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Article

Major and trace element abundances in Gondwana Group sediments from GDH-45, Khalaspir basin, Bangladesh

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Abstract

Subsurface Permo-Carboniferous sediments of the Gondwana Group occur in the Khalaspir basin of Bangladesh. Similar successions crop out in South America, Australia, South Africa and India. This report presents whole-rock major and trace element X-ray fluorescence analyses of 93 sandstones and mudrocks from drill hole GHD-45 in the Khalaspir basin. For convenience the succession is divided into three units (Units 1 to 3, from oldest to youngest), based on lithofacies. Geochemical contrasts occur with the succession, between both units and lithotypes. Average SiO_2 contents fall in Unit 3, and hence Al_2O_3 contents increase. Average CaO contents are less than the upper continental crust, suggesting minimal effect of secondary calcite cements. Na_2O and K_2O and most of the other major elements generally decrease upward. In all units average trace element concentrations are greater in mudrocks than in sandstones, indicating control of their abundances by clay mineral content. Average large ion lithophile element (Ba, Rb, Sr) contents decrease from Unit 1 to 3. Other trace elements (Nb, Zr, Y, Cr and Ni) show little systematic variation between units in mudrocks, but some contrasts in sandstones. The data will be used in future work to unravel the role that climatic, tectonic and other factors play in the composition of the Gondwana succession in Bangladesh, and for comparison and correlation with other Gondwana basins elsewhere.

Key words: Gondwana Group, geochemistry, sandstones, mudrocks, Bangladesh

Introduction

Gondwana Group sediments of Permo-carboniferous age on several continental blocks (South America, Australia, South Africa and India) record Gondwanaland continental breakup, widespread glaciations, and dramatic climatic, environmental and biosphere changes (Suttner and Dutta, 1986; Martini, 1997; Scheffler *et al.* 2003; Catuneanu *et al.* 2005; Stephenson *et al.* 2007). The Permo-Carboniferous Gondwana basin sediments of northwestern Bangladesh (Fig. 1A) have characteristics similar to the other Gondwana basins, and have been correlated based on spore-pollen study (Akthar, 2001). The Bangladesh Gondwana Group sediments have not as yet been correlated with specific formations in the other regional Gondwana basins in India, South America, South Africa and Australia. The Bangladesh Gondwana succession consists of sediments deposited in lacustrine and braided to meandering river depositional environments created by changes in tectonic and climatic conditions (Islam *et al.,* 1992; Akthar, 2001). These sediments thus contain potentially important information on the tectonic and climatic evolution of the region at the time. The total thickness of the Gondwana Group in Bangladesh is estimated to be about 1400+ m (Khan, 1991).

Geochemical compositions of sediments can be used to infer the influence of tectonic and climatic factors, and assist with basin-wide correlation. Geochemical characteristics of sediments in relation to provenance (Roser and Korsch, 1988; McLennan *et al.* 1993), weathering and climate in the source (Nesbitt and Young, 1982; Rieu *et al.,* 2007; Clift *et al.,* 2008), hydrodynamic sorting during transportation (Ohta, 2008), tectonic setting of the source area and depositional basin (Bhatia, 1983; Roser and Korsch, 1986), and post-depositional K-metasomatism (Fedo *et al.*, 1995) have been well documented in the literature. Numerous processes thus influence the composition of sediments from source to sink, but they also leave characteristic geochemical imprints. Therefore, the geochemical compositions of sediments give the opportunity to scrutinize the role of these factors, and aid the reconstruction of past sedimentary environments.

The Gondwana Group sediments of Bangladesh have been investigated from several viewpoints, including general description and characterization (Islam *et al.,* 1992), palynomorphs (Akthar, 2001), provenance based on modal composition (Rahman and Ahmed, 1995; Hossain *et al.*, 2000), depositional environment (Islam *et al.*, 1992; Hossain *et al.*, 2002), and geochemical composition (Islam *et al.*, 2004). The study of Islam *et al.* (2004) included modal, major and trace element, and rare-earth element (REE) data for samples from the nearby Barapukuria basin. Although these data are valuable, the number of samples analyzed was relatively small (n = 19), and all were either medium or fine-grained sandstones.

This present account reports whole-rock major and trace element analyses of Gondwana Group sandstones and mudrocks (siltstones and mudstones) from drill hole GDH-

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45 from the Khalaspir basin. This data for the Bangladesh succession adds to a growing database for Gondwana basins in adjacent India and in other continental blocks. The data contained in this report will be interpreted and discussed in a future publication, in the light of climatic fluctuation during the Carboniferous-Permian period and its significance.

Geological Outline

The Permo-Carboniferous Gondwana sediments analyzed here were intersected in drill hole GDH-45 in the Khalaspir basin (Islam *et al*., 1992). Gondwana sediments are not exposed at the surface in Bangladesh. GDH-45 provides a continuous 808 m (290-1098 m) section through the Gondwana succession (Fig. 1B). Although the Gondwana Group in Bangladesh has not been divided into formal formations, we have informally divided the succession into three units (Unit 1, 2, and 3, in ascending order), based on facies and depositional environment change (Fig. 2).

