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Geochemical characteristics of Recent sediments of channel bar of the Ganges (Padma) River, Bangladesh

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Abstract

The present research deals with the geochemical characteristics of Recent sediments of channel bar of the Ganges (Padma) River, Bangladesh. The main objectives of the study are to delineate source area weathering, sorting and sediment recycling, provenance and tectonic setting of the Ganges sediments. The geochemical characteristics of the sediments display relatively a wide variation in accordance with lithosequences in their major element contents (e.g. SiO_2: 59.24-73.44, Al_2O_3: 10.39-15.25 in wt.%), reflecting the distinctive provenance and in part an unstable period in terms of tectonic activity. Oxides of some major elements (viz., K_2O, TiO_2, and MgO) and trace elements (viz., Rb and Ni) exhibit comprehensive correlations with Al_2O_3 confirming their possible hydraulic fractionation. The geochemical composition reveals that the studied sands are arkose and litharenite in type. The values of SiO_2/Al_2O_3, CIA (Chemical Index of Alteration), ICV (Index of Compositional Variability) and PIA (Plagioclase Index of Alteration) derived from the geochemical analyses of the studied sediments show low degree of maturity indicating poor chemical weathering in source areas. The entire rock geochemistry data reveals that the sediments were derived from mostly felsic to intermediate igneous rock provenance. These kinds of source rocks are present in a vast region of the Himalayan belt and catchment areas of Ganges. The tectonic setting discrimination plots (K_2O/Na_2O vs. SiO_2 and SiO_2/Al_2O_3 vs. K_2O/Na_2O) shows the sediments in the source area belong to Passive Margin (PM) to Active Continental Margin (ACM).

Keywords: Weathering, sorting and sediment recycling, provenance and tectonic setting.

Introduction

The Ganges River is one of the largest and most dynamic river in the world by discharge. This river begins from the Gangotri-glacier in the Himalayas, which drains through northern India and enters into Bangladesh through Chapainawabganj district in Rajshahi division of the western part of Bangladesh as the Padma River and finally, the river falls in the Bay of Bengal. The Padma is one of the largest rivers of Bangladesh, which is about 120 km long, 1.6 to 8.0 km wide and annually carries

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huge amount of sediments, which are generally laid down in the beds of the river forming sand bars (ALLISON *et al*. 1998). These types of river sediments give some significant information for source rock characteristics with relief and climate, weathering, transportation and depositional mechanisms from the geochemical analysis (DICKINSON *et al*. 1983; BASU 1985; DICKINSON 1985; BHATIA 1983; TAYLOR & MCLENNAN 1985; BHATIA & CROOK 1986; ROSER & KORSCH 1986; ROSER & KORSCH 1988; MCLENNAN *et al*. 1993; CONDIE 1993; FEDO *et al*. 1995; NESBITT *et al*. 1996; CULLERS & PODKOVYROV 2000; BHATT & GHOSH 2001). Moreover, several studies have been carried out focusing on the geochemical characteristics of clastic sediments as depicted by GAILLARDET *et al*. (1999), SINHA *et al*. (2007), TRIPATHI *et al*. (2007), NAJMAN *et al.* (2008), SINGH (2009, 2010), HOSSAIN *et al*. (2010), JANNATUL *et al*. (2010), GARZANTI *et al*. (2010, 2011), LUPKER *et al*.(2012), ROY & ROSER (2012), SHARMA *et al*. (2013), HOSSAIN *et al*. (2014), HAQUE *et al*. (2016), HENRY *et al.* (2017) and ABEDEN *et al.* (2018).

The present study deals with the geochemical characteristics of Recent sediments of channel bar of the Ganges (Padma) River, Bangladesh. This type of research work is still lacking in the study area though clastic sediments put up with endure a great tectonic significance. In this present research, the geochemical composition of sediments has been utilized for delineating source area weathering, sorting and sediment recycling, provenance and tectonic setting of the source rocks. This will help in comprehension of the geochemical evolution of the Himalayas as well as catchment areas of the Ganges River.

Geological Setting

The Bengal Basin is one of the thickest sedimentary basins of the world. It stands on the eastern side of the Indian sub-continent and involves a large portion of Bangladesh and West Bengal of India and part of Bay of Bengal (ALAM 1989; HOSSAIN *et al*. 2019). It was formed during the collision of Indian and Eurasian Plate in the north and with the Burmese sub-plate in east and built the extensive Himalayan and Indo-Burman Ranges and thereby, loaded the lithosphere to form flanking sedimentary basin (UDDIN & LUNDBERG 1998; HOSSAIN *et al*. 2020).

All the rivers flow from the north to south direction because of lessening pattern of elevation from north to south. The Ganges-Padma River from the northern and western slope of the Himalayas has a catchment territory of around 907,000 sq. km. The river begins from the Gangotri–ice sheet in the Himalayas. The amount of alluvial sediments conveyed by this river is huge and the sediments contain an enormous amount of sandy materials that are generally laid down in the beds of the river forming sand bars. Geologically the study area lies in the Padma or Ganges floodplain in the southwestern part of Bogra Slope just along the northern margin of the Hinge Zone (KHAN 1991; ALAM 1992; KHAN & RAHMAN 1992; REIMANN 1993).

Geographically the study area is situated near the erosional right bank of mid channel bar of the Padma River, opposite side of Shaheed Minar Ghat, Talaimari, Rajshahi, Bangladesh which lies between latitudes 24^0 18′20″ N to 24^0 22′48″ N and longitudes 88^0 30′50″ E to 88^0 43′11″ E (Fig. 1). The geochemical analysis was carried out along the vertical lithosuccession (Fig. 3), which is located at the erosional right bank of mid channel sand bar of the Padma River.

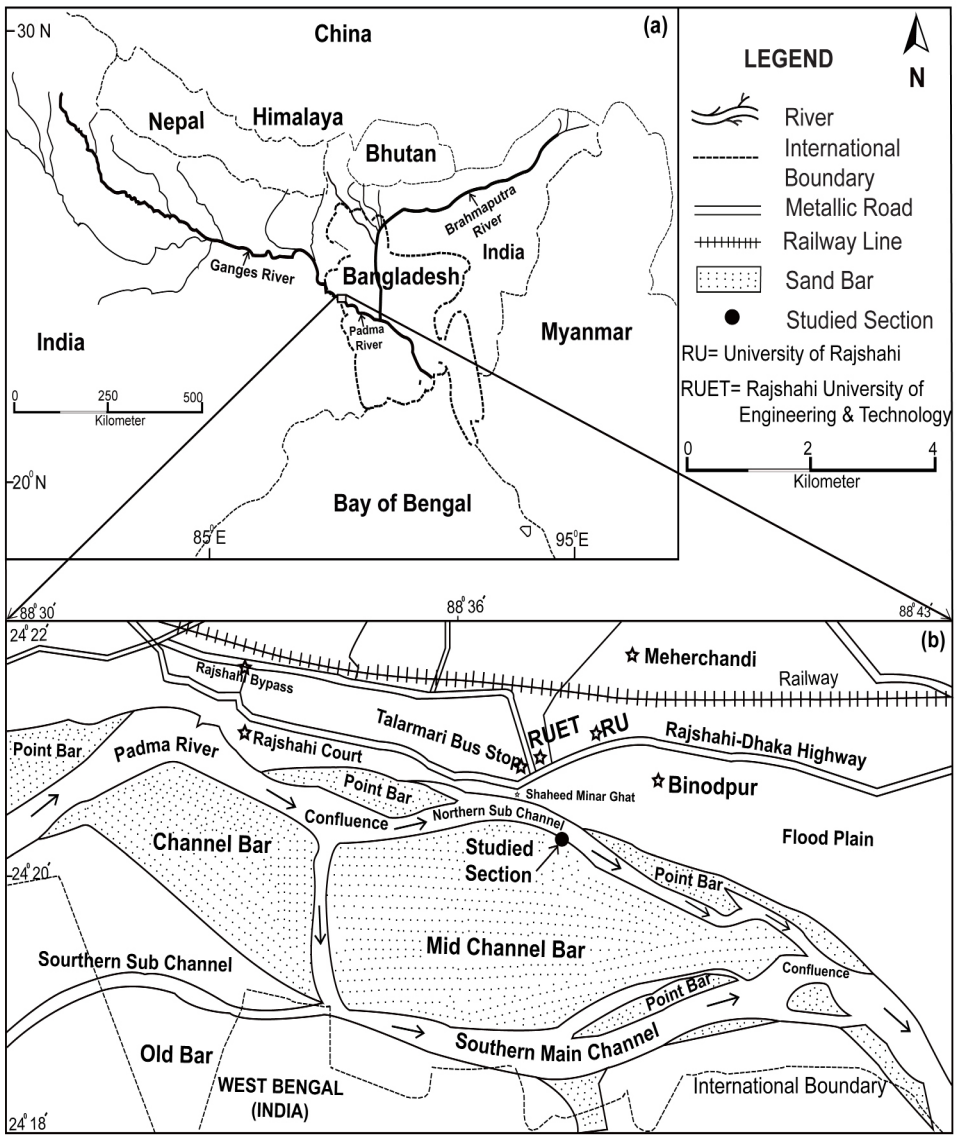

Fig. 1. Location map of the study area showing (a) the flow paths of Ganges-Padma River System and (b) geomorphic features of the Padma River (drawn after Google Earth Image).

