

Supplemental Information

Literature values are divided into three categories based on analytical methods such as NAA, NI-NGMS and others such as IC, ID-MS, and ICP-MS. Literature values are summarized in Supplementary Material Tables S3, S4 and S5. When more than two data are reported, mean values are calculated in Supplementary Material Tables S3, S4 and S5, and these mean values are used for normalization in Figures 2, 3 and 4.

Literature

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Table S1. Abundances of Cl and Br (in $\mu\text{g g}^{-1}$) in GSJ geochemical reference materials analyzed by INAA and RNAA*.

Sample Name	INAA or RNAA	Sample Mass (g)	Cl						Br					
			1642 keV		2168 keV		Mean		554 keV		776 keV		Mean	
JA-1	RNAA	0.2310	46.0	± 9.0	43.7	± 8.6	44.9	± 2.0	0.106	± 0.021	0.110	± 0.030	0.108	± 0.004
JA-1	RNAA	0.3169	41.2	± 8.1	44.7	± 8.7	43.0	± 3.0	0.113	± 0.022	0.118	± 0.032	0.116	± 0.005
JB-2a	RNAA	0.3232	320	± 63	319	± 62	320	± 1	0.630	± 0.123	0.625	± 0.172	0.627	± 0.004
JB-2a	RNAA	0.2795	294	± 57	299	± 58	296	± 4	0.645	± 0.126	0.637	± 0.175	0.641	± 0.007
JB-3a	RNAA	0.3568	336	± 66	332	± 65	334	± 4	0.700	± 0.136	0.658	± 0.180	0.679	± 0.037
JB-3a	RNAA	0.2782	289	± 56	302	± 59	296	± 12	0.635	± 0.125	0.644	± 0.177	0.640	± 0.008
JCp-1	RNAA	0.1195	827	± 162	821	± 160	824	± 5	4.29	± 0.84	4.09	± 1.12	4.19	± 0.18
JCp-1	INAA	0.0707	827	± 32	821	± 30	824	± 5	4.29	± 0.16	4.09	± 0.16	4.19	± 0.18
JCp-1	INAA	0.0669	634	± 28	607	± 29	620	± 24	2.86	± 0.15	2.87	± 0.18	2.86	± 0.005
JCt-1	RNAA	0.3168	119	± 23	138	± 27	128	± 17	0.254	± 0.050	0.249	± 0.068	0.251	± 0.004
JCt-1	RNAA	0.3307	96.3	± 19	98.7	± 19.3	97.5	± 2.2	0.209	± 0.041	0.222	± 0.061	0.216	± 0.012
JF-2	RNAA	0.3008	32.5	± 6.4	33.1	± 6.5	32.8	± 0.5	0.103	± 0.020	0.114	± 0.031	0.108	± 0.010
JF-2	RNAA	0.3586	37.0	± 7.2	35.6	± 6.9	36.3	± 1.2	0.110	± 0.021	0.102	± 0.028	0.106	± 0.006
JG-3	RNAA	0.2930	178	± 35	182	± 36	180	± 4	0.113	± 0.022	0.110	± 0.030	0.112	± 0.003
JG-3	RNAA	0.2984	170	± 33	182	± 36	176	± 11	0.188	± 0.037	0.205	± 0.056	0.197	± 0.015
JGb-1	RNAA	0.3464	1790	± 360**	1730	± 340	1760	± 54	0.158	± 0.032	0.141	± 0.039	0.150	± 0.015
JGb-1	RNAA	0.3328	61.5	± 12.0	59.1	± 11.5	60.3	± 2.1	0.0626	± 0.0122	0.0576	± 0.0157	0.0601	± 0.0044
JH-1	RNAA	0.3029	251	± 49	265	± 52	258	± 13	0.130	± 0.026	0.123	± 0.034	0.126	± 0.007
JH-1	RNAA	0.3183	153	± 30	157	± 31	155	± 3	0.0827	± 0.0162	0.0837	± 0.0230	0.0832	± 0.0008

