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Major and trace element compositions of Cretaceous-Paleocene sandstones and mudrocks from the Idonnappu Zone and the Yezo Supergroup, Urakawa, Hokkaido

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Abstract

The Idonnappu Zone, a Cretaceous-Paleocene accretionary complex, occurs between the Hidaka and Sorachi-Yezo Belts in central Hokkaido. This report contains whole-rock X-ray fluorescence analyses of 75 Cretaceous-Paleocene sandstones and mudrocks from the accretionary complex Idonnappu Zone and the Yezo Supergroup forearc sequence in the Urakawa district, southern central Hokkaido. The Idonnappu Zone suite comprises 45 samples from the MN-Unit of the Naizawa Complex and the PT-, MH- and T-Units of the Horobetsugawa Complex. The remaining 30 samples are evenly divided between the Upper and Lower Yezo Groups. The suites generally exhibit linear or curvilinear trends on oxide- or element-Al_2O_3 variation diagrams, typical of sorting fractionation. Elemental abundances and trends in the three suites generally overlap, suggestive of a common source. However, contrasts in abundances for some elements between suites, and trends in Basicity Index and K_2O/Na_2O ratios suggest some change in provenance over time, with shift from a mature or dissected arc source in the Early Cretaceous to a more primitive (but still relatively evolved) arc source in the Late Cretaceous and Paleocene. This change is recorded in both the accretionary complex and the forearc sequence.

Introduction

Kiminami et al. (1986) divided Central Hokkaido into two major north-south trending belts, the Sorachi-Yezo Belt in the west, and the Hidaka Belt in the east (Fig. 1). The Sorachi-Yezo Belt (Cretaceous-earliest Paleogene) consists of a forearc basin sequence, represented by the Upper Sorachi Group and the Yezo Supergroup (Fig. 2), overlying a higher-grade upper Jurassic to Cretaceous accretionary complex (Lower Sorachi Group and Kamuikotan Complex). The Hidaka Belt (Cretaceous-early Paleogene) is also an accretionary complex, deposited above a west-dipping subduction zone (Watanabe and Maekawa 1985).

A third belt, the Idonnappu Zone, has since been recognised, occurring at the boundary between the Sorachi-Yezo and Hidaka belts (Kiyokawa, 1992; Watanabe et al. 1994). The Idonnappu Zone is a severely deformed polylithologic accretionary complex of greenstone, chert, limestone and terrigenous sediments, associated with subduction with west to northwest vergence (Kiyokawa, 1992; Ueda et al. 1994). The zone is bounded in the east by the Hidaka Main Thrust (Fig. 3), but the western margin is less well defined.

This report contains analyses of 45 sandstones and mudrocks (shales, silstones and mudstones) collected from the Idonnappu Zone in the Urakawa area, and 30 analyses of clastic rocks from the Upper and Lower Yezo Supergroup nearby. At present, the whole rock geochemistry of Idonnappu sediments is not well known. The purpose of the collection was to characterise the rocks in the area, and contribute to a growing database of comprehensive analyses of Cretaceous sediments deposited at the Asia margin (e.g. Roser et al. 1998, 1999). The purpose of this report is to present the data, brief description of elemental abundances, and preliminary discussion of tectonic setting signatures. A more detailed account focusing on provenance and relation to depositional environment will be published elsewhere (Roser, Ueda & Kimura, in prep.)

Geological Outline and Sample Suites

The field area lies east and northeast of Urakawa, toward the southern end of the Idonnappu Zone in Hokkaido, in the catchment of the Horobetsugawa River and its tributaries (Figs 1 and 3). The Idonnappu Zone was originally termed the "Idonnappu Belt" by Kiyokawa (1992). Recent work (Ueda et al. ms[a])

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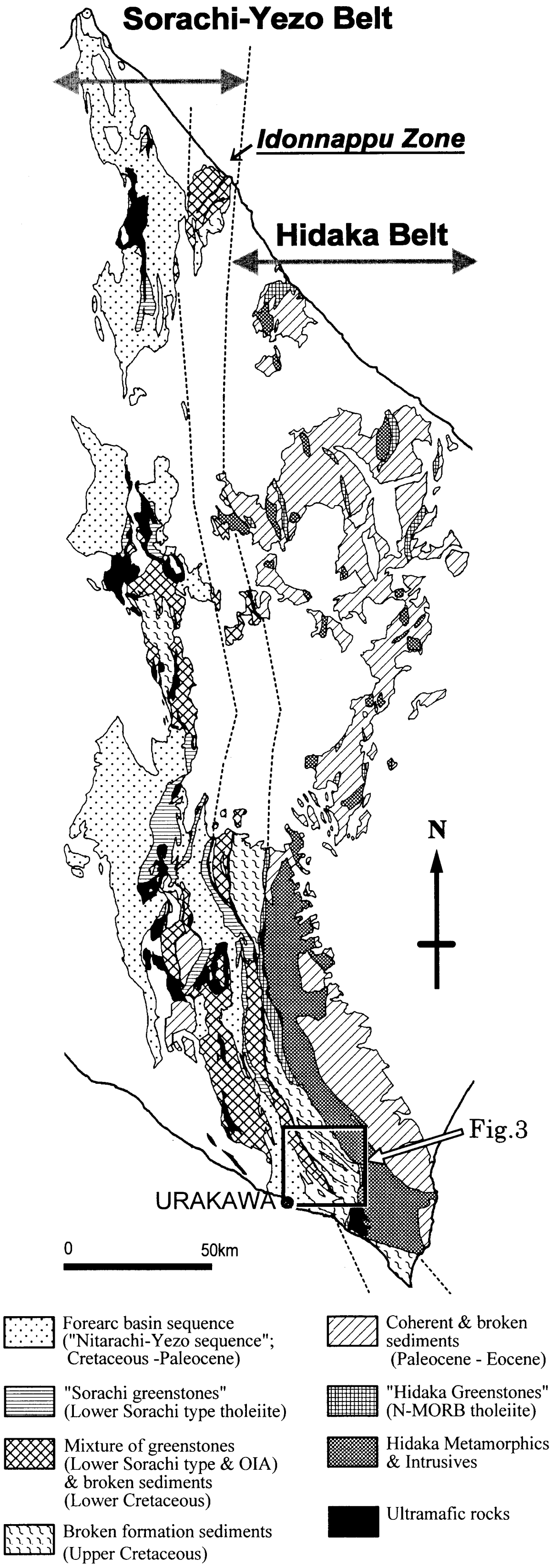

Fig. 1. Map of central Hokkaido showing the distribution of the Sorachi-Yezo Belt, Idonnappu Zone, and the Hidaka Belt; major lithotypes, and the location of the field area near Urakawa. Figure modified from Ueda et al. (ms[a]).

favours description as a "Zone", because individual lithofacies are not sufficiently continuous to permit designation as a separate tectonic belt. That usage is adopted here.

The Idonnappu Zone in the Urakawa area trends NW-SE, and is bounded by the Hidaka Main Thrust and the Hidaka Belt to the NE, and by the Nitarachi-Yezo sequence of the Sorachi-Yezo Belt to the SE (Fig. 3). The Idonnappu Zone here is further divided into the Naizawa and Horobetsugawa Complexes, as defined by Ueda et al. (ms[a]). These complexes are separated by the Westernmost Hidaka Serpentinite and the Redatoi-Okada Thrust (Fig. 3). Detailed descriptions of the local geology are given by Sakai and Kanie (1986) and Ueda et al. (ms[a,b]). Relevant units are outlined below. These descriptions are summarised from Sakai and Kanie (1986) and Ueda et al. (ms[a,b]), supplemented by additional field observation during sample collection. Schematic stratigraphy showing the relationships between the units and position of the sample sites is given in Fig. 2. Sample sites are also plotted on Fig. 3, and latitudes and longitudes given in the Appendix. Alphanumeric numbers (e.g. PT 2) contained in the following text refer to the samples listed in Table 1.

Idonnappu Zone

Naizawa Complex

Naizawa Complex is greenstone-dominant, and is correlated with the Okuniikappu Sub-belt of Kiyokawa (1992). In the Urakawa area the Naizawa Complex forms a wedge-shaped body, bounded by the Redatoi-Okada Thrust to the east, and by the Yezo Group to the west (Fig. 3). The complex is divided into two units on lithological grounds :

1. B-UNIT

The B-UNIT consists of 1-2 km thick slabs of both massive and pillowed MORB-like tholeiitic greenstones. Because of its volcanic nature, this unit was not sampled in this study.

