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Heavy mineral distribution in sand deposits from the lower reaches of the Jamuna River, Bangladesh

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Abstract

The present study deals with the concentration and types of heavy minerals from the sand deposits of the lower reaches of the Jamuna River. The sand deposits are characterized by large-scale trough cross-stratified sandy facies (St), planar to low angle cross-stratified sandy facies (Sp), parallel laminated sandy facies (Sh), climbing ripple (Sr_1) and ripple laminated sandy facies (Sr_2) and massive sandy facies (Sm). The large-scale trough, planar cross-stratified sandy facies and massive sandy facies are generally medium (2-1φ) to fine (3-2φ) grained, whereas low-angle cross-stratified, parallel laminated and climbing rippled sandy facies are fine to very fine (4-3φ) grained. In sand deposits of the Jamuna River, the average heavy mineral concentration is around ~6%, where the concentration of epidote (~31.4%), amphibole (~17.9%), tourmaline (~12.3%), opaque (~9.8%), garnet (~8.6%), pyroxene (~5.0%), apatite (3.5%), zircon (~2.7%), sillimanite (~2.7%), kyanite (~2.7%), staurolite (~1.6%), rutile (~0.6%), andalusite (~0.5%), sphene (~0.2%) and monazite (~0.1%) has been identified. The stable heavy minerals like zircon, tourmaline and rutile are around 15.6%. The trough, planar cross-stratified, parallel stratified and ripple cross-laminated sands show higher abundance of garnet and opaque minerals. All lithofacies are dominated by the presence of SiO_2 (68.75%-76.41%) and Al_2O_3 (10.23%-13.35%), indicating a high proportion of quartz and/or aluminosilicates. The sands are also characterized by relatively high Fe_2O_3 (3.05% - 5.86%) that are consistent with the presence of heavy aluminosilicate mineral phases such as amphiboles, garnet and epidote.

Keywords: Jamuna River sand deposits, Lithofacies, Grain size, Heavy minerals, Major element geochemistry.

Introduction

Minerals with specific gravity >2.9 are known as heavy minerals and occur as oxides in sediments or rocks. Most of the heavy minerals have economic significance. However, heavy mineral concentrations are very low and constitute varying suites in igneous, metamorphic and sedimentary rocks. In addition, heavy minerals are very resistant to chemical weathering and travel long distance before being deposited. Thus, the heavy minerals are good indicators for provenance study.

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Fluvial sand bars and shore-line beach environments are suitable places for heavy mineral concentrations.

The Bengal delta is situated at the confluence of the Ganges- Brahmaputra -Meghna (GBM) River system which forms the world's largest sediment dispersal system (KUEHL *et al.*1989). The Brahmaputra-Jamuna River carries an estimated 7.35–8×10^8 ton of sediment per year (COLEMAN, 1969; RAHMAN *et al.* 2012) which may have the opportunities for heavy mineral concentrations. While current heavy minerals exploration focus is centered on the high-grade coastal sand deposits, there is considerable potential for sourcing heavy minerals from other regions in Bangladesh. The possible other source of heavy minerals can be the alluvial deposits of Brahmaputra- Jamuna River. Although the beach sands of Bangladesh is well known for heavy mineral occurrences (MITRA *et al.* 1992; ISLAM, 1997; KABIR *et al.* 2006; BARI *et al.* 2011), very little is known from the river sands. Though some works have been carried in the recent past (ZAMAN *et al.* 2012; RAHMAN *et al.* 2016, 2017; BISWAS *et al.* 2018), most of them are from the upstream part of the rivers and heavy minerals concentrations from the middle and lower reaches are rare. However, currently many national and international companies are looking for the economical concentrations of heavy minerals in river systems of Bangladesh. Therefore, heavy mineral studies from the bar sands of the lower Jamuna River will help to understand the prospects for placer deposits in the riverine environment of Bangladesh.

The sampling for this study started from near to the Jamuna Bridge and continued down about 33 km to the Aricha Ghat, which lies between latitudes $23^0$8′35′′N to $24^0$7′15′′N and longitudes $89^0$40′10′′E to $89^0$45′20′′E (Fig. 1). The present study focuses on the possible depositional environments of the bar facies, facies-wise heavy mineral concentration, types and their potential source areas.

Geological Setting

The Bengal Basin lies on the eastern side of the Indian sub-continent and occupies most of Bangladesh and West Bengal of India and part of Bay of Bengal (ALAM, 1989). The basin has its origin in the collision of Indian and Eurasian plate in north and with Burmese plate in east, building the extensive Himalayan and Indo-Burman Ranges and thereby loading the lithosphere to form flanking sedimentary basins (UDDIN & LUNDBERG, 1998). Due to decreasing trend of elevation from north to south, almost all of the rivers flow from north to south direction. The Brahmaputra-Jamuna River from the northern and eastern slope of the Himalayas has a catchment area of 5, 83,000 Sq. km. The river originates in the Kailas range of the Himalayas having highly braided channel characteristics (braiding indices 5.3 to 6.7) in Assam, northern part of the Shilong Massif, India (GOSWAMI, 1985) and in its Bangladesh reach, displays a braided pattern in plain view (COLEMAN, 1969; ALAM, 1991) but, some reaches are anastomosed or meandering (BRISTOW, 1987).

