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Article

Major and trace element abundances in the $<180\mu$ m and sand fractions of stream sediments from the Hino River, Tottori, Japan

Edwin Ortiz* and Barry P. Roser*

Abstract

X-ray fluorescence analyses for major elements and 14 trace elements were made of both the $<180 \,\mu$ m and sand fractions of 103 stream sediment samples collected from active channels of the Hino River, west Tottori Prefecture. Combined histograms of elemental abundances show clear dependence of composition on grain size, with the fine factions containing greater abundances of all elements except SiO₂, K₂O, Ba, Pb, and Rb. Distributions are representative of fractions taken from river sediments, with mainly positively skewed patterns. Bimodal or polymodal distributions in the sand fractions for a number of elements (Sr, SiO₂, K₂O, Al₂O₃, CaO, Na₂O, and Rb) reflect the influence of local source rocks on composition, as one of the modes is related to samples with catchments draining Mount Daisen. Variation diagrams also clearly display fractionation between the fine and sand fractions. The results show that samples originating from Mount Daisen are the most distinctive, especially with respect to high Sr abundances and relatively low Y, which reflect the adaktic nature of the source volcanics. Intermediate abundances in samples from the lower main channel reflect mixing and homogenization of detritus from two areas with contrasting lithologies, felsic granitoids and volcanics to the south, and volcanic products from Daisen to the northeast. Values of Cr are high in the upper reaches of the main channel, reflecting a strong provenance fingerprint from ultrabasic rocks. Abundances of this element then decrease steadily downstream due to dilution from Cr-poor lithotypes.

Key words: Geochemistry, stream sediments, $<180 \,\mu$ m fraction, sand fraction, Daisen products, granitoids, Hino River, Tottori.

Introduction

The geochemical compositions of modern stream sediments mainly reflect the chemical characteristics of the source lithotypes and derived soils contained in their catchments, and the influence of weathering, transport, sorting, and post-depositional processes. Studies of stream sediments have potential application in varied geological and geoenviromental research. This article presents the results of X-ray fluorescence (XRF) analysis of both fine (<180 μ m) and sand fractions (180-2000 μ m) of 103 stream sediments collected from the Hino River in the northern San -in District.

The Hino River catchment drains an area of about 860 km², and is located in west Tottori Prefecture, where its watershed constitutes the boundary with Shimane Prefecture. Study of the Hino River catchment and characterization of the sediments within it is of direct relevance to other work examining development of Yumigahama Peninsula related to past tatara mining, and of dispersion paths of sediments in Miho Bay.

The object of this report is to present the raw data obtained by XRF analysis, and to outline some of the general relations between abundances of elements in fractions of the bulk sediments from the Hino River. More detailed interpretation of the results will be published later. The dataset reported in this paper constitutes another step toward achieving a regional geochemical database for the northern San-in area. This work began with study of the Kando River (Ortiz and Roser, 2003; Ortiz and Roser, *this volume*), and is intended to extend to the Hii River.

Geological Outline

Most of the catchment area of the Hino River is occupied by felsic geological units, mainly Cretaceous to Paleogene granitoids and coeval volcanic rocks (Fig. 1). The granitoids are distributed throughout the central and southern regions of the watershed, and comprise granites, granite porphyries, diorites, granodiorites and gabbros. In contrast, the coeval volcanic rocks crop out mainly on the edges of the watershed, especially towards the southwest (Japan Institute of Construction Engineering "JICE", 1984; EBGMSP, 1997). Lithotypes include rhyolite, quartz andesite, andesite, and pyroclastics. Outcrops of several other less extensive units are scattered across the area (Fig. 1). These include Sangun Group ultrbasic-basic, calcareous, siliceous, and psammitic schists; Miocene-Pliocene augite basalts, olivine andesite lavas and pyroclastics; and Miocene to Jurassic sedimentary rocks (JICE, 1984).

Most of the rocks and units outlined above have been examined in varying detail during regional mapping or more specific studies of aspects such as granitoid petrogenesis (e.g., Ota, 1962; Hattori and Katada, 1964; Hashimoto, 1973; 1990; Hattori and Shibata, 1974; Murakami, 1974; Iizumi *et al.*, 1984; 2000; Research Group

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Fig. 1. Map showing the generalized distribution of lithotypes in the catchment of the Hino River and location of sample sites. Geology based on the 1:200,000 geological maps of Chugoku Area No 3 (Japan Institute of Construction Engineering, 1984) and Shimane Prefecture (Editorial Board of the Geological map of Shimane Prefecture, 1997).

for the Batholith in the San'in Zone, 1982; Nagao et al., 1990).

The geology in the downstream reaches consists of different lithotypes. Rhyolites, andesites, and andesitic pyroclastic rocks of the Hata Formation (EBGMSP, 1997) crop out in the northwest. Conversely, volcanic products associated with Mount Daisen dominate the northeastern corner of the study area. Daisen products include andesite to quartz andesite pyroclastics, websterites, amphibolite andesites, tuff-breccias, lapilli and volcanic ash deposits, among others. Several studies have examined the distribution of Daisen rocks and their characteristics (e.g., Ota, 1959; Miura *et al.*, 1991; Morris, 1995; Kimura *et al.*, 1999, 2003).

Considerable contrasts in source rock compositions thus exist within the catchment of the Hino River. For example, about one third of the total length of the main channel (corresponding to the lower reaches) receives material almost exclusively derived from the western flank of Mount Daisen. The rest of the main channel is primarily fed from felsic source rocks. Any modification of the drainage (e.g., dams, artificial channels) at specific locations could thus lead to changes in the chemical composition of detritus reaching Miho Bay. Such modification has occurred in the past, with massive influx of granitoid waste from historic tatara mining leading to accelerated growth of Yumigahama Peninsula.

Sampling and Sample Preparation

Field sampling

Field work to collect the stream sediments was carried on nine days in October and early November, 2003. Weather conditions were generally fine, and streams clear. Composite samples were collected with a plastic water scoop from active channels, and stored in plastic zip-top bags. Where possible, samples were taken from both sides of the streams over a channel length of 10-30 m.

An array of sampling sites was selected with the aim of establishing a uniform distribution that would cover all source lithologies present. Sites were identified on 1:50,000 topographic maps, according to the lithotypes present from the 1:200,000 geological maps of western Tottori and Shimane Prefectures (JICE, 1984; EBGMSP, 1997).

Samples were collected from 103 sites in the Hino catchment (Fig. 1), numbered in order of collection. Some sampling sites had to be displaced from the location originally planned due to unfavorable conditions, including lack of access, disturbance by current construction projects, or simply because of paucity of sand-sized sediment. The overall sampling density was one sample per 8.3 km².

Sample preparation

Bulk samples were dried at 80-90°C the day after collection. Dried bulk samples were than passed through an

8.6 mesh sieve to remove material coarser than 2 mm. Average weight of the <2 mm fractions was 1342 g. These were then split into manageable portions using a simple aluminium chute, and these later put through an 83 mesh stainless steel sieve to separate the <180 μ m (fine fraction) and the 180-2000 μ m (sand) fraction. For most samples, sieving of an eighth or quarter split was sufficient to provide enough <180 μ m material for the XRF analysis. For six samples, half the bulk <2 mm fraction had to be used, and for one particularly well-sorted sample three quarters of the bulk material was sieved. On average, the fine fractions comprised 12.1 wt% of the <2 mm bulk fraction. Only in ten samples did the fine fraction exceed 30 wt%.

The fine and sand fractions were then separately crushed in tungsten carbide mills. The fine fractions were crushed in a small puck mill for about 10-15 seconds, in loads of 12-20 g, whereas the sand fractions were crushed in a larger ring mill for 30 seconds, in loads ranging between 50 and 150 g. Subsamples (7-10 g) of the crushed material were then stored in glass vials and dried at 110°C for at least 24 hours before determination of loss on ignition (LOI).

Analytical Methods

Gravimetric LOI was determined for each sample from the net weight loss after ignition in a muffle furnace at 1000 $^{\circ}$ C for two hours. The ignited materials were then manually disaggregated in an agate pestle and mortar, and returned to a 110 $^{\circ}$ C oven for at least 24 hours prior to the preparation of fusion beads for X-ray fluorescence analysis (anhydrous basis).

Major elements and 14 trace elements (Ba, Ce, Cr, Ga, Nb, Ni, Pb, Rb, Sc, Sr, Th, V, Y, Zr) were determined using a Rigaku RIX-2000 XRF at Shimane University. All analyses were carried out on fused glass beads prepared with an alkali flux comprising 80% lithium tetraborate and 20% lithium metaborate. The flux to sample ratio was 2:1. The analytical methods, instrumental conditions, and calibrations used were those described by Kimura and Yamada (1996). Analyses were monitored using new beads for seven GSJ and USGS standards. More detailed descriptions of the methods utilized in this study are given by Roser *et al.* (2000, 2001) and Ortiz and Roser (2003).

Results and Discussion

Major and trace element results for the fine fractions and the sand fractions are given in Tables 1 and 2 respectively, reported on a hydrous basis. LOI values in the fine fractions were generally <10 wt%, but occasional higher values (>10%) suggest that some samples are enriched in organic matter. In contrast, LOI values for the sand fractions are considerably lower, with most <3 wt %. Only six samples have higher values, ranging up to 5.7 wt %.

