LETTER

1994 compilation values for GSJ reference samples, "Igneous rock series"

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New compilation data for major, minor and trace elements in 17 GSJ (Geological Survey of Japan) reference samples, "Igneous rock series" is presented as 1994 values. The compilation is based on reported data in publications and personal communications received by April 1994, which we have evaluated statistically in consideration of analytical methods and analytical procedures. In this 1994 compilation recommended or preferable values for 79 elements are proposed.

INTRODUCTION

The Geological Survey of Japan (GSJ) has issued a series of rock reference samples since 1967 for the analyses of major, minor and trace elements, isotopic compositions and isotopic ages. This project was completed with 17 samples in 1986, and recent compilations of the analytical data for the 17 samples have been published by Ando *et al.* (1987, 1989). Among those compilations, however, concentrations of some elements were remained uncertain, being due to the insufficient accumulation of analytical data, especially for the samples recently issued. After the 1978 and 1989 compilations, concentration data for selected several elements such as Ag, Au, Pd, Pt, Sc, Y, Zr, Hf, rare earth elements and major elements have fragmentarily been compiled (Terashima *et al.*, 1992, 1994; Itoh *et al.*, 1992).

In this paper, we evaluate all the analytical data received by April 1994 for major, minor and trace elements, and a new set of 1994 recommended and preferable values is proposed for the 17 reference samples.

NOTE ON THE SAMPLES

The 17 reference samples include three granitic rocks from Sori granodiorite JG-1, Naegi granite (ilmenite series) JG-2, and Mitoya granodiorite (magnetite series) JG-3; two rhyolites (obsidian) from Wada Toge JR-1 (north) and JR-2 (south); three andesites from Hakone volcano JA-1, Goshikidai sanukitoid JA-2 and Asama volcano JA-3; three basalts from Kitamatsuura flood basalt (alkali basalt) JB-1, O-shima volcano (tholeiitic basalt) JB-2 and Fuji volcano (high-alumina basalt) JB-3; one gabbro from Utsushigatake JGb-1; and one peridotite from Horoman dunite JP-1. Two mineral reference samples were also prepared from O-hira feldspar JF-1 (a mixture of orthoclase and albite, separated from a granite by mechanical grinding and sieving) and Kurosaka feldspar JF-2 (orthoclase occurring in a pegmatite). The details of sample descriptions including their locations and sample processing methods were described in a previous paper (Ando *et al.*, 1987).

Both JB-1 and JG-1 were exhausted in 1981 and JB-1a and JG-1a were prepared for their re-

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placement. However, the newly prepared JB-1a and JA-1 have also been exhausted.

ANALYTICAL DATA

We have received 911 reports, including 449 publications and 462 personal communications, for the 17 reference samples by April 1994. Table 1 summarizes the 1994 recommended or preferable values for the GSJ reference samples of igneous rock series. These values were obtained by calculating the mean, after eliminating aberrant data in consideration of analytical methods and analytical procedures and data outside two times the standard deviation from the mean (Gladney *et al.*, 1991). When the number of available data is more than five, the mean value is presented as the recommended value. When the number is less than four, the mean value is proposed as the preferable value which is designated by asterisk on the right side of the figures. This report is a brief summary of the analytical results. Full data including all the analytical data, analytical methods and references will be published elsewhere.

In this compilation we were able to assign the recommended and preferable values for many elements which were not presented in the previous compilations. However, most compilation data of platinum group (Ir, Pd, Pt, Ru), In, Hg, Se, W and halogen still remain as preferable values, and Rh and Te have no recommended nor preferable values. Much more reliable data are expected for those elements to obtain recommended values.

Geologists, geochemists or analytical chemists who are interested in participating in our analytical program for the GSJ geochemical reference samples are invited to write to Dr. Noboru Imai, Geochemistry Section, Geological Survey of Japan, 1-1-3 Higashi, Tsukuba 305, Japan.