The Khalaspir sediments were deposited in an isolated asymmetric and fault-bounded intracratonic half-graben basin floored by Paleoproterozoic basement (Islam *et al*., 1992; Hossain *et al*., 2007; Frielingsdorf *et al*., 2008). Details of lithology and depositional environment are presented by Islam *et al*. (1992). The lowermost Unit 1 (U1, 753-1098 m) is composed of feldspathic sandstones, sandstones, siltstones, and mudstones, and was deposited in a lacustrine or back swamp environment (Islam *et al*., 1992). Unit 2 (U2, 640-753 m) consists mainly of conglomerates and sandstones that were deposited in a braided river environment, whereas the overlying Unit 3 (U3, 290-640 m) is composed mainly of sandstones and mudstones, along with coals in its uppermost part (Islam *et al*., 1992; Hossain *et al*., 2002). Unit 3 was deposited from braided to sinuous streams (Hossain *et al*., 2002).

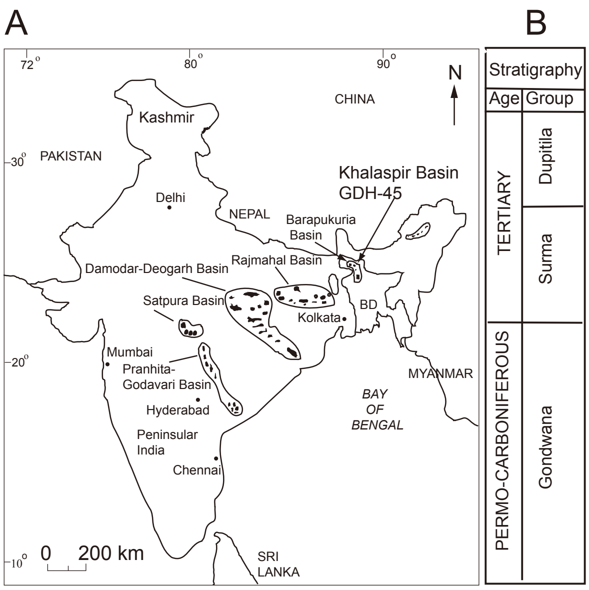

Fig. 1. (A). Location of Gondwana basins in the Indian subcontinent (after Singh and Singh, 2004; Islam, 2009). Arrow indicates the location of GDH-45 in the Khalaspir basin. BD = Bangladesh. (B) Stratigraphic succession in GDH-45.

Sampling and Analysis

Sampling

Depths of the sandstone and mudstone samples within the drillcore are listed in Table 1, and illustrated in Fig. 2. The number of sample collected in each unit was based on the availability from drill core. Ninety-three samples (41 sandstones and 52 mudrocks) were collected from GDH-45, with 66 taken from Unit 1, 11 from Unit 2, and 16 from Unit 3. Unit 1 is thus somewhat over-represented with respect to its thickness, and Unit 3 somewhat under-represented.

Analytical procedures

The drill core samples were broken manually into small chips (< 1 cm), washed with deionized water to remove surface dust, and then dried in an oven at 110°C. The dried samples were then powdered in a Rocklabs tungsten carbide ring mill, with mills times generally < 30

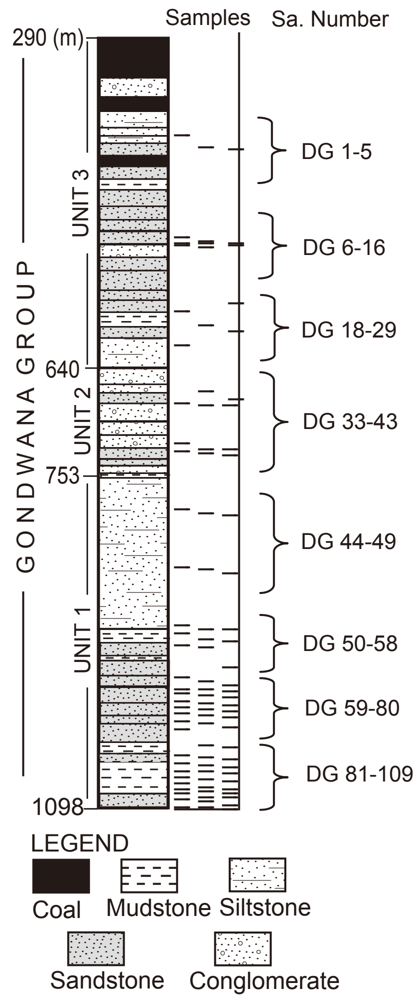

Fig. 2. Stratigraphy, lithology and sample positions in drill hole GDH-45, Khalaspir basin, Bangladesh.