Summary statistics for the fine and sand fractions are

Major and trace element abundances in the ${<}180\mu m$ and sand fractions of stream sediments from the Hino River, Tottori, Japan

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SaNr	TYPE	SiO ₂	TiO ₂	Al ₂ O ₃ F	e ₂ O ₃ T	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	SUM	Ba	Ce	Cr	Ga	Nb	Ni	Pb	Rb	Sc	Sr	Th	V	Y	Zr	% Fines
HN-1F HN-2F	MCBDPI HI	58.29 63.22	0.78 0.68	14.48 17.46	5.16 4.64	0.17 0.17	1.80 0.93	2.59 1.64	4.36 3.19	2.79 2.73	0.16 0.16	8.55 5.14	99.12 99.96	324 382	72 88	150 26	11 19	10 12	33 12	8 19	93 99	10.3 10.1	325 197	14.8 19.0	118 73	36 44	317 314	1.0 52.5
HN-3F HN-4F	GDP GDP	61.38 60.47	0.74 1.98	18.66 13.29	5.74 11.14	0.11 0.25	1.34 2.05	1.92 2.44	4.28 2.63	2.45 2.49	0.10 0.12	3.50 2.23	100.21 99.08	306 363	86 119	57 2052	21 17	12 19	21 53	16 18	89 87	11.2 15.1	233 185	27.0 26.7	96 307	39 53	404 755	5.9 16.9
HN-5F HN-6F	GDP DP	70.87 56.56	0.35	14.27 18.92	2.32	0.08	0.61	1.30	3.89	3.84 1.13	0.04	1.56 4.74	99.14 99.86	320 293	92 47	161 48	17 21	11 7	13 27	408 12	148 34	5.6 14.3	116 653	26.4 4 1	33 132	23 14	205 238	12.6 6.9
HN-7F	MCBDPI	59.63	0.87	16.62	7.07	0.16	2.58	4.39	3.29	1.78	0.15	2.93	99.46	312	59 71	266	19	9	39	18	61 111	14.2	504	10.8	143	24	241	7.6
HN-11F	GDP	63.14	0.58	15.33	4.20	0.08	0.91	1.37	1.88	3.40	0.02	8.67	99.51	457	67	72	16	10	12	10	139	9.5	233	11.8	54	25	287	11.2
HN-12F HN-13F	GDP	63.65 62.27	0.64	15.97 14.33	4.38	0.10	0.93	1.49 1.67	1.89	3.46 3.04	0.07	7.31	99.90 99.97	444 502	87 65	138 52	20 16	12 10	18 16	24 11	144 117	7.6 7.9	219 186	16.2 11.3	74 78	30 27	500 314	5.0 4.3
HN-14F	GDP	66.99	0.50	15.30	3.94	0.13	1.00	2.06	3.18	2.67	0.10	3.67	99.53	508	74	190	16	9	15	21	106	8.9	194	11.3	55	29	305	23.1
HN-15F	GDP	55.88	1.00	16.67	4.17	0.09	2.17	2.87	2.43	2.52	0.08	4.94 8.29	99.68 99.67	362	79	997	20	11	132	22 16	106	21.1	221	14.5 14.4	120	25 46	459 547	11.2
HN-17F HN-18F	GDP GDP	48.47 61.35	0.98 1.39	14.83 13.84	8.56 7.91	0.16 0.16	8.38 2.17	2.69 1.86	1.60 1.96	1.67 2.76	0.16 0.11	9.72 5.34	97.20 98.85	306 409	9 56	7425 3193	18 17	8 12	650 121	15 24	68 103	17.9 11.0	179 205	9.0 10.5	181 197	31 25	283 460	15.7 5.1
HN-19F HN-20F	GDP GDP	56.81 59.78	0.81 0.70	15.79 15.75	6.73 5.61	0.14 0.13	3.57 2.32	2.89 2.59	2.48 2.29	2.36 2.40	0.16 0.15	7.16 7.90	98.89 99.63	348 428	47 56	4173 1992	18 18	9 8	283 126	13 16	96 92	18.1 14.3	219 210	11.1 9.5	118 99	35 30	360 250	2.0 4.4
HN-21F	GDP	57.60	1.46	15.37	10.52	0.24	2.64	3.96	2.89	1.75	0.17	3.27	99.86	379	74	261	17	11	16	18	61	23.8	236	8.6	282	36	526	9.7
HN-22F HN-23F	GDP GDP	51.57 48.95	0.81 2.98	14.37 11.37	7.31 20.64	0.13 0.35	4.76 3.04	2.26 2.37	1.56 1.90	1.67 1.98	0.16 0.15	14.76 2.97	99.35 96.70	361 336	42 43	1724 6213	15 18	8 18	331 141	4 19	60 64	15.6 13.9	212 170	6.3 10.4	135 652	25 29	172 542	15.4 3.1
HN-24F HN-25F	GDP GDP	66.13 55.79	0.61 1.85	17.69 12.92	2.01 16.43	0.17 0.36	0.68 1.88	1.61 2.65	3.82 2.87	4.62 1.80	0.05 0.13	1.99 2.74	99.38 99.41	351 388	217 104	29 270	19 17	21 17	11 19	11 13	174 56	7.7 18.9	188 192	82.1 16.0	36 363	120 43	333 1013	13.1 12.8
HN-26F HN-27F	GDP GDP	57.10 57.83	1.40 0.86	15.30 17.51	12.58 8.15	0.31	1.31 1.38	2.36 2.48	3.79 3.08	2.09	0.10	3.44 6.00	99.79 100.22	439 505	106 95	328 131	19 20	20 12	22 25	19 16	67 85	12.9 18.9	190 223	13.5 19.6	234 140	40 45	744 555	2.7 4 9
HN-28F	GDP	59.44	0.64	19.44	4.75	0.17	1.15	2.30	4.13	2.63	0.08	5.23	99.95	332	97	34	22	14	10	13	105	14.8	199	29.3	77	41	560	7.5
HN-30F	GDP	56.96	0.84	17.32	6.83	0.15	2.21	2.95	2.04	2.36	0.16	8.08	99.92	398	72	123	18	9	66	12	104	20.8	209	12.8	127	42	372	49.3
HN-31F HN-32F	GDP	54.83 58.26	1.40	14.97 17.68	10.83	0.24	1.31	2.39	0.57	1.52	0.21	11.74	100.02	430 432	67 71	133 113	18 20	14 11	45 28	5 15	66 105	13.2 16.7	204	10.7	220	24 35	416 421	7.6
HN-33F	GDP	54.56	1.09	16.68	7.80	0.15	2.36	2.64	1.67	2.07	0.20	11.03	100.26	401	68	250	16	11	69	7	86	15.2	211	12.0	162	34	385	36.5
HN-34F	GDP	55.07 56.48	1.11	17.34	8.18	0.21	1.65	2.56	2.00	2.65 3.06	0.20	8.55 7.76	100.09	428 506	90	59 90	18	12	30	18	127	20.7 15.5	169	17.2	184	54 40	832 504	3.8
HN-36F HN-37F	GDP GDP	55.33 56.43	0.99 1.32	16.65 15.93	8.25 8.54	0.17 0.22	1.71 1.89	2.55 2.72	2.01 2.11	2.61 2.51	0.25 0.21	9.89 8.03	100.42 99.91	448 418	82 83	85 195	17 16	11 13	25 34	27 13	106 105	18.2 16.9	181 201	13.9 13.2	155 189	41 40	447 501	3.6 8.0
HN-38F HN-39F	GDP GDP	64.05 63.97	0.75 1.15	16.30 14.35	5.56 8.15	0.23	1.46 1.83	2.49 2.38	2.92 2.88	3.24 2.47	0.08 0.12	3.13 2.41	100.21 99.92	421 391	80 92	83 1157	18 17	11 13	16 46	16 36	146 90	15.0 15.4	185 199	24.3 18.9	100 180	46 44	385 578	10.3 10.1
HN-40F	GDP	65.32	0.75	15.38	5.71	0.18	1.48	2.29	2.99	2.63	0.10	2.89	99.73	408	85	91	17	11	21	17	98	11.2	208	16.6	101	39	350	16.4
HN-41F HN-42F	GDP GDP	59.59 52.50	1.12 0.59	14.79 18.91	7.54 5.71	0.16 0.16	2.77 1.03	2.68 1.55	2.23 2.80	2.31 2.32	0.16 0.21	6.08 14.95	99.43 100.73	400 363	62 106	2360 47	18 19	10 12	107 18	18 5	86 105	16.4 13.5	223 140	9.0 30.1	178 76	32 58	340 387	9.6 38.4
HN-43F HN-44F	GDP GDP	63.49 61.32	0.90	17.23 15.99	3.78	0.24	0.62	1.12	2.93	4.92	0.06	4.34	99.64 100.18	392 360	180 196	38 86	18 18	26 18	17 14	11 8	202	8.3 12.2	125 165	57.9 61.9	60 164	104	584 956	1.9
HN-45F	GDP	61.10	0.63	16.41	4.90	0.15	1.24	2.03	3.84	2.62	0.08	6.95	99.95	327	114	86	17	13	26	8	104	8.7	183	30.6	72	68	431	8.7
HN-47F	GDP	63.17	0.71	16.08	5.21	0.17	1.51	2.40	3.45	3.47	0.12	4.25	100.25	312	103	82	18	14	33	14	142	12.8	173	23.4 35.4	104	45 70	505 197	4.1
HN-48F HN-49F	GDP GDP	58.32 51.97	0.95 1.15	16.14 16.45	8.85 12.10	0.17 0.24	2.52 3.43	3.06 3.64	3.02 2.21	2.47 1.72	0.11 0.13	4.80 7.29	100.42 100.33	360 334	82 60	89 127	18 18	10 8	26 32	11 13	90 64	20.8 20.9	225 237	24.6 14.9	208 318	45 33	323 344	14.7 15.5
HN-50F	GDP	58.22	1.28	15.19	8.25	0.18	1.86	3.13	1.94	1.98	0.16	7.95	100.15	375	49	82	17	8	30	16	77	16.8	268	7.6	196	26	219	5.8
HN-51F	GDP	60.32	1.05	14.30	8.79	0.12	1.85	2.51	2.05	2.63	0.09	6.02	99.94 99.94	405	58 69	169	16	9 10	29 74	31 17	93 77	12.8	214	7.5 13.5	115	24 33	226	14.9
HN-53F HN-54F	GDP GDP	51.58 59.55	1.18 0.93	14.31 16.37	10.04 7.02	0.28 0.16	2.75 2.13	3.64 2.66	1.79 2.33	1.67 2.28	0.20 0.17	11.63 6.41	99.08 100.02	286 416	67 65	144 89	14 19	7 9	79 41	23 20	70 90	23.0 17.0	213 261	5.7 8.0	232 148	33 33	166 246	2.3 6.9
HN-55F	GDP	62.28	1.34	14.23	8.15	0.18	1.82	2.31	2.87	2.64	0.12	3.80	99.75	361	106	1207	16	16	45	14	99	13.1	181	25.8	193	49	514	23.5
SaNr	TYPE	SiO ₂	TiO ₂	Al ₂ O ₃ F	e ₂ O ₃ T	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	SUM	Ва	Ce	Cr	Ga	Nb	Ni	Pb	Rb	Sc	Sr	Th	V	Y	Z٢	% Fines
HN-56F HN-57F	GDP GDP	57.46 64.36	0.82	16.65 14.49	6.58 4.84	0.25	2.35	2.44	2.67	2.71 2.87	0.13	8.11 7.38	100.17 100.04	343 411	92 81	80 102	18 16	12 11	37 42	12 19	109 119	15.5 8.7	186 150	26.6 22.0	126 86	53 38	225 197	8.1 9.1
HN-58F HN-59F	GDP GDP	66.95 62.39	0.73 0.61	12.32 15.46	4.92 6.06	0.23 0.18	1.34 1.16	1.08 1.97	1.13 2.33	2.00 2.67	0.11 0.12	8.51 7.06	99.31 100.02	422 506	64 73	64 81	13 17	9 8	42 36	11 12	92 101	9.7 10.9	136 206	7.6 15.9	86 88	29 32	194 333	14.2 5.5
HN-60F HN-61F	GDP DP	62.08 60.40	0.60	17.19 17.93	6.74 5.59	0.25	0.92	2.30	3.92	2.53	0.09	3.90 4.01	100.52	428 293	114 61	37 25	19 19	9	14 17	33 12	87 66	9.6	236	35.8	98 87	36	649 227	10.5
HN-62F	DP	57.56	1.22	15.40	11.34	0.16	2.24	3.35	3.39	1.90	0.17	3.30	100.03	309	105	55	20	12	24	13	64	11.6	415	38.0	248	43	599	13.5
HN-64F	MCBDPI	62.42	0.94	14.92	6.46	0.20	1.74	2.25	2.75	2.72	0.13	5.33	99.85	384	77	610	17	11	44	20	105	14.3	185	35.6 18.0	141	38	331	6.2
HN-66F	DP	57.51	0.58	17.52	5.99	0.13	2.38	5.00	3.37	1.28	0.21	3.06	99.40	337	37	31	20	6	26	9 11	35	11.5	755	3.8	99	10	133	4.9
HN-67F	DP	58.31	0.61	17.76	5.98	0.10	2.02	4.90	3.59	1.35	0.20	4.97	99.80	320	43	40	19	6	20	9	36	9.6	710	4.1	109	10	209	5.8
HN-68F	DP	56.91	1.25	14.05	9.66	0.20	2.73	2.53 5.04	2.95	1.26	0.12	2.91	99.66 100.15	372 282	104 58	986 63	16 21	15 8	42 25	23 18	97 33	15.3 14.4	206 698	21.0 5.4	178 202	51 13	460 347	7.5 9.7
HN-70F HN-71F	DP	63.24 60.84	1.24 0.62	14.15 17.52	7.90 6.84	0.18	1.84 1.85	2.65 3.20	2.72 3.79	2.53 2.21	0.12 0.12	3.26 2.99	99.83 100.35	364 349	91 75	833 45	16 19	14 8	38 23	18 14	92 3	14.4 11.8	244 370	19.6 27.0	191 105	43 43	406 413	14.0 4.7
HN-72F HN-73F	DP MCBDPI	60.20 62.56	0.53 0.94	18.34 15.73	5.15 6.53	0.10 0.17	2.34 2.21	5.47 3.63	4.02 3.36	1.38 2.15	0.16 0.13	1.97 2.43	99.67 99.83	310 334	30 80	23 510	20 17	6 11	17 33	13 17	36 74	9.5 14.1	797 417	3.2 15.0	84 132	10 36	116 294	10.6
HN-74F HN-75F	GDP GDP	61.75 59.70	0.77	16.33 16.23	6.67 7.18	0.16	1.24 0.90	1.68	3.72 4 11	3.52	0.10	4.36	100.30	283 312	106 321	61 51	19 18	14 29	20	15	144	10.9	157	36.3	124	56 169	346	4.3
HN-76F	GDP	60.60	0.61	17.08	5.52	0.21	1.07	1.66	3.93	3.19	0.13	6.35	100.32	308	117	56	18	14	24	11	133	9.4	157	38.8	86	60	332	5.0
HN-77F HN-78F	GDP GDP	60.58 63.93	0.58 0.80	18.05 15.82	5.68 6.69	0.46 0.20	1.05 0.94	1.52 1.69	3.74 4.08	3.25 3.56	0.11	5.41 2.33	100.44 100.12	353 304	84 162	50 32	20 18	13 19	22 13	14 23	141 145	11.2 11.6	170 177	27.7 54.9	67 121	45 80	312 563	3.7 11.5
HN-79F	MCBDPI	58.31	1.63	14.14	12.77	0.26	2.04	3.23	3.19	2.19	0.14	1.99	99.89	316	124	708	18	18	37	13	74	15.1	351	32.2	305	58	568	4.1
HN-81F	DP	60.07	0.52	18.07	4.98	0.10	1.98	4.91	3.71	1.39	0.18	4.02	99.92	326	34	34	19	6	17	10	36	8.9	720	3.8	76	9	134	18.0
HN-83F	GDP	62.15	0.89	16.54	6.47	0.14	1.53	2.00	3.80	2.71	0.15	2.67	99.51 100.12	339	35 109	79 82	19	5 13	41 26	14 49	38 99	16.7 16.6	665 194	2.6 30.2	116 130	13 50	114 385	8.4 8.2
HN-84F HN-85F	GDP HI	62.33 65.62	0.75 0.77	17.66 15.29	6.36 6.38	0.18 0.29	0.89 0.89	1.56 1.70	3.99 3.39	2.65 2.53	0.10 0.09	3.97 3.07	100.43 100.02	376 371	123 94	31 38	20 17	14 13	10 14	17 20	96 87	9.1 10.9	193 193	36.6 28.7	91 108	49 43	448 385	20.3 8.4
HN-86F	н	64.40	0.84	15.08	6.17	0.31	0.89	1.52	2.29	2.55	0.17	5.77	100.00	403	65	34	17	10	12	16	90	14.8	180	12.1	110	30	283	7.4
HN-87F	GDP HI	57.59 61.22	1.24 0.68	16.45 17.64	11.03 5.61	0.28 0.21	1.09 0.97	1.44 1.42	4.02 3.24	2.77 2.55	0.11 0.22	4.14 6.61	100.15 100.38	385 446	265 103	54 29	20 20	26 12	20 16	12 15	96 91	12.4 10.3	159 168	67.5 25.2	180 76	129 50	1030 378	4.8 11.8
HN-89F HN-90F	HI HI	63.43 63.40	0.91 0.88	15.31 16.18	6.70 6.42	0.17 0.21	1.05 0.92	2.90 1.70	2.08 3.46	1.62 2.69	0.17 0.14	5.62 4.16	99.97 100.16	342 387	61 142	20 37	19 18	7 17	7 12	21 19	52 95	16.4 10.6	247 187	9.1 35.2	132 115	30 63	250 540	38.9 13.5
HN-91F HN-92F	HI GDP	62.08 52.17	1.22 1.72	16.89 19.86	5.56 9.69	0.21 0.17	0.94 2.17	1.51 2.74	2.93 1.85	2.92 1.25	0.15	5.64 8.45	100.06 100.23	410 355	217 76	20 126	18 23	20 12	11 49	37 16	104	14.7 19.0	179 331	69.0 12 1	103 214	88 25	799 554	9.3
HN-93F	HI	60.06	1.03	18.15	6.07	0.36	1.04	1.55	2.59	2.72	0.24	6.38	100.20	432	153	50	19	18	28	13	101	11.9	186	48.5	101	74	425	3.5
HN-95F	DP	61.67	0.44	18.57	4.65	0.09	1.99	5.69	4.11	1.49	0.21	0.53	99.01 99.39	207 331	40 35	38 18	20 19	6	20 10	9	29 34	9.5	794 834	∠./ 3.3	75	8	108	6.7 36.7
HN-96F HN-97F	DP DP	59.04 61.59	0.59	18.06 18.27	5.27 4.56	0.10	1.86	4.08	3.06	1.52	0.21	6.23	100.03	372	44	32	19 20	7	20	15	46	11.0	608	5.0	85	14	138	40.5
HN-98F	DP	55.25	0.53	16.15	4.81	0.09	1.61	3.57	2.73	1.53	0.51	13.11	99.87	338	49	44	15	7	22	9	52	9.4	497	6.6	82	17	156	38.7
HN-100F	MCBDPI	56.04	1.28	14.41	10.96	0.22	1.90	2.65	2.53	2.43	0.14	3.78 7.51	99.89	374	90	357	18	14	50	30	78	13.6	340 286	16.4 21.3	175 254	40 39	387 399	6.8 4.2
HN-101F	DP	60.46 60.17	0.62	18.14 17.77	6.02 5.59	0.11 0.09	2.11 2.15	5.34 5.23	3.97 3.81	1.52 1.53	0.19 0.18	1.16 1.96	99.64 99.07	328 321	41 40	43 26	20 20	7 7	18 17	11 11	37 39	10.4 9.5	783 765	4.7 5.3	99 95	10 12	158 174	10.4 28.3
HN-103F	MCBDPI	57.05	0.91	15.47	7.59	0.19	1.83	2.87	2.59	2.20	0.20	9.01	99.90	376	76	235	17	11	45	9	84	14.3	321	14.7	153	39	308	4.6