In the Bengal Basin the Brahmaputra-Jamuna River enters through the Rangpur Saddle and then follows southern slope of the Rangpur Saddle (Western Foreland shelf) and continental slope from north to south. The river flows in the western edge of the Madhupur-Tripura Threshold and meets with the Padma River at Aricha Ghat and then flows together and falls into the Bay of Bengal (Fig. 1).

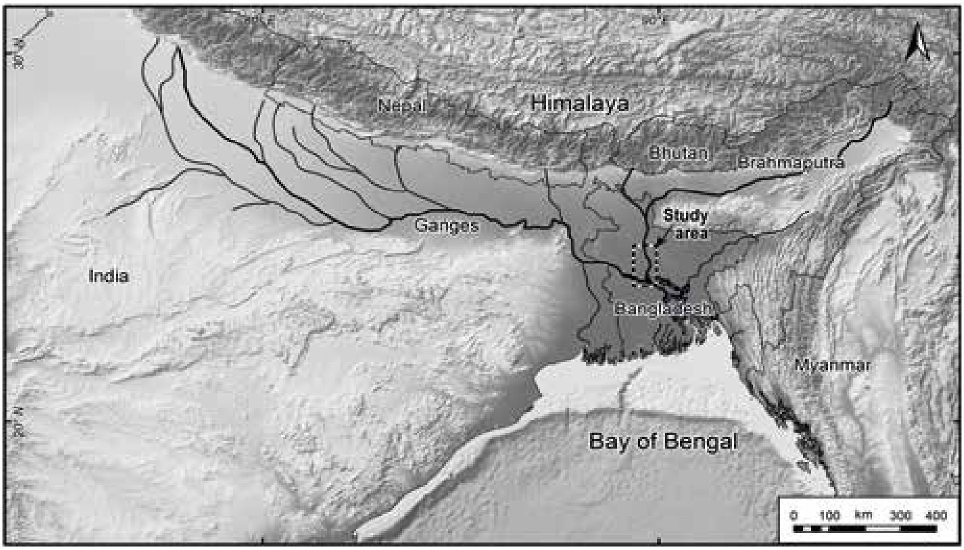


Fig. 1. Location map of the study area showing the flow paths and tributaries of Brahmaputra -Jamuna River.

Methodology

For the purpose of this research, a detailed field work has been carried out along the cut banks of bar deposits in the lower Jamuna River during the end of the rainy season (as the bank erosion is rapid) of 2014. Each section was logged in detail and sedimentary logs were measured in the outcrops to define different facies. Lithofacies types were classified on the basis of grain size and sedimentary structures following the facies classification schemes of MIALL (1978). Samples of each lithofacies type were collected for laboratory analysis to fulfill the purpose of this study.

Grain size is a fundamental characteristic of sediments and grain size analysis is a valuable tool for sediment transport dynamics and environmental analysis (FOLK & WARD, 1957; BOGGS, 2009). In this study, grain size analysis has been performed to discriminate the different depositional environment. Standard dry seiving technique has been adopted for performing grain size analyses. About 100 gm of each dried sample was taken and sieved by "Ro–Tap sieving machine" for 15 minutes using 18, 35, 60, 120 and 230 U.S. standard meshes and their size distributions were recorded. Then, the grain size parameters were calculated followed by FOLK and WARD (1957). All the samples were analyzed at the Department of Geological Sciences, Jahangirnagar University, Dhaka, Bangladesh.

Presence of heavy minerals in sediment may indicate their source rock. Heavy minerals from the sand fractions of 27 samples of different lithofacies have been separated using bromoform (sp.gr.2.89) following the procedure outlined by MANGE & MAURER (1992) at the Department of Geological Sciences, Jahangirnagar

University, Dhaka, Bangladesh. The light and heavy fractions were weighed and their weight percentages were calculated. After drying the heavy minerals are mounted on standard microscope glass slides by using Canada balsam. After preparing, the slides were observed under polarizing microscope (Motic PM-18 series, MEIJI ML 9000) and at least 200 grains were counted using ribbon counting method. Photographs of the representative heavy minerals were taken using a digital camera attached with the high level research polarizing microscope (Nikon eclipse 200).

