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Data

Major and trace element analyses of sandstones and mudstones from the Siwalik Group, Bakiya Khola, central Nepal

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Abstract

This report contains whole-rock major and trace element analyses of 206 Middle Miocene to Pleistocene sandstones and mudstones from the Siwalik Group in the Bakiya Khola area of Central Nepal, as part of a continuing study of their geochemistry. Data are presented for the Rapti (n=85), Amlekhganj (n=90), Churia Khola (n=10) and Churia Mai Formations (n=21). All were analyzed by X-ray fluorescence for the major elements and 18 trace elements. Lithotype averages for each formation show SiO_2 contents generally increase up section, whereas all other major elements decrease. CaO abundances are enriched in the Rapti and Amlekhganj suites. Trace element averages also fall up section in response to the increase in SiO_2. Average trace element contents in the mudstones of each formation are generally higher than in their companion sandstones, suggesting the proportion of clay minerals present controls their abundances. Zirconium is an exception, reflecting zircon concentration in the sandstones. Normalization against average upper continental crust (UCC) shows most elements are present at crustal levels, especially in the sandstones. However, Na_2O, Sr and to a lesser extent CaO are strongly depleted, whereas Zr, Th, Ce, Y are enriched relative to UCC. Ferromagnesian elements (Sc, Fe, Ti, Ni, Cr, V) are also enriched in the mudstones relative to UCC. The causes of these anomalies will be examined in future work.

Key words: Geochemistry, major and trace elements, sedimentary rocks, Siwalik Group, Bakiya Khola, Nepal

Introduction

The Mid-Miocene to Pleistocene Siwalik Group of Nepal is situated between the Lesser Himalaya in the north and the Indo-Gangetic plain in the south, and was deposited in a foreland basin setting. Structurally it is bounded by the Main Boundary Thrust (MBT) in the north and the Main Frontal Thrust (MFT) in the south (Fig. 1). The Siwalik Group consists of a 6000m+ thickness of fluvial sediments derived from the erosion of the Himalaya and Tibetan Plateau (Ulak and Nakayama, 1998). The dominant rock types are sandstone, mudstone, shale and conglomerate. The Siwalik Group is informally subdivided into three subgroups, the lower, middle and upper Siwaliks (Auden, 1935; Gautam and Rösler, 1999). The lowermost subgroup is composed mainly of mudstones and fine to medium grained sandstones, and accumulated in a meandering river environment. The middle Siwaliks consists of medium to coarse grained, mica-rich sandstone deposited from sandy meandering to sandy braided fluvial systems, whereas the upper part is predominantly composed of pebble to boulder sized conglomerates. These were deposited in gravelly braided river and alluvial fan environments (Gautam and Rösler, 1999; Beek et al., 2006).

The Siwalik succession in Nepal has been investigated in many studies, and from a variety of viewpoints (e.g. Dhital et al., 1995; Ulak and Nakayama, 1998; Gautam and Rösler, 1999; Nakayama and Ulak, 1999; Roser et al., 2002; Huyghe et al., 2005; Beek et al., 2006; Szulc et al., 2006 and many others). However, reports of whole-rock geochemical data are limited. The purpose of this publication is to record whole-rock major and trace element analyses of a stratigraphically controlled suite of 206 sandstones and mudstones spanning the Siwalik succession in the Bakiya Khola area. Preliminary interpretation of the major element data for these samples has already been given by Roser et al. (2002), who found that elemental abundances varied up section, due to decreasing carbonate content and possibly change in provenance. Intensification of source weathering and change in fluvial style also influenced compositions. Subsequent trace element analyses for the samples are also reported here. Interpretations of the trace element data will be given in future publications.

Sample suites

The sequence sampled is exposed mainly along the Bakiya Khola and Simat Khola areas of Central Nepal (Fig. 1). The lithostratigraphy of the Siwalik Group in the study area has been established by Sah et al. (1994) and Ulak and Nakayama (1998). The succession is divided into four formations, the Rapti, Amlekhganj, Churia Khola and Churia Mai Formations, in ascending order (Table 1). Ulak and Nakayama (1998) and Nakayama and Ulak (1999) described the lithostratigraphy and depositional environment of each

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Table 1. Stratigraphy of the Siwalik succession, Bakiya Khola area, Central Nepal (Ulak and Nakayama, 1998; Nakayama and Ulak, 1999; Ulak, 2006).

Formation	Membe	Lithology	Depositional environments	Thickness (m)
Churia Mai		Poorly-sorted, clast-supported gravel and boulder	Debris flow dominated braided system	500+
Churia Khola		Well-sorted, pebble to cobble size, clast-supported conglomerate	Gravelly braided system	1100
	Upper	Very coarse grained, pebbly sandstone	Shallow sandy braided system	2100
Amlekhganj	Middle	Coarse to very coarse grained, 'pepper and salt' sandstone	Deep sandy braided system	600
	Lower	Coarse grained sandstone and gray mudstone	Sandy meandering system	340
	Upper	Fine to medium grained sandstone and variegated mudstone	Flood flow dominated meandering system	450
Rapti	Middle	Fine grained sandstone and variegated mudstone	Fine grained meandering system in a proximal setting	350
	Lower	Variegated mudstone	Fine grained meandering system in a distal setting	210+

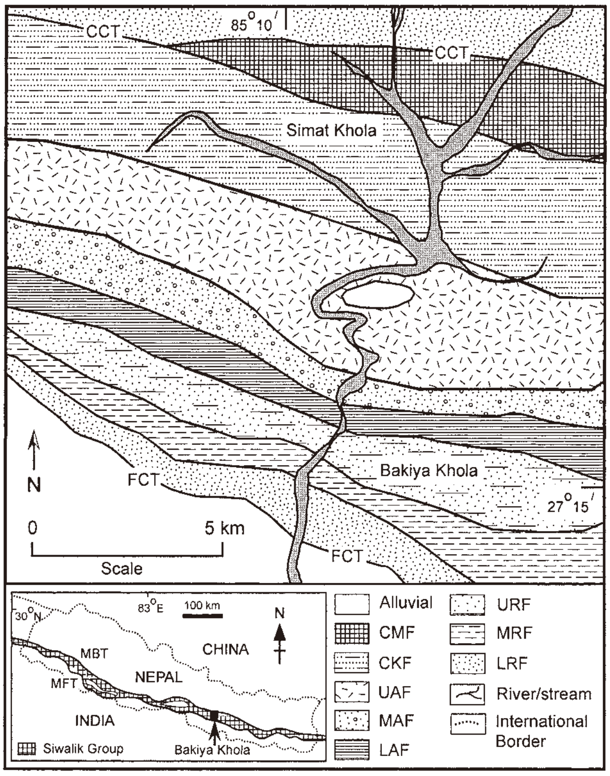

Fig. 1. Generalized geological map of the Siwalik succession, Bakiya Khola area, Central Nepal (modified after Nakayama and Ulak, 1999). Abbreviations: MBT, Main Boundary Thrust; MFT, Main Frontal Thrust; CCT, Central Churia Thrust; FCT, Frontal Churia Thrust; LRF, Lower Rapti Formation; MRF, Middle Rapti Formation; URF, Upper Rapti Formation; LAF, Lower Amlekhganj Formation; MAF, Middle Amlekhganj Formation; UAF, Upper Amlekhganj Formation; CKF, Churia Khola Formation; CMF, Churia Mai Formation.

formation in the Bakiya Khola section.

The lowermost Rapti Formation has a thickness of about 1010+ m. It is well exposed in the Rapti River (Ulak, 2006), and where it is composed mainly of fine- to medium-grained gray sandstones, interbedded variegated mudstones, and siltstones. The Rapti Formation is further subdivided into lower, middle and upper members based on dominant lithotypes (Ulak and Nakayama, 1998). The lower member (210+ m thick) is mudstone-dominated, and was deposited by meandering rivers in a distal setting. The middle member (350 m thick) consists of approximately equal proportions of sandstone and mudstone deposited by meandering rivers in a more proximal setting. The upper member (450 m thick) consists of fine- to coarse-grained sandstone beds and associated dark gray to variegated mudstones; these were deposited by flood flow-dominated meandering river systems (Ulak and Nakayama, 1998; Nakayama and Ulak, 1999). Analyses were made of 85 Rapti Formation sandstones and mudstones.