Table 1. Major and trace element analyses of the $<180 \,\mu$ m fraction, Hino River (hydrous basis). Major elements wt %, trace elements ppm.

 Notes:
 Same Lag
 <

Table 2. Major and trace element analyses of the sand fraction, Hino River (hydrous basis). Major elements wt %, trace elements ppm.

| SaNr | TYPE | SIO ₂ | TIO ₂ | Al ₂ O ₃ I
 | -e ₂ O ₃ T | MnO | MgO | CaO
 | Na ₂ O | K ₂ O | P_2O_5
 | LOI | SUM | Ва | Ce | Cr (| Ga Ni | D NI
 | Pb | Rb | Sc | Sr
 | Th | v | Y
 | Zr % | % Sand |
|--|---|---|---
--	---	--
---	--	--
---	---	---
--	--	
---	--	---
--	--	--
HN-1S	MCBDPI	80.77
 | 1.47 | 0.04 | 0.58 | 1.06
 | 1.67 | 3.47 | 0.03
 | 0.43 | 98.40 | 448 | 16 | 7 | 9 | 4 3
 | 9 | 123 | 1.2 | 160
 | 2.4 | 25 | 7
 | 66 | 99.0 |
| HN-3S | GDP | 71.75 | 0.22 | 15.36
 | 1.50 | 0.05 | 0.57 | 1.43
 | 3.40 | 3.97 | 0.09
 | 0.95 | 99.79
99.62 | 372 | 29 | 12 | 17 | / 5
6 2
 | 18 | 131 | 4.3 | 194
 | 6.2
6.4 | 18 | 16
 | 87
65 | 47.5
94.1 |
| HN-4S | GDP | 72.25 | 0.68 | 12.11
 | 4.09 | 0.09 | 1.34 | 1.60
 | 2.38 | 3.37 | 0.06
 | 1.28 | 99.25 | 463 | 41 | 427 | 14 | 7 37
 | 14 | 122 | 8.1 | 166
 | 6.8 | 86 | 17
 | 124 | 83.1 |
| HN-55
HN-65 | DP | 62.35 | 0.15 | 11.38
 | 1.00 | 0.03 | 0.50 | 0.88
 | 2.64
3.94 | 4.17 | 0.02
 | 0.66
2.03 | 98.75
99.89 | 377
339 | 24
23 | 39 | 13 . | 57
59
 | 182
12 | 165
42 | 1.8 | 96
724
 | 3.5 | 8
45 | 4
 | 53
85 | 87.4 |
| HN-7S | MCBDPI | 74.30 | 0.30 | 12.61
 | 2.25 | 0.06 | 0.88 | 1.95
 | 2.68 | 3.35 | 0.05
 | 0.67 | 99.09 | 428 | 23 | 19 | 13 | 5 10
 | 13 | 119 | 3.9 | 272
 | 5.0 | 29 | 11
 | 97 | 92.4 |
| HN-8S
HN-9S | В | 62.61
78.41 | 0.53 | 14.89
9.85
 | 4.64
1.10 | 0.10 | 2.46 | 5.99
 | 3.45 | 2.07 | 0.14
 | 1.85
0.88 | 98.73
98.25 | 328
513 | 36
11 | 20 | 18 10 | 6 16
3 2
 | 4 | 58
144 | 13.9 | 709
168
 | 3.9 | 68
11 | 15
 | 97
68 | 93.5 |
| HN-10S | GDP | 72.71 | 0.35 | 13.43
 | 3.10 | 0.06 | 0.95 | 1.12
 | 1.34 | 3.11 | 0.05
 | 3.23 | 99.43 | 540 | 48 | 94 | 17 | 7 16
 | 22 | 118 | 6.7 | 187
 | 9.7 | 36 | 17
 | 126 | 90.9 |
| HN-11S | GDP | 72.10 | 0.30 | 14.09
 | 2.37 | 0.05 | 0.57 | 1.05
 | 2.03 | 4.57 | 0.03
 | 2.25 | 99.40 | 539 | 33 | 16 | 17 | 74
 | 18 | 176 | 3.6 | 209
 | 8.4 | 27 | 16
 | 111 | 88.8 |
| HN-12S | GDP | 72.66 | 0.24 | 14.17
 | 2.05 | 0.04 | 0.50 | 0.95
 | 2.12 | 4.97 | 0.02
 | 1.60 | 99.33 | 547 | 32 | 5 | 17 | 7 3
 | 18 | 189 | 5.4 | 193
 | 9.7 | 15 | 15
 | 118 | 95.0 |
| HN-135 | GDP | 73.52 | 0.42 | 12.23
 | 2.69 | 0.08 | 0.56 | 1.10
 | 2.18 | 3.49 | 0.03
 | 1.44 | 99.29
99.38 | 552
560 | 40
34 | 23 | 15 15 | 82
56
 | 23 | 134 | 5.6
5.9 | 145
155
 | 8.4
7.0 | 43
35 | 17
16
 | 135 | 95.7
76.9 |
| HN-15S | GDP | 73.27 | 0.40 | 12.34
 | 3.08 | 0.06 | 0.79 | 0.90
 | 1.29 | 5.04 | 0.04
 | 1.76 | 98.96 | 608 | 34 | 36 | 14 | 76
 | 20 | 209 | 5.8 | 141
 | 7.9 | 34 | 15
 | 136 | 86.8 |
| HN-16S
HN-18S | GDP | 70.54 | 0.58 | 13.12
 | 4.26 | 0.08 | 1.22 | 1.78
 | 2.06 | 4.12 | 0.07
 | 1.58 | 99.41
99.07 | 533
506 | 45
28 | 332
1805 | 16
15 | 753
678
 | 18
16 | 158
140 | 12.0 | 189
181
 | 7.2 | 60
95 | 20
 | 138 | 88.8
94 9 |
| HN-19S | GDP | 71.24 | 0.36 | 11.97
 | 3.20 | 0.06 | 2.41 | 1.60
 | 1.96 | 3.89 | 0.06
 | 1.67 | 98.41 | 534 | 12 | 2132 | 13 | 4 166
 | 16 | 135 | 6.1 | 174
 | 3.5 | 43 | 14
 | 109 | 98.0 |
| HN-20S | GDP | /1.00 | 0.36 | 13.03
 | 3.14 | 0.07 | 1.67 | 1.55
 | 2.36 | 3.63 | 0.06
 | 1.90 | 98.77 | 538 | 28 | 1181 | 15 | 6 87
 | 16 | 128 | 5.7 | 173
 | 6.7 | 39 | 15
 | 121 | 95.6 |
| HN-21S
HN-22S | GDP | 67.92
60.22 | 0.74 | 14.05
14.75
 | 5.28
6.97 | 0.14 | 1.58 | 2.72
 | 2.81 | 2.58 | 0.07
 | 1.76 | 99.65
99.48 | 490
415 | 32
31 | 126 | 16
18 | 6 11
7 330
 | 16
20 | 86
70 | 13.9 | 210
 | 5.1 | 111 | 18
10
 | 137 | 90.3 |
| HN-23S | GDP | 64.70 | 1.39 | 11.66
 | 10.00 | 0.16 | 2.69 | 1.61
 | 1.90 | 2.89 | 0.08
 | 1.49 | 98.56 | 443 | 11 | 5312 | 16 | 9 140
 | 14 | 96 | 9.3 | 162
 | 6.4 | 296 | 18
 | 164 | 96.9 |
| HN-24S | GDP | 72.95 | 0.17 | 14.46
 | 0.80 | 0.06 | 0.38 | 0.81
 | 2.07 | 6.26 | 0.01
 | 1.17 | 99.12 | 463 | 33 | 1 | 16 | 8 5
 | 19 | 247 | 4.0 | 114
 | 10.0 | 1 | 19
 | 56 | 86.9 |
| HN-26S | GDP | 76.42 | 0.33 | 11.27
 | 2.48 | 0.08 | 0.71 | 1.02
 | 2.34 | 3.47 | 0.03
 | 0.92 | 99.04 | 579 | 25 | 72 | 12 | 9 II
6 7
 | 17 | 115 | 4.0 | 112
 | 5.7 | 26 | 14
 | 112 | 97.3 |
| HN-27S | GDP | 69.70 | 0.38 | 15.30
 | 2.96 | 0.10 | 0.74 | 1.61
 | 2.98 | 3.95 | 0.05
 | 1.82 | 99.59 | 633 | 24 | 24 | 17 | 6 10
 | 16 | 131 | 6.1 | 201
 | 5.9 | 35 | 15
 | 99 | 95.1 |
| HN-205 | GDP | 68.78 | 0.27 | 16.26
 | 2.88 | 0.06 | 0.61 | 1.26
 | 2.93 | 4.50
3.86 | 0.03
 | 1.58 | 99.39
99.89 | 448
432 | 40 | 13 | 17 | / 3
9 3
 | 16 | 168 | 4.8
8.4 | 142
 | 6.4
10.1 | 16
28 | 15
21
 | 74
94 | 92.5
62.6 |
| HN-30S | GDP | 66.89 | 0.72 | 14.22
 | 5.02 | 0.10 | 1.52 | 2.04
 | 1.90 | 3.74 | 0.08
 | 3.25 | 99.49 | 502 | 43 | 49 | 17 | 7 25
 | 20 | 149 | 11.8 | 186
 | 7.3 | 85 | 24
 | 190 | 50.7 |
| HN-31S | GDP | 66.20 | 1.06 | 14.68
 | 7.94 | 0.16 | 1.12 | 2.02
 | 0.66 | 1.73 | 0.09
 | 4.24 | 99.90 | 388 | 41 | 110 | 18 1 | 1 36
 | 18 | 72 | 10.0 | 233
 | 6.7 | 169 | 14
 | 195 | 92.4 |
| HN-325
HN-335 | GDP | 67.99 | 0.58 | 13.79
 | 4.16 | 0.08 | 1.08 | 1.55
 | 1.66 | 4.23 | 0.08
 | 2.34 | 99.37
99.42 | 574
529 | 31
30 | 41
122 | 16
14 | / 12
7 42
 | 21 | 159 | 9.7 | 191
198
 | 6.1
4.6 | 58
113 | 18
16
 | 138 | 85.4
63.5 |
| HN-34S | GDP | 75.27 | 0.49 | 11.00
 | 2.97 | 0.06 | 0.78 | 1.09
 | 1.39 | 4.56 | 0.04
 | 1.13 | 98.79 | 581 | 38 | 17 | 12 | 6 5
 | 14 | 165 | 5.3 | 120
 | 6.0 | 49 | 16
 | 141 | 88.2 |
| HN-35S | GDP | 76.57
75.84 | 0.37 | 10.59
 | 2.66 | 0.09 | 0.73 | 1.15
 | 1.44 | 4.37 | 0.04
 | 1.05 | 99.06
98.70 | 557
548 | 34
27 | 16
20 | 11 | 55
46
 | 16 | 162 | 8.3 | 119
 | 6.4 | 42 | 16
 | 132 | 96.2 |
| HN-37S | GDP | 72.84 | 0.62 | 11.55
 | 4.06 | 0.08 | 1.08 | 1.62
 | 1.84 | 3.94 | 0.06
 | 1.33 | 99.01 | 529 | 39 | 81 | 13 | 6 19
 | 19 | 139 | 8.7 | 160
 | 5.8 | 87 | 17
 | 141 | 92.0 |
| HN-38S | GDP | 75.03 | 0.40 | 11.36
 | 2.68 | 0.09 | 0.84 | 1.15
 | 1.74 | 4.62 | 0.03
 | 0.97 | 98.91 | 540 | 31 | 23 | 13 | 6 6
 | 14 | 180 | 5.1 | 121
 | 7.5 | 43 | 19
 | 133 | 89.7 |
| HN-40S | GDP | 72.04 | 0.49 | 14.08
 | 2.42 | 0.08 | 0.83 | 1.38
 | 2.63 | 4.04 | 0.08
 | 1.50 | 99.32
99.38 | 522 | 25 | 408 | 16 | 6 32
6 10
 | 16 | 146 | 7.0 | 166
 | 6.0 | 32 | 13
 | 90 | 83.6 |
| HN-41S | GDP | 70.57 | 0.64 | 12.39
 | 4.29 | 0.09 | 2.22 | 1.68
 | 2.27 | 2.98 | 0.08
 | 1.86 | 99.09 | 467 | 34 | 1053 | 14 | 7 93
 | 14 | 102 | 7.8 | 184
 | 6.6 | 95 | 19
 | 134 | 90.4 |
| HN-42S | GDP | 76.94 | 0.24 | 10.95
 | 1.82 | 0.06 | 0.42 | 0.72
 | 2.06 | 4.21 | 0.02