Table 1. Whole rock major (wt%) and trace element (ppm) analyses of Gondwana Group sandstones and mudrocks from GDH-45, Khalaspir basin, Bangladesh.
Index: SaNR-sample number, Lith-lithology (see footnote for codes), total iron as Fe_2O_3, LOI-Loss on ignition. Note that data are tabulated on an *anhydrous normalized basis*. The normalizing factors were applied to both the major and trace element data. Original anhydrous analysis total (Total*) and LOI data are included to allow recalculation to a hydrous basis if desired.

SaNr	Depth (m)	Lith	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Ba	Ce	Cr	Ga	Nb	Ni	Pb	Rb	Sc	Sr	Th	V	Y	Zr	LOI	Total*
Gondwana Group																												
Unit 3																												
DG-1	396	fsst	69.76	1.00	22.16	5.73	0.05	0.33	0.12	0.13	0.68	0.03	142	88	131	21	20	37	16	29	28.7	38	7.3	154	41	306	9.31	99.61
DG-4	409	fsst	59.83	0.73	24.90	13.30	0.12	0.29	0.21	0.11	0.37	0.14	161	150	83	25	18	34	12	26	23.8	107	5.9	138	43	156	12.21	99.37
DG-5	410	mst	62.36	0.85	23.49	11.05	0.12	0.65	0.26	0.16	0.97	0.09	142	89	118	26	20	34	10	36	16.0	72	10.7	130	26	192	12.02	99.73
DG-6	502	mst	62.23	1.16	31.80	1.83	0.00	0.48	0.13	0.13	2.21	0.03	465	110	129	38	29	35	20	88	28.8	55	14.5	160	25	171	11.36	99.96
DG-8	507	mst	60.88	1.44	32.60	1.90	0.00	0.53	0.15	0.13	2.33	0.04	18	38	55	14	9	35	9	22	20.6	38	3.8	55	18	110	13.07	98.68
DG-10	508	mst	62.23	1.06	30.37	3.35	0.02	0.67	0.26	0.10	1.89	0.05	262	140	139	36	25	60	16	79	29.8	90	12.6	170	53	291	13.01	99.77
DG-11	509	fsst	73.66	0.65	20.43	2.37	0.02	0.57	0.55	0.20	1.49	0.05	125	83	98	20	15	24	13	52	8.5	61	7.8	84	19	334	8.44	99.90
DG-12	509	fsst	70.26	0.83	23.29	2.59	0.02	0.55	0.68	0.13	1.59	0.06	152	102	120	26	19	30	14	60	10.6	77	8.7	117	23	358	10.51	99.48
DG-13	510	msst	54.37	0.56	15.34	9.87	0.17	5.38	12.44	0.20	1.61	0.06	145	56	82	17	14	30	8	44	17.5	99	5.6	71	35	263	19.66	98.62
DG-14	510	msst	53.96	0.52	14.67	10.10	0.18	5.67	13.21	0.12	1.54	0.05	148	52	81	16	13	41	6	42	19.5	98	5.5	70	38	240	20.05	98.69
DG-16	512	msst	61.35	0.43	12.82	9.48	0.15	4.25	9.82	0.12	1.56	0.03	130	37	66	14	10	30	8	41	24.4	83	4.6	68	33	243	16.02	98.96
DG-18	572	mst	59.09	1.32	32.84	4.31	0.01	1.13	0.18	0.19	0.86	0.07	218	109	99	37	24	68	9	61	23.4	52	17.8	197	30	231	17.38	98.76
DG-19	579	mst	63.21	1.53	30.86	2.66	0.01	0.55	0.14	0.10	0.91	0.04	185	165	136	37	36	43	6	63	29.0	47	26.5	190	49	306	21.90	99.85
DG-24	595	fsst	65.55	1.19	24.24	5.42	0.01	1.31	0.14	0.15	1.96	0.04	578	96	119	31	27	38	2	86	20.0	58	12.5	132	29	494	19.31	99.08
DG-25	601	fsst	63.22	0.90	28.05	4.37	0.00	1.00	0.18	0.12	2.08	0.07	529	117	105	32	21	23	28	81	22.1	62	11.5	170	30	188	10.58	100.48
DG-29	616	mst	56.08	1.30	31.59	6.17	0.02	1.74	0.20	0.15	2.72	0.03	584	116	253	37	32	58	4	132	30.9	63	31.3	196	39	249	18.68	99.98
Unit 2																												
DG-33	663	csst	79.38	0.47	11.78	2.05	0.04	0.55	2.85	0.09	2.78	0.02	231	70	32	15	13	11	15	96	12.4	98	14.8	59	29	207	4.23	99.60
DG-34	671	csst	81.17	0.43	12.22	1.98	0.03	0.46	1.55	0.08	2.07	0.02	176	64	21	12	13	14	17	68	12.0	85	12.1	52	21	231	3.62	99.71
DG-35	675	zst	62.02	1.15	28.59	4.14	0.01	0.86	0.36	0.17	2.66	0.04	379	85	148	35	25	43	31	100	27.4	88	28.2	170	19	245	10.66	100.22
DG-36	677	csst	81.24	0.46	12.18	1.86	0.03	0.46	1.53	0.17	2.05	0.02	168	69	22	12	13	11	43	68	9.6	82	16.4	53	20	208	3.72	100.22
DG-37	678	csst	78.32	1.28	11.11	3.52	0.07	0.81	3.09	0.20	1.57	0.03	125	157	44	13	31	41	39	54	10.0	87	41.7	90	40	458	5.17	98.74