Table 1. 1994 recommended and preferable (asterisked) values for GSJ reference samples, "Igneous rock series" (major elements in % and minor and trace elements in ppm, unless otherwise noted)

	JA-1	JA-2	JA-3	JB-1	JB-1a	JB-2	JB-3	JF-1	JF-2	JG-1	JG-1a	JG-2	JG-3	JGb-1	JP-1	JR-1	JR-2
SiO ₂	63.97	56.42	62.27	52.37	52.41	53.25	50.96	66.69	65.30	72.30	72.30	76.83	67.29	43.66	42.38	75.45	75.69
TiO ₂	0.85	0.66	0.70	1.32	1.28	1.19	1.44	0.005	0.005	0.26	0.25	0.044	0.48	1.60	0.006*	0.11	0.07
Al ₂ O ₃	15.22	15.41	15.56	14.53	14.45	14.64	17.20	18.08	18.52	14.24	14.30	12.47	15.48	17.49	0.66	12.83	12.72
Fe ₂ O ₃	2.59	2.16	1.15	2.33	2.55	3.33	3.20	0.06	0.06	0.38	0.51	0.33	1.62	4.79	1.98	0.35	0.27
FeO	3.98	3.69	4.83	5.99	5.78	9.98	7.85	<0.04*	<0.03*	1.61	1.36	0.57	1.83	9.43	5.99	0.49	0.44
MnO	0.157	0.108	0.104	0.153	0.148	0.218	0.177	0.001	0.001	0.063	0.057	0.016	0.071	0.189	0.121	0.099	0.112
MgO	1.57	7.60	3.72	7.71	7.83	4.62	5.19	0.006	0.004*	0.74	0.69	0.037	1.79	7.85	44.60	0.12	0.04
CaO	5.70	6.29	6.24	9.25	9.31	9.82	9.79	0.93	0.09	2.20	2.13	0.70	3.69	11.90	0.55	0.67	0.50
Na ₂ O	3.84	3.11	3.19	2.77	2.73	2.04	2.73	3.37	2.39	3.38	3.39	3.54	3.96	1.20	0.021	4.02	3.99
K ₂ O	0.77	1.81	1.41	1.43	1.40	0.42	0.78	9.99	12.94	3.98	3.96	4.71	2.64	0.24	0.003	4.41	4.45
P ₂ O ₅	0.165	0.146	0.116	0.255	0.260	0.101	0.294	0.01	0.003*	0.099	0.083	0.002	0.122	0.056	0.002*	0.021	0.012
H ₂ O*	0.72	1.12	0.20	1.02	0.92	0.25	0.18	0.23	0.24	0.54	0.59	0.33	0.67	1.28	2.39	1.16	1.19
H ₂ O ⁺	0.30	1.25	0.11	0.95	0.92	0.13	0.07	0.13	0.18	0.07	0.12	0.12	0.17	0.13	0.44	0.20	0.22
T-Fe ₂ O ₃	7.07	6.21	6.60	8.99	9.05	14.25	11.82	0.08	0.06	2.18	2.00	0.97	3.69	15.06	8.37	0.89	0.77

Table 1. (continued)