The overlying Amlekhganj Formation (3040 m thick) consists of coarse to very coarse grained gray sandstones and interbedded dark gray mudstones, and is well exposed in the Dudhaura Khola near Amlekhganj village (Ulak and Nakayama, 1998). The Amlekhganj Formation is also subdivided into lower, middle and upper members. The lower member (340 m thick) consists mainly of coarse-grained "pepper and salt" sandstones with alternating gray mudstones. The "pepper and salt" appearance arises from abundance of quartz and biotite. The lower member was deposited by a flood flow-dominated sandy meandering system (Nakayama and Ulak, 1999; Roser et al., 2002). The middle member (600 m thick) is composed predominantly of coarse to very coarse-grained "pepper and salt" sandstones and gray mudstones. The depositional system in this

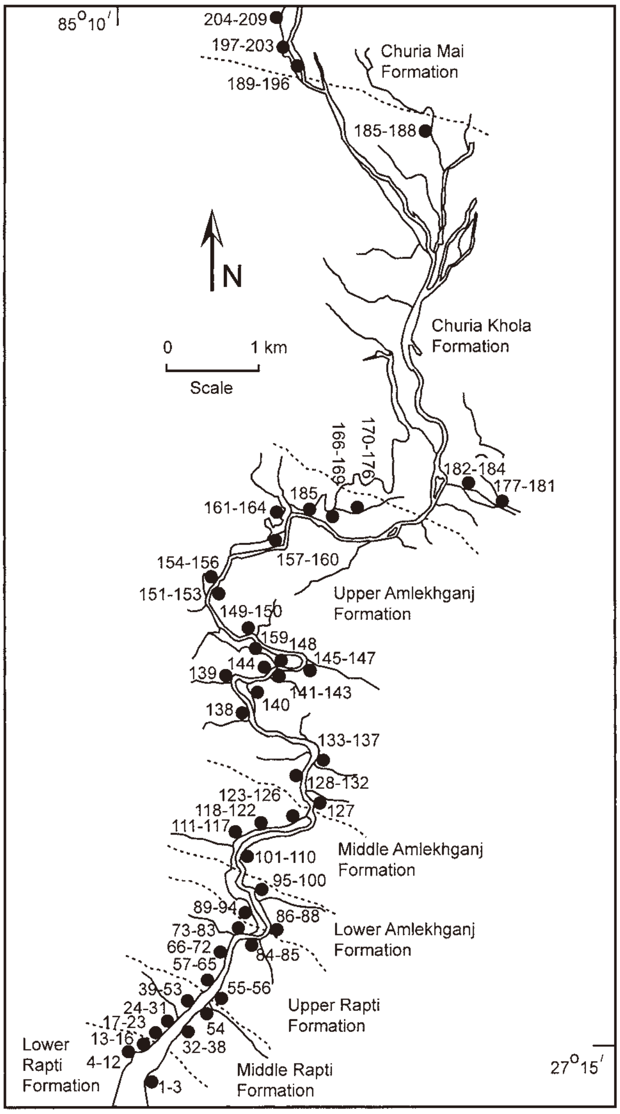

Fig. 2. Map showing location of sample sites in the Bakiya Khola area, Central Nepal, grouped by analysis number.

member was a deep and sandy braided river. The upper member (2100 m thick) of the Amlekhganj Formation is characterized by pebbly, very coarse-grained sandstones and gray mudstones, and was deposited by a shallow sandy braided system. Ninety Amlekhganj sandstones and mudstones were analyzed in this study.

The Churia Khola Formation (1100 m thick) is composed mainly of unconsolidated cobble to pebble-sized conglomerates with associated reddish-brown sandstones and gray mudstones, and accumulated from a gravelly braided river system (Ulak and Nakayama, 1998). Clasts of quartzite and limestone suggest derivation from the Lesser Himalaya. Analyses of 10 Churia Khola sandstones and mudstones are included here.

The Churia Mai Formation (500+ m thick) is composed of poorly sorted boulder conglomerates with interbedded cobbles and pebbles, along with subordinate gray sandstones and mudstones. Presence of boulder-sized Siwalik sandstone clasts (mainly Rapti Formation) is typical. The Churia Mai Formation was deposited by a debris flow-dominated braided fluvial system (Nakayama and Ulak, 1998). Twenty-one Churia Mai Formation sandstones and mudstones were analyzed.

Methods

Samples (n=206) were collected from measured sections in the Bakiya Khola and Simat Khola areas of Central Nepal (Fig. 1), indexed to the paleomagnetic framework established for the area by Harrison et al. (1993). The sections were located between latitude 27°13′N to 27°28′N and longitude 85°05′E to 85°15′E, southeast of Kathmandu, the capital of Nepal. Locations of the sample points are indicated in Fig. 2, grouped by analysis number. Sample preparation and analytical techniques are described in Roser et al. (2002), but are also briefly summarized below.

Samples weighing 70-100 g were manually disaggregated or chipped, and their grain size estimated visually using a grain size comparator. They were then rinsed in distilled water and dried at 110℃ prior to crushing. All samples were crushed in a tungsten carbide ring mill, with mills times generally of 30-45 seconds. Splits (8-10 g) of the resulting powders were stored in glass vials and dried at 110℃ for at least 24 h prior to determination of loss on ignition (LOI). The LOI values were determined by net weight loss after ignition in a muffle furnace at 1020℃ for at least 2 hours. The ignited samples from the LOI determinations were returned to glass vials and stored at 110℃ prior to preparation of glass fusion beads for X-ray fluorescence (XRF) analysis (ignited basis). The beads were prepared using an alkali flux (80% lithium tetraborate; 20% lithium metaborate) with a sample to flux ratio of 2:1, following the method of Kimura and Yamada (1996). The whole-rock major and trace element analyses were made using a Rigaku RIX 2000 XRF at Shimane University. Major elements and 14 trace elements (Ba through Zr in Table 2) were determined from the glass beads, using methodology and calibrations after Kimura and Yamada (1996). Four additional trace elements (La, As, Cu, Zn) were subsequently determined from pressed powder briquettes, using conventional peak over background method and calibration against eight Geological Survey of Japan rock standards.

Results

Major and trace element analyses (hydrous basis) of the Bakiya Khola samples are listed in Table 2, arranged in stratigraphic order. Average values for sandstones and mudstones in each formation are given in Table 3.

Amongst the major elements, the most conspicuous feature of the sandstone averages is an increase in SiO_2 content from the Rapti Formation (67.89 wt%) through to the Churia Khola Formation (83.07 wt%), and only slight

Table 2. XRF major and trace element analyses of Siwalik Group sandstones and mudstones from the Bakiya Khola section, Nepal. Major elements wt%, trace elements ppm. An#=analysis number. Lith=lithology: Med=medium sandstone; FS=fine sandstone; VFS=very fine sandstone; Mst=mudstone. LOI=loss on ignition.