The chemical composition of detrital sediments is primarily controlled by the nature of the source rock. In this study major elements (Si, Al, Fe, Ca, Na, K, Mg, Mn, Ti and P) of the bulk samples of each facies types were performed to discriminate the different depositional environment and chemical composition of the source area. For this purpose16 representative samples were selected and analyzed at the Geological Survey of Bangladesh (GSB) Dhaka. According to SMITH (1991), the samples were subjected to hydrofluorization treatment to analyze the content of Na, K, Ca, Mg, Al, Fe, Ti, P, and Mn. Classical method is used to determine the silica content and the oxides like Al_2O_3, Fe_2O_3 TiO_2, and MnO are determined by UV spectrometer using 475 nm, 555 nm, 430 nm, and 525 nm absorbance filters respectively. CaO and MgO are determined by EDTA solution in titration. K_2O and Na_2O are determined by flame photometer.

Results

Sedimentary Lithofacies

The braided belt environment of the Jamuna River consists of channel, levee and bar deposits. Every year significant migration of channel occurs within the braid belt and causes major erosion in the form of channel scour and bank cutting, as well as rapid deposition on developing lateral and medial bars. A detail field work has been carried out along the cut banks of the lower Jamuna River and lithologic, textural and structural variations have been noted. The sands are trough and planar cross-stratified, parallel and ripple laminated and massive in structure. The thicknesses of each lithofacies were measured and named and coded following the facies classification schemes of MIALL (1977, 1978). Based on lithology, sedimentary structure, texture and bounding surfaces, a total of six prominent sedimentary lithofacies have been identified (Fig. 2a-f; ABEDEN, 2016). These are: large-scale trough cross-stratified sands (St), planar to low-angle cross-stratified sands (Sp), parallel laminated sands (Sh), climbing ripple laminated (Sr_1), ripple cross-laminated (Sr_2) and massive sands (Sm). A detail description and interpretation of the individual lithofacies are summarized in the Table 1.

Textural characteristic of the depositional facies

Overall, the lower Jamuna River exposed bar sands are medium to very fine grained (1.9φ to 4.2φ) and poorly to very well sorted (1.2φ to 0.3φ) (Fig 3a). The sands are near symmetrical to strongly fine skewed, where ~7% samples are negatively skewed and ~93% are positively skewed (Fig.3b-c). The kurtosis ranges from