 | 1.39 | 98.83 | 460 | 38 | 4 | 12 | 7 1
 | 14 | 159 | 1.9 | 94
 | 7.2 | 20 | 15
 | 82 | 61.6 |
| HN-435
HN-44S | GDP | 75.05 | 0.15 | 13.29
 | 2.45 | 0.04 | 0.32 | 0.39
 | 1.38 | 6.53
4.57 | 0.01
 | 1.28 | 99.21
99.23 | 470
457 | 17
32 | 31 | 14
15 | 73
74
 | 15
15 | 272 | 0.0 | 62
115
 | 5.7
13.0 | 34 | 13
17
 | 59
104 | 98.1
90.5 |
| HN-45S | GDP | 73.39 | 0.27 | 13.53
 | 1.87 | 0.07 | 0.60 | 1.02
 | 2.91 | 4.33 | 0.02
 | 1.27 | 99.27 | 432 | 35 | 28 | 16 | 76
 | 14 | 169 | 4.4 | 107
 | 8.4 | 18 | 19
 | 74 | 91.3 |
| HN-46S
HN-47S | GDP | 75.51 | 0.37 | 12.33
 | 2.63 | 0.06 | 0.94 | 1.28
 | 2.45 | 3.82
4.34 | 0.05
 | 1.44 | 99.14
98.98 | 465
347 | 35
35 | 92
10 | 14
13 | 621
78
 | 16
13 | 143
181 | 5.1
5.1 | 146
96
 | 6.0
11.3 | 43
18 | 15
26
 | 94
76 | 80.9
95.9 |
| HN-48S | GDP | 70.50 | 0.38 | 13.99
 | 3.21 | 0.08 | 1.20 | 1.76
 | 3.02 | 3.83 | 0.05
 | 1.38 | 99.38 | 453 | 22 | 23 | 15 | 69
 | 13 | 141 | 6.6 | 179
 | 7.1 | 51 | 16
 | 81 | 85.3 |
| HN-49S | GDP | 67.97
66.72 | 0.60 | 13.36
 | 5.80 | 0.11 | 1.97 | 2.48
 | 2.49 | 2.92 | 0.06
 | 1.79 | 99.55
99.76 | 449 | 29 | 44
24 | 14 | 5 16
7 11
 | 12 | 100 | 12.3 | 211
 | 5.8 | 121 | 18
 | 95
161 | 84.5 |
| HN-51S | GDP | 73.10 | 0.48 | 12 72
 | 3 12 | 0.07 | 0.91 | 1 27
 | 2.88 | 3.06 | 0.06
 | 1 76 | 00.42 | 400 | 40 | 25 | 14 | 6 11
 | 20 | 100 | 6.5 | 176
 | 7.0 | 45 | 17
 | 144 | 95.1 |
| HN-52S | GDP | 71.84 | 0.54 | 12.74
 | 3.94 | 0.09 | 1.26 | 1.75
 | 2.89 | 2.98 | 0.07
 | 1.33 | 99.43 | 453 | 40 | 41 | 14 | 6 28
 | 18 | 105 | 7.7 | 192
 | 8.1 | 73 | 19
 | 135 | 94.0 |
| HN-53S
HN-54S | GDP | 64.79
71.23 | 1.00 | 12.64
13.16
 | 8.42
3.86 | 0.22 | 2.46 | 3.05
 | 2.27 | 1.89
2.89 | 0.12
 | 2.38 | 99.25
99.39 | 321
460 | 42 | 144
29 | 15
14 | 6 51
6 16
 | 31
16 | 71 | 20.4 | 175
224
 | 9.0
6.4 | 196
69 | 26
18
 | 133 | 97.7
93.1 |
| HN-55S | GDP | 70.56 | 0.57 | 40.00
 | 0.75 | | |
 | | | 0.00
 | | 00.00 | 445 | 31 | 220 | 15 | 8 31
 | 10 | 404 | |
 | | |
 | | |
| | 001 | 70.00 | 0.57 | 13.30
 | 3.75 | 0.08 | 1.25 | 1.66
 | 2.66 | 3.55 | 0.06
 | 1.84 | 99.33 | 445 | 51 | 230 | 10 | 0 51
 | 10 | 134 | 6.5 | 1/4
 | 7.1 | 69 | 18
 | 119 | /6.5 |
| | | 10.00 | 0.57 | 13.30
 | 3.75 | 0.08 | 1.25 | 1.66
 | 2.66 | 3.55 | 0.06
 | 1.84 | 99.33 | 445 | 51 | 230 | | 0 51
 | 10 | 134 | 6.5 | 1/4
 | 7.1 | 69 | 18
 | 119 | 76.5 |
| | | 10.00 | 0.07 | 13.30
 | 3.75 | 0.08 | 1.25 | 1.66
 | 2.66 | 3.55 | 0.06
 | 1.84 | 99.33 | 445 | 51 | 230 | 10 | 0 01
 | 10 | 134 | 6.5 | 1/4
 | 7.1 | 69 | 18
 | 119 | /6.5 |
| | | 10.00 | 0.57 | 13.30
 | 3.75 | 0.08 | 1.25 | 1.66
 | 2.66 | 3.55 | 0.06
 | 1.84 | 99.33 | 445 | 51 | 230 | | 0 01
 | 10 | 134 | 6.5 | 1/4
 | 7.1 | 69 | 18
 | 119 | /6.5 |
| SaNr | TYPE | SiO ₂ | TiO ₂ | Al ₂ O ₃
 | | 0.08
MnO | 1.25
MgO | 1.66
CaO
 | 2.66
Na ₂ O | 3.55
K ₂ O | P ₂ O ₅
 | 1.84
LOI | 99.33
SUM | Ba | Ce | Cr | Ga N | b Ni
 | Pb | Rb | 6.5
Sc | 1/4
Sr
 | 7.1
Th | 69
V | 18
Y
 | Zr % | Sand |
| SaNr
HN-56S | TYPE
GDP | SiO ₂
75.54 | TiO ₂ | Al ₂ O ₃
 | | 0.08
MnO
0.07 | 1.25
MgO
0.88 | 1.66
CaO
 | 2.66
Na ₂ O
2.34 | 3.55
K ₂ O
3.87 | 0.06
P ₂ O ₅
0.04
 | LOI | 99.33
SUM
99.14 | Ba
385 | Ce
24 | Cr 12 | Ga N | b Ni
5 6
 | Pb
15 | Rb | 6.5
Sc
4.8 | 1/4
Sr
104
 | 7.1
Th
7.5 | 69
V
26 | 18
Y
 | Zr % | 76.5
Sand
91.9 |
| SaNr
HN-56S
HN-57S
HN-58S | TYPE
GDP
GDP
GDP | SiO ₂
75.54
77.14
73.36 | TiO ₂
0.25
0.25
0.52 | Al ₂ O ₃
11.79
10.86
12.44
 | | 0.08
MnO
0.07
0.07
0.18 | 1.25
MgO
0.88
0.67
1.13 | 1.66
CaO
1.06
0.65
0.69
 | 2.66
Na ₂ O
2.34
1.75
1.40 | 3.55
K ₂ O
3.87
3.87
2.66 | P ₂ O ₅
0.04
0.04
0.06
 | LOI
1.06
1.50
2.57 | 99.33
SUM
99.14
98.92
99.42 | Ba
385
397
529 | Ce
24
25
50 | Cr 12
111
30 | Ga N
13
12
16 | b Ni
5 6
6 12
7 20
 | Pb
15
23
28 | Rb
155
159
106 | 6.5
Sc
4.8
4.7
7.9 | 1/4
Sr
104
88
111
 | 7.1
Th
7.5
6.9
7.1 | 69
V
26
28
75 | 18
Y
14
14
18
 | Zr % | 76.5
Sand
91.9
90.9
85.8 |
| SaNr
HN-56S
HN-57S
HN-58S
HN-59S | TYPE
GDP
GDP
GDP
GDP | SiO ₂
75.54
77.14
73.36
70.90 | TiO ₂
0.25
0.25
0.52
0.46 | Al ₂ O ₃
11.79
10.86
12.44
13.85
 | | 0.08
MnO
0.07
0.07
0.18
0.10 | 1.25
MgO
0.88
0.67
1.13
0.85 | 1.66
CaO
1.06
0.65
0.69
1.52
 | 2.66
Na ₂ O
2.34
1.75
1.40
2.52 | 3.55
K ₂ O
3.87
3.87
2.66
3.55 | P ₂ O ₅
0.04
0.06
0.06
 | LOI
1.06
1.50
2.57
1.56 | 99.33
SUM
99.14
98.92
99.42
99.69 | Ba
385
397
529
534 | Ce
24
25
50
55 | Cr 12
111
30
12 | Ga N
13
12
16
16 | b Ni
5 6
6 12
7 20
7 7
 | Pb
15
23
28
21 | Rb
155
159
106
131 | 6.5
Sc
4.8
4.7
7.9
8.6 | 174
Sr
104
88
111
189
 | 7.1
Th
7.5
6.9
7.1
13.6 | 69
V
26
28
75
49 | 18
Y
14
14
18
23
 | Zr %
75
80
136
174 | 76.5
Sand
91.9
90.9
85.8
94.5 |
| SaNr
HN-56S
HN-57S
HN-58S
HN-59S
HN-60S
HN-61S | TYPE
GDP
GDP
GDP
GDP
GDP
GDP
DP | SiO ₂
75.54
77.14
73.36
70.90
71.96
67.72 | TiO ₂
0.25
0.52
0.46
0.37
0.32 | Al ₂ O ₃
11.79
10.86
12.44
13.85
13.74
15.98
 | | 0.08
MnO
0.07
0.07
0.18
0.10
0.11
0.07 | 1.25
MgO
0.88
0.67
1.13
0.85
0.70
1.28 | 1.66
CaO
1.06
0.65
0.69
1.52
1.48
3.50
 | 2.66
Na ₂ O
2.34
1.75
1.40
2.52
2.94
3.30 | 3.55
K ₂ O
3.87
3.87
2.66
3.55
3.53
3.06 | P ₂ O ₅
0.04
0.04
0.06
0.06
0.05
0.08
 | LOI
1.06
1.50
2.57
1.56
1.19
0.83 | 99.33
SUM
99.14
98.92
99.42
99.69
99.50
99.50
99.17 | Ba
385
397
529
534
472
337 | Ce
24
25
50
55
50
29 | Cr 12
111
30
12
8
8 | Ga N
13
12
16
16
16
16 | b Ni
5 6
6 12
7 20
7 7
7 3
5 7
 | Pb
15
23
28
21
17
13 | Rb
155
159
106
131
129
109 | 6.5
Sc
4.8
4.7
7.9
8.6
4.6
7.9 | 174
Sr
104
88
111
189
178
530
 | 7.1
Th
7.5
6.9
7.1
13.6
12.9
4.5 | 69
V
26
28
75
49
34
37 | Y
14
14
18
23
19
10
 | Zr %
75
80
136
174
125
86 | 76.5
Sand
91.9
90.9
85.8
89.5
89.5
83.7 |
| SaNr
HN-56S
HN-57S
HN-58S
HN-59S
HN-60S
HN-61S
HN-62S | TYPE
GDP
GDP
GDP
GDP
GDP
DP
DP | SiO ₂
75.54
77.14
73.36
70.90
71.96
67.72
67.79 | TiO ₂
0.25
0.25
0.52
0.46
0.37
0.32
0.54 | Al ₂ O ₃
11.79
10.86
12.44
13.85
13.74
15.98
14.71
 | 3.75
=e ₂ O ₃ T
2.24
2.12
4.42
4.42
3.45
3.04
5.22 | 0.08
MnO
0.07
0.18
0.10
0.11
0.07
0.08 | 1.25
MgO
0.88
0.67
1.13
0.85
0.70
1.28
1.24 | 1.66
CaO
1.06
0.65
0.69
1.52
1.48
3.50
2.74
 | 2.66
Na ₂ O
2.34
1.75
1.40
2.52
2.94
3.30
3.18 | 3.55
K ₂ O
3.87
3.87
2.66
3.55
3.53
3.06
2.98 | P ₂ O ₅
0.04
0.04
0.06
0.06
0.05
0.08
0.08
 | LOI
1.06
1.50
2.57
1.56
1.19
0.83
1.17 | 99.33
SUM
99.14
98.92
99.42
99.69
99.50
99.50
99.17
99.72 | Ba
385
397
529
534
472
337
373 | Ce
24
25
50
55
50
29
49 | Cr 1
12
111
30
12
8
8
16 | Ga N
13
12
16
16
16
16
17 | b Ni
5 6
6 12
7 20
7 7
5 7
7 9
 | Pb
15
23
28
21
17
13
13 | Rb
155
159
106
131
129
109
109 | 6.5
Sc
4.8
4.7
7.9
8.6
4.6
7.9
6.5 | 174
Sr
104
88
111
189
178
530
387
 | 7.1
Th
7.5
6.9
7.1
13.6
12.9
4.5
11.0 | 69
V
26
28
75
49
34
37
94 | Y
14
14
18