An#	Field No.	Metres	Lith	SiO_2	TiO_2	Al_2O_3	Fe_2O_3T	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Ba	Ce	Cr	Ga	Nb	Ni	Pb	Rb	Sc	Sr	Th	V	Y	Zr	La	As	Zn	Cu
Churia Mai Formation																																	
209	BKS 225	5547	Mst	82.69	0.54	7.93	2.65	0.04	0.78	0.28	0.40	1.99	0.05	2.15	99.49	363	97	34	4	11	18	17	95	6	25	20	48	24	347	40	4	44	10
208	BKS 224	5521	Mst	79.25	0.63	9.82	3.09	0.03	0.70	0.31	0.22	2.09	0.01	3.03	99.20	426	100	48	8	14	22	17	112	8	24	20	67	27	339	41	5	45	15
207	BKS 223	5496	Mst	82.42	0.57	8.67	2.00	0.02	0.68	0.29	0.15	1.67	0.01	3.14	99.61	342	92	34	7	12	20	17	96	6	22	19	55	25	343	45	5	40	14
206	BKS 222	5485	Mst	74.16	0.67	11.14	4.22	0.07	1.09	1.16	0.36	2.87	0.09	3.38	99.22	485	106	48	10	15	24	26	130	10	33	23	76	31	353	44	4	63	18
205	BKS 221	5474	Mst	69.89	0.73	13.91	4.59	0.10	1.25	0.43	0.15	3.39	0.03	4.02	98.48	561	114	65	14	17	31	28	161	11	32	25	96	32	267	53	4	71	22
204	BKS 220	5462	VFS	76.10	0.63	9.84	3.01	0.03	1.00	1.64	0.28	2.53	0.07	4.04	99.18	429	104	41	9	15	22	22	117	7	33	20	68	26	366	42	5	59	18
203	BKS 219	5454	VFS	75.98	0.55	8.81	2.86	0.03	0.97	3.09	0.29	2.20	0.06	4.68	99.53	369	89	41	7	13	22	21	105	8	37	19	55	24	318	42	4	52	14
202	BKS 218	5447	Mst	77.72	0.65	10.63	3.10	0.03	0.89	0.28	0.28	2.61	0.02	2.73	98.96	458	100	50	10	14	23	22	123	9	29	20	72	29	343	49	4	58	15
201	BKS 217	5440	Mst	81.08	0.58	8.85	3.20	0.04	0.72	0.23	0.25	2.12	0.02	2.33	99.42	383	91	42	9	12	22	19	106	7	25	18	57	26	369	46	5	57	23
200	BKS 216	5422	VFS	84.36	0.48	7.74	2.25	0.03	0.72	0.16	0.17	1.81	0.01	2.00	99.73	320	87	35	7	12	18	22	94	5	19	17	50	19	304	35	3	43	13
199	BKS 215	5402	Mst	71.96	0.71	13.52	4.29	0.03	1.22	0.34	0.19	3.47	0.03	3.31	99.05	565	108	61	14	17	28	31	163	11	31	22	87	31	286	54	5	75	21
198	BKS 214	5391	Mst	67.56	0.74	14.75	5.17	0.06	1.38	0.72	0.16	3.12	0.04	4.98	98.68	570	107	77	17	17	40	28	165	13	39	23	104	31	252	52	6	86	26
197	BKS 213	5378	Mst	66.71	0.76	14.70	4.58	0.07	1.38	0.81	0.18	3.52	0.05	5.68	98.45	591	108	79	19	18	37	31	176	12	38	22	104	31	253	52	6	85	27
196	BKS 212	5354	Mst	76.72	0.61	11.37	3.12	0.03	0.99	0.35	0.18	2.36	0.02	3.29	99.04	437	96	50	14	15	27	26	128	10	27	19	71	28	271	49	6	61	17
195	BKS 211	5344	Mst	77.15	0.60	9.93	3.06	0.04	0.82	1.43	0.29	2.41	0.02	3.45	99.20	414	93	44	11	13	23	21	117	7	29	18	61	26	292	45	4	52	13
194	BKS 210	5327	Mst	71.14	0.67	13.49	4.95	0.04	1.03	0.45	0.06	3.16	0.03	3.81	98.82	521	92	69	16	16	28	27	156	12	28	20	84	29	234	49	4	68	22
193	BKS 209	5319	Mst	74.83	0.70	12.11	3.29	0.02	0.97	0.44	0.09	2.87	0.02	3.59	98.93	496	101	50	15	17	27	29	147	10	30	20	85	28	290	53	4	71	22
192	BKS 208	5301	Mst	67.71	0.66	12.24	4.16	0.06	1.40	3.42	0.23	3.21	0.08	5.64	98.82	492	100	52	14	15	28	25	144	10	48	20	78	28	269	42	4	65	18
191	BKS 207	5292	Mst	73.91	0.65	11.90	4.65	0.05	1.03	0.40	0.14	2.89	0.03	3.26	98.91	479	93	55	13	14	28	20	141	8	27	20	83	28	281	52	5	61	20
190	BKS 206	5285	Mst	69.20	0.73	14.51	4.50	0.03	1.47	0.38	0.14	3.81	0.06	3.99	98.82	581	111	67	18	17	30	32	175	12	33	22	97	33	254	56	5	82	21
189	BKS 205	5280	Mst	57.70	0.75	19.47	7.37	0.04	2.10	0.41	0.07	5.28	0.10	4.81	98.11	688	107	96	26	18	44	42	234	17	42	27	133	33	163	62	9	101	31
Churia Khola Formation																																	
188	BKS 204	5045	VFS	82.58	0.57	8.85	2.18	0.03	0.92	0.26	0.23	2.12	0.05	2.23	100.01	375	87	36	11	12	21	217	100	8	25	16	62	26	327	44	4	51	15
185	BKS 201	5020	FS	82.34	0.47	8.61	3.42	0.06	0.51	0.07	0.06	1.89	0.07	2.41	99.91	269	74	29	10	11	19	13	102	5	15	15	60	22	284	36	7	40	14
184	BKS 200	4870	Mst	78.60	0.54	10.31	4.04	0.07	0.65	0.11	0.11	2.39	0.04	2.84	99.69	405	84	40	8	14	24	21	126	11	20	20	68	26	253	41	8	54	20
183	BKS 199	4860	Mst	72.72	0.54	13.58	2.87	0.02	1.33	0.44	0.10	3.16	0.02	4.27	99.04	471	92	49	17	15	27	26	169	13	25	17	69	31	156	43	3	67	19
182	BKS 198	4243	Mst	70.69	0.53	14.43	3.25	0.02	1.48	0.56	0.14	3.38	0.02	4.27	98.78	468	95	50	17	15	28	28	178	10	28	19	70	33	164	45	3	63	20
181	BKS 197	4231	Mst	69.72	0.59	15.83	2.57	0.01	1.45	0.26	0.09	3.85	0.02	4.35	98.74	500	91	61	19	14	31	24	195	13	20	21	82	31	166	50	3	93	22
180	BKS 196	4224	Mst	70.80	0.56	15.10	2.92	0.02	1.32	0.54	0.11	3.45	0.02	4.56	99.41	499	102	56	18	15	36	40	191	11	29	21	79	40	188	52	7	95	31
179	BKS 195	4212	FS	83.46	0.31	8.07	2.21	0.01	1.11	0.22	0.41	2.29	0.06	1.65	99.82	311	54	29	9	7	16	11	117	5	12	11	57	19	133	35	3	44	12
178	BKS 194	4196	FS	83.88	0.36	8.24	1.96	0.02	0.68	0.32	0.51	2.21	0.04	1.69	99.92	330	74	25	9	10	13	28	114	5	27	12	37	19	241	35	4	37	8
177	BKS 193	4170	Mst	82.16	0.48	9.12	1.99	0.02	0.79	0.27	0.66	2.44	0.04	1.98	99.95	398	97	31	9	11	15	21	118	6	26	15	49	23	356	39	3	49	14
Amlekhganj Formation																																	
Upper Member																																	
176	BKS 192	3718	Mst	65.15	0.68	15.34	6.75	0.06	1.63	0.58	0.27	3.58	0.08	4.84	98.96	547	116	67	12	16	37	34	191	16	27	30	107	37	271	56	8	102	40
174	BKS 190	3667	Med	81.97	0.29	9.18	2.30	0.04	0.79	0.50	1.01	2.13	0.06	1.47	99.73	347	59	28	6	8	14	19	108	5	51	13	41	19	162	30	2	35	7
173	BKS 189	3655	Med	66.29	0.50	12.18	4.96	0.14	1.80	3.87	0.82	3.10	0.08	5.57	99.31	459	73	45	13	12	25	26	154	10	68	19	72	24	170	35	7	62	21
172	BKS 188	3614	Med	74.14	0.27	8.01	2.17	0.05	0.87	5.28	1.05	2.01	0.06	5.13	99.03	272	55	14	6	9	11	22	104	7	70	13	33	17	133	25	6	30	5
171	BKS 187	3602	Mst	58.57	0.68	14.32	4.93	0.06	2.42	5.39	0.53	4.14	0.10	7.74	98.87	580	96	64	15	16	33	29	187	13	121	24	90	29	219	45	6	75	27
170	BKS 186	3545	FS	73.90	0.56	12.03	4.55	0.04	1.36	0.26	0.43	3.12	0.02	2.80	99.07	437	88	47	12	13	25	26	154	10	46	21	71	28	261	47	4	62	26
169	BKS 185	3515	FS	69.90	0.51	11.61	3.83	0.05	1.24	3.41	0.91	2.80	0.07	4.72	99.05	410	84	40	12	13	22	29	151	8	77	20	65	26	222	38	4	58	19
168	BKS 184	3492	Mst	58.16	0.76	18.65	6.59	0.04	2.42	0.69	0.20	5.34	0.07	5.09	98.01	690	96	81	22	19	39	48	253	17	119	29	116	35	145	52	5	100	42
167	BKS 183	3371	FS	79.46	0.31	8.60	2.34	0.03	0.97	2.16	0.83	1.98	0.06	2.81	99.54	298	59	29	8	8	13	15	103	4	51	12	48	15	150	24	9	37	6
166	BKS 182	3354	Med	77.70	0.33	8.56	2.55	0.04	1.38	2.44	0.99	2.11	0.07	3.54	99.70	316	60	29	9	9	15	56	99	8	59	12	52	17	146	22	3	35	4
165	BKS 181	3238	Med	85.02	0.27	6.59	2.38	0.08	0.94	0.69	0.64	1.57	0.05	1.72	99.96	215	60	16	5	8	12	13	88	4	25	12	33	18	127	30	4	33	5
164	BKS 180	3157	Med	78.91	0.29	9.17	2.13	0.04	0.91	2.17	1.30	2.15	0.05	2.55	99.68	373	51	21	6	9	10	18	105	4	101	13	30	14	171	23	3	25	2
163	BKS 179	3148	Mst	70.55	0.69	13.21	4.35	0.04	1.68	0.44	1.36	3.43	0.01	2.74	98.50	590	94	50	10	17	29	24	180	11	59	26	77	29	266	41	5	56	17
162	BKS 178	3138	Mst	61.26	0.82	15.99	7.09	0.09	2.97	1.14	0.19	4.30	0.15	4.26	98.25	689	115	72	18	19	39	25	222	15	78	27	112	33	281	43	4	89	26
161	BKS 177	3128	Mst	63.15	0.64	16.84	5.87	0.07	1.82	0.69	0.22	4.24	0.02	4.84	98.41	561	99	77	19	16	38	31	222	14	63	25	108	33	212	52	6	80	29
160	BKS 176	3119	Mst	68.20	0.66	14.29	5.32	0.09	1.72	0.55	0.10	3.89	0.06	4.08	98.98	543	103	64	15	16	37	30	185	14	41	24	98	31	223	47	5	83	28
159	BKS 175	3084	Mst	48.16	1.02	17.42	9.04	0.12	3.88	5.34	0.17	5.24	0.10	8.32	98.81	786	68	107	13	21	54	31	268	16	67	34	131	31	122	42	4	89	32
158	BKS 174	3003	Mst	74.59	0.51	11.68	4.40	0.03	1.05	0.41	0.36	2.79	0.03	3.47	99.33	406	87	50	13	12	28	23	169	11	36	19	78	26	216	47	4	84	26