2. MN-UNIT (MNU1-8)

This unit consists of a complex mixture of greenstone, chert, limestone, deformed turbiditic sandstone-mudstone alternations, and mudstone. The greenstones occur as both sheets and fault bounded blocks, and consist mainly of ocean-island-type alkali basalt (Ueda at al. ms[b]). The MN-UNIT is interpreted as a

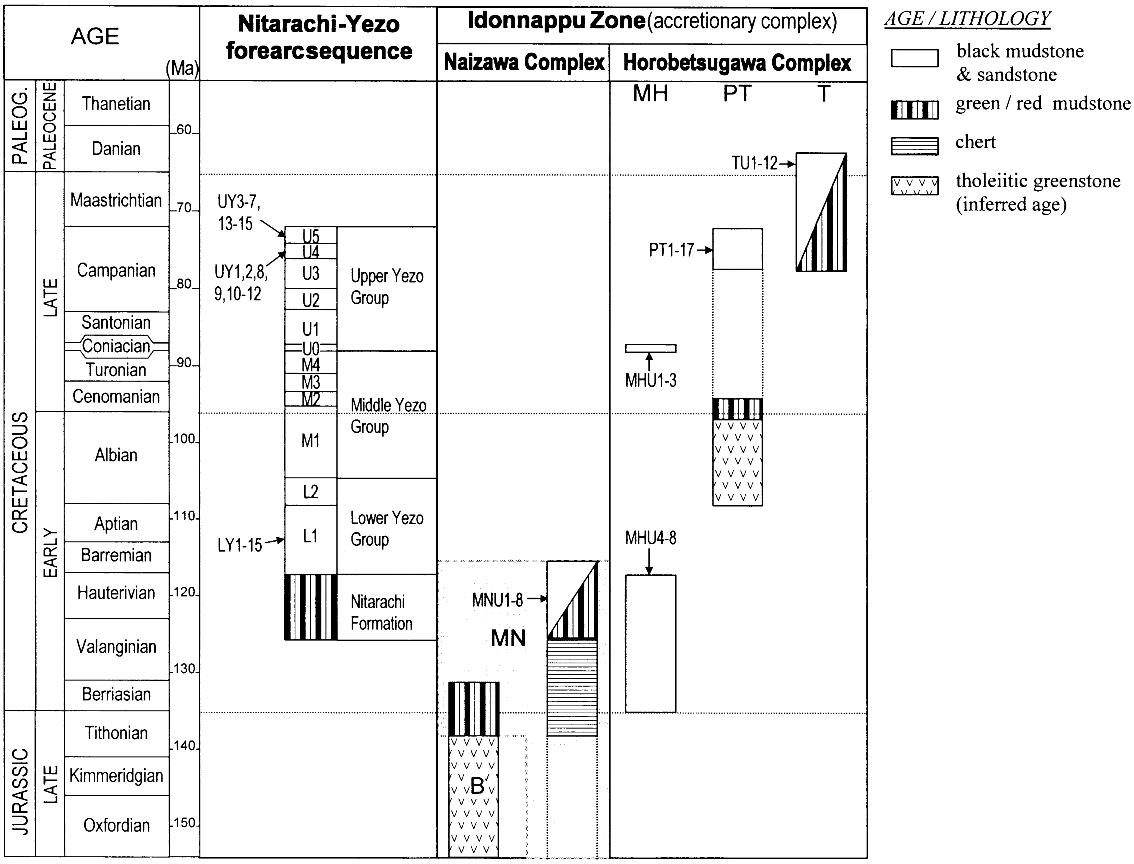

Fig. 2. Stratigraphic relationships between the Nitarachi-Yezo forearc sequence and units in the Naizawa and Horobetsugawa Complexes of the Idonnappu Zone, and stratigraphic position of samples suites analysed. Figure based on data and references compiled in Ueda et al. (ms[a,b]).

deformed trench-fill sequence (Ueda at al. ms[a]). Eight samples (5 sandstones, 3 mudstones) were collected from three localities in the Horobetsugawa River (Fig. 3). Most were taken from lensoidal packets of 1-3 dm bedded sandstone-shale alternations. All showed disruption, with tectonic thinning and bunching in the sandstones, and pervasive shearing in the mudstones. Sandstones generally displayed little grading or lamination.

Horobetsugawa Complex

In contrast to the Naizawa Complex, the Horobetsugawa Complex is dominated by clastic sediments. Intercalated bodies of greenstone, chert and limestone do occur, but are of less significance volumetrically. The clastic sediments comprise black mudstones and disrupted sandstone-mudstone alternations. Ueda et al. (ms[a]) correlated the Horobetsugawa Complex with the Koiboku Sub-belt of Kiyokawa (1992), and divided it into three units, all of which were sampled.

1. MH-UNIT (MH1-8)

The MH-UNIT (Berriasian-Hauterivian to Coniacian) is a mixed unit consisting of blocks of greenstone, chert, limestone and sandstone in a generally sheared black mudstone matrix. Much of the unit is thought to have been deposited by debris flows and landslides (Ueda et al. ms[a]). Geochemically, the included greenstones are mostly ocean-island-type alkali basalts or tholeiites similar to those contained in the MN-UNIT (Ueda et al. ms[b]). Eight samples (5 sandstones, 3 mudstones) were collected from three localities in a tributary of the Horobetsugawa River. The sandstones were collected from disturbed 50-70m thick sand packets at two localities. In both, beds were broken, and the sandstones strongly jointed and veined (MH1, 3, 5). Intervening mudstones (MH2, 7) were typically strongly cleaved, though some displayed bedding (MH6).

2. PT UNIT (PT1-17)

The PT-UNIT (~Cenomanian-Campanian) forms

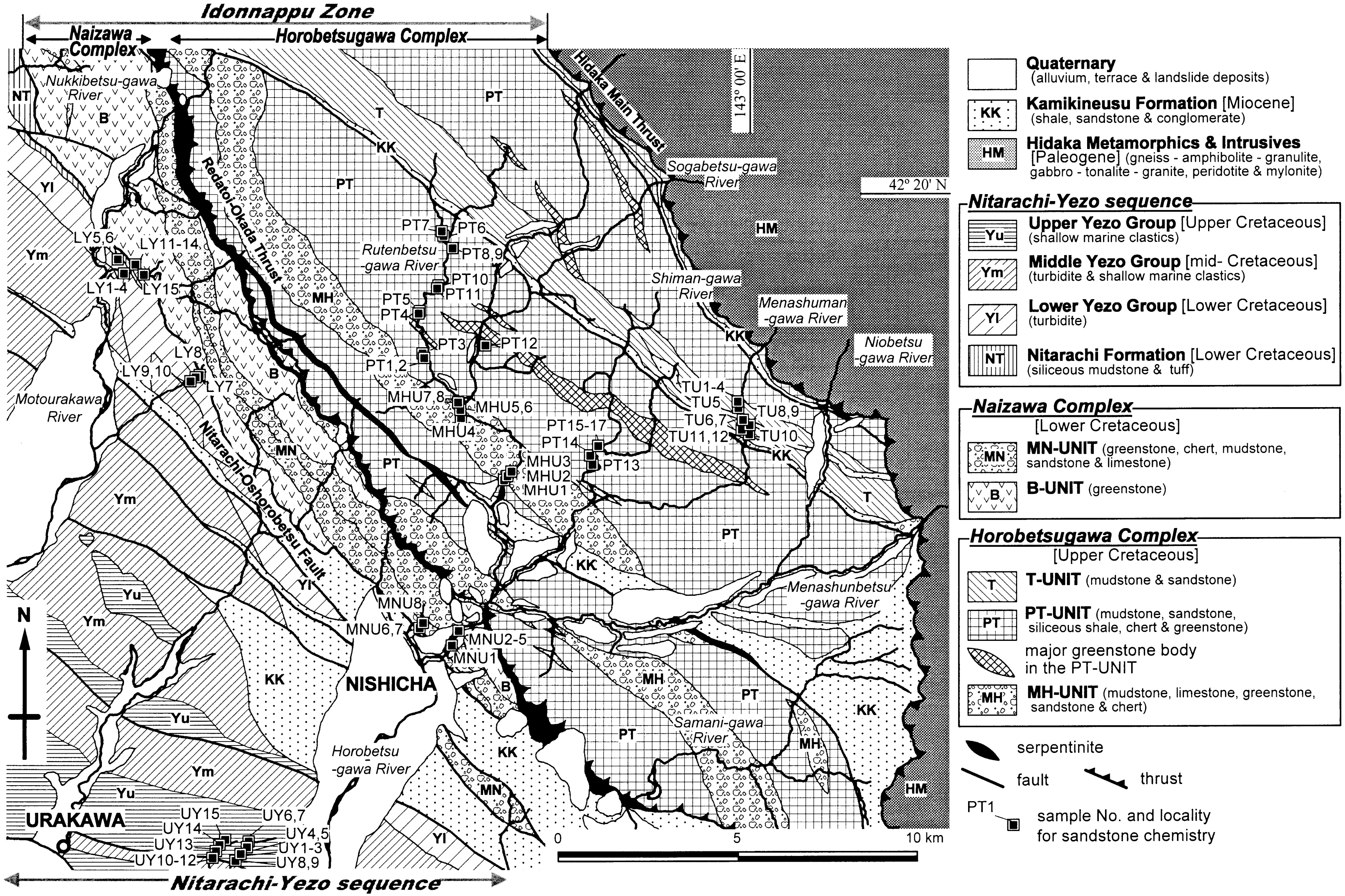

Fig. 3. Geological map of the Urakawa area, showing sample sites. Map based on and extended from that in Ueda et al. (msa).