23
19
10
15
 | Zr %
75
80
136
174
125
86
109 | 76.5
Sand
91.9
90.9
85.8
94.5
89.5
83.7
86.5 |
| SaNr
HN-56S
HN-57S
HN-59S
HN-60S
HN-61S
HN-62S
HN-63S
HN-64S | TYPE
GDP
GDP
GDP
GDP
DP
DP
GDP
MCBDPI | SiO ₂
75.54
77.14
73.36
70.90
71.96
67.72
67.79
72.54
77.10 | TiO ₂
0.25
0.25
0.52
0.46
0.37
0.32
0.54
0.49
0.21 | Al ₂ O ₃
11.79
10.86
12.44
13.85
13.74
15.98
14.71
12.72
11.12
 | 3.75
=e ₂ O ₃ T
2.24
2.12
4.29
3.45
3.04
5.22
3.25
1.52 | 0.08
MnO
0.07
0.18
0.10
0.11
0.07
0.08
0.08
0.05 | 1.25
MgO
0.88
0.67
1.13
0.85
0.70
1.28
1.24
1.10
0.64 | 1.66
CaO
1.06
0.65
0.69
1.52
1.48
3.50
2.74
1.52
0.98
 | 2.66
Na ₂ O
2.34
1.75
1.40
2.52
2.94
3.30
3.18
2.51
2.24 | 3.55
K ₂ O
3.87
3.87
2.66
3.55
3.53
3.06
2.98
3.76
4.08 | P ₂ O ₅
0.04
0.04
0.06
0.05
0.08
0.08
0.08
0.03
 | LOI
1.06
1.50
2.57
1.56
1.19
0.83
1.17
1.19
0.79 | 99.33
SUM
99.14
98.92
99.69
99.50
99.17
99.72
99.23
98.75 | Ba
385
397
529
534
472
337
373
477
482 | Ce
24
25
50
55
50
29
49
37
17 | Cr 12
111
30
12
8
8
16
127
38 | Ga N
13
12
16
16
16
17
17
14
11 | b Ni
5 6
6 12
7 20
7 7
7 3
5 7
7 9
7 27
7 9
7 27
4 12
 | Pb
15
23
28
21
17
13
13
16
14 | Rb
155
159
106
131
129
109
106
139
151 | 6.5
Sc
4.8
4.7
7.9
8.6
4.6
7.9
6.5
4.5
4.0 | 174
Sr
104
88
111
189
178
530
387
166
121
 | 7.1
Th
7.5
6.9
7.1
13.6
12.9
4.5
11.0
6.6
3.8 | 69
V
26
28
75
49
34
37
94
60
19 | Y
14
14
18
23
19
10
15
18
11
 | Zr %
75
80
136
174
125
86
109
115
72 | 76.5
Sand
91.9
90.9
85.8
94.5
89.5
83.7
86.5
91.3
93.8 |
| SaNr
HN-56S
HN-57S
HN-58S
HN-59S
HN-60S
HN-61S
HN-63S
HN-64S
HN-65S | GDP
GDP
GDP
GDP
GDP
DP
DP
GDP
MCBDPI
DP | SiO ₂
75.54
77.14
73.36
70.90
71.96
67.79
72.54
77.10
62.78 | TiO ₂
0.25
0.25
0.52
0.46
0.37
0.32
0.54
0.49
0.21
0.39 | Al ₂ O ₃
11.79
10.86
12.44
13.85
13.74
15.98
14.71
12.72
11.12
18.68
 | 3.75
=e ₂ O ₃ T
2.24
2.12
4.42
3.45
3.04
5.22
3.25
1.52
3.70 | 0.08
MnO
0.07
0.07
0.07
0.07
0.010
0.11
0.07
0.08
0.08
0.05
0.07 | 1.25
MgO
0.88
0.67
1.13
0.85
0.70
1.28
1.24
1.10
0.64
1.73 | 1.66
CaO
1.06
0.65
0.69
1.52
1.48
3.50
2.74
1.52
0.98
5.22
 | 2.66
Na ₂ O
2.34
1.75
1.40
2.52
2.94
3.30
3.18
2.51
2.24
4.26 | 3.55
K ₂ O
3.87
3.87
2.66
3.55
3.53
3.06
2.98
3.76
4.08
1.69 | P ₂ O ₅
0.04
0.04
0.06
0.05
0.08
0.05
0.03
0.03
0.11
 | LOI
1.06
1.50
2.57
1.56
1.19
0.83
1.17
1.19
0.79
0.73 | 99.33
SUM
99.14
99.92
99.42
99.50
99.50
99.77
99.72
99.72
98.75
98.75 | Ba
385
397
529
534
472
373
477
482
367 | Ce
24
25
50
55
50
29
49
37
17
33 | Cr
12
111
30
12
8
8
16
127
38
10 | Ga Ni
13
12
16
16
16
17
17
14
11
21 | b Ni
5 6
6 12
7 20
7 7
5 7
7 9
7 27
4 12
6 10
 | Pb
15
23
28
21
17
13
13
16
14
11 | Rb
155
159
106
131
129
106
139
151
40 | 6.5
Sc
4.8
4.7
7.9
8.6
4.6
7.9
6.5
4.5
4.0
8.1 | 174
Sr
104
88
111
189
178
530
387
166
121
823
 | 7.1
Th
7.5
6.9
7.1
13.6
12.9
4.5
11.0
6.6
3.8
4.1 | 69
V
26
28
75
49
34
37
94
60
19
49 | Y
14
14
18
23
19
10
15
18
11
8
 | Zr %
75
80
136
174
125
86
109
115
72
97 | 76.5
Sand
91.9
90.9
85.8
94.5
89.5
83.7
86.3
91.3
93.8
95.1 |
| SaNr
HN-56S
HN-57S
HN-58S
HN-60S
HN-61S
HN-61S
HN-62S
HN-64S
HN-65S
HN-65S | TYPE
GDP
GDP
GDP
GDP
GDP
DP
DP
DP
DP
DP
DP
DP
DP | SiO ₂
75.54
77.14
73.36
70.90
67.72
67.79
72.54
77.10
62.78
63.89 | TiO ₂
0.25
0.25
0.52
0.46
0.37
0.32
0.54
0.49
0.21
0.39
0.43 | Al ₂ O ₃
11.79
10.86
12.44
13.85
13.74
15.98
14.71
12.72
11.12
18.68
17.81
 | 3.75
=e ₂ O ₃ T
2.24
2.12
4.42
3.45
3.04
5.22
3.04
5.22
3.70
3.99 | 0.08
MnO
0.07
0.18
0.10
0.11
0.07
0.08
0.05
0.07
0.07 | 1.25
MgO
0.88
0.67
1.13
0.85
0.70
1.28
1.24
1.10
0.64
1.73
1.83 | 1.66
CaO
1.06
0.65
1.52
1.48
3.50
2.74
1.52
0.98
5.22
4.77
 | 2.66
Na ₂ O
2.34
1.75
1.40
2.52
2.94
3.30
3.18
2.51
2.24
4.26
4.17 | 3.55
K ₂ O
3.87
3.87
2.66
3.55
3.55
3.06
2.98
3.76
4.08
1.69
1.86 | P ₂ O ₅
0.04
0.04
0.06
0.05
0.08
0.05
0.03
0.11
0.12
 | LOI
1.06
1.50
2.57
1.56
1.19
0.83
1.17
1.19
0.79
0.73
0.64 | 99.33
SUM
99.14
99.42
99.69
99.50
99.17
99.72
99.72
99.35
99.35
99.57 | Ba
385
397
529
534
472
337
373
477
482
367
397 | Ce
24
25
50
55
50
29
49
37
17
33
30 | Cr
12
111
30
12
8
8
16
127
38
10
12 | Ga N
13
12
16
16
16
16
17
17
14
11
21
20 | b Ni
5 6
6 12
7 20
7 7
5 7
7 9
7 27
4 12
6 10
6 12
 | Pb
15
23
28
21
17
13
13
16
14
11
11 | Rb
155
159
106
131
129
109
106
139
151
40
48 | 6.5
Sc
4.8
4.7
7.9
8.6
4.6
7.9
6.5
4.5
4.0
8.1
7.6 | 174
Sr
104
88
111
189
178
530
387
166
121
823
750
 | 7.1
Th
7.5
6.9
7.1
13.6
12.9
4.5
11.0
6.6
3.8
4.1
4.4 | 69
V
26
28
75
49
34
37
94
60
19
49
59 | Y
14
14
14
23
19
10
15
18
11
8
9
 | Zr %
75
80
136
174
125
86
109
115
72
97
108 | 76.5
Sand
91.9
90.9
85.8
94.5
89.5
89.5
91.3
93.8
95.1
91.5
1.9
1.5
1.9
1.5
1.9
1.9
1.9
1.9
1.9
1.9
1.9
1.9 |
| SaNr
HN-56S
HN-57S
HN-58S
HN-60S
HN-61S
HN-63S
HN-64S
HN-65S
HN-66S
HN-66S
HN-66S | TYPE
GDP
GDP
GDP
GDP
GDP
GDP
GDP
MCBDPI
DP
DP
DP
DP
DP
MCBDPI | SiO ₂
75.54
77.14
73.36
70.90
67.72
67.79
72.54
77.10
62.78
63.89
63.89
63.75 | TiO ₂
0.25
0.52
0.46
0.37
0.32
0.54
0.49
0.21
0.39
0.43
0.43
0.43
0.33 | Al ₂ O ₃
11.79
10.86
12.44
13.85
13.74
15.98
14.71
12.72
11.12
18.68
17.81
17.79
12.46
 | 3.75
=e ₂ O ₃ T
2.24
2.12
4.42
3.45
3.04
5.22
3.04
5.22
3.70
3.99
4.12
2.37 | 0.08
MnO
0.07
0.07
0.18
0.10
0.11
0.07
0.08
0.05
0.07
0.07
0.07
0.07
0.06 | 1.25
MgO
0.88
0.67
1.13
0.85
0.70
1.28
1.24
1.10
0.64
1.73
1.83
1.73
1.83
1.75 | 1.66
CaO
1.06
0.65
1.52
1.48
3.50
2.74
1.52
0.98
5.22
4.77
4.82
4.77
4.82
 | 2.66
Na ₂ O
2.34
1.75
1.40
2.52
2.94
3.30
3.18
2.54
4.26
4.17
4.15
2.58 | 3.55
K ₂ O
3.87
3.87
2.66
3.55
3.53
3.06
2.98
3.76
4.08
1.69
1.86
1.70
3.75 | P ₂ O ₅
0.04
0.06
0.05
0.08
0.05
0.08
0.05
0.03
0.11
0.12
0.00
0.05
 | LOI
1.06
1.50
2.57
1.56
1.19
0.83
1.17
0.79
0.73
0.64
0.73
0.64 | 99.33
SUM
99.14
99.92
99.69
99.50
99.17
99.72
99.23
98.75
99.35
99.57
99.41 | Ba
385
397
529
534
472
373
477
482
367
397
360
478 | Ce
24
25
50
55
50
29
49
37
17
33
30
27
30 | Cr
12
111
30
12
8
8
16
127
38
10
12
9
66 | Ga N
13
12
16
16
16
17
17
14
11
20
20
13 | b Ni
5 6
6 12
7 20
7 7
5 7
7 9
7 27
4 12
6 10
6 12
6 10
5 19
 | Pb
15
23
28
21
13
13
16
14
11
11
16 | Rb
155
159
106
131
129
109
106
139
151
40
48
43
137 | 6.5
Sc
4.8
4.7
7.9
8.6
4.6
7.9
6.5
4.5
4.0
8.1
7.6
9.2
7.7 | 174
Sr
104
88
111
189
178
530
387
166
121
823
750
713
166
 | 7.1
Th
7.5
6.9
7.1
13.6
12.9
4.5
11.0
6.6
3.8
4.1
4.4
2.8
4.9 | 69
V
26
28
75
49
34
37
94
60
19
49
59
59
32 | 18
Y
14
14
18
23
19
10
15
18
11
8
9
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Notes: SaNr= Sample number. TYPE= Catchment type; GDP- granitoid-dominated products; DP- Daisen products; MCBDPI- main channel below Daisen products input; HI- Hata input; B- beach samples. LOI= loss on ignition. %Sand: wt % of sand in each sample. Dash (-) = not detected.