Methodology

The present study comprises with field and laboratory based work. A comprehensive field work was carried out along the erosional right bank of channel bar deposits of the Padma River during the dry season. During field session, some selected sections were prepared and the vertical lithosequences were studied carefully. On the basis of color, texture, bedding and different types of sedimentary structures, various types of lithofacies were identified in the study area. The thickness of each lithofacies was measured and named and coded following the facies classification schemes of MIALL (1978) and RUST (1978). A total of 23 samples were collected from different lithofacies types and depths from the vertical section. Out of the 23 samples, 12 representative samples were selected for geochemical analysis. Geochemical analysis were carried out at the Institute of Mining, Mineralogy and Metallurgy (IMMM), BCSIR, Joypurhat, Bangladesh following the procedures of GOTO & TATSUMI (1994, 1996) and also following instrumental precisions and standards described in HOSSAIN *et al*. (2014). Sample preparation techniques of the selected samples for XRF (X-Ray Fluorescence) analysis were followed according to HOSSAIN *et al*. (2014). Analytical ambiguities for XRF, major and minor elements are ~2% and trace elements are <10-15%.

Based on geochemical data, different indices and diagrams are constructed utilizing significant oxides. CaO* exhibits the CaO in the silicate fraction merely (FEDO *et al*. 1995). The content of CaO amended for apatite utilizing P_2O_5 (CaO* = CaO-(10/3XP_2O_5). If the amended CaO* was lower than the measure of Na_2O, this adjusted CaO* value accepted. Once more, if the CaO* value is higher than the measure of Na_2O, it was accepted that the corrected value of CaO equivalent that of Na_2O.

Results and Discussion

Sedimentary Lithofacies

Facies analysis of recent sedimentary sequence was carried out in a vertical section, lying at the erosional right bank of mid channel bar of the Padma River, Rajshahi, Bangladesh. The exposed section of the study area consists of predominantly sand with silt, clay, mud and plenty of root trace and organic matters. The whole section is divided into five benches (Fig. 2). The thicknesses of the benches are 2.8 m (bench-1), 1.7 m (bench-2), 1.8 m (bench-3), 2.5 m (bench-4) and 0.43 m (bench-5). Based on lithology, color, texture and different types of sedimentary structures, altogether six types of lithofacies were identified in the study area (Fig. 3). These lithofacies are planner cross stratified sand facies (Sp), ripple cross stratified sand facies (Src), ripple laminated sand facies (Sr), horizontal laminated sand facies (Sh), silt and clayey silt laminated facies (Sl) and massive mud facies (Fm). The twelve representative samples were taken from different lithofacies type for geochemical

analysis. The samples are located in the lithosequences accordingly in Fig.3.

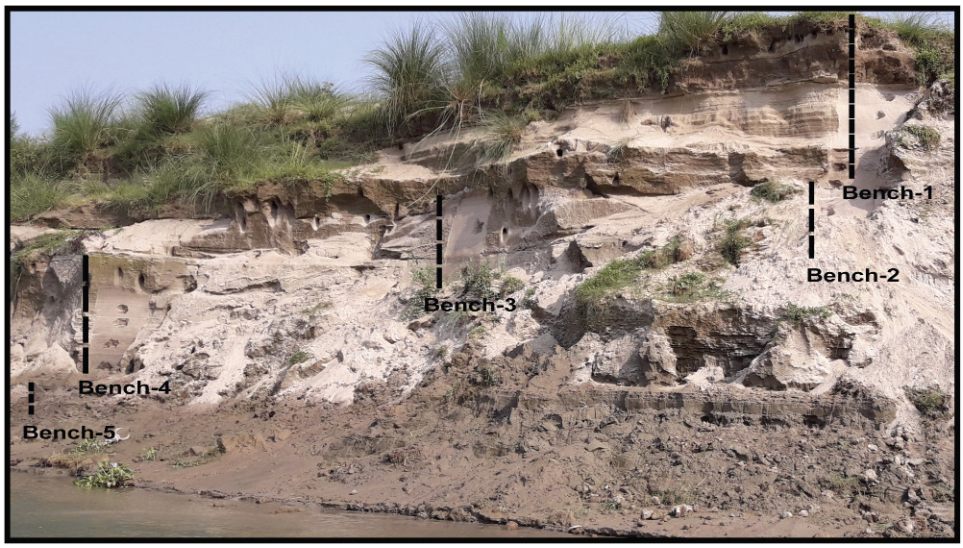

Fig. 2. A vertical section showing different benches of the erosional right bank of mid channel bar of the Padma River, Rajshahi, Bangladesh.

Geochemical Results

The geochemical results of XRF analysis of major oxides (in wt.%) and trace element abundances (in ppm), some calculated ratio and weathering indices from the geochemical data of the studied samples of channel bar of the Padma River, Rajshahi are presented in the Table 1.

Table 1. Major and trace elemental abundances, some ratio and weathering indices of the studied samples.

Major Oxides (wt.%)	Sample No.												Mean Value	UCC Value	PASS Value
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	S-11	S-12			
SiO_2	66.32	73.44	71.16	59.24	67.79	69.14	62.4	67.88	64.48	65.5	62.2	66.02	66.3	66	62.8
TiO_2	0.68	0.49	0.46	0.95	0.86	0.61	0.82	0.67	0.78	0.72	0.89	0.72	0.72	0.5	1
Al_2O_3	11.79	10.39	10.57	15.25	11.04	12.79	13.16	11.7	13.53	13.14	13.59	11.97	12.41	15.2	18.9
Fe_2O_3*	7.46	4.6	4.37	8.49	6.4	5.27	8.2	7.23	6.81	6.33	8.6	7.34	6.76	4.5	6.5
MgO	2.02	1.42	1.43	2.83	1.78	2	2.38	1.45	2.36	2.18	1.8	1.61	1.94	2.2	2.2
MnO	0.1	0.07	0.07	0.11	0.11	0.08	0.11	0.09	0.09	0.09	0.11	0.1	0.09	–	–
CaO	5.58	4.27	6.23	6.56	6.38	3.71	6.46	5.25	5.81	6.04	6.57	6.3	5.76	4.2	1.3
CaO*	5.1	3.9	5.8	6	5.6	3.3	5.9	4.8	5.3	5.6	6	5.8	5.25	4.2	1.3
Na_2O	1.33	1.35	1.43	0.97	1.2	1.34	1.15	0.98	1.12	1.15	0.91	0.97	1.16	3.9	1.2
K_2O	3.35	3.23	3.33	4.54	3.21	4.24	4.03	3.59	3.95	4.06	4.07	3.63	3.77	3.4	3.7
P_2O_5	0.16	0.12	0.14	0.17	0.23	0.12	0.17	0.15	0.14	0.14	0.16	0.15	0.15	0.17	0.16
ZrO_2	0.071	0.031	0.044	0.061	0.099	0.037	0.061	0.052	0.057	0.036	0.059	0.054	0.664	–	–
Trace Elements (ppm)															
Mn	740	535	511	819	882	632	821	730	689	671	866	756	721	–	–
Ba	666	432	488	782	664	525	564	500	558	697	928	754	630	550	660
Rb	207	189	187	286	184	243	253	227	236	239	268	228	229	112	160