the majority of the Horobetsugawa Complex in the area. Black mudstone, sandstone-mudstone alternations and massive sandstone are the main lithotypes. Although greenstone, siliceous mudstone and chert also occur, coloured mudstone is rare, and limestone is absent. In contrast to the above units, the greenstones exhibit n-MORB geochemical signatures (Ueda et al. ms[b]). Although the sequences are disrupted, individual lithofacies are traceable a few kilometers along strike, and several repetitions from greenstone and chert, through mudstone, to sandstone-mudstone alternations are observed (Ueda at al. ms[a]). The PT-UNIT is interpreted as trench-fill deposits, and is regarded as a clastic-dominant accretionary complex (Ueda at al. ms[a]).

Seventeen samples (9 sandstones, 8 siltstones and mudstones) were collected from sites across the entire width of the unit in the Rutenbetsugawa River, and from several localities in the Shiman-gawa River (Fig. 3). Most of the sandstones (e.g. PT3, 4, 9, 12-14) were collected from relatively thick packets (50-150 m) of massive or amalgamated sands which contained only subordinate interbedded mudstone. Others (PT6, 8, 10) were taken from thinly-bedded (1-2 dm) sandstone-mudstone alternations. In these the sandstones were typically disrupted, and the mudstones cleaved. Mudstones were also collected from massive mudstone intervals (PT5, 17).

3. T-UNIT (TU1-12)

The T-Unit (Campanian-Danian) is correlated with the K-3 unit of Kiyokawa (1992), and is interpreted as an inner trench-slope basin facies. It consists solely of terrigenous detritus (mudstone, sandstone-mudstone alternations, sandstone) ; pelagic lithotypes such as greenstones, chert and limestone are absent, although coloured siliceous mudstones do occur. It is also distinguished by a lower degree of deformation than in the units above, although sandstone beds within sand packets are often dismembered. Mudstones are less lithified than in PT- and MH-units, as verified by lower illite crystallinity (Ueda et al ms[a]). Twelve samples (9 sandstones, 3 mudstones) were collected across regional strike in the headwaters of the Menashuman-gawa River (Fig. 3). Beds at one site were coherent T_b-T_e turbidite sequences in which bed thicknesses varied from 1-10 dm (TU1-4), and sand : mud ratio was ~8 : 2. The sandstones contained mud rip-up clasts, and exhibited moderate grading, and plane and convolute lamination. Other sites consisted of massive or amalgamated sand packets (TU8, 9) or broken formation (TU5, 11, 12). One sample (TU10) was taken from an isolated glauconite-rich sandstone block, interpreted as redeposited upper shelf sediments.

Yezo Supergroup

Coherent Lower to Upper Cretaceous forearc basin sediments of the Nitarachi Formation (Valanginian-Hauterivian) and the Yezo Supergroup (Barremian to Maastrichtian) outcrop in the southwest of the field area (Fig. 3). The Yezo succession is divided into the Lower, Middle and Upper Yezo Groups (Fig. 2). Flysch sandstones and shales are common in the Lower Yezo Group, and sediments generally become progressively muddier upward (Matsumoto and Okada 1971). Sampling for this study was confined to the Lower and Upper Yezo Groups (Tsukenai and Chinomigawa Formations, respectively). These horizons were selected because the Tsukenai Formation (LY) is nearly coeval with the MN-UNIT of the Naizawa Complex, and the U4 and U5 members of the Chinogawa Formation (UY) are coeval with the upper Campanian PT-UNIT of the Horobetsugawa Complex (Fig. 2). The suites collected thus allow direct comparison of the forearc sequence and the accretionary complex.

1. Lower Yezo Group (LY1-15)

In the Urakawa area the Lower Yezo Group consists mainly of sandstone in its lower part (Tsukenai Formation), and claystone and sandstone in its upper part (Becchari Formation) (Sakai and Kanie 1986). Fifteen samples (9 sands, 6 silts and muds) were collected from the Barremian-Aptian Tsukenai Formation in the Motourakawa River, in the northwest of the field area (Fig. 3). Sample sites included alternating Tb-Te turbidite sandstone-mudstone packets (LY1-4), with sand: mud ratios of 8 : 2, and individual beds up to one metre thick; packets of amalgamated sands with little mud (LY9, 15) ; and thinly bedded Td-Te alternations (LY10). In all outcrops, disruption and induration was much less pronounced than in any of the Idonnappu units sampled.

2. Upper Yezo Group (UY1-15)

Upper Yezo Group (Coniacian to Campanian) sediments in the area are dominated by fossiliferous clay-

Table 1 Major and trace element analyses of Idonnappu Zone and Yezo Supergroup sandstones, siltstones and mudstones, Urakawa district, Hokkaido. Major elements wt%, trace elements p.p.m. LOI=loss on ignition. LITH=lithology (MS=medium grained sst; FS=fine sst; VFS=very fine sst; ZST=siltstone; MST=mudstone/shale).