		Fine Fra N= 1	otion 01			Sand Fraction N= 102							
Element	Mean	Min	Max	SDp	Mean	Min	Max	SDp					
Major eler	nents (wt%)												
SiO ₂	63.55	52.22	73.74	3.59	72.60	62.04	82.45	4.88					
TiO₂	0.98	0.36	3.18	0.42	0.43	0.13	1.43	0.22					
AI_2O_3	17.14	12.13	22.05	1.75	14.04	8.84	21.14	2.46					
Fe ₂ O ₃ T	7.52	2.06	22.02	2.84	3.35	0.79	10.30	1.74					
MnO	0.20	0.09	0.48	0.08	0.08	0.03	0.22	0.03					
MgO	1.94	0.62	9.57	1.10	1.13	0.33	5.72	0.74					
CaO	2.89	1.18	5.99	1.23	2.06	0.40	6.18	1.47					
Na₂O	3.09	0.65	4.82	0.81	2.76	0.69	4.47	0.83					
K₂O	2.54	1.19	5.16	0.76	3.50	1.41	6.67	1.09					
P_2O_5	0.15	0.04	0.58	0.07	0.06	0.01	0.14	0.03					
Trace elerr	ents (ppm)												
Ва	396.5	287.9	574.8	63.9	456.0	293.6	647.5	77.8					
Ce	91.8	10.7	340.8	49.5	31.1	6.0	61.0	9.6					
Cr	493.7	13.4	8487.9	1234.1	179.6	0.4	5471.7	645.0					
Ga	19.0	12.5	24.7	1.9	15.7	9.5	22.3	2.8					
Nb	12.4	5.5	30.9	4.8	6.4	3.1	15.6	1.7					
Ni	48.2	7.5	743.5	86.6	20.1	0.7	361.3	43.0					
Pb	20.7	5.2	418.2	40.4	18.4	3.9	185.2	18.8					
Rb	94.4	3.5	212.3	37.7	126.7	34.1	277.3	49.9					
Sc	14.2	5.8	26.3	4.1	6.8	0.05	21.0	3.6					
Sr	313.1	118.6	850.0	204.3	272.7	63.3	908.9	227.8					
Th	21.9	2.7	118.8	18.7	6.6	2.5	13.9	2.5					
V	149.7	33.4	696.0	88.4	53.8	0.5	304.8	46.1					
Y	42.8	8.3	179.1	26.3	15.2	3.8	32.7	5.2					
Zr	406.5	105.5	1072.7	203.0	106.2	50.4	203.5	31.9					
Min	Minimum												
Max	Maximum												