DG-38	716	csst	74.17	0.38	13.47	4.55	0.05	1.62	1.49	1.87	2.33	0.06	1067	22	73	15	9	28	19	74	15.5	216	4.8	100	11	84	2.53	99.08
DG-39	723	csst	72.64	0.59	14.79	2.87	0.04	1.05	1.25	2.44	4.25	0.07	1622	113	43	16	40	29	25	108	12.0	280	8.6	66	21	880	1.59	99.66
DG-40	724	csst	73.68	0.25	13.43	2.49	0.04	0.87	3.18	2.78	3.21	0.06	2082	2	29	10	7	18	20	82	9.4	294	3.9	35	15	84	2.74	98.31
DG-41	726	csst	72.88	0.56	13.50	3.14	0.06	1.09	3.30	2.74	2.66	0.07	1757	67	46	13	14	17	19	78	12.0	277	7.7	69	24	567	3.18	98.92
DG-42	727	csst	76.17	0.32	11.98	3.96	0.06	1.35	2.06	2.28	1.78	0.06	818	23	39	10	7	21	15	60	12.1	215	6.5	44	12	78	2.62	100.33
DG-43	729	csst	75.66	0.35	12.15	3.93	0.06	1.32	2.37	2.27	1.85	0.06	849	20	54	11	9	21	17	60	12.3	227	5.0	45	15	83	2.91	99.63
Unit 1																												
DG-44	785	zst	64.84	0.82	16.15	6.77	0.10	2.49	2.76	2.68	3.19	0.21	1192	114	93	22	23	35	23	122	16.0	374	19.7	111	42	386	3.52	99.55
DG-45	790	mst	65.17	0.87	15.85	6.77	0.10	2.45	2.85	2.65	3.08	0.21	1106	122	97	22	24	37	21	116	17.6	369	19.9	118	44	409	3.36	99.41
DG-46	793	mst	65.30	0.81	15.78	6.71	0.10	2.43	2.87	2.76	3.03	0.21	1117	111	93	20	23	35	24	112	14.8	371	19.6	110	42	398	3.31	99.49
DG-47	846	zst	60.82	1.20	17.95	8.39	0.12	3.48	1.49	1.58	4.73	0.23	1052	147	135	31	34	47	22	193	19.7	217	30.4	185	47	379	4.93	99.47
DG-48	849	msst	75.22	0.41	12.72	3.22	0.07	1.10	3.51	1.73	1.93	0.08	710	59	29	12	12	21	19	63	10.0	439	6.9	47	34	355	3.39	98.89
DG-49	853	fsst	74.11	0.33	13.34	3.68	0.06	1.31	3.17	1.90	2.02	0.08	721	49	27	13	9	14	22	67	8.6	458	5.7	33	21	262	3.66	99.19
DG-50	907	mst	59.50	0.99	17.72	9.44	0.12	3.79	1.74	1.69	4.76	0.25	1041	117	113	27	28	58	29	235	16.8	235	31.0	168	41	179	4.40	99.91
DG-51	910	msst	75.62	0.30	12.53	2.61	0.05	0.93	3.62	2.44	1.83	0.08	701	47	17	13	9	10	21	59	10.6	324	4.8	34	20	231	3.47	98.70
DG-52	912	mst	59.24	1.00	17.64	9.19	0.12	3.69	1.99	1.91	4.84	0.38	1051	133	118	27	29	57	28	236	16.7	242	30.0	164	43	185	4.41	99.63
DG-53	914	mst	60.13	1.00	17.71	8.86	0.11	3.57	1.77	1.78	4.85	0.22	1052	124	125	26	28	56	25	238	17.1	243	29.5	163	41	198	4.41	99.91
DG-54	921	msst	72.88	0.61	12.16	4.79	0.11	1.55	2.77	2.79	2.19	0.13	632	105	51	15	17	16	23	71	13.0	225	12.0	67	40	529	2.15	99.06
DG-55	922	mst	54.66	1.43	16.31	11.83	0.19	4.63	3.01	3.00	4.28	0.66	1217	207	174	28	42	80	42	128	22.6	276	44.7	200	79	256	3.77	99.66
DG-56	927	msst	73.70	0.50	12.32	3.97	0.09	1.34	3.00	2.77	2.18	0.12	637	87	43	14	15	19	21	70	13.4	249	8.7	53	33	427	2.49	98.84
DG-57	930	fsst	69.54	0.37	15.64	3.31	0.06	1.26	4.81	2.51	2.34	0.15	708	60	34	17	11	16	22	73	10.8	480	8.0	51	23	251	4.50	99.16
DG-58	951	msst	72.90	0.61	12.23	4.77	0.11	1.56	2.89	2.64	2.15	0.14	641	87	42	14	14	12	22	71	13.2	212	9.8	54	34	414	2.24	99.47
DG-59	960	fsst	73.07	0.51	11.50	4.12	0.10	1.34	4.43	2.58	2.25	0.11	653	102	56	15	18	16	23	68	14.1	230	11.2	71	42	525	3.32	98.91
DG-60	965	fsst	67.37	0.59	15.00	5.72	0.08	2.03	3.55	2.97	2.46	0.23	718	87	59	20	18	29	28	76	13.5	342	13.4	86	35	326	3.66	99.83
DG-61	970	mst	65.10	0.58	15.61	5.91	0.09	2.20	3.25	2.46	4.66	0.16	1291	70	61	18	17	35	24	195	11.6	337	13.8	84	29	221	2.76	99.56
DG-62	973	fsst	68.21	0.55	15.14	4.58	0.08	1.78	4.25	2.68	2.54	0.19	709	86	66	17	17	28	24	80	12.6	393	12.4	72	33	305	3.82	99.31
DG-63	974	msst	73.27	0.43	12.92	3.63	0.07	1.28	2.89	3.01	2.36	0.15	654	79	47	15	13	15	23	78	8.4	234	8.8	51	28	361	2.39	99.45