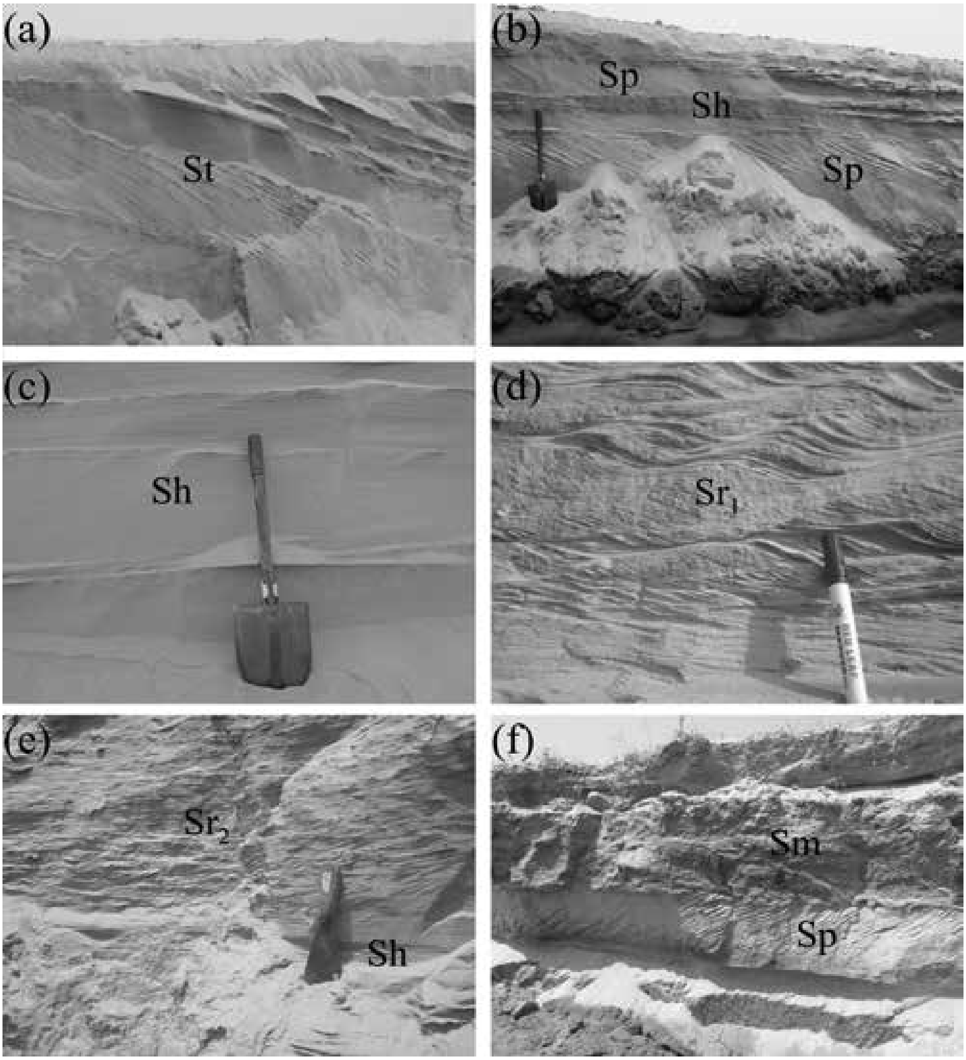


Fig. 2. Characteristics sedimentary lithofacies observed along the cut banks of lower Jamuna River: (a) large-scale trough cross bedded sands (St); (b) planar to low-angle cross-stratified sands (Sp); (c) parallel laminated sands (Sh), (d) climbing ripple laminated (Sr_1); (e) ripple cross-laminated (Sr_2); and (f) massive sands (Sm).

platykurtic to very leptokurtic (Fig. 3d).

Facies wise textural variations of the bar sands are also distinctive (Fig. 3a-d). Large-scale trough cross-stratified sands (St) are medium to very fine grained, moderate to well sorted, near symmetrical to strongly fine skewed and mesokurtic to very leptokurtic in nature, whereas planar to low-angle cross-stratified sands (Sp) exhibits fine grained, moderate well sorted, fine to strongly fine skewed and very leptokurtic. Parallel laminated sands (Sh) are characterized by fine to very

Table 1. Summary of lithofacies observed along the cut-banks of the lower Jamuna River.

Facies codes	Lithofacies	Description	Interpretation
St	Large-scale trough cross-stratified sands	Medium to fine grained, well sorted sands; troughs are well defined by shallow scours; foresets are commonly symmetrically curved and parallel to the current direction; foresets are tangential to the underlying erosional surfaces; trough depth averaging for medium scale cross-strata, 7 cm to 65 cm thick; individual troughs traced down current for up to 10 m; occur in bottom part of the longitudinal and diagonal bars of major and secondary channels (Fig. 2a).	Migration of 3D sandy dunes (lower flow regime) (TODD, 1996); migration of sandy bar forms (CAIN and MOUNTNEY, 2009).
Sp	Planar to low-angle cross-stratified sands	Medium to fine grained, well sorted sands; planar low angle (<10^0) stratified sets; 30 cm to 90 cm thick; sets are continuous across the width of the outcrop, but in places truncate each other vertically and laterally; individual sets are about 2 cm thick and flattening to horizontal at the base of each set; cosets are 5 cm to 10 cm thick and persistent in down current direction at least 10 m (Fig. 2b).	Migration of 2D sandy dunes (lower flow regime) (TODD, 1996), migration of sandy bar forms (CAIN and MOUNTNEY, 2009).
Sh	Parallel laminated sands	Medium to fine sands; each lamina is parallel to the lower set boundary; thickness of laminae ranges from 1mm to 1cm; individual facies are 50 cm - 1 m thick and laterally extends up to few tens of meters; developed at the lower part of active channel bars (Fig. 2c).	Downstream migration of ripples within shallow, low energy fluvial channel (EBINGHAUS *et al.*, 2017).
Sr_1	Climbing ripple laminated sands	Medium to fine sands; associated with horizontal lamination, but in few places, small-scale trough cross stratification also occurs; presents a clear view of completely preserved lee side and partially or completely eroded stoss side; average thickness ranges from 80 cm to 1 m and decreases towards downstream; occurs in longitudinal and side channel bars of active channel (Fig. 2d).	Migration of 2D or 3D ripples within the lower flow regime (MIALL, 1977); rapid deposition from suspended sediments.
Sr_2	Ripple cross-laminated sands	Medium to fine grained; internally cross laminated; thickness varied from 10 cm and 50 cm; occurs in secondary and abandoned channel bars (Fig. 2e).	Migration of 2D or 3D ripples within the lower flow regime (MIALL, 1977).
Sm	Massive sands	Coarse to fine sand; lack of internal lamination; thickness of the individual facies ranges from 20 cm to 1 m and extend laterally for a few meters (Fig. 2f).	Lack of lamination due to rapid deposition; flocculation of fine sands, silts and clays or bioturbation activity.

fine grained, moderate to very well sorted, near symmetrical to strongly fine skewed and mesokurtic to very leptokurtic. On the other hand, rippled sands (Sr) are extremely fine grained/coarse silt, moderately well to poorly sorted, near symmetrical to strongly fine skewed and platykurtic to very leptokurtic nature. Massive sands (Sm) are classified as medium to fine grained, moderate well sorted, near symmetrical to strongly fine skewed and mesokurtic to very leptokurtic.