Table 3. Summary statistics for all $<180 \,\mu m$ and sand fraction samples (anhydrous normalized data).

Max Maximum SDp Population standard deviation

given in Table 3, calculated from analyses normalized to 100% to negate the effects of varying LOI. Average elemental abundances show considerable contrast between the fractions, especially for some trace elements (e.g. Cr, Zr). The average compositions of both fractions over the entire suite broadly correspond with that of average Upper Continental Crust (UCC), although some differences are also evident (Fig. 2). The fine fraction is slightly depleted in Nb, K, Ca and Ba with respect to UCC, whereas Zr, Th, and Ce abundances are a little greater. The greatest divergence from UCC in the fine fraction average is observed in the segment Sc-V, where all elements are progressively enriched, with a marked peak in Cr of more than 10 times UCC abundance. All of this group of elements are associated with mafic components. The pattern for the fine fraction average is generally linear, and is inclined from left to right, similar to the composition of average Mesozoic-Cenozoic greywacke (Condie, 1993; Dinnelli et al., 1999). In contrast, the pattern of the sand fraction average is almost flat, and most elements are slightly depleted compared to UCC, especially for Nb, Ca-Sr, and Mg-Ce. Abundances also tend to increase in the segment Sc-V, as in the fine fraction, but generally remain less than or equal to UCC levels. Only the content of Cr is significantly enriched relative to UCC, although to a lesser degree than in the fine fraction.

Combined histograms (bar charts) of anhydrousnormalized elements for the fine and sand fractions display clear dependence on grain size, although overlap is considerable. The fine fractions tend to have greater abundances of most elements, except for SiO₂, K₂O, and to a lesser extent Ba, Pb, and Rb, which are enriched in the sand fraction (Fig. 3 and 4). Na₂O (Fig. 3), Sr, and Pb show



Fig. 2. Multi-element plot showing the average composition (anhydrous normalized) of the fine (<180 μ m) and sand fractions from the Hino River (data from Tables 1 and 2) normalized against the Upper Continental Crust (UCC) average of Taylor and McLennan (1985). Elements are arranged from left to right in order of increasing normalized abundance in average Mesozoic-Cenozoic greywacke (Condie, 1993) relative to UCC, following the methodology of Dinelli *et al.*, (1999). The major elements are normalized as oxides.

relatively little contrast in the ranges of their distributions in the fractions. However, statistical tests suggest that the means of all elements except Sr and Pb differ significantly (95% confidence level) between the two fractions.

Fine Fraction

Most of the major elements have variable distributions and contain anomalous values. Distribution of SiO₂ (Fig. 3a) is relatively normal except for lower values in several samples, coupled with higher abundances of other elements. This is especially marked in sample HN 23, which has the lowest SiO₂ content (52.2%) due to enrichment in Fe₂O₃ (22.02%), TiO₂ (3.18%), and MnO (0.38%), probably as a result of Fe-Ti-Mn oxide heavy mineral concentration or authigenic Fe-Mn-O crust material. TiO₂ (Fig. 3b), Fe₂O₃T and MnO are markedly skewed to higher values. MnO and P₂O₅ show the same characteristic, but to a lesser extent. The remaining distributions are more irregular, with K₂O (Fig. 3c) and Na₂O (Fig. 3d) possibly bimodal, whereas Al₂O₃ and CaO are polymodal.

Trace elements have also variable abundances. Ba (Fig. 4a) and Ga resemble normal distributions, with few anomalous values. Cr (Fig. 4b), Ce, Ni, Pb, Th, V, and Y are strongly skewed to higher values, with some of the most anomalous values recorded in sample HN 23 (e.g. Cr 6629 ppm; V 696 ppm; Zr 578 ppm). Several other samples also have extreme values, such as HN 17 (Cr 8488 ppm; Ni 744 ppm), HN 87 (Zr 1073 ppm), and HN 25 (Zr 1048 ppm). The distribution of Sr (Fig. 4c) is clearly bimodal, with a marked contrast between one group with relatively low values (100 to 400 ppm) and another with high values (500-900 ppm). The latter group is associated with samples collected from streams draining Mount Daisen. The



Fig. 3. Examples of combined histograms of major element abundances (anhydrous normalized data) in the $<180 \,\mu$ m and sand fractions, Hino River. (a) SiO₂ - normal distribution; (b) TiO₂ - skewed to higher values; one sample with >2.2 wt% not plotted; (c) K₂O - bimodal, two samples >5.6 wt% not plotted; (d) Na₂O - distinctly polymodal.



Fig. 4. Examples of combined histograms of trace element abundances (anhydrous normalized data) in the $<180 \,\mu$ m and sand fractions, Hino River. (a) Ba - normal distribution; (b) Cr - strongly skewed to higher values, five samples with 3400-8500 ppm not plotted; (c) Sr - clear bimodal distributions and (d) Zr - polymodal, five samples with 845-1080 ppm not plotted.

remaining trace elements analyzed (Zr (Fig. 4d), Nb, Rb, and Sc) have comparatively wide ranges and polymodal distributions.