Table 1 (ctd). Whole rock major (wt%) and trace element (ppm) analyses of Gondwana Group sandstones and mudrocks from GDH-45, Khalaspir basin, Bangladesh.

SaNr	Depth (m)	Lith	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Ba	Ce	Cr	Ga	Nb	Ni	Pb	Rb	Sc	Sr	Th	V	Y	Zr	LOI	Total*
Unit 1(ctd)																												
DG-64	976	mst	61.75	0.98	15.16	9.48	0.13	3.60	2.49	3.03	3.15	0.24	911	136	123	24	29	54	27	97	18.8	281	23.6	157	45	303	3.31	99.93
DG-65	977	msst	75.03	0.36	12.22	3.07	0.06	1.09	2.90	2.84	2.33	0.11	634	64	33	14	11	13	24	77	9.4	220	7.0	40	25	293	2.29	99.32
DG-66	979	zst	63.04	0.88	15.38	8.00	0.13	3.21	2.63	2.92	3.55	0.27	999	118	115	21	28	47	28	116	16.7	297	20.2	129	47	315	2.91	100.16
DG-67	982	fsst	70.83	0.50	13.76	4.31	0.07	1.54	3.85	2.84	2.13	0.17	579	83	57	17	15	22	25	68	12.0	305	10.9	67	33	393	3.27	99.60
DG-68	985	zst	61.25	1.22	14.53	9.73	0.15	3.58	2.84	2.79	3.49	0.42	927	186	156	27	38	62	37	104	20.6	249	31.7	173	67	454	3.04	99.59
DG-69	988	mst	65.79	0.77	14.84	6.70	0.11	2.51	3.34	2.84	2.85	0.23	787	120	92	21	24	37	30	89	14.2	321	18.4	115	42	351	3.41	99.58
DG-70	989	fsst	72.93	0.31	14.31	2.51	0.04	0.95	4.03	2.78	2.02	0.11	529	56	28	14	9	13	19	67	8.4	351	6.0	34	22	236	2.54	99.38
DG-71	991	mst	63.95	0.79	15.58	7.10	0.11	2.68	3.19	2.68	3.72	0.20	942	106	94	21	24	46	29	134	15.7	337	19.6	109	38	266	3.15	99.62
DG-72	994	zst	67.07	0.73	14.51	6.05	0.10	2.25	3.35	3.00	2.71	0.23	693	125	76	19	23	32	26	87	13.4	317	18.2	94	42	436	3.22	99.57
DG-73	997	mst	58.36	1.23	16.84	9.57	0.16	3.58	2.47	2.72	4.83	0.25	1123	150	156	28	36	70	31	209	20.7	274	41.6	167	49	153	2.99	99.75
DG-74	998	fsst	72.93	0.41	13.22	3.72	0.07	1.32	2.79	2.91	2.49	0.14	664	73	44	15	13	18	26	81	9.6	239	8.8	11	27	297	2.49	99.20
DG-75	1000	mst	61.00	1.05	15.69	8.89	0.13	3.42	2.60	2.77	4.18	0.27	1049	135	131	23	31	57	30	153	17.3	284	30.2	147	47	236	2.71	99.64
DG-76	1003	msst	73.23	0.73	11.67	5.25	0.14	1.55	2.82	2.37	2.11	0.12	591	121	63	14	20	15	21	69	13.6	188	14.6	84	49	647	1.91	99.24
DG-77	1006	fsst	67.56	0.56	15.47	4.89	0.08	1.85	4.67	2.25	2.50	0.18	670	82	58	18	16	28	24	85	12.7	418	13.3	75	32	307	4.36	99.41
DG-78	1008	zst	58.32	1.12	15.95	10.68	0.16	4.06	2.64	2.95	3.72	0.39	998	221	110	26	30	52	31	122	20.2	275	44.1	176	61	227	3.33	99.57
DG-79	1012	mst	54.45	1.60	16.48	12.76	0.20	4.69	2.09	3.08	4.36	0.30	1143	206	125	29	35	58	41	131	26.8	259	73.2	226	68	253	3.89	99.96
DG-80	1015	zst	63.99	0.66	16.13	6.82	0.11	2.44	4.09	2.60	2.93	0.23	856	96	43	19	14	24	33	88	14.7	396	22.6	95	44	417	4.12	99.57
DG-81	1032	msst	69.12	0.53	14.77	4.51	0.07	1.60	4.25	2.57	2.40	0.19	614	83	55	15	16	33	22	79	11.5	357	11.5	68	31	313	3.69	99.61
DG-82	1034	mst	70.68	0.54	13.18	4.79	0.07	1.53	3.90	2.71	2.42	0.20	607	83	65	15	17	26	25	78	13.9	262	12.1	76	34	286	3.17	99.00
DG-83	1041	msst	71.98	0.32	13.52	3.28	0.05	0.97	5.38	2.38	2.03	0.10	521	47	35	12	10	38	24	67	9.0	341	6.0	39	21	222	4.64	98.97
DG-84	1043	msst	71.19	0.54	12.51	4.72	0.09	1.77	3.89	2.72	2.39	0.17	582	81	52	14	16	24	23	78	13.1	202	10.5	62	37	344	3.14	99.39
DG-85	1046	mst	57.14	1.18	17.00	10.25	0.14	4.53	2.35	2.55	4.64	0.21	933	150	181	25	39	106	29	243	16.9	249	35.5	150	48	117	3.17	99.73