Sr	216	186	211	239	218	183	221	210	222	225	240	224	216	350	200
Zr	528	232	329	453	731	270	455	382	424	267	440	401	409	190	210
Ni	138	74	74	326	105	78	124	136	132	101	156	140	132	20	55
Cu	64	42	49	86	54	0	77	46	70	60	78	66	58	–	–
Cr	6288	2864	2645	3668	4254	2111	5571	5299	331	2359	4990	6041	3869	35	110
Zn	80	54	56	117	74	63	93	85	96	95	97	93	84	–	–
Cl	214	332	863	396	430	429	559	282	485	395	516	529	453	–	–
F	579	0	0	0	501	1413	0	0	1343	0	0	0	320	–	–
S	62	74	125	134	91	58	97	58	86	61	68	60	81	–	–
As	24	27	0	30	0	26	27	0	0	0	30	0	14	–	–
Y	137	76	0	200	146	92	135	85	93	150	107	114	111	22	27
Mn*	0.04	0.11	0.11	0.03	0.18	0.12	0.04	0.04	0.05	0.07	0.04	0.05	0.07	–	–
Some ratios and weathering indices															
CIA*	54.8	55.2	50.1	57	52.4	59	54.3	55.7	56.5	54.9	55.3	53.5	54.94	57	75
PIA*	56.9	57.9	50.2	60.6	53.4	64.8	56.4	58.6	59.7	57.5	57.9	55.2	57.42	59	86
MIA*	9.5	10.3	0.2	14	4.8	18.1	8.5	11.3	13	9.8	10.5	7.1	9.5	10.3	0.2
ICV*	1.7	1.5	1.6	1.6	1.8	1.3	1.8	1.6	1.5	1.6	1.7	1.7	1.62	1.3	0.8
CIW*	64.9	66.6	59.5	68.6	61.8	73.4	65.1	67.1	67.7	66.1	66.2	63.9	65.95	–	–
SiO_2 / Al_2O_3	5.625	7.071	6.732	3.884	6.140	5.404	4.743	5.802	4.766	4.983	4.577	5.516	5.437	–	–
K_2O / Na_2O	2.52	2.4	2.33	4.69	2.69	3.16	3.5	3.67	3.52	3.53	4.47	3.73	3.35	0.87	3.1
log (SiO_2/ Al_2O_3)	0.75	0.849	0.828	0.589	0.788	0.733	0.676	0.764	0.678	0.697	0.661	0.742	0.73	–	–
log (Na_2O/ K_2O)	–0.40	–0.38	–0.37	–0.67	–0.42	–0.50	–0.54	–0.56	–0.55	–0.55	–0.65	–0.57	–0.51	–	–
TiO_2/Zr	12.80	21.22	13.90	21.01	11.71	22.60	17.96	17.43	18.44	26.88	20.31	17.90	18.51	–	–
Cu/Zn	0.8	0.79	0.87	0.74	0.72	0	0.82	0.53	0.73	0.63	0.81	0.7	0.68	–	–
K/Rb	134.5	141.7	147.1	131.7	144.9	144.1	132.3	131.1	138.1	141.0	125.1	132.1	137.2	–	–
Rb/Sr	0.96	1.02	0.88	1.2	0.84	1.33	1.15	1.08	1.06	1.06	1.12	1.02	1.06	0.32	0.8
Cr/Zr	11.91	12.36	8.05	8.10	5.82	7.81	12.26	13.87	0.78	8.83	11.35	15.06	9.45	–	–
Ti/Zr	7.67	12.72	8.31	12.59	7.02	13.55	10.77	10.45	11.05	16.12	12.18	10.88	10.55	–	–
DF–1	–0.47	–2.91	–1.82	–0.31	–1.1	–3.62	–0.25	–0.48	–1.30	–1.48	0.97	0.008	–	–	–
DF–2	–0.53	0.05	1.125	0.231	–0.02	0.539	0.112	–0.17	0.05	0.624	0.486	0.159	–	–	–

Notes: Total iron as Fe_2O_3* and FeO=Fe_2O_3X0.8998, UCC=Upper Continental Crust and PASS=Post–Archean Australian Shale (Taylor & Mclennan 1985; Condie 1993). CIA*=100X[Al_2O_3/(Al_2O_3+CaO*+Na_2O+K_2O)],PIA*=[(Al_2O_3–K_2O)/(Al_2O_3+CaO*+Na_2O–K_2O]X100, MIA=2(CIA–50),ICV*=[Fe_2O_3*+K_2O+Na_2O+CaO+MgO+TiO_2/Al_2O_3],and CIW*=[Al_2O_3/(Al_2O_3+CaO*+Na_2O]X100, Mn*=log [(Mn_{sample}/Mn_{shale})/(Fe_{sample}/Fe_{shale}], Discriminant function (DF–1)=–1.773TiO_2+0.607 Al_2O_3+0.76Fe_2O_3*–1.5MgO+0.616CaO+0.509 Na_2O–1.224K_2O –9.09 and Discriminant function (DF–2)=0.445TiO_2+0.07Al_2O_3–0.25Fe_2O_3*–1.142MgO+ 0.438 CaO +1.475Na_2O+1.426K_2O–6.861 (after Roser & Korsch 1988).

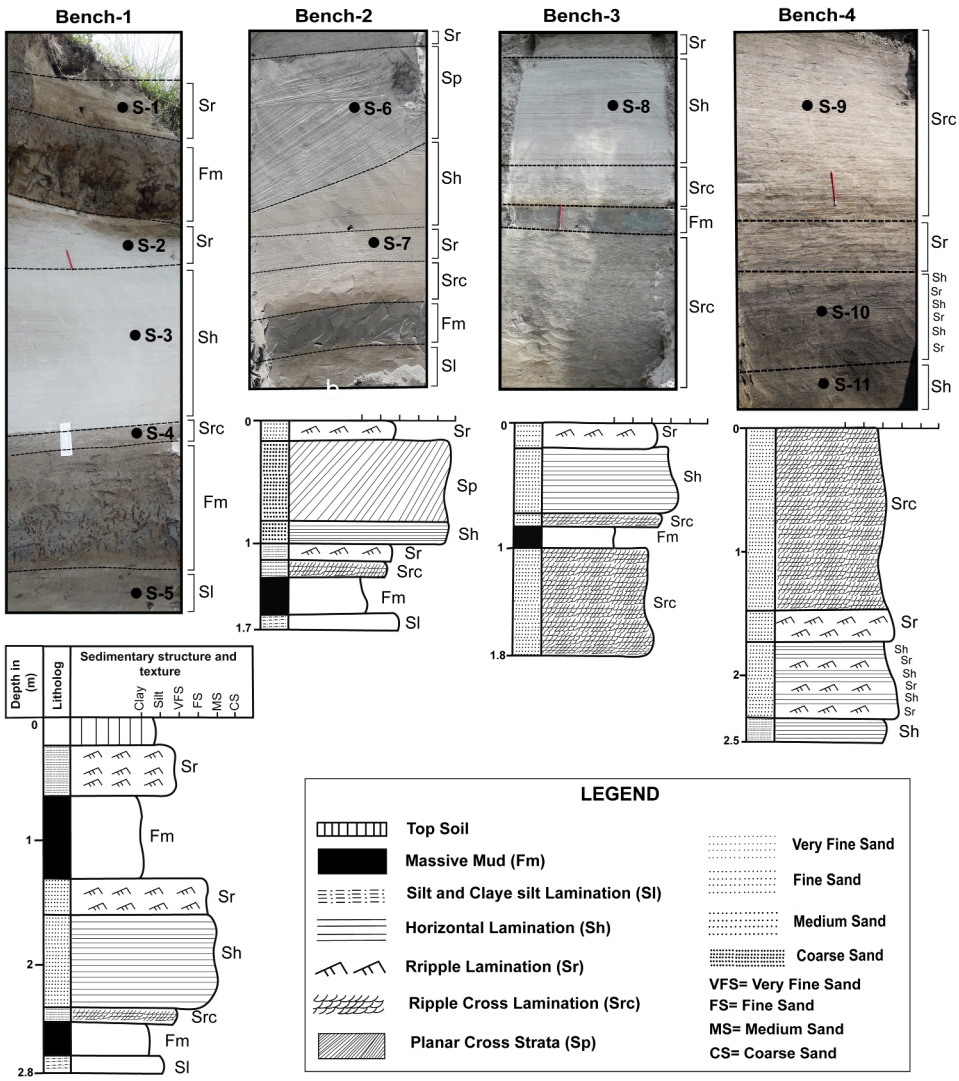

Fig. 3. Vertical lithosequences of the erosional right bank of mid channel bar of the Padma River, Rajshahi, Bangladesh. Sample points of the representative samples (viz. S-1, S-2, S-3……..S-11) for geochemical analysis are shown in the section.