	JA-1	JA-2	JA-3	JB-1	JB-1a	JB-2	JB-3	JF-1	JF-2	JG-1	JG-1a	JG-2	JG-3	JGb-1	JP-1	JR-1	JR-2
Ag	0.033*	0.043*	0.084	0.049	0.041*	0.072*	0.075	0.017*	0.019*	0.034	0.023*	0.019*	0.029*	0.024*	1.5*	0.031*	0.028*
Al (%)	8.06	8.16	8.23	7.69	7.65	7.75	9.10	9.57	9.80	7.54	7.57	6.60	8.19	9.26	0.35	6.79	6.73
As	2.78	0.85*	4.68*	2.33	2.30	2.87	1.84	0.92*	0.28*	0.33	0.43*	0.68*	0.37*	1.09	0.34	16.3	19.2
Au (ppb)	0.16	0.26	0.95*	0.79	0.71	5.64	1.99	0.11*	0.12*	0.11	0.21	0.059*	0.17	1.02	0.23*	0.25	0.13
B	21.0	20.7	24.8	9.35*	7.88	30.2	18.0	1.8*	1.6*	6.87	3.95	1.78*	2.15*	4.03	1.4*	117	145
Ba	311	321	323	493	504	222	245	1750	298	466	470	81.0	466	64.3	19.5	50.3	39.5
Be	0.50	2.05	0.80	1.33	1.44	0.26*	0.81	1.3*	0.77*	3.15	3.16	3.26	1.60*	0.34*	<0.1*	3.34	3.75
Bi	0.0091*	0.07*	0.05*	0.033		0.033*	0.023*			0.50	0.43*	0.64*	0.05*	0.014*		0.56	0.62
Br	271*	141*	61*	470*	312*	218*	120*	<20*	38*	216*	295*	35*	120*	300*	764*	70.8	63*
C	4.07	4.50	4.46	6.61	6.65	7.02	7.00	0.66	0.06	1.57	1.52	0.50	2.64	8.50	0.39	0.48	0.36
Ca (%)	0.11	0.078*	0.089*	0.11	0.10	0.14	0.081	0.003*	0.003*	0.040	0.026*	0.004*	0.054*	0.087	0.011*	0.026	0.023
Cd	13.3	32.7	22.8	67.8	65.9	6.76	21.5	4.19	0.84	45.8	45.0	48.3	40.3	8.17	0.19*	47.2	38.8
Ce	43.0			176	171*	281	259*			58.1	65*		156*	81*	97*	920	736*
Cl	12.3	29.5	21.1	38.2	38.6	38.0	34.3	0.12	0.68	4.06	5.90	3.62	11.7	60.1	116	0.83	0.46
Co	7.83	436	66.2	425	392	28.1	58.1	5.48	2.47*	53.2	17.6	6.37	22.4	57.8	2807	2.83	3.10
Cr	0.62	4.63	2.08	1.23	1.31	0.85	0.94	2.09	1.06	10.1	10.6	6.79	1.78	0.26	0.15*	20.8	25.0
Cs	43.0	29.7	43.4	55.1	56.7	225	194	0.82	0.78	2.52	1.67	0.49	6.81	85.7	6.72	2.68	1.36
Cu	4.55	2.80	3.01	4.14	3.99	3.73	4.54	0.39	0.036*	4.14	4.44	10.5	2.59	1.56	0.022*	5.69	6.63
Dy	3.04	1.48	1.57	2.27	2.18	2.60	2.49	0.31	0.034*	2.16	2.57	6.04	1.52	1.04	0.016*	3.61	4.36
Er	1.20	0.93	0.82	1.49	1.46	0.86	1.32	0.87	0.59	0.73	0.70	0.10	0.90	0.62	0.004*	0.30	0.14