JP-1	RNAA	0.2550	78.8 ± 15.4	75.6 ± 14.8	77.2 ± 2.9	0.279 ± 0.055	0.279 ± 0.077	0.279 ± 0.001
JP-1	RNAA	0.2721	93.4 ± 18.3	92.6 ± 18.1	93.0 ± 0.7	0.287 ± 0.058	0.258 ± 0.072	0.272 ± 0.026
JR-3	RNAA	0.1027	126 ± 25	128 ± 25	127 ± 2	0.476 ± 0.093	0.463 ± 0.127	0.469 ± 0.012
JR-3	RNAA	0.1098	159 ± 31	140 ± 28	150 ± 16	0.547 ± 0.107	0.584 ± 0.160	0.565 ± 0.033
JR-3	RNAA	0.2598	120 ± 23	123 ± 24	122 ± 3	0.448 ± 0.087	0.471 ± 0.129	0.459 ± 0.021
JR-3	RNAA	0.2506	143 ± 28	137 ± 27	140 ± 5	0.539 ± 0.105	0.535 ± 0.147	0.537 ± 0.004
JR-3	RNAA	0.1163	121 ± 24	118 ± 23	120 ± 2	0.488 ± 0.095	0.468 ± 0.128	0.478 ± 0.018
JR-3	RNAA	0.1859	127 ± 25	130 ± 25	128 ± 3	0.481 ± 0.094	0.492 ± 0.135	0.486 ± 0.010
JR-3	RNAA	0.1001	104 ± 20	119 ± 23	111 ± 13	0.422 ± 0.083	0.424 ± 0.117	0.423 ± 0.002
JR-3	RNAA	0.0955	154 ± 30	146 ± 29	150 ± 7	0.563 ± 0.115	0.522 ± 0.147	0.542 ± 0.037
JR-3	RNAA	0.2068	134 ± 26	125 ± 24	129 ± 8	0.483 ± 0.095	0.557 ± 0.153	0.520 ± 0.065
JR-3	RNAA	0.2028	139 ± 27	148 ± 29	143 ± 8	0.541 ± 0.105	0.588 ± 0.161	0.564 ± 0.042
JR-3	RNAA	0.2229	206 ± 40	198 ± 39	202 ± 7	0.621 ± 0.121	0.616 ± 0.169	0.618 ± 0.005
JSO-1	RNAA	0.0391	165 ± 32	160 ± 31	162 ± 5	101 ± 20	96.1 ± 26.3	98.8 ± 4.7
JSO-1	INAA	0.0311	<290	164 ± 35	164 ± 35	93.7 ± 1.7	96.3 ± 1.9	95.0 ± 2.3
JSO-1	INAA	0.0259	186 ± 38	181 ± 32	184 ± 4	94.3 ± 1.5	96.9 ± 1.6	95.6 ± 2.3
JDo-1	INAA	0.0729	38.0 ± 6.2	42.9 ± 5.3	40.5 ± 4.3	0.611 ± 0.081	0.534 ± 0.062	0.572 ± 0.068
JLk-1	INAA	0.0261	<390	<120	<120	9.26 ± 0.54	7.32 ± 0.57	8.29 ± 1.72
JLs-1	INAA	0.0845	<13	14.2 ± 2.5	14.2 ± 2.5	0.162 ± 0.032	0.171 ± 0.025	0.167 ± 0.008

* Individual values with their associated combined uncertainties (see text for details).

Table S2. Chemical yields (in %) of Cl and Br in RNAA*.