Major Elements Concentration

In accordance with the lithosuccession of the investigated area, the entire compositions of the sediments exhibit relatively wide variations in fine to medium grained sand, specifically SiO_2 ranges from 59.24 wt.% (sample S-4) to 73.44 wt.% (sample S-2) with an average of 66.30 wt.% and Al_2O_3 ranges from 10.39 wt.% (sample S-2) to 15.25 wt.% (sample S-5) with an average of 12.41 wt.%. These

high percentages of SiO_2 and Al_2O_3 demonstrate a high extent of quartz and aluminosilicates respectively. In addition, the results show low concentration of SiO_2 (59.24 wt.%) and high concentration of Al_2O_3 (15.25 wt.%), which demonstrates the predominance of aluminosilicate minerals. On the contrary, SiO_2 exhibits high concentration (73.44 wt.%) where Al_2O_3 shows low concentration (10.39 wt.%), which reveals that the dominant mineral is quartz.

Some samples are also characterized by relatively high Fe_2O_3 (4.37–8.60 wt.%), K_2O (3.21–4.45 wt.%) and CaO (3.71–6.57 wt.%) contents. The average value of Fe_2O_3* is 6.76 wt.% which is comparatively high that indicates the presence of Fe–rich minerals. The considerably high content of CaO (avg. 5.76 wt.%) of the sediments suggest that these were derived from plagioclase rich intermediate rocks with some contributions from carbonate minerals. Again, TiO_2 ranges from 0.46 wt.% to 0.95 wt.% which reveals that the presence of valuable titanium-rich heavy minerals such as ilmenite and rutile. Other oxides of ZrO_2 (0.036 to 0.099 wt.%) and P_2O_5 (0.12 to 0.23 wt.%) may be considered diagnostic of the valuable heavy minerals zircon and monazite, respectively.

In the vertical lithosuccession of the study area, the concentration of SiO_2 varies with depth. Again the average weight percentage of SiO_2 (66.30 wt.%) in the studied sediments is presumably near to the mean value (66 wt.%) for the Upper Continental Crust (UCC) (Taylor & Mclennan 1985; Mclennan 2001; Rudnick & Gao 2003). When the correlation coefficient (r) is nearly 1, above 0.75, between 0.45 and 0.75 and below 0.45, it considers strong, relatively strong, moderate and weak correlation. The major oxides, such as Al_2O_3, TiO_2, Fe_2O_3, show strong linear negative correlation with SiO_2 (i.e., r=-0.90) (Fig. 5a) due to the increase in mineralogical maturity (Bhatia 1983; Vďačný *et al*. 2013). MgO, CaO, K_2O and P_2O_5 display relatively strong, moderate and weak negative correlation with SiO_2. Only Na_2O shows positive moderate correlation with SiO_2 (Fig. 5a). These trends are remarkably significant and the mineralogical maturity of the studied sediments is characterized by a raise in the quartz content and reduces in unstable detrital grains, which also reflect a stratigraphic trend (Vďačný *et al*. 2013).

However, MgO and K_2O exhibit strong linear positive correlations with Al_2O_3 (Fig. 5b), which suggest major influences of hydraulic fractionation according to Roy & Roser (2012) and Hossain *et al*. (2014). Again Fe_2O_3 and TiO_2 show moderate positive correlation and P_2O_5 exhibit very weak positive correlation with Al_2O_3. On the other hand, Na_2O shows moderate negative correlation with Al_2O_3. The content of CaO is comparatively high ranges from 3.71-6.57 wt.% that indicates the presence of plagioclase with some carbonate minerals. Again, Sr shows positive correlation with Al_2O_3 (Fig. 6),which may be associated with feldspar since it is a common substitute for Ca in plagioclase. The average weight percentage of CaO (5.76 wt.%) contents is enriched with the UCC value (4.20 wt.%) and almost higher that of the

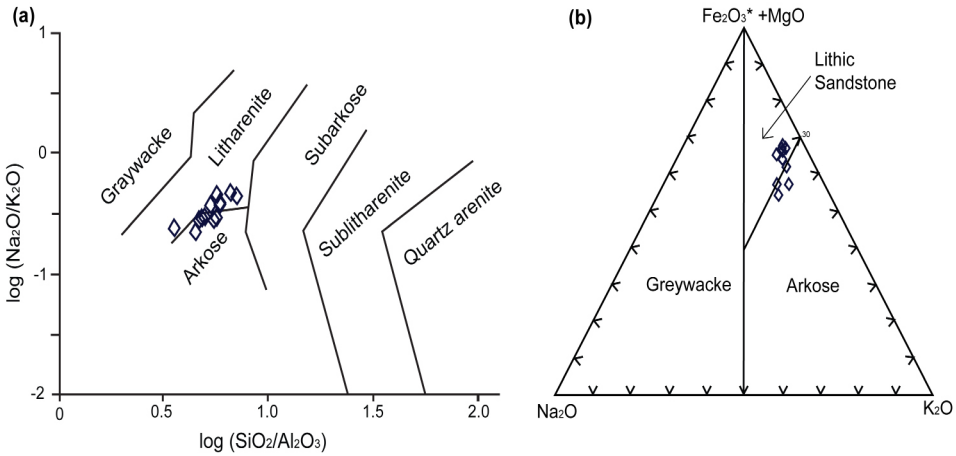

Fig. 4. (a) Plot of the investigated sediments for geochemical classification diagrams; log (Na_2O/K_2O) vs. log (SiO_2/Al_2O_3) diagram (After PETTIJOHN *et al*. 1972). (b) (Fe_2O_3*+MgO)-Na_2O-K_2O classification diagram for the investigated sediments (After BLATT *et al*. 1980).

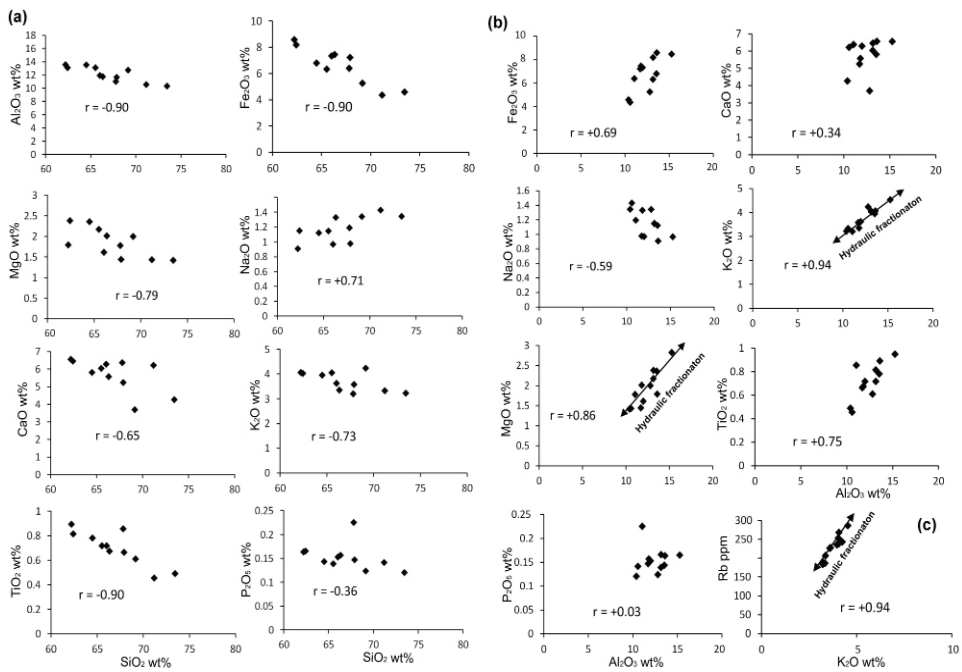

Fig. 5. Harker major element variations (in wt.%) diagram for the investigated sediments of the study area. (a) Plots of SiO_2 wt.% vs. different oxides; (b) Plots of Al_2O_3 wt.% vs. different oxides; and (c) Plots of K_2O wt.% vs. Rb.