SA#	LITH	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	SUM	Ba	Ce	Cr	Cu	Ga	La	Nb	Ni	Pb	Rb	Sc	Sr	Th	U	V	Y	Zn	Zr
IDONNAPPU ZONE																															
NAIZAWA COMPLEX																															
MN-UNIT																															
MNU1	FS	75.49	0.35	12.28	2.70	0.05	1.01	0.73	4.94	0.72	0.07	1.30	99.63	138	33	20	12	9	20	6	10	18	22	6	140	7.3	1.5	33	18	38	131
MNU2	MST	60.12	0.90	15.96	9.50	0.17	2.72	1.09	2.32	2.39	0.16	4.04	99.38	341	29	87	41	17	12	13	48	17	86	12	67	12.2	1.3	128	21	129	157
MNU3	FS	72.45	0.45	12.43	4.38	0.09	1.47	0.93	4.60	0.81	0.07	2.00	99.69	204	32	19	15	10	19	6	6	15	28	10	162	8.2	1.7	63	17	52	114
MNU4	FS	81.08	0.31	8.89	2.99	0.07	0.99	0.73	2.79	1.13	0.07	1.53	100.59	276	32	23	13	8	17	5	14	17	38	4	120	6.5	1.5	33	13	35	118
MNU5	MST	72.01	0.54	13.88	4.34	0.04	1.22	0.33	2.07	2.77	0.11	2.66	99.97	443	37	33	52	14	21	9	21	32	114	9	153	11.3	2.1	75	27	95	135
MNU6	MS	73.48	0.39	13.34	2.21	0.04	0.85	1.73	4.53	1.76	0.07	2.24	100.63	182	20	24	7	12	13	7	6	19	51	4	212	9.2	1.4	37	18	34	212
MNU7	MST	65.11	0.65	17.35	5.18	0.07	1.89	0.54	1.68	3.89	0.12	3.61	100.10	243	64	37	24	18	24	14	18	20	131	13	63	13.8	1.5	94	31	83	180
MNU8	MS	73.81	0.42	12.83	2.57	0.04	0.78	2.00	4.24	1.55	0.06	2.51	100.82	173	56	25	8	11	22	7	8	18	44	5	123	9.9	1.4	37	18	37	233
HOROBETSUGAWA COMPLEX																															
MH-UNIT																															
MH1	FS	74.26	0.44	12.75	3.69	0.07	1.19	1.08	3.20	2.04	0.06	1.50	100.28	510	36	20	11	13	16	9	6	15	59	4	218	7.6	1.8	50	20	52	129
MH2	MST	68.73	0.55	15.31	4.81	0.08	1.55	0.45	1.74	3.63	0.09	3.12	100.06	477	57	39	48	18	25	13	21	21	149	7	94	14.5	2.3	84	29	87	167
MH3	VFS	69.71	0.47	11.83	3.29	0.20	1.09	4.41	3.92	1.21	0.08	4.24	100.43	337	39	24	12	12	21	9	7	16	39	8	209	7.6	1.4	58	20	53	140
MH4	MST	66.23	0.56	16.00	4.64	0.07	2.11	1.37	2.87	3.10	0.10	3.16	100.20	292	73	39	24	17	25	15	19	24	130	10	120	16.1	2.1	78	31	82	113
MH5	FS	68.64	0.55	13.92	4.92	0.08	1.85	2.29	3.71	1.93	0.12	2.24	100.24	509	45	33	23	13	18	6	11	16	51	7	398	9.5	1.7	107	18	57	138
MH6	MST	66.73	0.54	16.45	4.11	0.05	2.32	1.00	1.64	4.40	0.09	3.04	100.36	971	68	40	24	18	25	15	18	25	178	8	204	19.6	2.7	75	31	76	161
MH7	VFS	68.38	0.51	14.38	4.08	0.07	1.56	2.32	4.63	1.68	0.11	2.57	100.28	420	50	36	16	13	23	8	13	19	52	7	332	9.2	1.7	64	19	57	158
MH8	FS	71.57	0.44	13.92	3.43	0.06	1.36	1.78	4.07	2.00	0.10	1.67	100.40	553	56	32	14	12	22	6	10	18	53	7	345	9.7	1.5	60	17	42	153
PT-UNIT																															
PT1	FS	75.06	0.37	12.90	3.38	0.05	0.93	0.99	3.55	1.44	0.06	1.75	100.49	420	33	20	12	12	17	7	8	17	49	8	276	8.6	1.7	39	18	47	117
PT2	MST	63.90	0.75	17.75	5.66	0.05	1.81	0.30	1.95	3.75	0.10	3.96	99.97	716	54	49	74	19	23	11	27	23	147	9	95	14.6	1.9	137	26	124	139
PT3	FS	75.18	0.44	13.81	2.60	0.04	0.71	0.92	3.40	1.93	0.05	1.56	100.63	570	44	19	13	14	20	8	5	18	68	8	260	8.5	1.8	47	21	55	151
PT4	FS	69.05	0.45	14.81	3.37	0.06	0.84	2.61	4.89	1.49	0.15	2.83	100.54	449	39	14	11	13	21	9	5	17	52	7	453	10.3	1.6	53	26	53	137
PT5	MST	68.53	0.64	15.75	4.38	0.04	1.32	0.23	3.05	2.82	0.10	3.39	100.25	673	27	37	31	16	12	10	17	24	104	11	172	11.2	2.2	104	21	66	148
PT6	VFS	66.17	0.66	16.25	4.83	0.07	1.79	2.42	4.32	1.88	0.11	2.00	100.49	491	38	44	20	15	17	6	19	17	56	12	362	6.9	2.1	108	19	70	141
PT7	MST	63.57	0.74	16.63	6.16	0.08	2.34	1.56	2.62	3.18	0.15	2.29	99.32	624	63	66	54	17	18	9	33	19	108	14	251	9.8	1.9	143	29	93	163
PT8	MST	61.75	0.65	16.64	5.22	0.13	1.94	3.94	3.86	2.26	0.17	3.04	99.59	567	51	52	40	17	26	11	24	24	69	12	426	11.2	1.8	107	31	85	182
PT9	FS	63.92	0.70	16.69	5.60	0.09	2.04	1.55	4.73	1.95	0.16	1.84	99.27	561	46	42	21	17	23	7	17	16	50	9	409	8.7	2.0	111	23	70	140
PT10	ZST	66.95	0.63	15.38	4.50	0.07	1.52	1.50	4.30	2.23	0.11	2.23	99.41	562	46	59	17	15	33	8	16	22	67	9	350	8.3	1.9	90	24	73	174
PT11	MST	65.74	0.68	16.00	5.45	0.06	2.05	0.86	2.55	3.08	0.13	2.77	99.35	640	47	56	36	19	18	9	26	17	103	13	202	11.1	2.5	130	26	86	168
PT12	VFS	67.00	0.66	14.55	5.11	0.07	1.69	2.47	4.04	1.39	0.11	2.41	99.50	432	30	49	16	13	13	6	13	18	40	12	366	6.4	1.1	113	18	75	142
PT13	FS	71.34	0.46	14.19	3.48	0.06	1.02	1.20	3.48	2.31	0.06	2.00	99.59	598	49	17	11	14	22	9	6	18	71	7	252	8.3	1.3	51	20	54	137
PT14	MS	68.46	0.43	14.56	4.64	0.07	1.16	1.76	3.24	2.70	0.46	2.18	99.65	610	33	17	14	15	20	9	7	20	81	6	279	9.5	1.5	45	28	54	148
PT15	MST	64.34	0.67	16.71	6.17	0.18	2.25	0.29	2.63	2.99	0.10	2.98	99.32	726	58	58	96	18	23	10	39	21	116	7	148	11.8	2.5	127	27	113	151
PT16	FS	70.68	0.51	13.27	4.67	0.14	1.46	1.17	4.21	1.09	0.08	2.05	99.33	407	39	25	16	12	17	6	9	16	34	10	326	6.5	1.4	81	18	64	115
PT17	MST	67.93	0.63	14.97	5.55	0.14	1.88	1.04	2.53	2.60	0.11	3.05	100.42	652	48	55	53	15	19	8	33	25	100	11	173	10.1	2.1	111	21	97	144

Table 1 (ctd)

