03	3
<u>L'Esperance</u>											18.76 ± 0.04			
14831	31°26'	178°54'	52.66	4.85	0.00	345	147.9	0.577	2.353	0.70404		0.04	0.04	2
<u>Rumble IV</u>											18.78 ± 0.03			
X168/1A	36°26'	-178°00'	52.03	7.27	1.00	255	197.2	0.669	2.057	0.70425	18.803	0.03	0.01	2
X169/1	36°26'	-178°00'	49.64	9.10	0.00	211	105.7	0.453	1.603	0.70335	18.705	0.03	0.02	3
<u>Clark</u>											18.79 ± 0.06			
X451a	36°27'	-177°52'	50.30	9.00	0.48	404	540.4	1.391	1.537	0.70548		0.02	0.04	3
<u>Ngatoro Ridge</u>											18.79 ± 0.03			
X196/1A	37°05'	n.a.	49.57	3.94	0.19	310	213.2	0.939	1.862	0.70513	18.832	0.03	0.04	3
X204/1B	37°05'	n.a.	48.41	5.44	0.19	271	157.6	0.487	1.723	0.70530	18.84	0.04	0.03	3

98 ^baverage $^{206}\text{Pb}/^{204}\text{Pb}$ for each island calculated based on the literature double-spike Pb data. Data source: Gamble et al., (1996); Ewart
99 et al., (1998); Hergt and Woodhead (2007); Regelous et al., (2010); Escrig et al., (2009); Todd (2011); Caulfield et al., (2012b);
100 Turner et al., (2012).

5. REFERENCES

- An, Y.-J., Li, X., and Zhang, Z.-F., Barium Isotopic Compositions in Thirty-Four Geological Reference Materials Analysed by MC-ICP-MS: Geostandards and Geoanalytical Research, v. n/a, no. n/a.
- Bridgestock, L., Hsieh, Y.-T., Porcelli, D., Homoky, W. B., Bryan, A., and Henderson, G. M., 2018, Controls on the barium isotope compositions of marine sediments: Earth and Planetary Science Letters, v. 481, p. 101-110.
- Caulfield, J., Turner, S., Dosseto, A., Pearson, N., and Beier, C., 2008, Source depletion and extent of melting in the Tongan sub-arc mantle: Earth and Planetary Science Letters, v. 273, no. 3-4, p. 279-288.
- Caulfield, J., Turner, S., Arculus, R., Dale, C., Jenner, F., Pearce, J., Macpherson, C., and Handley, H., 2012a, Mantle flow, volatiles, slab-surface temperatures and melting dynamics in the north Tonga arc–Lau back-arc basin: Journal of Geophysical Research: Solid Earth, v. 117, no. B11.
- Caulfield, J., Turner, S. P., Smith, I., Cooper, L., and Jenner, G. A., 2012b, Magma evolution in the primitive, intra-oceanic Tonga arc: petrogenesis of basaltic andesites at Tofua volcano: Journal of Petrology, v. 53, no. 6, p. 1197-1230.
- Escrig, S., Bézoz, A., Goldstein, S., Langmuir, C. H., and Michael, P., 2009, Mantle source variations beneath the Eastern Lau Spreading Center and the nature of subduction components in the Lau basin–Tonga arc system: Geochemistry, Geophysics, Geosystems, v. 10, no. 4.
- Ewart, A., Collerson, K., Regelous, M., Wendt, J., and Niu, Y., 1998, Geochemical evolution within the Tonga–Kermadec–Lau arc–back-arc systems: the role of varying mantle wedge composition in space and time: Journal of Petrology, v. 39, no. 3, p. 331-368.
- Gamble, J., Woodhead, J., Wright, I., and Smith, I., 1996, Basalt and sediment geochemistry and magma petrogenesis in a transect from oceanic island arc to rifted continental margin arc: the Kermadec–Hikurangi Margin, SW Pacific: Journal of Petrology, v. 37, no. 6, p. 1523-1546.
- Hauff, F., Hoernle, K., and Schmidt, A., 2003, Sr-Nd-Pb composition of Mesozoic Pacific oceanic crust (Site 1149 and 801, ODP Leg 185): Implications for alteration of ocean crust and the input into the Izu-Bonin-Mariana subduction system: Geochemistry, Geophysics, Geosystems, v. 4, no. 8.
- Hergt, J. M., and Woodhead, J. D., 2007, A critical evaluation of recent models for Lau–Tonga arc–backarc basin magmatic evolution: Chemical Geology, v. 245, no. 1-2, p. 9-44.