Post Archaean Australian Shales (PAAS) value of 1.3 wt.% (TAYLOR & MCLENNAN 1985).

The correlation coefficient between Al_2O_3 and K_2O is relatively higher (r= +0.94) than the other major oxides that suggests k-feldspar control on the major element composition of the sediments. The positive correlation between Rb and K_2O (r= +0.94) displays hydraulic fractionation (Fig. 5c). The average value of K_2O is 3.77 wt.% which is slightly enriched compared to the UCC value (3.4 wt.%) and PAAS value (3.7 wt.%) of CONDIE (1993); TAYLOR & MCLENNAN (1985). While the average contents of Na_2O (1.16 wt.%) is depleted in accordance to the UCC value (3.9 wt.%) and mostly close to the PASS value (1.2 wt.%).

The ratio of SiO_2/Al_2O_3 ranges from 3.88 to 7.07 reflects the presence of quartz as well as the feldspar content (POTTER 1978) (Table 1). The ratio of Na_2O/K_2O (0.21-0.42) of sediments is comparatively low, indicating the low degree of maturation of the sediments (PETTIJOHN *et al*. 1972; ROSER & KORSCH 1986; FEDO *et al*. 1995; PAIKARAY *et al*. 2008). TiO_2 shows higher value (0.72 wt.%) than the UCC value of 0.5 wt.% (TAYLOR & MCLENNAN 1985; CONDIE 1993), which suggests more evolved with mafic and ultramafic crystalline material in the source rocks. Most of the studied samples have low P_2O_5 (avg. 0.15 wt.%) contents, explaining the lesser amount of accessory phases such as apatite and monazite compared with UCC (CONDIE 1993).

Trace Elements Concentration

There are different kinds of trace elements found in the sediment samples of the investigated area for example, Large Ion Lithophile Elements (LILE), High Field Strength Elements (HFSE) and Transition Trace Elements (TTE). LILEs are relatively mobile and incompatible elements. The average concentrations of the LILE, like Rb (229 ppm) and Ba (630 ppm) are higher than average Upper Crustal Compositions (UCC) and Sr (216 ppm) is lower than average UCC (TAYLOR & MCLENNAN 1981) as shown in Table 1. Rb exhibits relatively strong linear positive correlation (r= +0.74) with Al_2O_3 (Fig. 6) and strong linear positive correlation (r= +0.94) with K_2O (Fig. 5c) confirming clear hydraulic fractionation (ROY & ROSER 2012; HOSSAIN *et al*. 2014). Sr and Ba display a moderate positive correlation with Al_2O_3. Strong positive correlations of mobile components recommend their relationship with finer particles denoted the hydraulic partition of quartz and clays. HFSEs are incompatible but immobile elements. They are enriched in felsic instead of mafic rocks (BAULUZ *et al*. 2000). Due to their immobile nature, they are regarded as provenance indicators (TAYLOR & MCLENNAN 1985). The concentration of Zr is mainly controlled by the heavy mineral zircon. The average concentrations of Zr (409 ppm), and Y (111 ppm) of the sediments are enriched compared to the average UCC value (Table 1). Controlling phases for Y abundance are probably rutile and monazite because of relatively strong positive correlations with TiO_2 (r= +0.79). The TTE like Cr and Ni have much higher concentrations range of (331-6288) ppm and (74-326) ppm than UCC (CONDIE, 1993) and PAAS (TAYLOR & MCLENNAN 1985) values but have lower concentration of Cu

(0-86) ppm (Table 1). The average concentration of the other trace elements are Mn (721 ppm), Zn (84 ppm), Cl (435 ppm), F (320 ppm), S (81 ppm) and As (14 ppm).

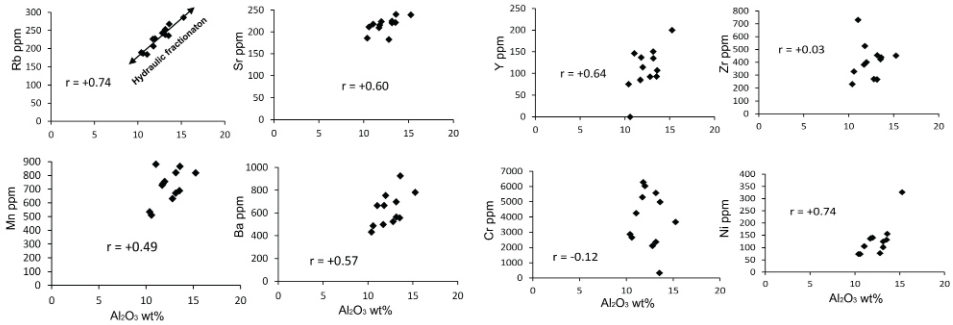

Fig. 6. Harker trace element variations (in ppm) diagram for the investigated sediments of the study area.

The UCC normalized major and trace element concentrations are showed in Fig. 7. In comparison with UCC (TAYLOR & MCLENNAN 1985), the studied recent sediments are often enriched and depleted of the major and trace elements (Table 1). The Multi–element normalized diagram exhibits enrichment of SiO_2, TiO_2, Fe_2O_3, CaO, K_2O, Ba, Rb, Zr and depletion of Al_2O_3, MgO, Na_2O, P_2O_5, Sr, Ni, Cr and Y. These normalized elemental distributions indicate that the chemical weathering led to removal of the soluble elements from the clastic fractions compared to the insoluble hydrolysates (NAGARAJAN *et al*. 2013). The comparative depletion or enrichment of various elements is broadly appropriate for provenance characteristics and weathering conditions (ETEMAD-SAEED *et al*. 2011). Moreover, the higher concentration of trace elements is probably due to the influence of heavy minerals presence as well as by the nature of source rock.

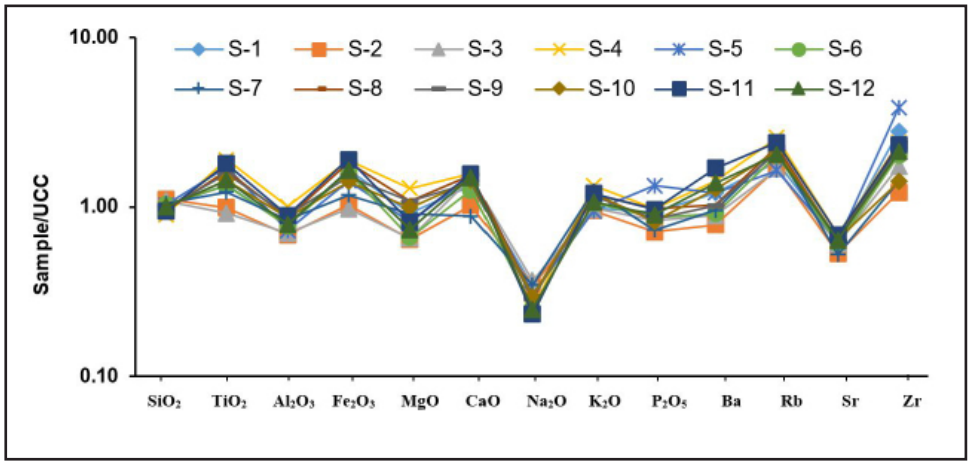

Fig. 7. Multi-element normalized diagram for the investigated sediment, normalized major and trace element against average UCC (Upper Continental Crust) values (After TAYLOR & MCLENNAN 1985).

Geochemical Classification

Based on geochemical compositions, numerous authors have proposed a few classifications for clastic sedimentary rocks or sediments although the geochemical classification of sediments is not well developed (e.g. PETTIJOHN *et al*. 1972; CROOK 1974; HERRON 1988; BLATT *et al*. 1980). The SiO_2 content and the SiO_2/Al_2O_3 proportion are the most usually utilized geochemical criteria for outlining the sediment maturity (POTTER 1978). They also reflect the abundance of quartz, feldspar and clay contents in the sediments. For the index of chemical maturity, the alkali content (Na_2O+K_2O) is appropriate for which quantifies the content of feldspar. PETTIJOHN *et al*. (1972) proposed a classification for Terrigenous sedimentary rocks dependent on a plot of log (Na_2O/K_2O) vs. log (SiO_2/Al_2O_3) utilizing the (Na_2O/K_2O) ratio and index of chemical maturity. On the basis of this scheme, the studied sediments show arkosic and litharenitic in composition (Fig. 4a). It is very noticeable that (Fe_2O_3*+MgO)–Na_2O–K_2O ternary diagram (BLATT *et al*. 1980) exhibits lithic with some arkose of the studied sediments (Fig. 4b). While, the applicability of the K_2O vs. Na_2O figure (CROOK 1974) for the studied sediments, it is enough to observe their quartz–rich characteristics (Fig. 10a).