SA#	LITH	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	SUM	Ba	Ce	Cr	Cu	Ga	La	Nb	Ni	Pb	Rb	Sc	Sr	Th	U	V	Y	Zn	Zr
HOROBETSUGAWA COMPLEX (ctd)																															
T-UNIT																															
TU1	VFS	65.33	0.71	15.63	5.15	0.07	2.10	1.54	3.89	2.39	0.11	2.39	99.31	774	31	51	21	15	21	7	16	19	71	10	327	7.6	1.7	106	24	75	155
TU2	MS	66.73	0.55	12.74	4.03	0.09	1.27	4.43	4.41	1.34	0.13	3.89	99.62	516	40	24	16	11	12	6	10	16	28	13	272	5.3	1.5	80	22	67	110
TU3	MST	60.89	0.83	17.99	5.83	0.05	2.13	0.65	3.03	3.72	0.12	3.87	99.12	688	52	67	48	20	24	10	31	23	152	14	177	11.4	2.2	155	25	105	180
TU4	VFS	67.06	0.59	14.54	5.25	0.07	1.72	1.80	3.71	2.05	0.11	2.55	99.44	760	24	47	22	13	14	7	18	19	57	11	323	8.5	1.8	92	22	71	138
TU5	ZST	72.11	0.34	13.55	2.91	0.12	0.84	0.38	3.25	3.33	0.08	2.86	99.76	873	53	22	21	14	26	10	13	23	105	7	110	18.4	3.3	46	29	57	108
TU6	VFS	61.81	0.64	16.40	5.58	0.10	1.69	2.95	3.87	2.27	0.13	3.42	98.87	867	33	72	21	14	18	8	39	26	65	12	348	9.2	2.0	93	23	80	153
TU7	VFS	63.48	0.70	16.33	6.11	0.09	2.10	1.71	3.07	2.50	0.11	3.19	99.38	696	40	78	31	15	18	9	38	21	78	12	224	10.2	2.1	110	24	90	172
TU8	VFS	63.39	0.63	15.02	5.11	0.10	1.74	3.34	3.71	2.49	0.13	3.77	99.42	917	31	74	20	13	23	8	23	19	76	12	221	8.6	2.4	97	25	74	162
TU9	VFS	61.54	0.59	16.23	5.29	0.12	1.96	3.56	3.11	3.06	0.12	3.94	99.53	799	59	68	21	16	22	12	26	21	100	12	246	11.9	2.2	88	32	78	177
TU10	ZSTG	61.85	0.46	9.49	14.48	0.06	3.95	0.93	0.93	2.10	0.13	4.26	98.65	204	30	337	25	10	14	6	80	16	92	11	65	6.8	2.1	133	16	106	104
TU11	VFS	72.85	0.47	12.36	3.83	0.22	1.14	1.38	3.68	1.83	0.11	1.95	99.81	553	37	110	24	10	19	6	31	17	56	9	233	7.1	1.6	68	20	55	134
TU12	MST	66.59	0.59	14.75	6.05	0.30	2.02	0.56	2.12	2.92	0.09	3.32	99.30	348	59	51	82	17	23	10	33	26	120	8	79	11.3	2.7	118	25	103	124
YEZO SUPERGROUP																															
LOWER YEZO GROUP (Tsukenai Formation)																															
LY1	FS	74.16	0.36	12.08	2.79	0.03	0.76	1.29	2.87	2.12	0.08	3.55	100.08	584	44	20	8	10	23	7	5	17	60	5	204	6.9	1.7	31	17	34	167
LY2	FS	70.73	0.38	14.01	2.81	0.04	0.96	1.20	2.50	2.78	0.09	4.36	99.87	707	50	17	9	14	44	8	6	19	82	5	217	8.6	2.0	33	22	43	174
LY3	MS	71.69	0.35	8.72	0.97	0.18	0.28	7.58	2.27	1.79	0.06	6.68	100.58	507	41	20	10	8	21	6	7	12	44	8	204	5.8	1.4	29	18	28	150
LY4	MST	64.20	0.73	19.47	2.52	0.02	1.65	0.96	0.03	4.70	0.11	5.58	99.97	506	63	42	23	21	27	16	10	26	191	9	179	17.2	3.0	86	35	86	205
LY5	MS	79.09	0.36	10.67	2.09	0.03	0.40	0.69	2.38	2.05	0.05	2.30	100.11	576	50	21	6	10	22	6	5	17	56	<4	176	7.6	1.4	26	14	29	185
LY6	FS	76.27	0.44	11.95	1.75	0.03	0.55	1.04	3.31	1.98	0.06	2.52	99.89	511	54	24	6	11	30	9	6	19	57	<4	212	10.0	1.6	29	19	32	279
LY7	MS	74.99	0.44	12.29	2.20	0.05	0.57	1.87	3.10	2.19	0.06	2.21	99.98	489	51	24	7	12	41	8	5	18	60	6	134	10.3	1.2	32	33	40	228
LY8	FS	75.66	0.40	12.16	3.82	0.03	0.90	0.60	3.22	1.64	0.06	1.49	99.99	423	51	23	7	11	28	7	8	16	49	5	160	9.2	1.8	31	26	42	195
LY9	FS	79.20	0.39	10.00	3.09	0.03	1.09	0.71	2.21	1.89	0.06	1.61	100.28	490	38	32	12	9	19	5	10	15	61	6	140	8.3	1.2	57	14	37	112
LY10	MST	63.34	0.69	17.50	4.56	0.03	2.40	0.68	1.70	4.21	0.10	4.35	99.57	413	51	60	36	19	23	13	23	24	200	15	116	15.6	2.4	122	30	97	165
LY11	ZST	69.31	0.45	14.73	3.04	0.05	0.85	1.65	3.21	1.81	0.08	4.35	99.53	294	46	35	15	14	25	11	15	21	69	9	179	11.5	1.5	50	23	56	208
LY12	ZST	67.65	0.52	15.26	4.01	0.06	1.08	1.06	2.72	2.22	0.10	4.95	99.61	320	58	37	18	16	28	12	16	21	86	9	160	10.6	1.9	60	27	69	196
LY13	MST	65.88	0.64	16.22	4.52	0.06	1.43	0.70	1.69	3.40	0.15	4.92	99.59	416	68	38	27	18	32	12	16	23	145	12	149	12.7	2.1	89	29	95	148
LY14	MST	66.30	0.66	19.16	2.26	0.02	1.40	0.37	1.50	4.24	0.10	3.89	99.90	405	63	51	32	22	28	14	13	21	188	9	126	16.5	2.9	96	26	61	165
LY15	FS	69.26	0.48	12.71	1.47	0.09	0.59	4.71	2.54	2.53	0.06	5.98	100.41	877	56	29	5	11	25	9	6	17	66	7	253	9.3	1.3	42	22	39	314
UPPER YEZO GROUP (Chinomigawa Formation)																															
UY1	MS	67.00	0.40	13.36	5.27	0.08	1.05	3.54	3.07	2.46	0.13	3.28	99.64	444	46	25	12	13	25	6	8	19	62	8	198	7.4	1.6	70	23	74	92
UY2	MS	68.06	0.46	14.39	5.22	0.05	1.14	2.21	3.38	2.68	0.12	2.09	99.81	598	58	24	11	14	31	6	6	19	68	9	210	6.8	1.4	69	22	67	85
UY3	MS	68.95	0.39	12.74	2.42	0.17	0.55	5.40	3.91	1.41	0.13	4.23	100.31	528	33	15	11	11	19	6	5	15	34	9	229	7.5	1.5	59	19	59	86
UY4	ZST	67.97	0.51	14.74	4.27	0.04	1.40	1.97	1.83	2.36	0.08	4.51	99.68	349	45	28	37	15	22	8	19	22	86	11	173	10.1	2.0	85	24	88	126
UY5	MST	65.87	0.55	15.70	4.84	0.03	1.48	1.81	1.93	2.58	0.08	4.71	99.58	363	47	29	38	16	14	9	19	22	97	12	164	11.2	1.6	91	24	91	131
UY6	MS	68.09	0.43	13.03	7.32	0.05	1.27	1.51	2.46	2.83	0.12	2.59	99.69	374	71	40	14	13	28	8	11	22	97	8	122	9.8	1.4	87	26	79	132
UY7	MS	63.93	0.37	11.57	5.67	0.13	0.96	6.68	2.32	2.39	0.08	5.63	99.74	357	63	34	12	11	22	6	9	17	76	9	191	5.3	1.4	67	20	56	113
UY8	ZST	64.19	0.68	16.14	4.97	0.06	1.72	2.46	2.25	3.12	0.11	3.89	99.59	445	44	49	35	16	15	8	21	19	101	13	227	7.9	1.9	118	24	93	148
UY9	ZST	64.36	0.68	16.59	5.51	0.04	1.60	1.71	2.32	2.68	0.11	3.97	99.57	324	38	42	37	16	19	8	19	22	93	14	198	10.0	1.7	120	23	90	147
UY10	FS	68.00	0.53	14.83	4.31	0.03	1.30	1.22	3.06	3.24	0.10	3.25	99.88	519	50	31	21	15	20	9	11	21	107	11	159	10.7	2.1	80	28	86	165
UY11	FS	68.33	0.50	13.92	4.32	0.05	1.05	2.11	3.08	2.57	0.10	3.50	99.54	416	40	28	21	15	16	8	10	19	85	9	191	10.7	2.1	78	24	77	156
UY12	MS	66.91	0.59	15.38	4.97	0.04	1.40	1.66	2.07	3.17	0.14	3.34	99.68	498	40	38	31	15	17	8	16	19	111	11	197	10.0	2.1	92	25	84	152
UY13	ZST	67.16	0.59	15.29	4.53	0.05	1.40	2.14	2.31	2.52	0.12	3.53	99.63	361	51	30	30	14	22	9	16	21	83	11	216	9.3	2.1	92	27	79	159
UY14	MS	66.37	0.31	12.02	4.01	0.16	0.81	6.28	2.47	2.73	0.12	5.17	100.43	469	51	19	12	11	24	6	6	19	70	8	190	7.0	1.3	45	25	56	85
UY15	ZST	67.49	0.60	14.56	4.91	0.03	1.39	1.64	1.98	2.42	0.15	4.40	99.57	457	31	32	31	15	21	9	15	19	86	11	167	9.0	2.7	92	33	91	137

stone and siltstone; sandstone is subordinate (Sakai and Kanie 1986). Fifteen samples (9 sands, 6 silts and muds) were collected from the Chinomigawa Formation along two traverses west of Urakawa (Fig. 3). Medium- to very-fined grained sandstone beds occurs in isolated beds ~1-5 m thick. The sandstone beds were usually massive (possibly amalgamated), and thus exhibited little grading or sedimentary structures. Many were strongly glauconitic (UY1, 2, 6, 7 14). Most of the sequence (~95%) consisted of monotonous grey to greenish-grey siltstone (UY4, 9, 12, 13, 15).

Analytical Methods

Samples were coarsely chipped (<1 cm diameter) in a manual hydraulic rock splitter, removing any surficial weathering or oxide staining. Any chips containing visible mud rip-up clasts or significant veining were also discarded. The fresh chip was rinsed repeatedly in tap water, followed by distilled water, and steeped overnight in deionised distilled water. Oven-dried sample chip was then crushed for 30-60 seconds in a tungsten-carbide ring mill, with sample weights ranging from 70 g in the shales to a maximum of 200 g in the sandstones.