Table 2. (ctd)

An#	Field No.	Metres	Lith	SiO_2	TiO_2	Al_2O_3	Fe_2O_3T	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Ba	Ce	Cr	Ga	Nb	Ni	Pb	Rb	Sc	Sr	Th	V	Y	Zr	La	As	Zn	Cu
Amlekhganj Formation (ctd)																																	
Upper Member (ctd)																																	
157	BKS 173	2961	Mst	73.15	0.63	12.22	4.66	0.03	1.52	0.46	0.22	3.17	0.06	2.94	99.06	507	103	50	14	16	26	17	154	9	37	21	76	32	278	45	3	62	22
156	BKS 172	2900	Mst	72.29	0.62	12.88	4.59	0.04	1.30	0.39	0.19	3.19	0.05	3.52	99.06	462	96	56	14	14	32	28	170	11	36	21	87	29	225	50	6	76	21
155	BKS 171	2880	FS	79.10	0.47	9.42	3.15	0.04	1.05	0.37	0.55	2.30	0.06	3.07	99.56	386	78	31	10	12	20	17	117	6	37	16	53	22	250	42	9	53	13
154	BKS 170	2840	FS	80.30	0.32	8.02	3.27	0.12	1.50	0.74	0.38	2.20	0.05	2.79	99.70	295	66	30	8	9	19	11	111	6	15	14	55	19	149	33	5	49	12
153	BKS 169	2825	Med	76.63	0.39	9.75	2.61	0.04	1.18	2.23	0.97	2.58	0.08	3.03	99.49	380	60	29	9	9	17	22	131	5	89	14	42	19	182	26	3	38	5
152	BKS 168	2800	Mst	62.04	0.55	16.42	6.80	0.04	2.57	0.45	0.06	5.08	0.07	4.58	98.65	608	82	69	18	15	37	35	260	13	50	22	113	28	175	43	20	106	35
151	BKS 167	2770	FS	70.49	0.65	13.14	4.81	0.06	1.62	0.69	0.81	3.01	0.02	3.79	99.09	477	105	56	12	16	32	22	172	11	72	24	87	30	299	44	11	61	24
150	BKS 161	2665	FS	77.50	0.34	9.37	2.40	0.03	1.08	2.14	1.17	2.43	0.06	3.01	99.53	381	54	20	7	9	13	21	120	5	72	15	33	14	176	27	3	36	3
149	BKS 160	2645	Mst	63.69	0.70	17.58	4.17	0.02	2.36	0.27	0.18	5.39	0.02	4.26	98.65	655	111	74	17	17	39	57	258	15	31	28	115	32	214	51	7	103	44
148	BKS 159	2630	Mst	60.55	0.70	18.07	5.78	0.03	2.52	0.48	0.16	5.29	0.06	4.70	98.35	640	102	86	21	17	46	33	246	17	48	25	115	35	190	54	6	104	38
147	Z	2615	FS	65.63	0.60	11.15	5.22	0.06	2.99	2.73	0.78	3.31	0.11	6.13	98.73	518	106	57	13	14	29	23	145	9	47	21	81	29	335	41	28	58	30
146	BKS 158	2600	Mst	70.71	0.60	13.39	4.49	0.04	1.66	0.41	0.19	3.52	0.03	3.66	98.72	500	101	56	14	15	28	21	180	12	40	21	90	30	252	47	4	76	26
145	Y	2592	Mst	59.54	0.71	14.45	5.17	0.05	2.48	5.02	0.59	4.18	0.12	6.92	99.23	592	92	56	16	17	32	30	205	13	110	25	97	29	229	41	4	88	30
144	BKS 157	2570	Med	74.57	0.43	7.02	2.84	0.21	1.24	5.34	0.50	1.62	0.11	5.94	99.81	253	86	33	5	10	14	15	80	6	57	17	35	27	222	39	3	34	6
143	X	2550	Mst	54.94	0.66	15.45	6.39	0.11	2.56	5.97	0.20	4.28	0.07	8.63	99.26	556	80	70	19	15	36	31	202	14	53	20	104	28	170	47	6	91	36
142	W	2545	FS	79.62	0.44	9.94	2.32	0.02	1.31	0.16	0.58	2.80	0.05	2.34	99.56	369	80	33	11	10	19	14	135	6	15	15	65	24	232	43	5	55	13
141	V	2535	VFS	71.62	0.59	12.04	4.43	0.05	1.84	1.07	0.80	3.05	0.12	3.43	99.03	487	95	54	14	14	27	26	168	10	56	21	80	28	274	39	6	66	22
140	U	2515	Mst	58.86	0.62	18.51	6.25	0.04	2.74	0.44	0.14	5.58	0.03	5.14	98.35	632	86	86	23	14	47	33	271	19	32	20	122	29	185	48	5	133	31
139	T	2480	Mst	53.10	0.85	14.68	5.84	0.08	2.48	7.63	1.50	4.90	0.12	8.25	99.44	852	89	67	18	18	35	40	195	14	170	23	95	34	137	49	7	87	23
138	S	2440	Med	56.32	0.34	7.68	2.79	0.53	0.98	15.33	1.00	1.86	0.11	13.16	100.10	267	62	24	4	9	12	14	86	9	82	18	36	24	163	24	2	28	4
137	R	2350	VFS	72.24	0.67	13.38	3.54	0.04	1.64	0.36	0.86	3.59	0.10	2.81	99.23	493	116	47	16	14	25	14	164	11	33	21	84	27	376	45	2	68	27
136	Q	2310	Mst	64.98	0.70	14.08	4.46	0.08	1.80	3.29	0.52	3.68	0.10	5.59	99.30	566	89	60	16	15	30	35	168	12	52	20	83	25	235	40	4	68	23
135	P	2300	Med	73.23	0.62	12.11	4.05	0.04	1.70	0.77	1.08	2.98	0.09	2.50	99.19	452	66	52	15	13	24	19	157	10	69	14	89	24	187	33	4	57	12
134	O	2290	Mst	58.43	0.74	18.49	6.96	0.04	2.61	0.37	0.13	5.78	0.03	5.11	98.70	606	103	84	23	17	41	30	246	18	44	23	118	30	196	53	6	92	39
133	N	2280	Mst	59.87	0.68	13.14	4.54	0.05	2.10	6.21	1.01	3.49	0.11	8.23	99.45	500	92	63	16	16	28	18	149	12	74	19	86	29	281	38	3	65	23
132	M	2120	Mst	45.31	0.68	13.30	5.88	0.30	2.71	13.73	0.38	3.85	0.14	13.96	100.26	546	76	53	14	16	33	31	189	14	98	20	78	29	148	40	6	77	28
131	L	2100	Mst	57.64	0.68	17.90	6.91	0.05	2.93	1.30	0.21	5.38	0.08	5.71	98.79	655	98	81	24	16	44	45	234	17	68	23	117	28	183	50	15	110	38
130	K	2080	Mst	58.11	0.74	16.55	6.59	0.06	2.93	1.34	0.58	4.74	0.10	7.17	98.92	735	90	83	23	17	44	45	212	15	46	11	119	29	179	48	5	95	41
129	J	2060	Mst	58.99	0.79	15.59	6.36	0.06	2.86	4.61	0.52	4.55	0.10	4.80	99.23	619	107	74	21	18	35	32	204	16	83	22	108	33	237	53	4	102	44
128	I	2005	Mst	59.11	0.68	15.58	6.32	0.03	3.02	2.74	0.29	4.91	0.09	6.16	98.93	647	85	80	20	17	41	33	214	14	43	22	137	26	210	45	7	91	40
127	H	1961	Med	74.05	0.42	8.67	5.10	0.07	1.76	2.56	0.52	2.11	0.07	4.30	99.63	265	69	32	10	10	18	14	99	6	38	14	51	22	189	29	6	44	7
Middle Member																																	
126	G	1830	VFS	67.64	0.62	11.01	3.66	0.04	1.86	4.50	1.45	2.85	0.14	5.51	99.28	445	111	47	14	14	20	18	126	10	98	20	60	31	428	45	5	53	16
125	F	1796	FS	78.05	0.37	8.82	3.22	0.04	1.49	1.78	0.97	2.12	0.06	3.10	100.01	355	46	41	12	10	21	14	106	8	46	9	48	16	147	25	5	41	11
124	E	1786	Mst	66.07	0.66	12.70	4.14	0.04	2.17	3.48	0.93	3.38	0.14	5.48	99.20	471	121	52	15	15	23	18	153	10	63	23	87	34	339	46	3	65	23
123	D	1730	VFS	68.21	0.73	14.50	5.35	0.04	1.76	0.42	0.70	3.76	0.02	3.54	99.03	600	108	67	19	17	35	27	205	11	81	21	101	31	295	49	3	86	30
122	BKS 156	1665	Mst	58.09	0.79	17.03	7.15	0.04	2.88	1.94	0.25	5.01	0.11	5.42	98.71	655	103	82	22	18	42	49	230	16	61	24	129	29	174	50	6	110	44
121	BKS 155	1647	Mst	61.89	0.68	17.87	5.84	0.05	2.16	0.41	0.59	5.06	0.11	3.91	98.56	807	92	82	24	16	36	42	223	15	80	23	112	31	204	52	8	100	36
120	BKS 154	1629	Mst	65.58	0.63	12.45	3.95	0.05	1.91	4.11	1.26	3.35	0.12	5.63	99.04	519	105	48	15	16	24	23	161	12	85	22	69	33	330	39	6	60	17
119	BKS 153	1609	Mst	61.03	0.71	12.20	4.75	0.10	2.24	6.47	1.09	3.12	0.13	7.33	99.16	525	100	56	15	16	29	21	140	12	124	19	81	32	387	36	7	70	24
118	BKS 152	1590	Mst	70.27	0.68	12.79	4.96	0.05	1.95	0.50	1.23	3.25	0.09	2.96	98.74	562	115	64	16	16	38	27	148	11	90	22	80	32	325	48	32	68	27
117	BKS 151	1576	FS	78.68	0.50	7.39	2.38	0.05	0.90	3.27	0.95	1.49	0.09	3.54	99.25	285	99	20	1	10	12	10	73	6	94	25	34	29	310	39	2	30	6
116	BKS 150	1561	Mst	69.68	0.69	13.58	4.68	0.04	1.63	0.47	1.29	3.30	0.05	2.91	98.31	605	106	59	11	16	33	31	156	10	87	27	81	36	341	48	5	72	29
115	BKS 149	1545	Mst	65.79	0.73	14.86	5.22	0.04	2.25	0.98	0.72	3.67	0.07	3.88	98.21	570	104	65	17	18	34	27	163	13	77	25	108	30	284	46	4	80	27
114	BKS 148	1527	Med	74.80	0.29	6.28	2.19	0.05	1.11	6.21	0.62	1.63	0.05	6.31	99.55	263	43	19	2	8	13	11	82	7	68	12	34	15	128	20	5	26	3
113	BKS 147	1511	Mst	65.25	0.24	4.39	1.95	0.23	0.84	10.24	0.38	1.20	0.04	15.34	100.10	172	37	14	1	6	10	7	57	7	77	12	20	14	122	41	9	81	31
112	BKS 146	1494	FS	80.26	0.54	8.97	3.35	0.04	0.95	0.25	0.75	1.96	0.01	1.99	99.08	398	97	39	5	12	22	18	100	7	47	23	59	29	326	45	3	45	13
111	BKS 145	1485	Med	62.95	0.69	13.59	5.21	0.03	1.57	0.31	0.73	3.80	0.01	9.91	98.79	625	84	61	13	16	29	30	192	11	67	23	95	24	223	18	3	24	3
110	BKS 144	1475	Mst	63.78	0.71	16.39	5.93	0.05	2.12	0.25	0.28	4.90	0.05	3.91	98.36	709	104	78	15	17	35	31	225	14	76	27	108	32	214	51	7	89	28
109	BKS 143	1464	Mst	67.52	0.66	14.85	5.23	0.05	1.88	0.49	0.40	4.25	0.09	3.26	98.68	672	106	70	13	17	31	24	192	12	73	26	87	36	277	50	3	80	28
108	BKS 142	1451	FS	70.34	0.71	13.37	5.20	0.04	1.73	0.67	0.95	3.31	0.09	2.86	99.26	584	105	59	11	18	32	30	159	10	72	29	85	31	311	48	6	84	32
107	BKS 141	1439	Med	86.31	0.36	6.34	2.01	0.03	0.70	0.26	0.55	1.53	0.05	1.29	99.43	253	59	21	1	11	13	9	80	5	27	16	39	19	183	30	3	30	2
106	BKS 140	1427	Med	66.76	0.41	6.71	2.75	0.19	0.95	9.89	1.04	1.73	0.08	8.91	99.42	274	76	23	<1	10	12	11	85	6	105	23	34	26	217	28	2	23	3
105	BKS 139	1411	Mst	72.54	0.63	13.11	4.88	0.04	1.41	0.26	0.75	2.82	0.01	2.90	99.36	480	99	59	9	15	25	24	153	10	69	27	80	31	300	42	3	67	23