Source Area Weathering

Weathering is the process which involves the physical disintegration and chemical decomposition of the older rocks to create solid particulate residue and dissolved chemical substance. The most useful tools for characterizing and determining the extent of weathering are identification of mechanism of weathering processes, degree of weathering or various chemical weathering indices. The extent of chemical weathering of the source territory materials can be obliged by computing the Chemical Index of Alteration (CIA) (NESBITT & YOUNG 1982). The determined CIA* values ranges from 50.12 to 59.03 (avg. 54.94) in the studied sediments which is lower than the average UCC value (Table 1). The CIA values range from (50-60), (60-80) and >80 indicate incipient, intermediate and extreme weathering respectively. The CIA* values ranges (50-60) of the sediments studied indicates poor/incipient weathering conditions in the source area. This low value of CIA is also supported by Plagioclase Index of Alteration (PIA*) (50.18-64.84, avg. 57.42) and Index of Compositional Variability (ICV) (1.34-1.80, avg. 1.62) values (NESBITT & YOUNG 1982; FEDO *et al*. 1995). Again high PIA value (>84) shows severe chemical weathering while lower value (~50) displays unweathered or fresh rock samples. The obtained average PIA values 57.42 exhibits relatively unweathered rock sources. The Mineralogical Index of Alteration (MIA) is another weathering parameter determined as: MIA= 2(CIA–50). MIA values between 0-20% are named as incipient, i.e. just starting; 20-40% (weak); 40-60% (moderate) and 60-100% as intense to extreme degree of weathering respectively. The extreme value of 100% show sthe total weathering of a primary material into its equivalent weathered. The calculated

MIA value ranges from 0.24% to 18.06% (Avg. 9.89%), which indicates incipient weathering condition of the source material. Because minerals show resistance to weathering, ICV can be utilized as a measure of sediment maturity.

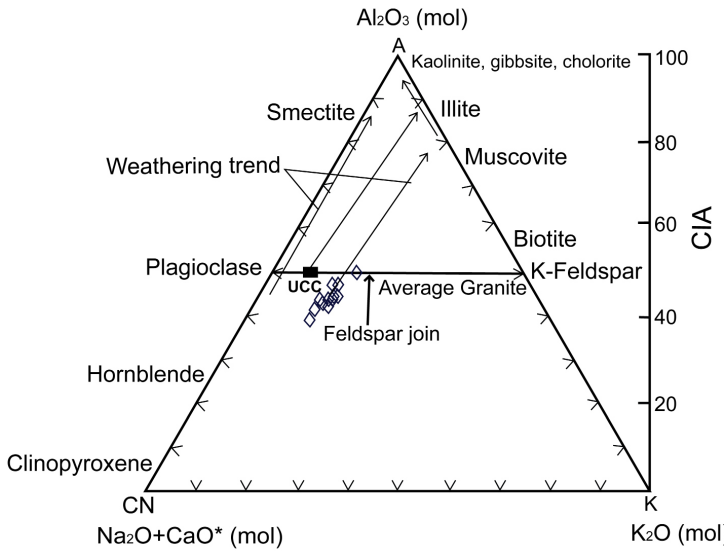

Fig. 8. Ternary plots of major element compositions of sediment samples plotted as molar proportions on an Al_2O_3–(CaO*+Na_2O)–K_2O or (A–CN–K) diagram (NESBITT & YOUNG 1997). Arrow indicate the weathering trend of the sediments, the scale showing the chemical index of alteration (CIA) is shown at the right side.

The ICV value >1 indicates immature sediments, while ICV values <1 exhibits matured sediments. The average ICV of the studied sediment is 1.62, which represents immature sediments. Chemical Index of Weathering (CIW) is an improved measure of the degree of weathering experience by a material comparative to its parent rock. The CIW values ranges from 50 to 60 show incipient weathering, 60 to 80 exhibits intermediate weathering, and above 80 demonstrate extreme weathering. The determined values of CIW of the samples range from 59.52 to 73.40 (avg. 65.95), which reflects incipient weathering.

A useful way to evaluate the chemical weathering trend is A-CN-K molecular proportion ternary diagram which represents the plot of Al_2O_3–(CaO*+Na_2O)–K_2O (NESBITT & YOUNG 1997). In the plots, most of the samples are near to the plagioclase and K-feldspar tie lines and below the UCC, indicating very poor weathering conditions or albitic-rich sources with less K mobility. The degrees of weathering are fairly different all through the succession (Fig. 8), demonstrating non steady-state

weathering conditions in the source area most likely because of increases in the intensity of tectonic activity throughout the certain timeframes, which permits rapid erosion of source rocks (NESBITT *et al*. 1997). The K_2O/Na_2O proportions range from 2.32 to 4.69 (avg. 3.35) which are >1 showing quartz enrichment in the sediments. The major elements, particularly the high content of SiO_2 (avg. 66.30 wt.%) also reflects quartz dominance in sediments and the variation in Al_2O_3 content (10.39-5.25 wt.%) shows feldspar input instead of clay minerals that are practically missing in the samples. In this case most of the weathering indices suggest poor weathering. In addition, the ratios of Rb/Sr also monitor the degree of source-rock weathering (MCLENNAN *et al*. 1993). The average value of the proportion of Rb/Sr of the studied sediments is 1.06 which is higher than the average upper continental crust (0.32) and near to the average PAAS (0.80) (Table 1). Therefore, all these data suggest that the degree of source area weathering was most likely poor weathering conditions.

Sorting and Sediment Recycling

The degree of sorting is controlled by the energy of the transport system, the source to sink distance, and many other factors (DOKUZ & TANYOLU 2006; ROY & ROSER 2012). Basically sorting produces geochemical contrasts among sand, silt and clay because of the detachment of these grains by hydraulic fractionation. By Harker variation diagrams, the evaluation of sorting effects and their degrees are so much helpful on such sediments. The major oxides Fe_2O_3, Na_2O, CaO and P_2O_5 display poor linear trends with Al_2O_3, (Fig. 5b) except K_2O (r= +0.94) and MgO (r= +0.86) indicating significant positive trends clarifying the degree of fractionation through mineral sorting. The average ICV value of the studied sediment is 1.62 (>1) which indicates compositionally immature to moderately mature sediments and these sediments are likely dominated by first cycle input (CULLERS & PODKOVYROV 2000). $15*Al_2O_3$–Zr–$300*\ TiO_2$ ternary diagram (Fig. 9) exhibits the impact of sorting processes (GARCIA *et al*. 1994). This gives information on the zircon concentration in sediments with a limited range of TiO_2–Zr, demonstrating insignificant sorting of the sediments and low compositional maturity. It is suggested that the studied sediments support a limited range of TiO_2/Zr variety and a reasonable sorting trend, and those comprising of sand-size components are immature indicating poor to moderate sorting and deposition without recycling. With an increasing in SiO_2/Al_2O_3 (3.88–7.07) proportion, the grain size likewise increases, as do the degree of recycling and maturity of sediment (Table 1).

Provenance

Inorganic geochemical data and their various applications are important for provenance studies (e.g. TAYLOR & MCLENNAN 1985; CONDIE *et al*. 1992; CULLERS 1995; ARMSTRONG-ALTRIN *et al*. 2004; KESKIN 2011). Accordingly MCLENNAN *et al*.