Major and trace element analyses were made by XRF, using a Philips PW1404 instrument at Hokkaido University. Analyses were carried out on an anhydrous basis, using the ignited material from loss on ignition (LOI) determinations. LOI was measured by weight loss in 5-6 g of oven dried (110℃) sample after ignition for two hours at 1000℃ in an electric furnace. Both major and trace element determinations were made on fused glass beads prepared with commercial lithium metaborate/tetraborate flux (Johnson Matthey Spectroflux 100B) in a Toyyo Kagaku NT-2000 automatic bead sampler, with preheat, fusion and agitation times of 120, 120 and 400 seconds, respectively. The fusion mixture comprised 1.8000 g sample, 3.6000 g of flux, and 0.54 g $LiNO_3$. Bead preparation essentially follows that of Tanaka and Orihashi (1997), except that their addition of 50 g lithium iodide during melt agitation was not necessary.

Major and trace element calibration was made using standard reference samples produced by the Geological Survey of Japan and the United States Geological Survey. Details of the methods, instrument conditions, precision and lower limits of detection are given by Tanaka and Orihashi (1997). Analyses were monitored by repeat analyses of several GSJ standards, from new beads not included in the calibration.

Results

Results for major and trace elements are listed in Table 1, by formation. The data are listed on a hydrous basis. Lithology was estimated from hand specimens using a hand lens and grain size comparator. All elements except Sc and U were present at levels above the theoretical lower limits of detection (LLD) in all samples. Sc was >LLD (3.8 ppm) in all except two samples. Although U was below the LLD (1.9 ppm) in over half the samples, data are listed as analysed in Table 1, as relatively coherent trends with Al_2O_3 are still displayed despite the low abundances.

Abundances and trends

Variation diagrams for selected elements plotted against Al_2O_3 are given in Fig. 4 (major elements) and Fig. 5 (trace elements). All are plotted on an anhydrous basis. Most elements show linear or curvilinear trends due to sorting fractionation between sand-sized detritus (quartz, feldspar and lithic fragments) and clays. Among the major elements this is most marked for SiO_2 (Fig 4a), as is usually the case in such suites. The majority of the Idonnappu and Upper Yezo sandstones have SiO_2 contents <75%, but Lower Yezo sandstones have up to 80%, and total fractionation between sandstone and mudstone is greater than in the other suites. These features are reflected by antipathetic variations of TiO_2 (Fig. 4b), Fe_2O_3, MgO, K_2O and P_2O_5, which increase with increasing Al_2O_3, reflecting residence largely in the clay fraction. Linear detrital trends (DT) of these elements intersect the Al_2O_3 axis at ~7.5%, indicative of quartz-feldspar-lithics verses clay unmixing (Fig. 4b). However, a small number of sandstones from the Lower Yezo Group lie closer to the silica dilution line (SDL), suggesting that simpler quartz-clay unmixing may be responsible for their chemistry.

Na_2O and CaO (Figs 4c and 4b) generally decrease with increasing Al_2O_3, and sandstones generally have higher abundances than mudstones in the same suite. This pattern is consistent with residence largely in

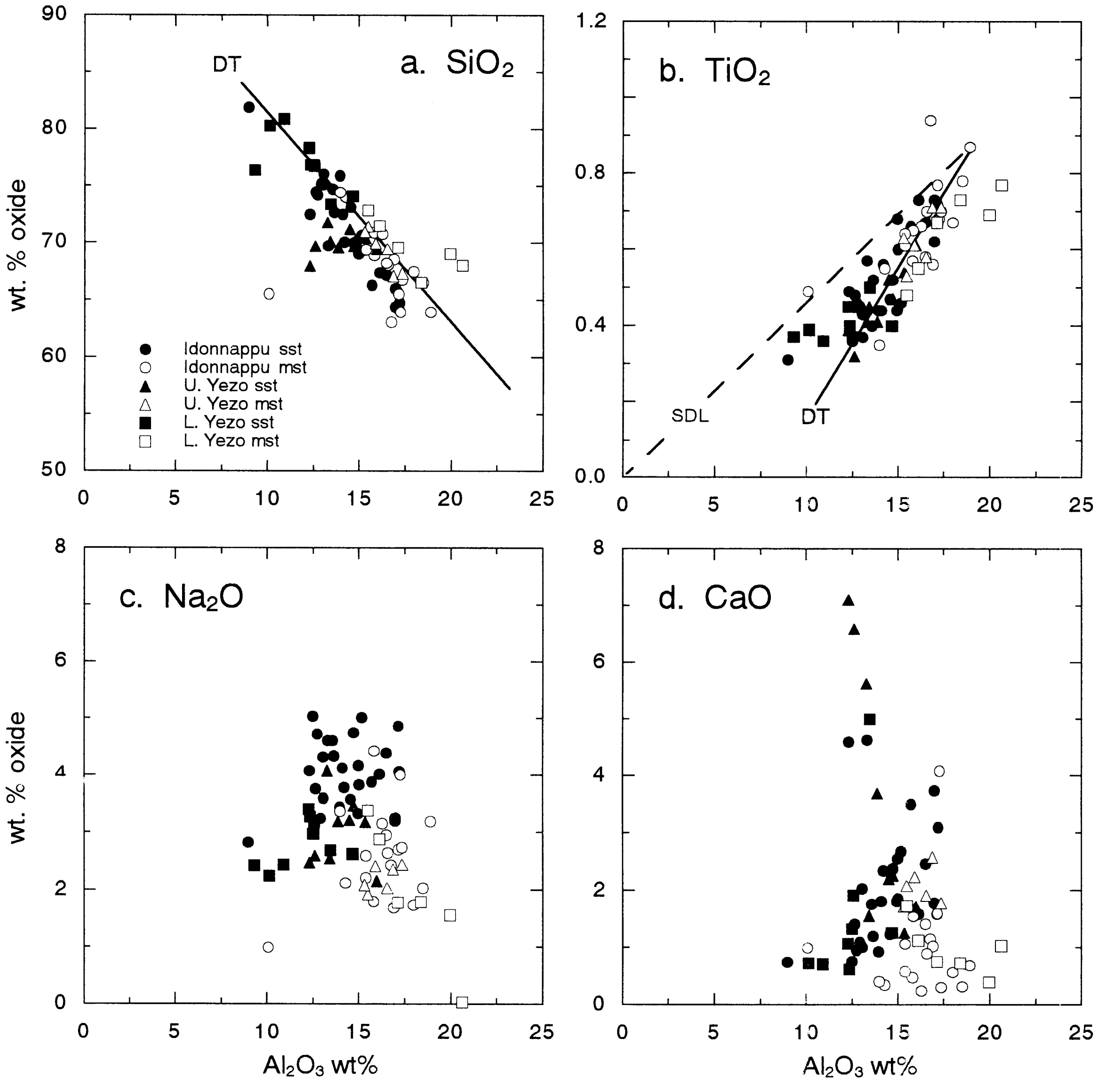

Fig. 4. Example oxide-Al_2O_3 variation dagrams, plotted on an anhydrous normalised basis. Sst=sandstone ; mst=siltstone and mudstone. Solid lines (DT) are illustrative detrital trends (draw by eye) ; dashed line (SDL) on the CaO plot is a silica dilution line drawn from the aluminous end of the detrital trend.

feldspar in the sandstones. Accretionary complex Idonnappu sandstones generally have greater Na_2O contents (>3 wt%) than the forearc sandstones from the Yezo Supergroup (<3%). CaO contents show little contrast, however, except that a small number of sandstones from all groups scatter to higher values of 3-8 wt% (Fig. 4d), probably due to presence of carbonate cement. MnO contents of both sandstones and mudstones are generally low (0.10 wt%), but some scatter to higher values (0.10-0.30) occurs in all suites. This is likely to be due to redistribution during surficial weathering.

The majority of the trace elements also show positive correlation with Al_2O_3 and thus highest concentrations in the mudstones, reflecting primary residence in the clay fraction. Correlation is strongest for Ga (Fig. 5a), reflecting its close geochemical affinity with Al, but relatively coherent trends are also observed for V (Fig. 5b), Cr (Fig. 5c), Cu, Nb, Ni, Pb, Rb, Sc, Th, U, Y and Zn. Two elements generally linked with mafic detritus (Cr, Ni) show some scatter to higher values in Idonnappu sandstones and mudstones (Fig. 5c). Most of the samples which exhibit enrichment are from the T-UNIT. A similar trend is shown by Cu.