Sample	Sample	Cl		Br		I	
Name	Mass (g)	1642 keV	2168 keV	554 keV	776 keV	443 keV	
JA-1	0.2310	79.4 ± 15.5	82.7 ± 16.1	68.4 ± 13.2	67.0 ± 19.8	77.8 ± 14.9	
JA-1	0.3169	79.2 ± 15.4	75.8 ± 14.8	65.6 ± 12.7	63.4 ± 17.2	71.3 ± 13.7	
JB-2a	0.3232	75.3 ± 14.7	77.0 ± 15.0	52.1 ± 10.1	50.5 ± 13.7	67.4 ± 13.0	
JB-2a	0.2795	70.5 ± 13.7	70.3 ± 13.7	58.9 ± 11.4	60.3 ± 16.4	73.5 ± 14.1	
JB-3a	0.3568	74.3 ± 14.5	74.7 ± 14.5	32.9 ± 6.4	34.0 ± 9.2	59.0 ± 11.3	
JB-3a	0.2782	91.3 ± 17.8	88.7 ± 17.3	89.0 ± 17.2	90.1 ± 24.5	83.9 ± 16.1	
JCp-1	0.1195	57.8 ± 11.3	58.5 ± 11.4	59.5 ± 11.5	62.1 ± 16.9	60.4 ± 11.6	
JCt-1	0.3168	74.9 ± 14.8	64.3 ± 12.7	71.7 ± 13.9	70.8 ± 19.2	55.6 ± 10.7	
JCt-1	0.3307	82.7 ± 16.1	81.2 ± 15.8	75.2 ± 14.5	79.3 ± 21.5	76.8 ± 14.8	
JF-2	0.3008	69.3 ± 13.5	68.4 ± 13.3	33.7 ± 6.5	32.9 ± 9.0	70.6 ± 13.6	
JF-2	0.3586	57.3 ± 11.1	58.2 ± 11.3	43.4 ± 8.4	43.6 ± 11.9	63.6 ± 12.2	
JG-3	0.2930	81.5 ± 15.9	80.5 ± 15.7	68.1 ± 13.2	69.3 ± 18.8	73.6 ± 14.1	
JG-3	0.2984	80.5 ± 15.9	73.3 ± 14.4	57.6 ± 11.2	55.2 ± 15.0	67.8 ± 13.0	
JGb-1	0.3464	1.9 ± 0.4**	1.9 ± 0.4	4.5 ± 0.9	4.5 ± 1.2	29.0 ± 5.6	
JGb-1	0.3328	82.5 ± 16.1	82.3 ± 16.0	64.9 ± 12.5	66.9 ± 18.2	69.5 ± 13.4	
JH-1	0.3029	37.7 ± 7.3	35.2 ± 6.9	6.6 ± 1.3	6.6 ± 1.8	42.3 ± 8.1	
JH-1	0.3183	80.9 ± 15.8	79.7 ± 15.5	73.2 ± 14.1	72.7 ± 19.7	72.2 ± 13.9	
JP-1	0.2550	66.4 ± 12.9	68.6 ± 13.3	13.5 ± 2.6	12.8 ± 3.5	73.9 ± 14.2	
JP-1	0.2721	56.9 ± 11.1	55.7 ± 10.9	7.5 ± 1.5	8.2 ± 2.2	63.4 ± 12.2	

JR-3	0.1027	81.8 ± 15.8	79.7 ± 15.4	45.0 ± 8.7	43.8 ± 11.9	64.9 ± 12.5
JR-3	0.1098	68.8 ± 13.4	72.1 ± 14.0	57.9 ± 11.2	57.9 ± 15.7	65.3 ± 12.6
JR-3	0.2598	71.2 ± 13.8	73.3 ± 14.2	52.9 ± 10.2	52.5 ± 14.3	53.0 ± 10.2
JR-3	0.2506	73.5 ± 14.3	76.1 ± 14.8	69.3 ± 13.4	70.2 ± 19.1	58.5 ± 11.3
JR-3	0.1163	83.5 ± 16.3	86.1 ± 16.8	74.3 ± 14.3	72.9 ± 19.8	84.0 ± 16.1
JR-3	0.1859	84.2 ± 16.4	83.4 ± 16.2	75.4 ± 14.6	75.5 ± 20.5	76.7 ± 14.8
JR-3	0.1001	86.2 ± 16.8	77.8 ± 15.2	68.9 ± 13.3	70.2 ± 19.1	69.7 ± 13.4
JR-3	0.0955	54.2 ± 10.5	53.6 ± 10.4	31.7 ± 6.1	32.5 ± 8.8	72.8 ± 14.0
JR-3	0.2068	75.4 ± 14.7	78.5 ± 15.3	47.9 ± 9.3	45.5 ± 12.4	81.4 ± 15.7
JR-3	0.2028	76.5 ± 14.9	73.3 ± 14.3	38.3 ± 7.4	37.6 ± 10.2	68.6 ± 13.2
JR-3	0.2229	53.6 ± 10.4	54.2 ± 10.5	66.5 ± 12.8	66.4 ± 18.0	70.6 ± 13.6

Table S3. Literature values (in $\mu\text{g g}^{-1}$) for Cl, Br, and I in the GSJ geochemical reference materials using NAA.