DG-86	1049	mst	55.70	1.21	17.23	11.12	0.15	4.94	2.28	2.49	4.69	0.19	984	147	194	26	38	110	28	240	17.8	239	37.0	162	47	97	4.07	99.84
DG-87	1052	mst	56.78	1.16	16.76	10.34	0.14	4.45	2.81	2.45	4.91	0.20	899	146	179	24	37	102	31	288	17.4	237	35.1	154	46	105	4.04	99.83
DG-88	1055	mst	59.17	1.05	16.43	9.45	0.13	4.11	2.43	2.70	4.33	0.20	867	135	153	22	34	86	29	236	16.7	244	30.5	146	44	137	3.20	99.87
DG-89	1058	mst	60.63	1.16	16.07	8.63	0.12	3.65	2.65	2.90	3.97	0.23	936	141	162	22	38	89	32	163	17.8	258	34.3	145	51	188	2.83	99.61
DG-90	1059	mst	59.22	1.00	16.54	9.52	0.13	4.16	2.14	2.88	4.19	0.21	902	123	142	21	32	84	23	208	17.5	236	27.9	132	40	91	2.48	99.79
DG-91	1061	mst	54.81	1.27	17.61	11.21	0.14	4.98	2.09	2.26	5.45	0.18	979	123	194	25	39	112	25	341	19.9	212	34.9	167	42	56	3.99	100.11
DG-92	1064	mst	56.62	1.22	17.25	10.44	0.14	4.64	2.18	2.57	4.75	0.20	969	117	193	24	40	114	30	254	20.1	231	33.6	155	43	76	3.55	99.71
DG-93	1067	mst	54.73	1.45	17.61	11.12	0.16	4.82	2.48	2.56	4.84	0.23	1084	148	214	25	44	116	24	233	22.8	241	38.5	187	51	124	3.85	99.89
DG-94	1070	fsst	66.93	0.68	12.72	5.25	0.10	1.65	8.15	2.26	2.07	0.18	493	112	56	13	18	20	22	67	16.6	277	17.3	81	43	629	6.56	99.03
DG-95	1070	fsst	61.83	0.69	16.83	6.85	0.10	2.79	5.78	2.55	2.36	0.21	722	90	75	18	19	48	23	86	14.4	445	13.3	97	31	235	4.82	99.35
DG-96	1076	mst	56.92	1.12	16.97	10.61	0.14	4.49	2.39	2.57	4.57	0.20	1021	127	167	24	34	98	34	264	17.4	278	32.0	156	43	110	3.72	99.84
DG-97	1077	mst	24.98	0.76	7.58	6.59	0.73	2.65	52.68	1.05	2.66	0.31	477	111	90	11	20	58	8	128	15.0	227	21.2	60	51	49	28.85	100.44
DG-98	1078	zst	62.61	0.77	16.69	6.47	0.11	2.65	4.64	2.75	3.10	0.21	897	101	101	17	24	47	30	103	14.6	392	17.5	86	38	258	4.18	99.20
DG-99	1079	mst	59.20	1.05	16.36	9.44	0.13	4.16	2.39	3.31	3.73	0.23	1055	116	157	24	33	83	26	125	19.3	263	25.0	154	44	114	3.05	99.79
DG-100	1081	mst	58.45	1.06	16.67	9.72	0.16	4.28	2.54	3.03	3.87	0.21	1082	110	145	23	33	84	33	137	17.0	268	27.0	157	43	129	3.34	100.12
DG-101	1082	mst	61.88	0.98	15.68	8.14	0.13	3.46	2.36	3.63	3.52	0.22	988	108	126	22	30	64	29	111	18.6	252	22.5	147	43	143	2.97	99.86
DG-102	1085	mst	56.80	1.11	17.00	10.51	0.16	4.68	2.30	3.17	4.08	0.21	1146	100	166	25	33	98	28	155	19.1	253	27.9	173	41	91	3.51	99.88
DG-103	1086	zst	61.10	1.03	15.73	8.39	0.14	3.50	3.03	3.31	3.55	0.23	1002	113	154	23	33	70	27	113	17.0	282	21.9	143	45	183	4.36	99.40
DG-104	1088	mst	64.43	0.73	15.34	6.76	0.11	2.78	3.74	3.03	2.88	0.20	820	96	93	19	23	38	27	94	14.7	322	13.9	118	38	286	4.87	99.76
DG-105	1090	mst	63.29	0.74	15.94	6.81	0.12	2.84	3.98	3.00	3.09	0.18	891	86	105	20	23	45	26	103	12.6	349	13.9	106	35	217	5.21	99.31
DG-106	1095	mst	61.39	0.94	15.76	8.25	0.13	3.39	2.78	3.61	3.53	0.22	1015	100	136	21	28	60	26	110	17.7	275	19.8	134	42	148	4.13	99.87
DG-107	1095	zst	65.36	0.64	15.07	6.46	0.11	2.78	3.44	3.25	2.71	0.18	804	86	89	19	20	35	28	87	11.4	295	10.9	96	35	265	4.32	99.74
DG-108	1096	mst	64.71	0.77	14.94	6.97	0.12	3.00	2.79	3.36	3.12	0.21	879	100	110	20	25	43	28	100	15.2	259	14.9	115	40	254	3.88	99.62
DG-109	1098	zst	61.97	0.82	16.04	7.73	0.13	3.27	4.12	2.69	3.01	0.22	900	107	103	22	25	49	32	96	17.8	347	18.2	117	43	257	5.42	99.44