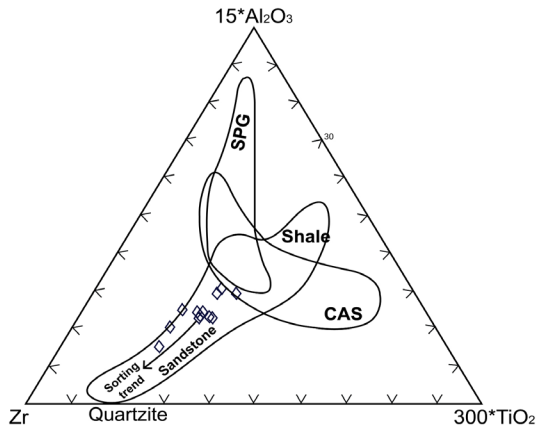

Fig. 9. Ternary plot of $15*Al_2O_3$-Zr-$300*\ TiO_2$ for the investigated sediments, CAS = field of calc-alkaline granites; SPG = field of strongly peraluminous granites (after GARCIA *et al*. 1994).

(1993) suggested that major elements give information on both the rock composition of the provenance and the impact of sedimentary processes, for example, weathering and sorting. These also depict the attribute of the source rocks and lastly give definite styles of sedimentary history (DICKINSON 1985, 1988).

It is noticeable that the ratios of SiO_2/Al_2O_3 (avg. 5.44) and K_2O/Na_2O (avg. 3.35) are higher than those ratios of UCC (TAYLOR & MCLENNAN 1985; CONDIE 1993), which indicate the studied sediments were originated largely from felsic sources (Table 1). Again, the Al_2O_3/TiO_2 ratio ranges from 12.89 to 23.14 with an average of 17.72, pointing out that the investigated sediments are derived from mostly felsic to intermediate rock sources (HAYASHI *et al*. 1997; KESKIN 2011 and references therein). The bivariate plot of K_2O vs. Na_2O (CROOK 1974) shows that all the samples are quartz-rich, which indicate the predominant of felsic origin (Fig. 10a).

The provenance discriminant function plot of ROSER & KORSCH (1988) characterized four (4) main provenances: mafic igneous provenance; intermediate igneous provenance; felsic igneous provenance; and quartzose sedimentary provenance (Fig. 10b). The samples plotted mainly in the felsic igneous and few quartzose sedimentary zones that are comparable fields with the quartzose sedimentary rocks in Bangladesh (HOSSAIN *et al*. 2014), however the studied recent sediments also fall in the Tertiary sedimentary rocks but maintain far distance from Siwalik deposits (Fig. 10b). Accordingly ROSER & KORSCH (1988), sediments recycled from felsic sources plot dynamically away from the igneous source line into the quartzose field. The concentration of zircon is utilized to characterize the composition and nature of source rock (HAYASHI *et al*. 1997; PAIKARAY *et al*. 2008). HAYASHI *et al*. (1997) suggest that the TiO_2/Zr ratios are great amount of supportive to recognize among three various types of source rock, i.e., felsic, intermediate and mafic. The

proportion of TiO_2/Zr ranges from 12 to 27 with an average of 19 shows that all the stream sediments are in the felsic zone. The studied sediments include relatively high K_2O and Rb concentrations (Fig. 11a) and their K/Rb ratios of approximately (126-148) with an average of 137 (Table 1), which lie near to the principal trend with a ratio of 230 of a typical differentiated magmatic suite after SHAW (1968), indicating chemically coherent nature of the sediments and mode of formation mainly from acidic to intermediate rocks.

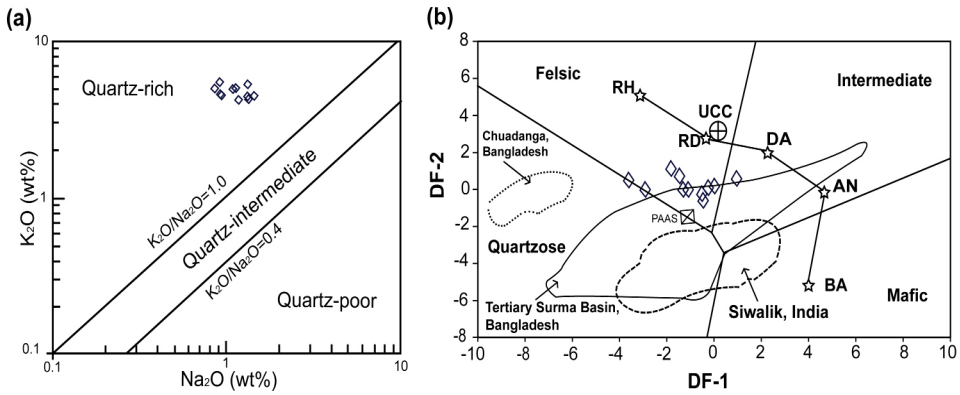

Fig. 10. (a) Bivariate plot of K_2O versus Na_2O of the studied sediments showing quartz rich nature, (after CROOK 1974). (b) Major element provenance discriminant plot (ROSER & KORSCH 1988), where fields for Siwalik, India from data in RANJAN & BANERJEE (2009), Tertiary Sedimentary Rocks, Surma Basin from HOSSAIN *et al*. (2010), Hatia trough from ROY & ROSER (2012), Quartzose Sedimentary Rocks in Chuadanga District, Bangladesh (HOSSAIN *et al*. 2014), UCC and PAAS from TAYLOR & MCLENNAN (1985). Star sign indicate average value i.e BA=Basalt, AN=Andesite, DA=Dacite, RD=Rhyodacite, RH=Rhyolite as plotted by ROSER & KORSCH (1988).

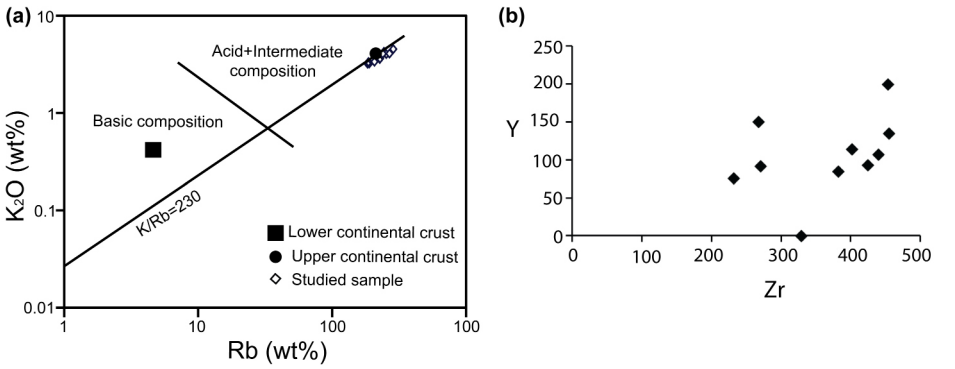

Fig. 11. (a) K_2O vs. Rb plot for the recent sediments from mid channel sand bar of the Padma River, Rajshahi, Bangladesh (After HAYASHI *et al*. 1997). (b) Harker plots showing the relations between Y and Zr trace element concentration (ppm) for the investigated sediments of the study area.

Though felsic source rocks contain relatively high Cr and Ni, some heavy mineral concentrations make uncertainty, such as Cr (331-6288) ppm with an average of

3869 ppm concentration (Table 1) of sediments are exceptionally high because of the high concentrations of chromium spinel, chromite and magnetite or significant ophiolitic component (NAGARAJAN *et al*. 2013). Usually those trace elements are necessary for the indicators of mafic and ultramafic source (WRONKIEWICZ & CONDIE 1987; HUNTSMAN–MAPILA *et al*. 2005). The studied sediments have moderate concentrations of Ba (432-928) ppm, Sr (183-240) ppm Ni (74-326) ppm, Y (0-200) ppm and Zr (232-731) ppm. If zircons are concentrated by hydraulic sorting in the sedimentary process, the Cr/Zr ratio is expected to decrease (TAYLOR & MCLENNAN 1985; SPALLETTI *et al*. 2008) (Table 1). The investigated sediments exhibit a wide range of Cr/Zr ratios (0.78-15.06), which are very much similar to the value of the originating from a mafic to felsic sources. Y displays remarkably scatter correlation with Zr (Fig. 11b), indicating a minor impact of zircon and other REE-rich heavy minerals, perhaps because it is controlled to a great extent by irregular distribution during sedimentation (LOPEZ *et al*. 2005).