135 Johnson, M. C., and Plank, T., 2000, Dehydration and melting experiments constrain the fate of
136 subducted sediments: *Geochemistry, Geophysics, Geosystems*, v. 1, no. 12.

137 Kelley, K. A., Plank, T., Ludden, J., and Staudigel, H., 2003, Composition of altered oceanic
138 crust at ODP Sites 801 and 1149: *Geochemistry, Geophysics, Geosystems*, v. 4, no. 6.

139 Kessel, R., Schmidt, M. W., Ulmer, P., and Pettke, T., 2005, Trace element signature of
140 subduction-zone fluids, melts and supercritical liquids at 120-180 km depth: *Nature*, v.
141 437, no. 7059, p. 724-727.

142 Li, W.-Y., Yu, H.-M., Xu, J., Halama, R., Bell, K., Nan, X.-Y., and Huang, F., 2020, Barium
143 isotopic composition of the mantle: Constraints from carbonatites: *Geochimica et*
144 *Cosmochimica Acta*, v. 278, p. 235-243.

145 Marschall, H. R., and Schumacher, J. C., 2012, Arc magmas sourced from melange diapirs in
146 subduction zones: *Nature Geosci*, v. advance online publication.

147 Nan, X.-Y., Yu, H.-M., Rudnick, R. L., Gaschnig, R. M., Xu, J., Li, W.-Y., Zhang, Q., Jin, Z.-D.,
148 Li, X.-H., and Huang, F., 2018, Barium isotopic composition of the upper continental
149 crust: *Geochimica et Cosmochimica Acta*, v. 233, p. 33-49.

150 Nielsen, S. G., Horner, T. J., Pryer, H. V., Blusztajn, J., Shu, Y., Kurz, M. D., and Le Roux, V.,
151 2018, Barium isotope evidence for pervasive sediment recycling in the upper mantle:
152 *Science Advances*, v. 4, no. 7.

153 Nielsen, S. G., and Marschall, H. R., 2017, Geochemical evidence for mélange melting in global
154 arcs: *Science Advances*, v. 3, no. 4, p. e1602402.

155 Nielsen, S. G., Shu, Y., Auro, M., Yogodzinski, G., Shinjo, R., Plank, T., Kay, S. M., and Horner,
156 T. J., 2020, Barium isotope systematics of subduction zones: *Geochimica et*
157 *Cosmochimica Acta*, v. 275, p. 1-18.

158 Plank, T., and Langmuir, C. H., 1998, The chemical composition of subducting sediment and its
159 consequences for the crust and mantle: *Chemical Geology*, v. 145, no. 3-4, p. 325-394.

160 Regelous, M., Gamble, J. A., and Turner, S. P., 2010, Mechanism and timing of Pb transport
161 from subducted oceanic crust and sediment to the mantle source of arc lavas: *Chemical*
162 *Geology*, v. 273, no. 1-2, p. 46-54.

163 Salters, V. J., and Stracke, A., 2004, Composition of the depleted mantle: *Geochemistry,*
164 *Geophysics, Geosystems*, v. 5, no. 5.

165 Todd, E., 2011, The youngest rocks from an old arc and the oldest rocks from a juvenile one:
166 The memoirs of a SW Pacific subduction zone, University of California, Santa Cruz.

167 Turner, S., Caulfield, J., Rushmer, T., Turner, M., Cronin, S., Smith, I., and Handley, H., 2012,
168 Magma evolution in the primitive, intra-oceanic Tonga arc: Rapid petrogenesis of dacites
169 at Fonualei volcano: *Journal of Petrology*, v. 53, no. 6, p. 1231-1253.

170 Turner, S., Hawkesworth, C., Rogers, N., Bartlett, J., Worthington, T., Hergt, J., Pearce, J., and
171 Smith, I., 1997, (238)U-(230)Th disequilibria, magma petrogenesis, and flux rates
172 beneath the depleted Tonga-Kermadec island arc: *Geochimica et Cosmochimica Acta*, v.
173 61, no. 22, p. 4855-4884.

174 van Zuilen, K., Nägler, T. F., and Bullen, T. D., 2016, Barium Isotopic Compositions of
175 Geological Reference Materials: *Geostandards and Geoanalytical Research*, v. 40, no. 4,
176 p. 543-558.