Sand fraction

The most notable feature of the patterns among the major elements is the relatively high number of bimodal distributions (five in total), all of which identify a group of samples from streams that drain catchments consisting almost exclusively of products from Mount Daisen. For SiO₂ (Fig. 3a) and K₂O (Fig. 3c) this mode is found at lower values, whereas for Na₂O (Fig. 3d), Al₂O₃, and CaO it occurs at higher values. In all cases, contrast between the two major modes is evident, and reflects the strong geochemical signature that volcanic products from Mount Daisen imprint to the sediments. The remaining major elements (TiO₂ (Fig. 3b), Fe₂O₃, MnO, MgO, and P₂O₅) exhibit variable and strongly right-skewed distributions. As in the fine fraction, several samples have lower SiO₂ values due to enrichment in Fe₂O₃, TiO₂, and MnO, and again this is most marked in sample HN 23.

Among the trace elements, a number of elements (Ba (Fig. 4a), Ce, Ga, and Sc) have normal distributions with relatively few anomalous values. In contrast Cr (Fig. 4b), Nb, Ni, Pb, and V are moderately to strongly skewed to higher values. Sr (Fig. 4c), Rb and to a lesser extent Y display bimodal distributions, with one of the modes associated with Daisen products. The contrast between the modes is particularly marked for Sr. Finally, abundances of Zr (Fig. 4d) and Th vary considerably, and distributions are polymodal.

Anomalous values

Elemental abundances in both fractions generally have positively skewed distributions. Most of the elements analyzed are not prone to disturbance from human activity, but several elements have elevated values (>2 s.d.) that could be considered exceptional. Anomalous values are most commonly observed for Cr, from samples (e.g., HN 17 -20, 22, 23) containing basic and ultrabasic rocks in their catchments. These values may have been increased by activity related to chromium mining in the area. Some of this group of samples also contain elevated levels of Ni. With one exception, abundances of the potentially environmentally sensitive element P2O5, are low and within the range expected for the source lithotypes. There is thus no clear evidence in the sediments for anthropogenic inputs (e.g. via fertilizers). The compositions observed suggest clear association with the characteristics of source rock lithotypes and derived products. Greater values for a group of elements including Fe, Mn, Ti, Cr, Ni, Ce, Th, V, Y, and Zr are very likely related to concentrations of high density accessory minerals (see Ortiz & Roser, 2003). This will be verified by future work.

The bimodal and polymodal distributions observed

reflect the control of rock source in the composition of derived sediments. As already stated, this is particularly distinctive in the sand fraction, including the bimodal patterns of SiO₂, K₂O, Al₂O₃, CaO, Na₂O, and Sr, elements for which one of the modes is clearly associated with samples collected from catchments draining Mount Daisen.

Classification of sample sites by source categories

As described above, the geology of the Hino river catchment differs spatially, with felsic igneous and volcanic rocks dominating the central and southern parts, volcanic products from Mount Daisen in the northeast, and volcanic rocks of the Hata Formation in the northwest. Following the methodology adopted by Ortiz and Roser (2003) for the Kando River, sample localities from the Hino watershed were divided into four categories according to the characteristics of their main source rocks. The sand fractions include an additional category consisting of two samples (HN 8, 9) collected from the beach in Miho Bay. The <180 μ m fraction in these two samples was too small to be analyzed.

The main categories are:

- Granitoid-dominated products (GDP) and felsic volcanics, covering a vast area and including more than 61% of the total sample sites;
- (2). Daisen products (DP), consisting of samples from catchments dominated by volcanic products from Mount Daisen, although sites HN 61, 62, 69, and 71 also contain other lithologies (e.g., granitoids, psammitic schists);
- (3). Main channel below Daisen product input (MCBDPI); namely HN 1, 7, 64, 68, 70, 73, 79, 99, 100, and 103;
- (4). Hata Formation input (HI); sites HN 2, 85, 86, 88, 89, 90, 91, and 93.

Simple element-Al₂O₃ variation diagrams constitute a useful tool to illustrate differences between abundances of elements according to the above categories. The first feature observed is that although there is significant overlap and scatter, the distributions of elements show broad linear trends from the sand fractions (concentrated at lower abundances of Al₂O₃) toward the fine fraction. These linear trends are especially clear for SiO₂ (Fig. 5) and Ga (Fig. 6). Distribution of the fractions with respect to Al₂O₃ corresponds with the histograms of elemental abundances (Figs. 3 and 4), and illustrate the dependence of chemical composition on grain size as reported by several authors (e.g., Fralick & Kronberg, 1997; Vital & Stattegger, 2000).

The distributions of the major elements generally overlap, but samples derived from Daisen products tend to be distinguishable. This is especially clear for CaO (Fig. 5b), and K₂O (Fig. 5c), for which samples in both fractions from that category have higher and lower values (respectively) compared to the other categories. Fe₂O₃ (Fig. 5d), TiO₂, and MnO abundances in the fine fractions tend to be greater



Fig. 5. Examples of major element-Al₂O₃ variations in the fine and sand fractions (anhydrous normalized data), Hino River, according to main source lithotypes. F - $<180 \,\mu m$ (fine) fraction; S - sand fraction; - GDP = granitoid-dominated, - DP= Daisen products; - MCBDPI = main channel below Daisen product input - HI= Hata input; - sea = beach sands. (a) SiO₂ - linear trend between sand and fine fractions, lower abundances in samples derived from Daisen products; (b) CaO - greater abundances in samples from Daisen products; (c) K₂O - lower abundances in samples from Daisen products, two samples with >6 wt% not plotted; and (d) Fe₂O₃T - abundances in the fine fractions greater than the sands in each category, one sample with >18 wt% not plotted.

than the sands in each category. Conversely, for Na₂O, MgO, and P₂O₅ only sand fractions derived from Daisen products have distinctively higher values, whereas for SiO₂ (Fig.5a) the same samples have lower values. Samples derived from Hata Formation rocks generally show little contrast with samples from granitoid-dominated sites, and tend to plot towards lower values only for CaO (Fig. 5b) and MgO, especially the fine fraction. Although scatter is considerable, samples from the main channel below Daisen product input tend to have values intermediate between Daisen products and the granitoid-dominated group, reflecting mixing of detritus in the lower reaches of the river. Beach sample HN 8, collected from the eastern part of Miho Bay, has high CaO (Fig. 5b) in its sand fraction, possibly reflecting abundance of Daisen detritus at that site.

Trace elements behave in a similar way to the major elements; and hence the most distinctive features are related to the distribution of samples derived from Daisen products. Both fractions of samples from this category plot well apart from the remaining groups, especially for Sr (Fig. 6a), with higher values; and for Y (Fig. 6b), Rb, Th, and to a lesser extent Ba and Pb, all of which have lower values than the other groups. The higher values for Sr and lower for Y reflect the adakitic nature of the Daisen volcanic products, as described in a number of studies (e.g., Morris, 1995; Kimura et al., 2003). For Cr (Fig. 6c), Ce, Nb, Zr, and to a lesser extent for V, only the fine fractions of samples derived from Daisen products have distinctive lower values. Daisen-derived sand fractions overlap with the remaining categories. Conversely, for Ga (Fig. 6d) and to some degree for Sc, the Daisen sand fractions tend to have higher values, and equivalent fine fractions show little contrast with the other categories. Samples derived from Hata sources are again scattered among the granitoid-dominated data, except for Cr (Fig. 6c) and Ni, for which concentrations tend to be lower in the fine fractions. This suggests the geochemical signatures of Hata inputs do not differ greatly from those derived from granitoid-dominated catchments.

Although overlap and scatter are significant, trace element abundances in samples from the lower main



Fig. 6. Examples of trace element-Al₂O₃ variations in the fine and sand fractions (anhydrous normalized data), Hino River, according to main source lithotypes. Symbols as in Fig. 5. (a) Sr - markedly greater abundances in samples form Daisen products; (b) Y - lower abundances in samples from Daisen products, four samples with >100 ppm offscale; (c) Cr - extreme abundances in some samples; 12 samples with >1400 ppm offscale (d) Ga - linear trend between fine and sand fractions.

channel tend to be intermediate between those of the granitoid- and Daisen-derived products. This represents mixing in the lower reaches of the main channel of Hino River of detritus originating from these two contrasting areas, the largest of which is mainly felsic in composition. Consequently, the primary source signatures of these two sources are obscured.

Abundances of Cr in the upper main channel are greater than those in the secondary drainages in all categories, excepting sites directly draining ultrabasic rocks (16, 17, 19). Levels in the main channel decrease relatively regularly downstream, reflecting dilution of Cr-rich detritus from the ultrabasics with Cr-poor detritus from all other lithotypes. This is most marked for the <180 μ m fraction, but is also evident in the sands.

Conclusions

The chemical compositions of sediments from the Hino River system are representative of the nature of their source lithotypes. Dependence of composition on grain size is displayed by contrasting elemental distributions of the <180 μ m and sand fractions. The distributions reflect the influence of different lithotypes, with especially distinctive contrasts produced in sediments mainly derived from Mount Daisen. Sediments originating from Daisen record adakitic signatures from such products. Elevated concentrations for a number of elements (e.g. Zr, Cr) are likely related to local concentrations of heavy minerals. The intermediate chemistry of sediments collected from the main channel below the first input of Daisen products reflects mixing and homogenization of detritus in the lower reaches of the Hino River.

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(要 旨)

E. Ortiz · B.P. Roser, 2004, 鳥取県, 日野川の河川堆積物の 180 µm 以下と砂部分の堆積物の主成分 ならびに微量成分組成.島根大学地球資源環境学報告, 23, 27-37

鳥取県,日野川の現河床から採取した103の試料を180 μmより細粒な堆積物と砂部分に分け, それぞれについて XRF 分析による主成分元素と14の微量成分元素の解析を行った.元素含有量の ヒストグラムからは明らかに組成が粒径に依存していることが示された.とくに細粒な堆積物では SiO₂, K₂O, Ba, Pb, Rb を除くすべての元素がより多く含まれていた.細粒堆積物,粗粒堆積物 それぞれの分布のパターンは主に正の歪みを示し,それぞれにはっきりとした違いが見られた.多 くの元素(Sr, SiO₂, K₂O, Al₂O₃, CaO, N₂O, Rb)について,砂部分は二峰性または多峰性のパター ンを示す.これは局所的な供給源の影響を反映している.とくにモードのうちの1つが大山を集水 域にもつサンプルと関係している.組成の変化を表したダイアグラムは細粒部分と砂部分で分別が 起きていることをはっきりと示している.この結果から,大山からのサンプルは特に Sr 含有量が 高く,Y 含有量がかなり低い,起源火山岩のアダカイト質の特徴を反映していることが示された. 下流の流路堆積物からは中間的な組成が得られた.そのことは岩相の対照的な2つの地域,すなわ ちフェルシックな花崗岩類と火山岩からなる南部と大山からの火山噴出物からなる北部からの砕屑 物が混合,均質化していることを反映している.Cr の値が上流域で高く,このことは超塩基性岩 からの供給を強く示唆している.この元素量は下流に向かって安定的に減少するが,それは Cr を あまり含まない砕屑物による希釈を表している.