Table 2. (ctd)

An#	Field No.	Metres	Lith	SiO_2	TiO_2	Al_2O_3	Fe_2O_3T	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Ba	Ce	Cr	Ga	Nb	Ni	Pb	Rb	Sc	Sr	Th	V	Y	Zr	La	As	Zn	Cu
Amlekhganj Formation (ctd)																																	
Middle Member (ctd)																																	
104	BKS 138	1403	Mst	59.17	0.73	15.17	5.80	0.06	2.48	3.94	0.78	4.32	0.10	6.40	98.95	675	97	71	15	19	33	31	200	13	98	25	98	29	203	43	4	90	30
103	BKS 137	1387	Med	65.48	0.40	7.66	3.01	0.09	1.21	10.10	0.91	1.84	0.08	9.40	100.18	287	63	25	2	10	13	14	89	8	119	18	36	24	155	25	3	31	6
102	BKS 136	1374	Mst	60.01	0.72	15.74	5.88	0.05	2.08	3.24	1.03	4.47	0.11	5.34	98.66	802	94	71	18	17	32	29	192	15	70	24	102	29	229	40	3	88	26
101	BKS 135	1362	Mst	72.02	0.79	13.74	3.75	0.02	1.21	0.40	0.89	3.07	0.02	3.22	99.14	505	119	62	10	19	33	28	164	11	75	28	90	33	388	49	12	97	19
Lower Member																																	
100	BKS 129	1260	Med	66.12	0.43	6.05	3.06	0.09	1.67	10.14	0.63	1.63	0.07	9.86	99.76	240	82	24	<1	10	12	13	77	7	92	21	39	28	266	32	8	29	6
99	BKS 128	1222	Mst	50.90	0.67	12.97	4.96	0.09	2.28	10.99	1.04	4.02	0.11	11.26	99.28	642	88	64	12	16	29	40	164	13	124	26	75	30	153	42	7	72	22
98	BKS 127	1218	FS	74.93	0.65	11.66	3.97	0.05	1.47	0.66	1.05	2.43	0.03	2.77	99.67	473	107	43	10	15	27	31	131	9	53	24	72	33	355	52	4	74	18
97	BKS 126	1197	Mst	66.94	0.80	14.99	5.66	0.06	1.87	0.26	0.80	4.14	0.02	3.21	98.74	699	102	63	16	18	33	38	211	13	47	26	104	34	216	52	5	85	28
96	BKS 125	1178	Med	72.62	0.38	6.78	2.34	0.13	1.11	6.85	0.74	1.81	0.06	6.91	99.74	288	59	22	3	9	14	13	87	8	87	17	38	24	182	26	4	30	4
95	BKS 124	1170	Med	62.97	0.51	8.16	2.48	0.06	1.06	16.36	1.27	2.43	0.13	4.36	99.79	378	99	24	4	12	13	31	92	7	155	22	29	32	462	43	15	77	22
94	BKS 123	1163	Mst	64.75	0.55	11.03	5.27	0.04	1.12	0.60	0.73	2.49	0.22	12.77	99.57	427	90	44	12	14	22	13	138	8	41	22	70	28	289	34	4	30	8
93	BKS 122	1148	Med	87.71	0.34	5.70	1.91	0.02	0.56	0.36	0.63	1.46	0.06	1.28	100.03	228	57	17	2	9	12	11	81	3	23	14	31	19	173	30	8	26	3
92	BKS 121	1141	Mst	61.44	0.64	11.36	4.20	0.04	1.85	7.13	1.53	3.04	0.14	7.76	99.12	515	94	45	11	16	23	21	124	10	122	22	64	29	306	38	6	56	13
91	BKS 120	1120	VFS	72.02	0.71	13.18	4.15	0.02	1.38	0.23	1.40	3.68	0.02	2.39	99.19	627	129	53	14	17	27	34	169	10	46	28	79	43	440	56	6	93	27
90	BKS 119	1078	Med	68.84	0.38	6.96	2.42	0.06	1.32	8.61	0.86	1.86	0.07	8.36	99.74	303	70	23	3	9	14	13	86	7	101	18	34	24	237	33	7	29	7
89	BKS 118	1066	FS	77.73	0.57	10.25	3.42	0.04	1.06	0.35	1.08	2.53	0.06	2.02	99.10	435	96	38	10	14	22	18	125	9	45	21	64	29	330	45	3	48	16
88	BKS 117	1055	Mst	44.16	0.69	13.59	5.02	0.14	2.29	14.77	0.83	4.04	0.11	14.55	100.18	574	82	63	15	17	28	36	159	14	144	23	84	33	154	42	7	91	27
87	BKS 114	1040	Mst	68.56	0.74	14.52	5.38	0.06	1.79	0.39	1.12	3.42	0.07	3.18	99.24	596	119	60	14	19	35	31	148	10	64	28	92	41	280	57	4	69	28
86	BKS 113	1022	Mst	57.90	0.77	14.79	5.54	0.05	2.69	5.00	1.05	4.11	0.17	7.23	99.30	606	106	72	18	19	31	26	171	15	95	24	91	34	245	49	6	73	25
Rapti Formation																																	
Upper Member																																	
85	BKS 112	1000	Mst	66.36	0.81	14.67	5.20	0.04	2.21	1.34	1.10	3.09	0.01	3.88	98.72	734	134	72	13	20	35	46	155	13	116	34	95	43	370	55	5	82	27
84	BKS 111	980	VFS	45.33	0.44	8.23	2.98	0.44	1.78	20.51	0.74	2.20	0.10	17.91	100.65	310	61	32	2	11	15	24	94	9	87	19	45	23	160	30	3	39	14
83	BKS 110	965	Med	66.16	0.37	4.75	2.27	0.10	0.89	12.70	0.48	1.19	0.05	11.26	100.22	183	79	17	<1	8	10	10	54	7	111	19	24	23	251	31	3	22	4
82	BKS 109	940	VFS	38.81	0.49	9.43	4.09	0.17	1.58	23.85	0.65	2.46	0.09	20.06	101.68	331	77	44	8	11	19	20	99	13	83	17	53	27	150	40	9	53	11
81	AA	935	Mst	54.17	0.71	14.93	4.63	0.07	1.72	8.99	0.69	3.69	0.14	9.72	99.45	531	96	72	15	17	37	25	160	16	128	26	111	29	165	50	4	84	28
80	AB	925	Mst	50.19	0.73	14.28	5.43	0.07	2.40	9.81	0.96	4.31	0.10	11.19	99.46	694	90	67	16	18	29	60	188	14	129	25	94	29	146	42	9	81	33
79	BKS 108	915	Mst	59.52	0.61	12.34	4.69	0.06	1.90	7.26	1.42	3.17	0.11	8.03	99.12	535	79	54	12	15	26	25	133	12	101	21	68	29	226	34	11	58	19
78	AC	907	VFS	70.58	0.66	13.68	4.47	0.03	1.72	0.35	1.08	3.66	0.01	2.83	99.08	584	104	58	16	17	30	21	192	10	52	25	80	36	279	45	3	66	23
77	BKS 107	900	Mst	67.51	0.85	16.75	3.13	0.02	1.69	0.30	0.59	4.20	0.03	4.03	99.11	674	105	80	21	19	32	31	228	13	83	25	107	23	238	56	5	94	20
76	BKS 106	890	FS	76.03	0.32	6.85	2.34	0.05	1.51	4.76	0.41	1.87	0.06	5.89	100.07	246	55	25	6	7	17	13	81	7	51	11	38	16	129	31	8	38	4
75	BKS 105	880	Med	65.66	0.52	7.75	3.10	0.08	1.30	9.40	0.95	1.89	0.10	9.06	99.80	303	82	33	6	11	20	19	82	9	113	17	43	24	308	32	4	42	9
74	BKS 104	870	Mst	51.67	0.80	17.66	7.21	0.11	2.99	4.68	1.08	5.59	0.13	7.42	99.33	837	65	95	23	19	42	26	239	17	97	21	118	37	134	36	7	80	23
73	AD	860	Mst	43.20	0.58	12.22	4.69	0.16	3.06	16.36	0.54	3.67	0.21	16.02	100.71	512	80	58	13	15	25	43	142	14	122	21	72	32	142	42	5	66	25
72	BKS 103	845	Mst	57.36	0.69	12.70	4.59	0.07	2.04	8.28	0.70	3.41	0.10	9.59	99.52	493	97	56	14	17	28	27	139	14	87	22	81	30	246	44	4	70	21
71	BKS 102	835	FS	68.02	0.57	8.16	3.20	0.04	1.83	6.59	0.67	2.32	0.08	7.97	99.47	340	113	25	7	13	17	17	91	6	70	21	49	27	563	45	8	46	11
70	BKS 101	810	VFS	69.69	0.69	12.72	4.50	0.02	1.49	1.70	0.98	3.37	0.03	3.89	99.07	549	106	53	16	16	32	28	149	10	52	22	84	31	312	51	6	69	27
69	BKS 100	790	Mst	66.89	0.69	12.88	4.11	0.05	1.57	3.29	1.20	3.34	0.07	4.92	99.04	637	100	57	17	16	26	34	142	13	63	20	82	29	336	47	4	68	15
68	BKS 99	782	VFS	76.53	0.67	11.08	3.77	0.02	1.19	0.21	0.90	2.52	0.02	2.57	99.49	455	114	53	13	17	28	22	120	8	38	20	81	30	263	55	6	63	17
67	BKS 98	775	VFS	73.66	0.76	12.26	3.87	0.01	1.12	0.40	1.05	3.45	0.02	2.51	99.11	561	133	52	14	18	20	25	164	9	49	24	83	29	544	50	6	57	13
66	BKS 97	758	VFS	78.11	0.57	10.41	3.31	0.02	0.93	0.16	1.61	2.45	0.04	1.81	99.42	429	113	36	10	14	28	23	104	6	35	22	55	31	338	50	15	52	23
65	BKS 96	735	VFS	74.07	0.63	12.36	4.21	0.03	1.53	0.19	1.05	2.81	0.06	2.49	99.43	526	92	51	15	15	26	25	134	10	46	18	77	27	291	48	4	60	22
64	BKS 95	724	Mst	65.13	0.73	14.11	4.47	0.03	1.97	2.51	0.95	3.92	0.09	4.86	98.76	592	106	65	19	16	32	37	179	13	63	23	91	27	245	53	6	67	22
63	BKS 94	713	VFS	61.31	0.60	10.99	3.95	0.09	1.30	8.48	1.51	2.78	0.12	8.32	99.45	452	84	41	12	14	21	18	112	11	113	19	63	29	340	40	4	54	16
62	BKS 93	695	Mst	46.98	0.69	12.73	5.47	0.12	2.38	13.28	0.85	3.71	0.09	13.92	100.21	675	80	61	16	16	30	31	152	16	103	20	80	33	173	39	4	69	25
61	BKS 92	668	Mst	45.71	0.60	10.73	3.71	0.14	1.46	18.35	1.08	3.01	0.13	15.81	100.73	480	81	50	11	14	22	26	121	13	138	19	60	27	231	36	3	57	15
60	BKS 91	633	VFS	72.29	0.65	12.21	5.23	0.02	1.46	0.26	0.89	3.40	0.07	2.62	99.11	524	96	48	15	16	31	31	160	9	46	21	89	30	347	51	9	68	19
59	BKS 90	602	FS	81.70	0.60	9.18	1.98	0.01	0.75	0.15	0.90	2.76	0.01	1.60	99.64	422	110	30	9	13	14	27	113	6	30	17	48	22	512	43	4	43	10
58	BKS 89	593	VFS	69.66	0.70	13.34	5.81	0.02	1.62	0.20	1.03	3.65	0.04	2.75	98.83	584	104	60	17	16	33	32	168	9	42	22	91	31	332	44	8	86	24
57	BKS 88	583	VFS	49.10	0.59	10.56	3.34	0.09	2.30	15.63	0.94	3.07	0.11	14.65	100.37	451	83	41	12	13	22	38	121	12	145	17	59	29	210	38	4	60	15
56	BKS 77	579	Mst	46.70	0.56	12.26	5.43	0.08	4.95	11.03	0.75	3.77	0.09	14.66	100.27	515	92	53	15	14	29	28	148	11	37	20	80	27	292	38	9	68	26
55	AF	566	Mst	68.34	0.63	12.65	4.23	0.04	1.95	2.29	0.81	3.20	0.08	4.83	99.06	548	98	55	16	15	25	31	147	12	58	19	81	31	250	44	9	72	24

Table 2. (ctd)