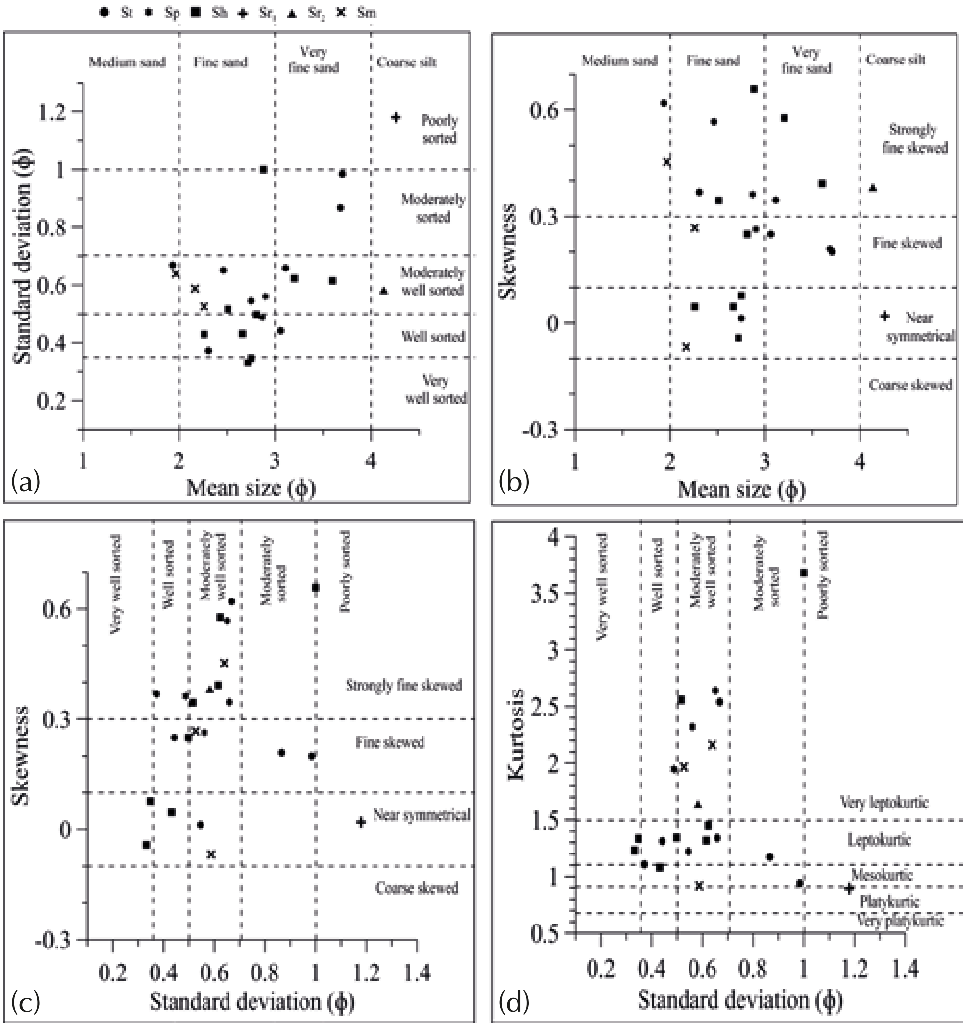


Fig. 3. Scatter plots of: (a) mean vs. standard deviation; (b) mean vs. skewness; (c) skewness vs. standard deviation; and (d) kurtosis vs. standard deviation.

Heavy mineral concentrations

The average concentration of heavy minerals in the exposed bar sands of lower Jamuna River is ~6.25%. The sands are characterized by higher concentration of epidote (31.4%), followed by amphibole (17.9%), tourmaline (12.3%), opaque (9.8%), garnet (8.6%), pyroxene (5.0%), apatite (3.5%), zircon (2.7%), sillimanite (2.7%) and kyanite (2.7%). Staurolite (1.6%), rutile (0.6%), andalusite (0.5%), sphene (0.2%) and monazite (0.1%) are present as minor constituents (Abeden, 2016). Some representative photomicrographs of heavy minerals are shown in Fig. 4. The facies-wise distribution of heavy mineral concentrations is displayed in Fig. 5.