Eu	161	223*	286*	385	357	98.5	253	78*	16*	498	439	972*	317*	133	14*	991	1109
F	4.95	4.34	4.62	6.29	6.33	9.97	8.27	0.06	0.04	1.52	1.40	0.68	2.58	10.53	5.85	0.62	0.54
Fe (%)	16.7	16.9	16.3	17.9	17.9	17.0	19.8	17.4	17.9	17.8	16.5	18.6	17.1	17.9	0.70*	16.1	17.9
Ga	4.36	3.06	2.96	4.90	4.67	3.28	4.67	0.93	0.072*	4.28	4.08	8.01	2.92	1.61	0.015*	5.06	5.83
Gd	1.33	1.05*		0.90	1.02*	1.35	1.12			1.44	1.5*	1.70*	1.06*	1.01	0.49*	1.88	1.88*
Ge	2.42	2.86	3.42	3.31	3.41	1.49	2.67	1.18	0.19	3.56	3.59	4.73	4.29	0.88	0.20	4.51	5.14
Hf	11.7*	1.8*	1.9*	29.9	6.65*	4.78	2.4*	1.6*	1.7*	16.5	4.1*	3.3*	2.4*	4.2*	5.3*	3.4*	0.9*
Hg (ppb)	0.95	0.50	0.51	0.79	0.71	0.75	0.80	0.11	0.021*	0.81	0.82	1.67	0.38	0.33	0.018*	1.11	1.39
I	0.015*	0.005*		0.030*	0.021*	0.049*	0.028*	0.11		0.012*						0.080*	0.067*
In	0.0494*			0.058*	0.057*	0.094*	0.069*			0.044*	0.025*	0.021*				0.028*	
Ir (ppb)	0.0028*	0.013*	0.014*		0.023*		0.037*					0.0040*	0.0016*		2.0*		0.0022*
K (%)	0.64	1.50	1.17	1.19	1.16	0.35	0.65	8.29	10.74	3.30	3.29	3.91	2.19	0.20	0.002	3.66	3.69
La	5.24	15.8	9.33	38.6	37.6	2.35	8.81	2.80	0.63	22.4	21.3	19.9	20.6	3.60	0.084	19.7	16.3
Li	10.8	27.3	14.5	11.5	10.9	7.78	7.21	9.81	2.19	86.6	79.5	42.2	20.9	4.59	1.79*	61.4	79.2
Lu	0.47	0.27	0.32	0.31	0.33	0.40	0.39	0.053	0.020	0.39	0.44	1.22	0.26	0.15	0.0044*	0.71	0.88
Mg (%)	0.95	4.58	2.24	4.65	4.72	2.79	3.13	0.004		0.45	0.42	0.02	1.08	4.73	26.9	0.07	0.02
Mn (%)	0.122	0.084	0.081	0.118	0.115	0.169	0.137	0.001	0.001	0.049	0.044	0.012	0.055	0.146	0.094	0.077	0.087
Mo	1.59	0.60	1.89	27.4*	1.57	1.08	1.09	0.30*	0.21*	1.75	0.45	0.37	0.45	0.59	0.087*	3.25	3.35
Na (%)	2.85	2.31	2.37	2.05	2.03	1.51	2.03	2.50	1.77	2.51	2.51	2.63	2.94	0.89	0.02	2.98	2.96
Nb	1.85	9.47	3.41	33.3	26.9	1.58*	2.47	0.74	0.70	12.4	11.4	14.7	5.88	3.34	1.48	15.2	18.7
Nd	10.9	13.9	12.3	26.8	26.0	6.63	15.6	1.46	0.33*	19.3	20.4	26.4	17.2	5.47	0.072*	23.3	20.4