An#	Field No.	Metres	Lith	SiO_2	TiO_2	Al_2O_3	Fe_2O_3T	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Ba	Ce	Cr	Ga	Nb	Ni	Pb	Rb	Sc	Sr	Th	V	Y	Zr	La	As	Zn	Cu
Rapti Formation (ctd)																																	
Middle Member																																	
54	BKS 76	555	VFS	57.81	0.68	12.67	3.83	0.07	2.09	8.55	0.97	3.67	0.10	9.28	99.73	559	71	60	16	15	26	30	158	15	98	18	76	25	239	34	15	69	30
53	BKS 62	527	VFS	65.79	0.54	8.62	3.22	0.07	1.40	8.26	1.04	2.22	0.11	8.54	99.81	345	94	35	10	12	17	19	93	8	97	17	50	23	391	31	4	41	12
52	BKS 61	521	VFS	65.03	0.61	10.77	3.80	0.05	1.65	6.12	0.88	2.96	0.11	7.27	99.25	448	85	45	11	14	21	19	124	10	79	18	63	29	289	35	5	55	15
51	BKS 60	515	Mst	50.98	0.72	16.85	7.25	0.09	2.83	6.01	0.74	5.21	0.11	8.65	99.43	745	102	86	23	18	40	38	201	17	82	26	116	36	194	54	20	91	26
50	BKS 59	510	VFS	73.95	0.64	12.48	4.03	0.02	1.04	0.15	0.86	3.23	0.03	2.73	99.17	532	112	51	15	16	30	22	146	12	43	21	74	34	343	51	14	62	24
49	BKS 58	499	Med	75.17	0.38	5.09	2.13	0.05	1.41	6.93	0.48	1.30	0.05	7.37	100.38	204	70	19	5	8	12	8	60	5	71	12	26	18	287	33	2	26	5
48	BKS 57	492	Mst	56.66	0.61	14.05	5.15	0.12	2.98	6.17	0.67	4.58	0.11	8.30	99.39	599	84	65	20	15	35	17	194	14	68	20	82	27	165	33	5	66	15
47	BKS 56	485	Med	79.53	0.36	4.38	1.68	0.06	0.50	6.56	0.44	1.01	0.05	6.19	100.77	177	59	12	4	9	9	21	47	2	87	10	29	19	257	25	4	24	6
46	BKS 55	480	VFS	76.31	0.68	11.34	3.24	0.01	1.04	0.44	0.94	2.95	0.03	2.62	99.60	454	108	57	13	16	25	21	145	8	49	18	67	22	403	44	24	62	22
45	BKS 54	473	VFS	65.06	0.60	11.98	4.05	0.06	2.29	4.45	0.96	3.25	0.11	6.48	99.29	501	93	55	15	14	25	22	139	11	66	17	73	27	251	38	5	63	20
44	BKS 53	468	Mst	45.51	0.55	13.29	5.59	0.11	6.46	9.14	0.35	3.76	0.07	15.31	100.13	603	90	56	17	13	32	40	159	13	121	18	85	28	134	41	43	77	27
43	BKS 52	465	Mst	57.37	0.75	18.65	7.31	0.03	2.38	1.06	0.31	5.46	0.05	5.43	98.80	739	93	87	26	17	47	40	254	19	57	25	128	33	172	55	19	119	36
42	BKS 51	462	FS	62.57	0.37	4.01	1.68	0.08	0.65	16.10	0.45	1.11	0.06	13.55	100.65	176	67	9	4	8	8	21	47	7	159	12	22	20	327	31	4	19	4
41	BKS 50	458	Mst	46.03	0.62	12.33	5.27	0.11	2.70	14.60	0.68	3.67	0.10	14.61	100.71	503	82	54	15	15	28	40	141	13	123	19	79	33	170	44	7	69	20
40	BKS 49	454	Mst	34.99	0.63	11.28	3.83	0.07	2.16	24.59	0.77	3.66	0.07	20.40	102.45	528	50	53	14	11	17	21	130	15	123	15	60	18	117	27	7	61	11
39	BKS 48	451	FS	65.75	0.36	5.45	1.24	0.12	1.09	12.84	0.57	1.39	0.05	11.57	100.43	281	58	16	6	7	11	76	58	7	132	11	25	20	213	26	6	25	11
38	BKS 47	430	VFS	72.47	0.67	12.34	4.63	0.03	1.41	0.60	0.85	2.94	0.03	3.35	99.30	525	94	51	17	15	26	29	135	10	54	19	85	24	296	42	35	66	15
37	BKS 46	425	Mst	68.80	0.59	10.72	3.21	0.05	1.70	4.72	0.82	2.76	0.09	6.35	99.81	451	88	43	14	13	24	24	120	9	73	16	69	29	246	39	6	57	17
36	BKS 45	422	Mst	61.33	0.72	17.54	6.00	0.03	2.45	0.48	0.71	5.20	0.09	4.47	99.03	643	116	77	24	18	39	27	227	16	57	24	102	32	243	57	11	103	21
35	BKS 44	418	VFS	77.16	0.52	7.40	2.22	0.03	0.76	4.52	0.74	1.74	0.11	4.97	100.19	305	112	32	8	11	15	13	77	7	86	16	37	24	341	51	5	33	9
34	BKS 43	397	Mst	68.45	0.66	13.47	4.06	0.04	1.92	1.69	0.91	3.45	0.11	4.32	99.08	576	95	53	17	16	31	12	148	10	57	18	82	28	287	44	4	72	20
33	BKS 42	394	Mst	69.80	0.57	11.11	3.83	0.08	1.78	3.47	1.03	2.59	0.09	5.23	99.60	447	84	48	15	13	25	20	113	10	65	16	73	28	259	37	5	60	19
32	BKS 41	391	FS	65.28	0.41	5.93	1.70	0.06	0.70	12.82	0.73	1.46	0.07	11.16	100.32	248	76	19	6	10	11	13	60	9	106	13	30	23	258	33	3	30	6
31	BKS 40	334	VFS	59.13	0.51	10.11	3.84	0.20	1.76	10.29	1.04	2.68	0.08	10.40	100.04	446	65	43	12	11	22	21	115	9	105	15	57	23	195	31	6	51	16
30	BKS 39	331	FS	71.44	0.68	12.32	5.87	0.10	1.44	0.29	0.74	3.43	0.04	2.85	99.21	497	138	53	16	16	43	41	154	8	36	22	79	34	495	60	7	88	31
29	BKS 38	317	VFS	79.41	0.53	9.92	3.45	0.03	0.97	0.19	0.87	2.29	0.09	2.08	99.81	400	84	36	13	13	20	19	105	8	41	15	60	26	260	38	11	56	17