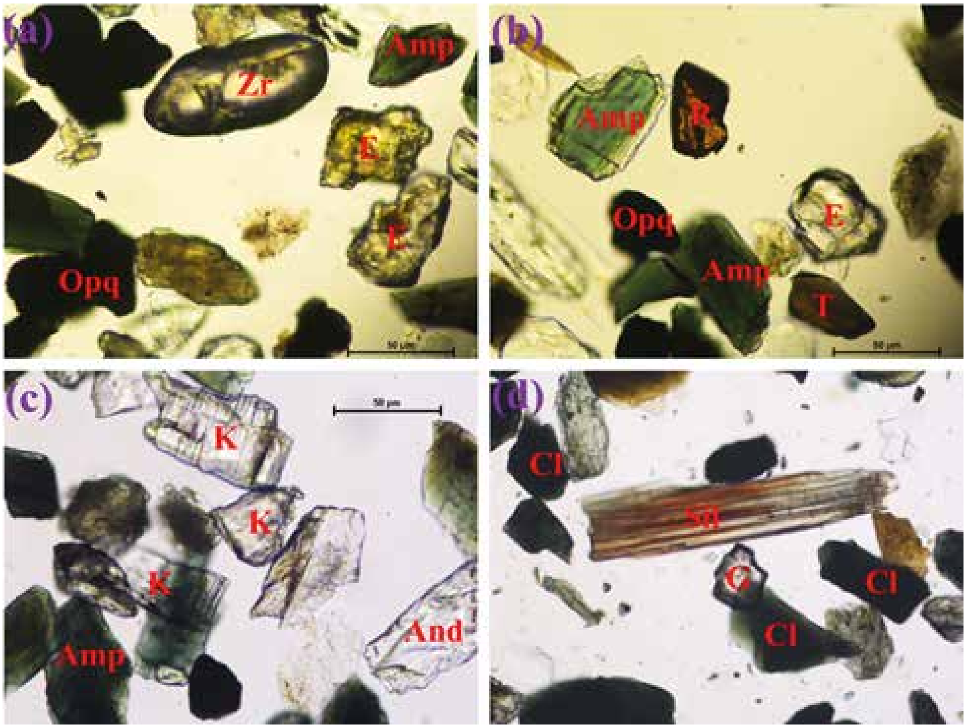
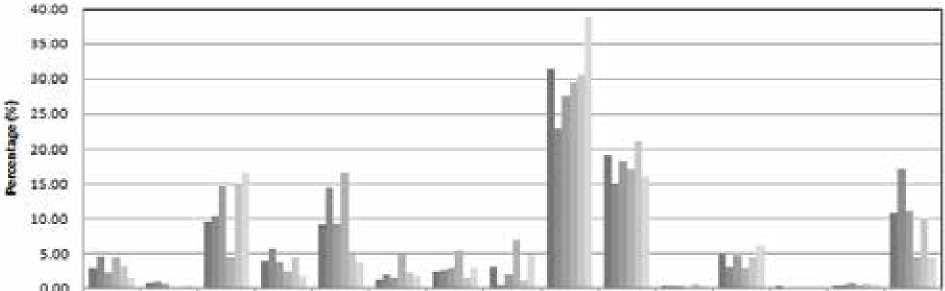


Fig. 4. Photomicrographs of characteristic heavy minerals of bar sands exposed at the lower Jamuna River: (a-b) parallel laminated sand facies (Sh); (c) large scale trough cross-bedded sand facies (St); (d) massive sands facies (Sm). [Zr = zircon, T = tourmaline , E = Epidote, Amp = amphibole, G = garnet, K = kyanite, R = rutile, Sil = sillimanite, Cl = chlorite, And = andalusite, Opq = opaque].

Among all types of sedimentary facies, epidote shows highest concentration in Sm (~39%) and lowest in Sp (~23%). Highest concentration of amphiboles is present in Sr_2 (~21%) and lowest in Sp (~15%). Opaque mineral shows higher concentration in Sp (~17) and lowest in Sm (~4%). The concentration of garnet in St, Sp, Sh and Sr_2 are 9.1%, 14.5%, 9.3% and 16.5%, respectively, with low concentration in the other facies. The concentration of zircon ranges from 1.5% to 2.5% in Sm and Sh facies, whereas it varies from 2.5% to 4.6% in the other facies. The concentration of tourmaline is higher in all facies (9.5% to 16.5%) except in Sr_1 facies (4.5%).The concentrations of other heavy minerals including rutile, sphene and monazite are very low in all types of facies.