Footnote: Lithology codes: csst-coarse-grained sandstone; msst-medium-grained sandstone; fsst-fine-grained sandstone; vfsst-very fine-grained sandstone; zst-siltstone; mst-mudstone.

seconds for mudrocks and 40-45 seconds for sandstones. Additional description of the crushing procedures used is given by Roser *et al.* (1998). Total loss on ignition (LOI) was determined gravimetrically on 8-10 g splits of oven-dried powder (> 24 hours at 110°C), from net weight loss after ignition in a muffle furnace for at least 2 h at 1020°C. The ignited samples from the LOI determinations were then hand-ground in an agate pestle and mortar and returned to a 110°C oven before preparation of glass fusion beads for X-ray fluorescence (XRF) analysis.

Abundances of major elements and 14 trace elements (Ba, Ce, Cr, Ga, Nb, Ni, Pb, Rb, Sc, Sr, Th, V, Y, Zr) were determined at Shimane University. Analyses were made on glass fusion beads prepared using an alkali flux (80% lithium tetraborate ($Li_2B_4O_7$) and 20% lithium metaborate ($LiBO_2$)), with a flux to sample ratio of 2:1 (Kimura and Yamada, 1996). The instrument used was a Rigaku RIX 2000 XRF spectrometer, equipped with a Rh-anode X-ray tube. Calibration and correction for spectral interferences followed the methodology of Kimura and Yamada (1996). Internal correction for intra-run drift was made using secondary calibration against ten Geological Survey of Japan rock standards spanning the compositional range from gabbro (JGb-1) through to granite (JG-2).

Results

Major and trace element analyses of the Gondwana Group sediments are listed in Table 1, on an anhydrous normalized basis. Each unit shows variations in their elemental composition. LOI values in Unit 1 and 2 are generally low (< 5 wt%), whereas all except two samples in Unit 3 have considerably higher values (> 10 wt%), and a maximum of 21.9 wt%. There is no consistent association of the higher LOI values in Unit 3 with a single element. Some samples with high LOI are also enriched in CaO, whereas others have low CaO, but are enriched in Al_2O_3. The higher LOI values in Unit 3 are thus most likely due to either high $CaCO_3$ or clay contents, or a combination of both. However, enrichment in organic matter may also be a factor. Nevertheless, when the anhydrous normalized data are considered, some chemical contrasts and variations are observed between units and between lithotypes.