Four elements (Ba, Sr, Ce and La) show little

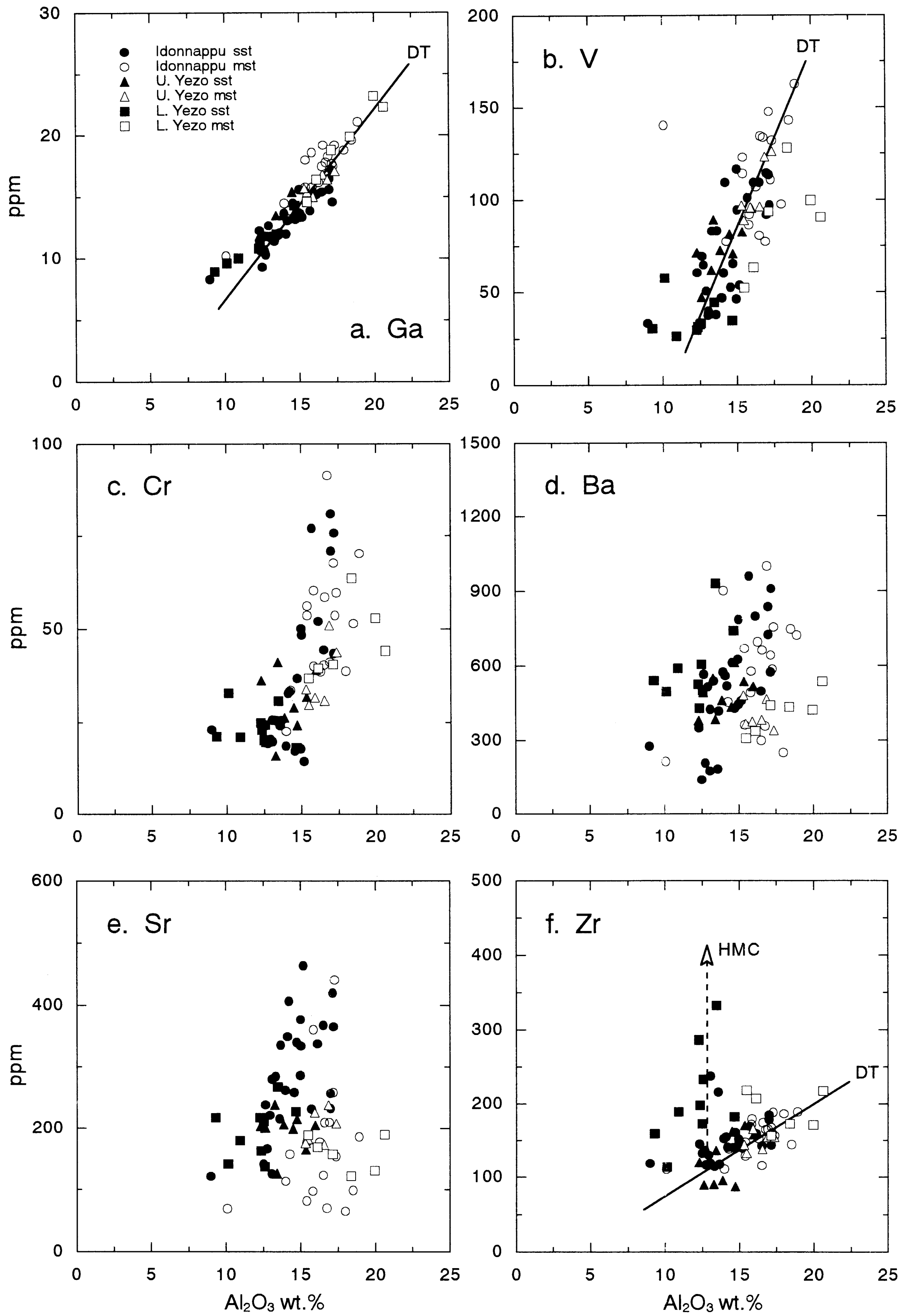

Fig. 5. Example trace element-Al_2O_3 variation dagrams, plotted on an anhydrous normalised basis. Sst =sandstone ; mst=siltstone and mudstone. Solid lines (DT) are illustrative detrital trends (draw by eye). Dashed arrowed line (HMC) on the Zr plot illustrates the trend expected from zircon concentration in sandstones.

overall correlation with Al_2O_3 content. Within individual suites, however, both Ba and Sr tend to have higher values in sandstones than in mudstones (Fig. 5d and 5e). This pattern is not uncommon in clastic sediments (e.g. Roser et al., 1999), and most likely reflects partial Sr and Ba residence in feldspar. Scatter is induced by varying feldspar proportions, diagenetic effects, and, in the case of Sr, carbonate contents. In detail, Ce and La show the opposite trend, with a tendency for higher contents in muds than in sands within individual suites, reflecting primary control by the clay fraction. Scatter may be due in part to heavy mineral concentration, but may also be influenced by poor analytical precision. At the amounts present in the samples, analytical precision is poorer for both elements (coefficients of variation of ~10-11%; Tanaka and Orihashi, 1997) than it is for the other elements positively correlated with Al_2O_3 (<5%).

Zirconium shows contrasting behaviour between the suites (Fig. 5f). Idonnappu and Upper Yezo samples exhibit a relatively coherent increase with increasing Al_2O_3. Although this might imply residence in the clay fraction, Zr abundances are usually controlled by zircon in suites such as these. The coherence of the Idonnappu and Upper Yezo Group trends suggests that if zircons are the control, they must be finely comminuted. The Lower Yezo suite shows a trend more common in accretionary sediments, with sandstones scattering to higher values above the detrital trend, with concentrations up to twice those of the mudstones. This is typical of density concentration of zircons in the sandstones.

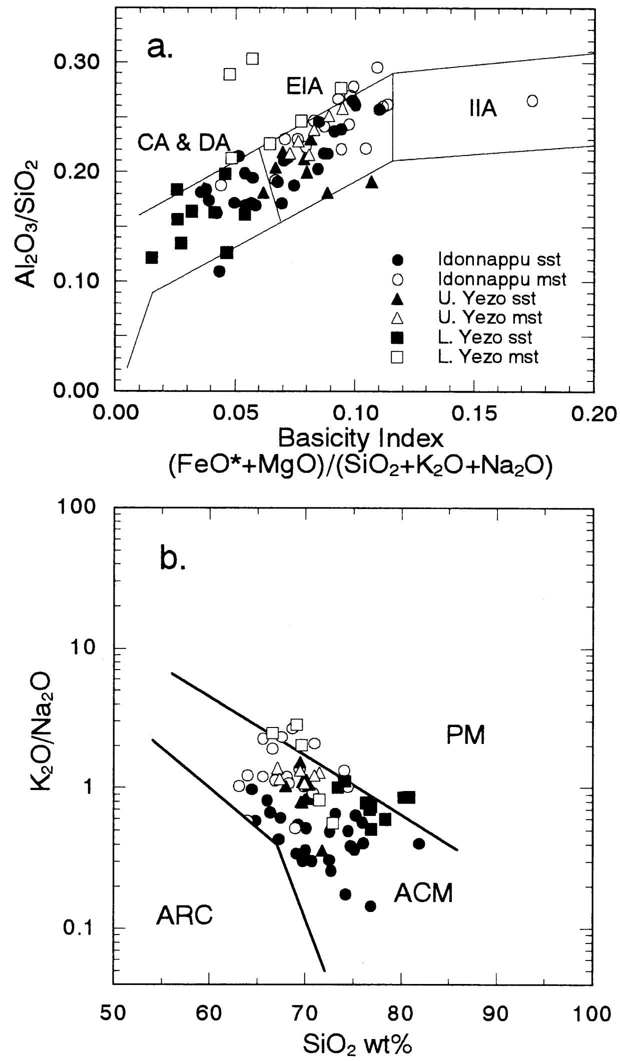

Fig. 6. Tectonic setting discrimination plots. Symbols as in Figs 3 & 4. (a) Basicity Index plot of Kiminami et al. (1992); fields modified after Kiminami (1998). IIA =immature island arc; EIA=evolved island arc; CA& DA=continental island arc and dissected arc. (b) SiO_2-K_2O/Na_2O plot of Roser & Korsch (1986). PM=passive margin; ACM=active continental margin; ARC=arc.