Geochemical characteristics

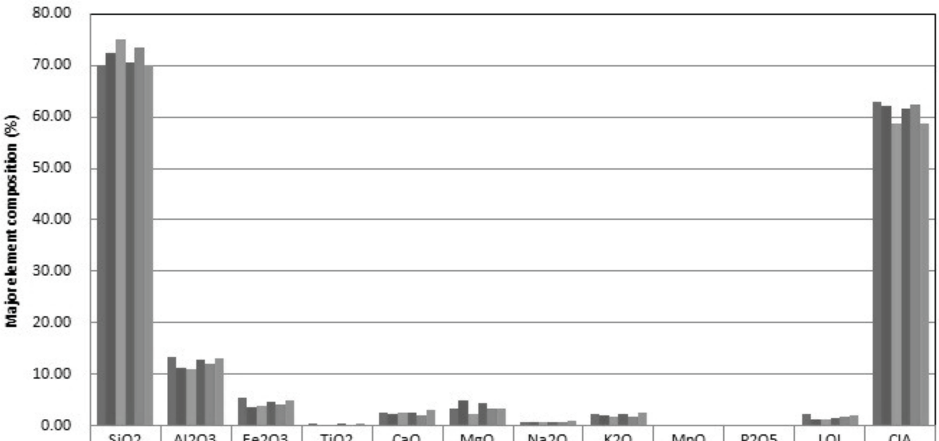
The major element concentrations of lower Jamuna River bar sands are shown in Fig. 6. All the facies are dominated by the presence of SiO_2 (69.99% to 75.05%). Al_2O_3 exhibits highest occurrence in St facies (13.18%) and lowest in Sh (11.02%). The facies are also characterized by relatively higher concentrations of Fe_2O_3 (3.70% in Sp to 5.28% in St), K_2O (2% Sr_2 to 2.38% in Sm) and CaO (2.24% in Sr_2 to 3.08%



	Zr	R	T	Apa	G	St	K	Sil	E	Amp	Sp	Pyr	Monz	And	Opq
St	2.89	0.72	9.54	3.89	9.14	1.29	2.46	3.09	31.37	19.05	0.22	5.12	0.24	0.22	10.78
Sp	4.57	0.97	10.34	5.74	14.45	1.93	2.66	0.48	22.83	15.11	0.24	3.12	0.00	0.48	17.10
Sh	2.34	0.68	14.65	3.84	9.22	1.68	2.92	1.95	27.60	18.19	0.34	4.71	0.14	0.69	11.04
Sr1	4.50	0.00	4.50	2.50	16.50	5.00	5.50	7.00	29.50	17.00	0.00	3.00	0.00	0.50	4.50
Sr2	3.33	0.00	15.00	4.44	5.00	2.22	1.67	1.11	30.56	21.11	0.56	4.44	0.00	0.56	10.00
Sm	1.52	0.23	16.51	1.76	3.83	1.75	3.01	4.98	39.01	16.12	0.23	6.06	0.12	0.45	4.44

Fig. 5. Facies-wise heavy mineral distribution of bar sands exposed at the lower Jamuna River, Bengal Basin, Bangladesh.

in Sm). These analyses were consistent with the presence of heavy aluminosilicate mineral phases such as amphiboles, garnet and epidote (Fig. 5).The other elements occur as minor amount. The CIA values (Fig. 6) ranges from 58.52% in Sm facies to 62.86% in St facies.



	SiO2	Al2O3	Fe2O3	TiO2	CaO	MgO	Na2O	K2O	MnO	P2O5	LOI	CIA
St	69.99	13.18	5.28	0.29	2.38	3.30	0.73	2.32	0.10	0.10	2.20	62.86
Sp	72.45	11.36	3.70	0.28	2.52	5.20	0.77	2.09	0.12	0.09	1.30	62.16
Sh	75.05	11.02	4.01	0.22	2.63	2.56	0.77	2.03	0.10	0.09	1.36	58.83
Sr1	70.45	12.83	4.69	0.30	2.50	4.40	0.74	2.34	0.13	0.10	1.40	61.42
Sr2	73.52	12.13	4.22	0.32	2.24	3.44	0.79	2.00	0.12	0.08	1.80	62.28
Sm	70.05	13.00	4.81	0.40	3.08	3.20	0.79	2.38	0.12	0.11	2.00	58.52

Fig. 6. Facies-wise major element concentrations of bar sands exposed at the lower Jamuna River, Bengal Basin, Bangladesh.

Discussion

Depositional environment

The characteristic features of the depositional facies suggest a fluvial bar deposits. Large-scale trough (St) and low-angle planar (Sp) cross-stratified sands are deposited due to migration of 3D/2D sandy dunes (lower flow regime) and/or migration of sandy bar forms (TODD, 1996; CAIN & MOUNTNEY, 2009). The medium to fine-grained and trough cross and low-angle planar cross-strata with erosional surfaces suggests the sediments of facies St and Sp were deposited by fluvial channel. The textural behavior like mean size, moderately to well sorting, positive skewness support a river–link deposit (FREIDMANN, 1979) (Fig. 3c). The positive skewness also indicates deposition with high energy condition. The mesokurtic to very leptokurtic nature (Fig. 3a) suggest continuous addition of coarser or finer materials after the winnowing action and retention of their original character during deposition (AVRAMIDIS *et al.* 2013).