Geochemical compositions of sediments are mainly controlled by source rock composition, weathering in the source area, hydrodynamic fractionation of constituent minerals during transport and deposition, and by post-depositional diagenesis. Especially, the system is strongly influenced by relative proportions of quartz plus feldspar versus clays i.e. compositions of the end products are influenced by the dilution effect of quartz (SiO_2) or the abundance of clays (Al_2O_3).

In all units SiO_2 contents are characteristically greater in sandstones than in companion mudrocks; conversely contents of Al_2O_3, TiO_2 and most other elements are greater in the mudrocks than in the sandstones. Average SiO_2 contents in sandstones increase from Unit 1 (71.34 wt%) to Unit 2 (76.53 wt%), and subsequently decrease in Unit 3 (63.55 wt%). However, there is no significant variation of SiO_2 in the mudrocks of Unit 1 (60.05 wt%), Unit 2 (62.02 wt%) and Unit 3 (60.87 wt%). Average Al_2O_3 contents of the mudrocks increases significantly from Unit 1 (15.98 wt%) through Unit 2 (28.59 wt%) to Unit 3 (30.51 wt%). Average Al_2O_3 content of Unit 3 sandstones (20.65 wt%) is also greater than equivalents in Unit 1 (13.48 wt%). Average CaO contents are similar in all units (< 5 wt%), and are generally lower than in average upper continental crust (Taylor and McLennan, 1985). Some samples in Unit 1 contain anomalously high CaO (maximum, 52.68 wt%). Average Na_2O content decreases significantly from Unit 1 through Unit 2 and Unit 3, in both sandstones and mudrocks. Contents of K_2O also decrease upward from Unit 1 to Unit 3. Overall, most of the major elements except Al_2O_3 decrease stratigraphically upward, from Unit 1 to Unit 3.

Barium is the most abundant trace element in both mudrocks (M) and sandstones (S) in Unit 1 (M = 970 ppm, S = 640 ppm), Unit 2 (M = 379 ppm, S = 889 ppm) and Unit 3 (M = 268 ppm, S = 234 ppm). However, average Ba contents are lower in the younger units. Average Rb contents in Unit 1 (M = 157 ppm, S = 73 ppm) are greater than in Unit 2 (M = 100 ppm, S = 75 ppm) and Unit 3 (M = 69 ppm, S = 51 ppm), and thus Rb also decreases to the younger units, similar to Ba. Strontium contents also show similar behavior. Average Sr content in Unit 1 (M = 282 ppm, S = 315 ppm) decreases in Unit 2 (M = 88 ppm, S = 186 ppm), and is lower still in Unit 3 (M = 60 ppm, S = 76 ppm). Average contents of all these large ion lithophile elements thus decrease from the oldest to the youngest unit.

Average contents of Nb, Y, Th and Zr do not show any great variation between the units, especially in the mudrocks. However, average Zr concentration in Unit 1 sandstone (359 ppm) is greater than in Unit 2 (288 ppm) and Unit 3 (287 ppm). Average Ga concentration increases from Unit 1 (M = 23 ppm, S = 15 ppm) through Unit 2 (M = 35 ppm, S = 13 ppm) and Unit 3 (M = 32 ppm, S = 22 ppm). Average Ga concentration thus increases from the oldest to youngest unit, paralleling the trend in Al_2O_3.

Among the ferromagnesian elements, average Cr and Ni contents in the mudrocks show relatively little contrast between units. However, average Cr content in Unit 3 sandstones (98 ppm) is significantly greater than in Unit 1 and 2 equivalents (40 and 47 ppm, respectively). Similarly, average Ni content is higher in Unit 3 sandstone (S = 32 ppm) than in Unit 1 and 2 sandstones (both averaging 21 ppm). Average Sc concentration increases from the oldest to youngest, from Unit 1 (M = 17 ppm, S = 12 ppm) to Unit 2 (M = 27 ppm, S = 12 ppm) and Unit 3 (M = 25 ppm, S = 19 ppm). Average V content also increases slightly from oldest to youngest: Unit 1 (M = 139 pp, S = 58 ppm); Unit 2 (M = 170 ppm, S = 61 ppm); Unit 3 (M = 157 ppm, S = 111 ppm).

These broad variations in major and trace element abundances between units and lithotypes thus record the signatures of differing factors and processes.

Conclusions

Average geochemical compositions of sandstones and mudrocks in the three units of the Gondwana Group show significant variations. These contrasts represent the imprint of the factors that influence the composition of the sediments. Gondwana sediments on other continental blocks (India, Australia, South America, and South Africa) record the signature of dramatic climate change. The variations in the geochemical composition of the sediments of the Gondwana Group in Bangladesh will be interpreted in detail in a future publication, with the emphasis on climatic influence and possible correlation with the Gondwana successions on other continental blocks.

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