Tectonic setting

The tectonic setting of deposition of clastic sediments can be assessed using a number of chemical parameters, including SiO_2-K_2O/Na_2O (Roser and Korsch 1986) and Al_2O_3/SiO_2-Basicity Index relations (Kiminami et al. 1992; Kumon and Kiminami 1994). On a Basicity Index plot (Fig 6a), the three suites analysed lie almost entirely within the EIA (Evolved Island Arc) and CA&DA (continental arc-dissected arc) fields. Middle Yezo Group sandstones were used by Kiminami et al. (1992) to originally define the EIA field. Data plotted in a later revision of the fields (Kiminami 1998) mostly lie at the upper end of EIA. A clear contrast, however, is seen between the Lower and Upper Yezo suites analysed here. The Lower Yezo data fall within CA&DA, whereas Upper Yezo samples lie almost entirely within the lower part of the EIA field. This shows that the nature of the Yezo source changed from a relatively mature dissected arc in the Early Cretaceous to an evolved island arc in the Late Cretaceous.

The Idonnappu suite sandstones spread across both CA&DA and EIA (Fig. 6a). Although not distinguished at a formation level on the figure for clarity, they also show shifts in Basicity Index and Al_2O_3/SiO_2 with time, with the MH- and MN-units falling mostly within CA&DA, and the younger PT- and T-units largely within EIA. The forearc Yezo sediments and the Idonnappu accretionary complex thus both record the same shift in source, supporting their correlation.

The three suites fall almost entirely within the active continental margin (ACM) field on an SiO_2-K_2O/Na_2O plot (Fig. 6b), with only a few mudstones spreading into the passive margin (PM) field, probably as a result of diagenetic K-enrichment. This result is compatible with the CA&DA-EIA signatures from the Basicity Index, since both categories share chemical signatures with more classical Andean-type margins. Lower Yezo samples lie high in the ACM field along the ACM-PM join, and show marked fractionation of both SiO_2 and K_2O/Na_2O ratio between sandstones and mudstones. Both features are typical of derivation from a relatively evolved source. Upper Yezo Group samples, however, have lower SiO_2 and K_2O/Na_2O, plotting near the middle of the ACM field. Although decrease in both parameters is partly due to their finer grain size, it is also consistent with a less evolved source. Idonnappu sediments span almost the entire width of the ACM field. Examination on at a formation level, however, shows that SiO_2 decreases and K_2O/Na_2O increases progressively from the MN-Unit through to the T-UNIT. All sandstones plotting at the low-SiO_2, high K_2O/Na_2O end of the data cloud near the ARC-ACM boundary are from the T-UNIT, and are the least evolved of the Idonnappu units. Plot positions of the individual suites and formations thus show the same pattern as the Basicity Index plot, with decreasing arc maturity upsequence in both the forearc and in the accretionary complex.

Conclusions

Sediments from the Idonnappu Zone, Lower Yezo Group and Upper Yezo Group in the Urakawa area generally exhibit linear or curvilinear trends on Al_2O_3 variation diagrams. Such trends are typical of sorting fractionation. The overall similarity of elemental abundances and trends in the three suites are suggestive of a common source. In detail, however, some contrasts in abundances occur (e.g. enriched Na_2O, Cr, and Ni in the Idonnappu suite ; CaO in the Upper Yezo, and more extensive fractionation and greater Zr contents in the Lower Yezo Group). These features and trends in Basicity Index and K_2O/Na_2O ratio suggest changes in provenance occurred over time, with a shift from a mature or dissected arc source in the Early Cretaceous to a more primitive (but still relatively evolved) arc source in the Late Cretaceous, recorded in both the forearc sequence and in the accretionary complex. The significance of these changes in relation to depositional environment, provenance, and variation at a formation level will be discussed in more detail in a future paper.

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（要　旨）

Barry Roser・植田勇人・前原恒祐，1999，北海道浦河における白亜系～古第三系イドンナップ帯および蝦夷累層群の砂岩・泥岩の主成分および微量成分組成，島根大学地球資源環境学研究報告，18, 11-24

白亜紀から古第三紀の付加帯コンプレックスであるイドンナップ帯は，北海道中部，日高帯と蝦夷帯の間に露出する．本報告では，中部北海道南部，浦河地域における白亜系から古第三系イドンナップ帯付加帯コンプレックス，ならびに蝦夷累層群前弧シークエンスの，砂岩・泥岩 75 試料の全岩蛍光 X 線分析結果を報告する．イドンナップ地域の試料は，内沢コンプレックス MN-ユニット，幌別川コンプレックスの PT-, MH-, T-ユニットからの 45 試料である．残り 30 試料は上部および下部蝦夷層群から層序学的に均等に採取したものである．これらの試料群は全般に，Al_2O_3 変化図において分級分別に典型的な直線的あるいはやや屈曲した直線的トレンドを示す．上記の 3 試料群における元素濃度および元素トレンドはお互いに重複し，共通の起源物質を有することがわかる．しかしながら，いくつかの元素に見られる試料群間の元素濃度の違い，塩基性度や K_2O/Na_2O 比にみられる違いは，時間とともに給源地域に変化があったことを示している．これは前期白亜紀にみられる「成熟もしくは開析された島弧」給源から，後期白亜紀～古第三紀の「より始原的であるが比較的発達した島弧」給源への変化である．この変化は，付加帯コンプレックスと前弧シークエンスの双方に共通して認められる．

APPENDIX: Sample Localities

IDONNAPPU ZONE

SaNr	lat N deg	min	sec	long E deg	min	sec
MNU1	42	13	21	142	53	59
MNU2	42	13	32	142	54	16
MNU3	42	13	32	142	54	16
MNU4	42	13	32	142	54	16
MNU5	42	13	32	142	54	16
MNU6	42	13	34	142	53	21
MNU7	42	13	35	142	53	23
MNU8	42	13	37	142	53	24
MHU1	42	15	41	142	55	5
MHU2	42	15	43	142	55	9
MHU3	42	15	45	142	55	10
MHU4	42	16	37	142	54	16
MHU5	42	16	41	142	54	16
MHU6	42	16	42	142	54	14
MHU7	42	16	48	142	54	15
MHU8	42	16	50	142	54	15
PT1	42	17	25	142	53	34
PT2	42	17	25	142	53	34
PT3	42	17	28	142	53	33
PT4	42	18	5	142	53	23
PT5	42	18	7	142	53	25
PT6	42	19	16	142	53	57
PT7	42	19	18	142	53	56
PT8	42	19	8	142	54	5
PT9	42	19	7	142	54	5
PT10	42	18	33	142	53	49
PT11	42	18	28	142	53	44
PT12	42	17	38	142	54	40
PT13	42	15	52	142	56	53
PT14	42	16	0	142	56	56
PT15	42	16	3	142	56	58
PT16	42	16	2	142	56	59
PT17	42	16	2	142	56	59
TU1	42	16	39	142	59	49
TU2	42	16	38	142	59	47
TU3	42	16	37	142	59	47
TU4	42	16	37	142	59	47
TU5	42	16	37	142	59	49
TU6	42	16	28	142	59	52
TU7	42	16	28	142	59	51
TU8	42	16	23	142	59	53
TU9	42	16	22	142	59	53
TU10	42	16	15	142	59	56
TU11	42	16	18	142	59	53
TU12	42	16	20	142	59	53

YEZO SUPERGROUP

Sample No.	lat N deg	min	sec	long E deg	min	sec	Unit*
LY1	42	18	47	142	47	33	L1
LY2	42	18	47	142	47	33	L1
LY3	42	18	47	142	47	32	L1
LY4	42	18	47	142	47	34	L1
LY5	42	18	58	142	47	26	L1
LY6	42	18	58	142	47	26	L1
LY7	42	17	17	142	48	58	L1
LY8	42	17	15	142	48	56	L1
LY9	42	17	10	142	48	48	L1
LY10	42	17	10	142	48	48	L1
LY11	42	18	50	142	47	43	L1
LY12	42	18	50	142	47	43	L1
LY13	42	18	50	142	47	43	L1
LY14	42	18	50	142	47	43	L1
LY15	42	18	47	142	47	52	L1
UY1	42	10	12	142	49	35	U5a
UY2	42	10	13	142	49	37	U5a
UY3	42	10	14	142	49	37	U4b
UY4	42	10	17	142	49	41	U4b
UY5	42	10	19	142	49	42	U4b
UY6	42	10	21	142	49	43	U4a
UY7	42	10	22	142	49	45	U4a
UY8	42	10	12	142	49	35	U5b
UY9	42	10	10	142	49	34	U5b
UY10	42	10	13	142	49	9	U5b
UY11	42	10	14	142	49	11	U5b
UY12	42	10	16	142	49	10	U5b
UY13	42	10	11	142	49	12	U4b
UY14	42	10	22	142	49	15	U4b
UY15	42	10	24	142	49	17	U4b

* Units are the horizons of Sakai & Kanie (1986)