Table 1. (continued)

	JA-1	JA-2	JA-3	JB-1	JB-1a	JB-2	JB-3	JF-1	JF-2	JG-1	JG-1a	JG-2	JG-3	JGb-1	JP-1	JR-1	JR-2
Ni	3.49*	130	32.2	133	139	16.6	36.2	1.36*	1.38*	7.47	6.91	4.35*	14.3	25.4	2460	1.67*	1.99*
Os (ppb)	0.072	0.064	0.051	0.111	0.11	0.044	0.128	0.004		0.043	0.036	0.001	0.053	0.024	7.9*	0.009	0.005
P (%)	6.55	19.2	7.70	10.0*	6.76	5.36	5.58	33.4	48.7	25.4	26.4	31.5	11.7	1.92	0.12*	19.3	21.5
Pb	<0.2*	0.5*	1.0*	0.7*	0.6*	6.3*	3.2*	<0.2*	<0.2*	<0.2*	<0.2*	<0.2*	<0.2*	0.18*	1.3*	<0.2*	<0.2*
Pd (ppb)	1.71	3.84	2.40	7.01	7.30	1.01	3.11	0.48	0.088*	4.83	5.63	6.20	4.70	1.13	0.020*	5.58	4.75
Pr	0.5*	1.3*	1.7*	1.6*	1.6*	4.0*	4.3*	<0.5*	<0.5*	<0.5*	<0.5*	<0.5*	<0.5*	<0.5*	4.9*	<0.5*	<0.5*
Pt (ppb)				0.72*						1.24*							
Ra (ppb)	12.3	72.9	36.7	41.3	39.2	7.37	15.1	266	218	182	178	301	67.3	6.87	0.80*	257	303
Rb	0.45*	0.063*	0.65*	0.18*	0.38*		0.24*			0.098*	0.015*	0.016*	0.033*	0.27*	0.015*	0.046*	0.023*
Re (ppb)																	
Rh																	
Ru (ppb)	21.6	8*	214*	19.4	10.2*	17.9	9.86	<5*	2.8*	10.9	11*	7.0*	54.7*	1910	6.5*	13.3	9.6*
S	0.22	0.14*	0.32*	0.28	0.25*	0.25	0.12	0.055*	0.04*	0.13	0.048*	0.057*	0.08*	0.085*	0.034*	1.19	1.51
Sb	28.5	19.6	22.0	27.5	27.9	53.5	33.8	0.23	0.089	6.53	6.21	2.42	8.76	35.8	7.24	5.07	5.59
Se	0.0088*			0.023	0.021*	0.19*	0.069*			0.0030				0.15*		0.006*	0.0028*
Si (%)	29.90	26.37	29.11	24.48	24.50	24.89	23.82	31.17	30.52	33.80	33.80	35.91	31.45	20.41	19.81	35.27	35.38
Sn	3.52	3.11	3.05	5.13	5.07	2.31	4.27	0.41	0.11	4.62	4.53	7.78	3.39	1.49	0.019	6.03	5.63
Sn	1.16*	1.68	0.95*	1.92	2.24	0.95	0.94	0.3*	0.13*	3.60	4.47	3.00	1.40	0.48	0.05*	2.86	3.51
Sr	263	248	287	444	442	178	403	172	200	184	187	17.9	379	327	3.32*	29.1	8.11
Ta	0.13	0.80	0.27	2.93	1.93	0.13	0.15	0.079	0.045*	1.79	1.90	2.76	0.70	0.18	0.02*	1.86	2.29
Tb	0.75	0.44	0.52	0.82	0.69	0.60	0.73	0.076	0.009*	0.78	0.81	1.62	0.46	0.29	0.003*	1.01	1.10
Tc																	
Th	0.82	5.03	3.25	9.30	9.03	0.35	1.27	1.17	0.31	13.2	12.8	31.6	8.28	0.48	0.19	26.7	31.4
Ti (%)	0.51	0.40	0.42	0.79	0.77	0.71	0.86	0.003	0.003	0.16	0.15	0.026	0.29	0.96		0.066	0.04
Tl	0.13*	0.32	0.23*	0.10	0.087*		0.048*	1.18	1.10	1.03	0.98	1.55	0.40*	0.066*	0.003*	1.56	1.85
Tm	0.47	0.28	0.28*	0.35	0.33	0.41	0.42	0.04*	0.05*	0.41	0.38	1.16	0.24	0.16	<0.041*	0.67	0.74
U	0.34	2.21	1.18	1.67	1.57	0.18	0.48	0.33	0.078*	3.47	4.69	11.3	2.21	0.13	0.036	8.88	10.9
V	105	126	169	211	205	575	372	5.43	4.86	25.2	22.7	3.78	70.1	635	27.6	7.0	3.00
W	0.34*	0.99*	8.07*	17.1	1.83*	0.26*	1.06*	0.8*	4.3*	1.58*	12.4	23.0	14.1*	0.81*	0.85*	1.59	1.8*
Y	30.6	18.3	21.2	24.3	24.0	24.9	26.9	2.84	2.67	30.6	32.1	86.5	17.3	10.4	1.54	45.1	51.1
Yb	3.03	1.62	2.16	2.13	2.10	2.62	2.55	0.35	0.045*	2.47	2.70	6.85	1.77	1.06	0.022	4.55	5.33
Zn	90.9	64.7	67.7	85.2	82.1	108	100	4.41	1.40	41.1	36.5	13.6	46.5	109	41.8	30.6	27.8
Zr	88.3	116	118	141	144	51.2	97.8	38.6	6.73	111	118	97.6	144	32.8	5.92	99.9	96.3

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