Sample Name	Source	Method	Cl	Br	I
JA-1	Ebihara et al. (1992)	RNAA			0.015
	Shinonaga et al. (1994)	RNAA	49	0.41	
	Sano et al. (2004)	PGA	45.5		
	Mean value		47		
J Cp-1	Sekimoto et al. (2019)	RNAA	620	3.22	6.14
J Ct-1	Sekimoto et al. (2019)	RNAA	103	0.301	0.031
J F-2	Shinonaga et al. (1994)	RNAA	40	0.15	0.034
	Korotev (1996)	INAA		0.10	
	Mean value			0.13	
J G-3	Korotev (1996)	INAA		0.22	
J Gb-1	Shinonaga et al. (1994)	RNAA	68	0.28	0.074
J P-1	Shinonaga et al. (1994)	RNAA	85		
	Shinonaga et al. (1994)	RNAA		0.29	
	Shinonaga et al. (1994)	RNAA			0.086
	Korotev (1996)	INAA		0.25	
	Mean value			0.27	
J R-3	Ozaki and Ebihara (2007)	RNAA	129	0.533	0.462
	Sekimoto and Ebihara (2013)	RNAA	134	0.577	0.482
	Mean value		132	0.555	0.472
J B-2	Ebihara et al. (1992)	RNAA			0.049
	Shinonaga et al. (1994)	RNAA	321	0.8	0.059
	Korotev (1996)	INAA		0.6	
	Mean value			0.7	0.054
J B-3	Shinonaga et al. (1994)	RNAA	336		
	Ebihara et al. (1992)	RNAA			0.028
	Korotev (1996)	INAA		0.53	

Table S4. Literature values (in $\mu\text{g g}^{-1}$) for Cl, Br, and I in the GSJ geochemical reference materials using NI-NGMS.

Sample Name	Source	Method	Cl	Br	I
JA-1	Kobayashi et al. (2021)	NI-NGMS	17.1	0.0464	0.01016
	Kobayashi et al. (2021)	NI-NGMS	5.24	0.0620	0.0143
	Mean value		11.2	0.0542	0.0122
JGb-1	Kobayashi et al. (2021)	NI-NGMS	64.6	0.0246	0.0447
	Kobayashi et al. (2021)	NI-NGMS	62.0		
	Mean value		63.3		
JP-1	Kobayashi et al. (2021)	NI-NGMS	44.7	0.1273	0.0277
	Kobayashi et al. (2021)	NI-NGMS	46.3	0.161	0.0284
	Mean value		45.5	0.144	0.0281
JB-2	Kobayashi et al. (2021)	NI-NGMS	165	0.706	0.0501
	Kobayashi et al. (2021)	NI-NGMS	170	0.530	0.0368
	Mean value		168	0.618	0.0435
JB-3	Kobayashi et al. (2021)	NI-NGMS	214	0.604	0.0258
	Kobayashi et al. (2021)	NI-NGMS	201	0.630	0.0274
	Mean value		208	0.617	0.0266

Table S5. Literature values (in $\mu\text{g g}^{-1}$) for Cl, Br, and I in the GSJ geochemical reference materials using other methods.

Sample Name	Source	Method	Cl	Br	I
JA-1	Shinonaga et al. (1994)	ID-MS	40.7	0.41	
	Shimizu et al. (2007)	IC	41.3		
	Wang et al. (2010)	IC	42		
	Shimizu et al. (2015)	IC	40		
	Mean value		41		
JCp-1	Chai and Muramatsu (2007)	ICP-MS		3.25	5.5
JG-3	Fujitani and Nakamura (2006)	ID-MS	156.6		
JGb-1	Schnetger et al. (1998)	ICP-MS			0.075
	Shimizu et al. (2015)	IC	60		
	Mean value				0.075
JP-1	Schnetger et al. (1998)	ICP-MS			0.068
	Schnetger et al. (1998)	ICP-MS		0.21	
	Shimizu et al. (2007)	IC	82.1		
	Shimizu et al. (2015)	IC	74		
	Mean value		78		
JSO-1	Chai and Muramatsu (2007)	ICP-MS		98	26.9
JB-2	Shinonaga et al. (1994)	ID-MS	297		
	Fujitani and Nakamura (2006)	ID-MS	266.3		
	Chai and Muramatsu (2007)	ICP-MS		0.708	0.063
	Shimizu et al. (2007)	IC	278		
	Shimizu et al. (2015)	IC	293		
	Mean value		284		
JB-3	Schnetger et al. (1998)	ICP-MS			0.02
	Fujitani and Nakamura (2006)	ID-MS	260.8		
	Shimizu et al. (2007)	IC	262		
	Shimizu et al. (2015)	IC	293		
	Mean value		272		