28	BKS 37	311	VFS	64.87	0.50	9.16	2.86	0.10	1.40	8.94	0.94	2.30	0.08	8.96	100.11	369	70	37	11	11	20	27	94	7	103	14	44	22	251	30	6	51	9
27	BKS 36	305	Mst	74.80	0.68	11.84	4.10	0.02	1.04	0.24	0.87	3.04	0.03	2.83	99.48	506	100	53	16	16	31	22	149	8	46	17	77	26	360	44	29	79	18
26	BKS 35	300	VFS	32.38	0.37	7.41	3.08	0.20	1.49	29.41	0.72	1.65	0.09	24.27	101.09	290	53	29	2	9	16	35	63	9	154	18	29	24	97	26	10	48	6
25	BKS 34	286	VFS	77.68	0.58	10.84	3.86	0.02	0.89	0.13	0.85	2.66	0.04	2.28	99.82	433	88	39	14	14	23	30	120	7	37	16	65	25	266	40	15	113	18
24	BKS 33	278	Mst	40.40	0.52	10.86	5.63	0.28	2.14	19.78	0.51	2.91	0.10	18.06	101.18	433	81	45	12	13	24	49	103	12	114	18	68	34	128	37	15	67	17
23	BKS 32	269	VFS	79.73	0.59	9.79	3.55	0.02	0.82	0.15	0.77	2.36	0.03	2.22	100.03	395	113	35	12	13	22	20	106	6	33	18	58	28	424	45	12	47	15
22	BKS 31	261	FS	49.20	0.33	5.35	2.08	0.09	0.75	22.29	0.72	1.27	0.08	18.31	100.46	222	57	17	2	7	11	16	48	9	105	14	25	16	232	23	5	27	6
21	BKS 30	248	VFS	75.29	0.69	11.75	3.90	0.02	1.17	0.10	0.76	3.30	0.03	2.48	99.50	531	121	51	15	16	27	23	143	8	50	21	79	31	434	56	11	68	19
20	BKS 29	240	Med	80.85	0.29	4.81	1.91	0.04	1.45	4.42	0.38	1.22	0.05	5.44	100.85	200	49	17	6	6	11	6	58	6	46	8	29	14	159	26	2	28	3
19	BKS 28	228	VFS	68.04	0.48	7.93	2.43	0.07	1.23	8.61	0.82	1.97	0.08	8.56	100.23	396	70	31	10	11	16	19	85	7	103	13	43	19	290	31	5	39	13
18	BKS 27	223	VFS	67.69	0.66	11.66	4.40	0.03	1.16	4.30	0.76	3.14	0.05	5.74	99.58	499	120	53	15	15	26	21	136	10	55	20	77	31	339	50	35	69	17
17	BKS 26	213	Mst	66.46	0.36	4.54	1.71	0.06	0.88	13.33	0.47	1.07	0.05	11.78	100.72	180	69	11	5	8	9	15	46	7	139	11	22	17	267	29	3	23	6
Lower Member																																	
16	BKS 10	207	Mst	61.73	0.81	16.53	6.62	0.05	2.42	1.06	0.49	4.77	0.02	4.53	99.02	661	101	83	24	19	37	45	252	15	57	20	113	27	197	50	5	108	34
15	BKS 25	199	FS	54.90	0.68	14.51	5.38	0.05	1.86	8.03	0.53	4.54	0.11	9.24	99.83	586	94	59	20	16	31	32	180	14	101	21	93	31	187	51	10	81	23
14	BKS 24	192	Mst	66.96	0.73	14.92	5.59	0.02	1.93	0.19	1.12	4.24	0.08	3.22	99.00	580	107	75	21	18	36	70	184	10	61	19	104	25	303	49	7	90	27
13	BKS 23	172	Mst	69.68	0.76	14.89	4.05	0.02	1.58	0.18	0.74	4.06	0.08	3.14	99.19	725	89	73	20	17	32	21	172	12	56	20	99	29	284	48	5	74	20
12	BKS 22	160	Mst	60.80	0.71	16.67	6.27	0.03	2.08	1.94	0.46	4.86	0.07	5.11	99.00	730	87	80	23	16	42	24	218	16	62	21	113	27	203	46	7	107	41
11	BKS 21	138	Mst	52.49	0.60	12.82	5.04	0.19	2.16	11.20	0.68	3.46	0.08	11.60	100.33	499	73	56	17	13	29	32	144	13	101	16	86	26	170	35	5	66	29
10	BKS 20	125	VFS	60.78	0.41	5.78	2.17	0.24	0.94	14.74	0.92	1.48	0.11	12.76	100.34	270	73	17	6	9	11	33	58	8	149	13	28	16	306	25	5	30	11
9	BKS 19	109	Mst	65.71	0.72	15.95	5.96	0.05	2.13	0.20	1.20	3.40	0.09	3.52	98.94	585	58	67	23	14	33	24	158	16	55	16	104	18	219	26	6	84	28
8	BKS 18	105	Mst	62.09	0.60	16.24	5.96	0.07	2.31	1.50	0.43	4.66	0.09	5.09	99.05	648	85	68	23	15	32	32	205	13	51	20	95	28	170	40	10	81	29
7	BKS 17	100	Mst	74.01	0.70	13.59	3.11	0.01	1.11	0.16	0.54	3.29	0.02	3.04	99.58	536	96	60	19	16	25	26	169	10	46	19	91	26	280	46	6	85	19
6	BKS 16	94	Mst	73.15	0.72	12.65	4.91	0.02	1.01	0.12	0.91	3.10	0.04	2.83	99.46	458	108	63	18	17	33	24	150	10	48	19	93	28	362	47	10	71	19
5	BKS 15	90	VFS	70.81	0.46	8.15	1.87	0.06	1.04	7.40	1.39	1.59	0.08	7.34	100.18	286	62	31	10	10	18	15	69	7	96	11	40	18	223	29	3	44	10
4	BKS 14	78	FS	74.57	0.45	6.77	1.97	0.05	0.76	6.92	0.65	1.65	0.07	6.72	100.58	300	78	28	8	10	16	18	72	8	85	13	36	19	277	33	5	36	11
3	BKS 3	59	Med	76.36	0.37	8.53	3.11	0.04	1.55	2.96	0.77	2.31	0.06	4.22	100.30	344	52	33	12	10	19	16	117	8	46	10	46	17	158	25	4	40	6
2	BKS 2	26	FS	75.05	0.67	12.20	4.00	0.02	1.05	0.45	0.59	2.67	0.01	2.98	99.69	483	101	55	16	16	26	24	152	11	40	20	78	29	350	46	4	71	22
1	BKS 1	14	FS	69.82	0.58	13.11	4.58	0.05	1.72	1.53	1.98	3.39	0.11	2.41	99.28	582	76	43	20	18	23	16	224	9	105	20	66	30	210	35	2	43	7