Tectonic Setting

Several geochemical classification schemes have been proposed to discriminate from the various origin and tectonic settings (BHATIA 1986; ROSER & KORSCH 1986, 1988). Sedimentary rocks have various geochemical characteristics from different tectonic settings (BHATIA 1983; ROSER & KORSCH 1986). Major and trace elements and their distinctive bivariate and multivariate plots with discrimination functions are generally suitable for tectonic setting of the sedimentary basins. Despite the fact that these applications are not constantly legitimate for explicit nearby plate-tectonic settings, for example, back-arc basin, a few correlations between geochemical composition and tectonic settings of sediments could be established and the relationships among temporal and spatial variations inside different lithostratigraphic units, can be assessed. The plot of (K_2O/Na_2O) vs. SiO_2 (Fig. 12a) gives the tectonic setting discrimination for the studied Recent sediments after ROSER & KORSCH (1986). Most of the data of the studied samples shows Passive Margin (PM) to Active Continental Margin (ACM) tectonic setting. In such a setting, the sediments are quartz rich, which are originated from plate interior or stable continental areas and finally deposited in intra-cratonic basins or passive continental margins (ROSER & KORSCH 1986). BHATIA (1983) characterized SiO_2/Al_2O_3 vs. K_2O/Na_2O plot (Fig. 12b) based on the chemical analysis of the clastic sediments, which demonstrates comparability to (K_2O/Na_2O) vs. SiO_2 plot (Fig. 12a), where average data plot in a similar pattern. Passive margin sediments are portrayed by higher values of both ratios. ACM sediments delineate the lower SiO_2/Al_2O_3 ratio with variable low (K_2O/Na_2O) ratio (MCLENNAN *et al*. 1993). On the Major element–based diagram of BHATIA (1983), the present study is plotted in the field of passive margin (PM) to active continental margin (ACM) setting.

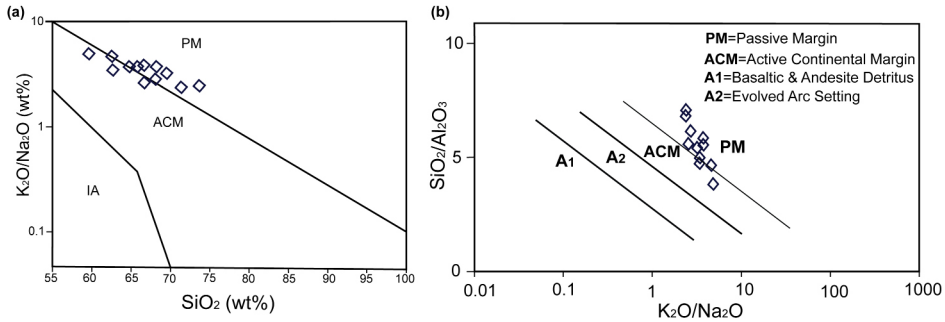

Fig. 12. (a) Tectonic setting discrimination diagram of (K_2O/Na_2O) vs. SiO_2 for the investigated Recent sediments (after ROSER & KORSCH 1986). (b) Tectonic Discriminant diagram of SiO_2/Al_2O_3 vs. K_2O/Na_2O for the investigated Recent sediments showing in the field of passive margin (PM) to active continental margin (ACM) (after ROSER & KORSCH 1986).

Several trace element concentrations (e.g. Ba, Rb and Y) and the ratios of Ti/Zr also demonstrate clearly tectonic setting. BHATIA & CROOK (1986) have exhibited that ocean island arc derived sediments are shown by Ti/Zr ratios generally >40, those originate from continental island arcs have Ti/Zr ratios between 10 and 35, while those derive from passive margins generally have Ti/Zr ratios <10. So the Ti/Zr ratios of the studied sediments (7–16, avg. 11) clearly indicates passive margin (Table 1). Therefore, on the basis of major and trace elements discrimination, the tectonic setting of the sediments demarcates typically passive margin to active continental margin.

Conclusions

The investigated Recent sediments of the channel bar of the Ganges (Padma) River, Bangladesh show mostly wider variations in fine to medium grained sand of their major element geochemistry, reflecting the nonsteady-state conditions for provenance and tectonic setting. The tectonic setting discrimination plots (K_2O/Na_2O vs. SiO_2 and SiO_2/Al_2O_3 vs. K_2O/Na_2O) of the sediments in the source area belong to Passive Margin (PM) to Active Continental Margin (ACM). The values of the ratio of SiO_2/Al_2O_3 (3.88-7.07), CIA* (50.12-59.03), ICV (1.62) and PIA* (50.18-64.84) show low degrees of maturity suggesting poor/incipient chemical weathering in source areas. From the Al_2O_3-(CaO^*+Na_2O)-K_2O molecular proportion ternary plot, it reveals that the analyzed samples are very close to the plagioclase and K-feldspar tie lines and beneath the UCC (Upper Continental Crust), indicating very poor weathering conditions. The values of SiO_2/Al_2O_3 (3.88-7.07), K_2O/Na_2O (2.32-4.69) and Al_2O_3/TiO_2 (12.89-23.14) indicates that the investigated sediments are derived from mostly felsic to intermediate source rock that are present in a vast region of the Himalayan belt as well as catchment areas of the Ganges River.

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বাংলাদেশের গঙ্গা (পদ্মা) নদীর চরের নব্য পললের ভূ-রাসায়নিক বৈশিষ্ট্যসমূহ

সোহাগ আলী, মোঃ শফিকুল আলম, সৈয়দ সামসুদ্দিন আহমেদ
মোহাম্মদ নাজিম জামান, ইসমাইল হোসেন ও প্রদীপ কুমার বিশ্বাস

সারসংক্ষেপ

বর্তমান গবেষণায় বাংলাদেশের গঙ্গা (পদ্মা) নব্য পললের ভূ-রাসায়নিক বৈশিষ্ট্য নিয়ে আলোচনা করা হয়েছে। এই গবেষণার মূল উদ্দেশ্য হলো উৎস অঞ্চলের বিচূর্নিভবন, বাছাইকরণ এবং পলির পুনর্ব্যবহারযোগ্য, উৎস শিলার উৎপত্তি এবং টেকটোনিক সেটিং বর্ণনা করা। পলির ভূ-রাসায়নিক বৈশিষ্ট্যসমূহ, তাদের প্রধান উপাদানগুলোর স্তরবিন্যাস অনুসারে তুলনামূলক বিস্তৃত ভিন্নতা প্রদর্শন করে (উদাহরণস্বরূপঃ SiO_2: 59.24–73.44, Al_2O_3:10.39–15.25 in wt.%), যা উৎস শিলার উল্লেখযোগ্য বৈশিষ্ট এবং টেকটনিক সক্রিয়তার ক্ষেত্রে একটা পরিবর্তনশীল সময়ের অংশ হিসেবে প্রতিফলিত করে । কিছু প্রধান উপাদানগুলোর অক্সাইডসমূহ (যেমন K_2O, TiO_2, and MgO) এবং ট্রেস উপাদানগুলো (যেমন Rb and Ni) এর সাথে বিস্তৃত সম্পর্ক প্রদর্শন করে যা তাদের সম্ভাব্য হাইড্রোলিক ভগ্নাংশ নিশ্চিত করে। অধীত পললের ভূ-রাসায়নিক শ্রেণিবিন্যাস চিত্র ইঙ্গিত করে যে, উৎস শিলা আরকোজ এবং লিথারেনাইট গোত্রের । SiO_2/Al_2O_3, CIA*, ICV* and PIA* মানগুলো উৎস শিলার নিম্ন পরিপক্কতা ও উৎস শিলা অঞ্চলের নিম্ন রাসায়নিক বিচূর্নিভবন নির্দেশ করে। সমগ্র ভূ-রাসায়নিক ফলাফল থেকে প্রতীয়মান হয় যে, অধীত পললের উৎস শিলা মূলত ফেলসিক ও মধ্যবর্তী আগ্নেয় শিলা থেকে উৎপন্ন হয়েছিল। এই ধরণের শিলা হিমালয় পর্বতমালার বিস্তীর্ণ অঞ্চল সমূহে এবং গঙ্গা নদীর উৎস অঞ্চলে বিদ্যমান। অধীত পললের টেকটোনিক সেটিং বৈষম্য চিত্র সমূহ (K_2O/Na_2O vs. SiO_2 এবং SiO_2/Al_2O_3 vs. K_2O/Na_2O) ইঙ্গিত করে যে, উৎস অঞ্চলের শিলা প্যাসিভ মার্জিন (PM) ও অ্যাক্টিভ কন্টিনেন্টাল মার্জিন (ACM) এর অন্তর্গত ।