Table 3. Average sandstone (S) and mudstone (M) compositions, Siwalik Group, Bakiya Khola section. n = number of samples.

Fmtn	Rapti		Amlekhganj		Churia Khola		Churia Mai	
Lithology	S	M	S	M	S	M	S	M
n	49	36	41	49	4	6	3	18
Major elements (wt%)								
SiO_2	67.89	58.83	73.68	62.29	83.07	74.12	78.82	73.43
TiO_2	0.54	0.67	0.47	0.69	0.43	0.54	0.56	0.66
Al_2O_3	9.52	13.66	9.54	14.62	8.44	13.06	8.80	12.16
Fe_2O_3T	3.35	4.93	3.31	5.44	2.44	2.94	2.71	4.00
MnO	0.07	0.07	0.07	0.06	0.03	0.03	0.03	0.04
MgO	1.30	2.23	1.32	2.16	0.80	1.17	0.90	1.11
CaO	6.63	6.38	3.33	2.99	0.22	0.36	1.63	0.67
Na_2O	0.86	0.78	0.86	0.60	0.30	0.20	0.25	0.20
K_2O	2.47	3.76	2.41	4.05	2.13	3.11	2.18	2.94
P_2O_5	0.06	0.08	0.07	0.08	0.05	0.03	0.05	0.04
LOI	7.19	8.24	4.41	5.97	1.99	3.71	3.57	3.70
Total	99.89	99.63	99.46	98.96	99.92	99.27	99.48	98.96
Trace elements (ppm)								
Ba	399	579	378	593	321	457	373	492
Ce	87	90	79	97	72	93	93	101
Cr	38	62	35	66	30	48	39	57
Ga	11	17	9	16	10	15	7	13
Nb	13	16	12	16	10	14	13	15
Ni	21	31	19	34	17	27	20	28
Pb	23	31	20	30	67	27	22	25
Rb	111	164	119	190	108	163	105	143
Sc	9	13	7	13	6	11	7	10
Sr	77	83	65	73	20	24	30	31
Th	17	20	18	23	14	19	19	21
V	56	88	55	96	54	69	58	81
Y	25	29	24	31	21	31	23	29
Zr	293	226	238	233	246	214	329	289
La	39	43	35	46	37	45	40	49
As	8	9	5	6	4	5	4	5
Pb	21	27	18	27	19	27	22	25
Zn	51	76	46	83	43	70	51	66
Cu	14	23	12	29	13	21	15	20

subsequent decrease in the Churia Mai (78.82 wt%). Average SiO_2 contents in the mudstones are also lower in the Rapti and Amlekhganj Formations (58.83 and 62.29 wt%, respectively) than in the Churia Khola and Churia Mai equivalents (74.12 and 73.43 wt%). As a consequence of these changes in SiO_2 content, average levels of most of the other major elements decrease stratigraphically upward, although not regularly (Table 3). Average CaO contents in the Rapti sandstones and mudstones are high (both >6 wt%), and remain significant (3 wt%) in Amlekhganj sandstones and mudstones before falling to <1 wt% in the Churia Khola Formation. A similar pattern is shown by the LOI values, reflecting the abundance of diagenetic and detrital carbonate.

Average abundances of most of the trace elements in the sandstones and mudstones tend to decrease from the Rapti to Churia Mai Formations in response to increasing average SiO_2 content (Table 3). Strontium is the exception, falling from average values of 77 and 83 ppm in Rapti sandstone and mudstone to 20 and 24 ppm in Churia Khola equivalents; levels remain low in the Churia Mai averages (30 and 31 ppm). This pattern and that of CaO and LOI suggests association of Sr with the carbonate fraction. The main feature of the trace element data is that average concentrations in the mudstones of each formation are generally greater than in their companion sandstones, suggesting the proportion of clay minerals present controls their abundances. Zirconium is an exception, being higher in the sandstone average in each formation than in companion mudstone, suggesting preferential concentration of the heavy mineral zircon in the former. Stratigraphic variation in the averages suggest that the trace element concentrations have also been affected by

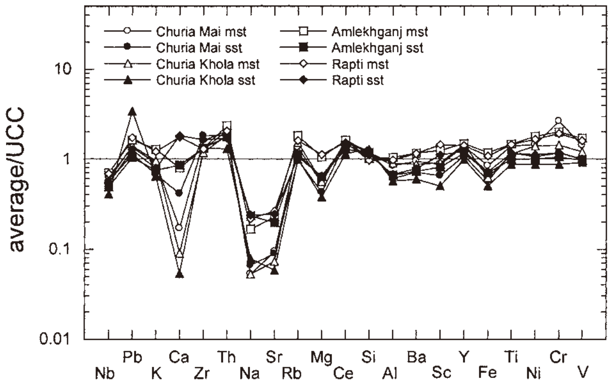

Fig. 3. Multi-element plot sandstone and mudstone averages for each formation normalized against the average upper continental crust (UCC) composition of Taylor and McLennan (1985). Elements are arranged from left to right in order of increasing abundance in average Mesozoic-Cenozoic greywacke (Condie, 1993) relative to UCC, following the methodology of Dinelli et al. (1999).

change in provenance and fluvial style, as have the major elements (Roser et al., 2002).

The sandstone and mudstone averages of each formation were normalized against the average upper continental crust (UCC) composition of Taylor and McLennan (1985) for comparative purposes. A spidergram of the elements determined from glass beads (Fig. 3; following the method of Dinelli et al., 1999) shows that many elements are present at levels at or near that of UCC, especially in the sandstones. However, there are some conspicuous departures, with marked depletion (0.05-0.5x) in Na_2O and Sr relative to UCC in all averages. Calcium is also depleted in all averages except those of the Rapti Formation, which are enriched relative to UCC. Four elements (Zr, Th, Ce, Y) are persistently enriched relative to UCC. The association suggests concentration of resistant heavy minerals, including zircon, monazite, and apatite. Although the patterns for average sandstone and mudstone in each formation are similar, the mudstones are generally enriched relative to the sandstones, especially in the "ferromagnesian" elements at the right of the figure (Sc to V), to levels above those in UCC. This reflects association with clays and the influence of sorting.

These patterns show that although the Siwalik sediments were derived from the crustal section of the Himalaya, their compositions have been significantly modified in the process. Local provenance variations, tectonism, varying intensity of weathering, sedimentary processes (e.g. sorting), differing transport times (e.g. fluvial storage) and change in fluvial style are all factors which may have contributed. The possible roles of these factors will be examined in future work.

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