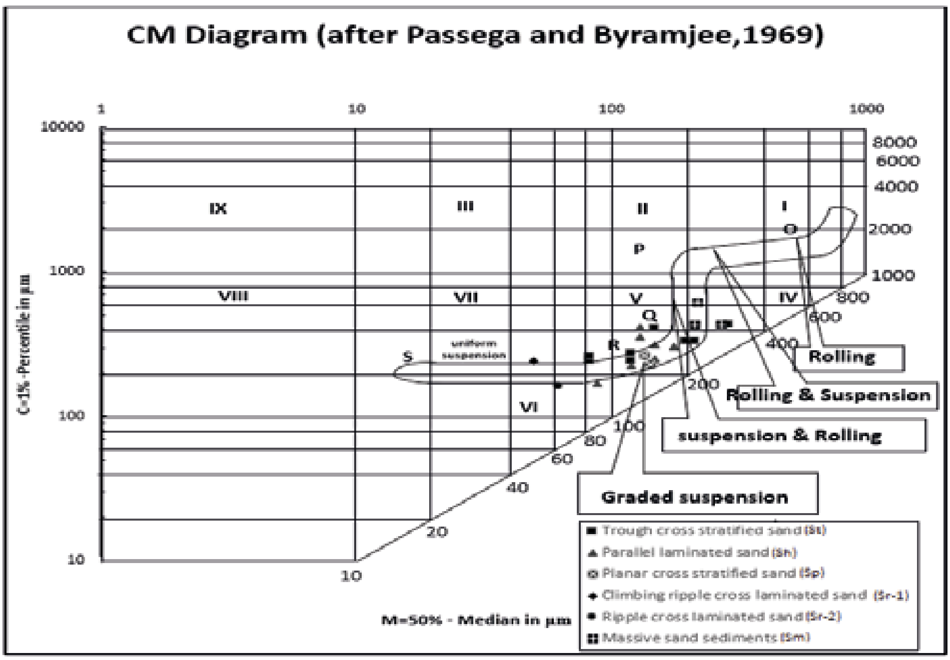


Fig. 7. CM plot of the lower Jamuna River sands (fields are after PASSEGA & BYRAMJEE, 1969).

Parallel laminated facies (Sh) suggest downstream migration of ripples within shallow, low energy fluvial channel (EBINGHAUS *et al.* 2017). The textural behavior of fine to very fine grained, moderate to very well sorting supports a river–link deposit for Sh. Both positive and negative skewness and mesokurtic to very leptokurtic nature suggest fluctuations of energy level during deposition. The ripple structured facies (Sr_1 and Sr_2) imply migration of 2D or 3D ripples within the lower flow regime (MIALL, 1977) and rapid deposition from suspension. Fine to very fine-grained, moderately sorting and platykurtic to very leptokurtic nature suggest continuous addition of finer materials under suspension. Massive sandy facies indicates rapid deposition and flocculation of fine sands, silts and clays and/or bioturbation activity. The CM plot (Fig. 7) of the lower Jamuna River sands represents all the lithofacies were mainly deposited from suspension with minor rolling and graded suspension settings.

Provenance inferred from heavy mineral composition

A broad range of metamorphic source rocks is reflected from the characteristic heavy mineral assemblages as deduced from amphibole, epidote, garnet, staurolite, and kyanite. Epidote and green hornblende may be related to mafic ophiolite sequences. The ophiolite rocks are believed to be associated with suture belt. The traces of green amphibole suggests unroofing of arc and ophiolite rocks. The low grade metamorphic series of the source area is indicated by the occurrence of epidote. Mafic rocks may be indicated by the abundance of various aluminous silicates and epidote minerals indicate orogenic input from low to high grade metamorphic rocks in the orogenic belt.

The presence of garnet and staurolite suggest mica schist complexes and related metamorphic rocks. The presence of apatite is believed to have been derived from biotite rich source rocks (Faupl *et al.* 1998). Based on petrological data of metamorphic and granitic rocks from the Higher Himalaya, garnet is a common mineral in both the biotite-schists and gneisses (Yokoyama *et al.* 1990). The Lesser Himalayan crystalline basement is built up of low chlorite to medium (biotite + garnet + kyanite + staurolite) grade terrains. Kyanite is a typical marker of the Higher Himalayan crystalline but it also found locally in Lesser Himalaya (Pecher 1989). Silimanite crystallizes in high temperature metamorphic rocks and also presents in granulite facies rocks (Mange & Maurer 1992).

River draining in Lhasa block carry blue green hornblende, zircon, epidote and garnet (Garzanti *et al.* 2004). The Tsangpo and south of Lhasa is enriched in blue green hornblende from arc batholiths. Largely green brown hornblende, garnet and sillimanite were derived from high grade, high relief, northern part of the Greater Himalaya by Bhutan and Sikkim Mountain Rivers. The Kuru River sourced in the Tethyan zone carries garnet, staurolite from amphibolite-facies metasediments (Garzanti *et al.* 2004). Lower amphibolite facies of the Lesser Himalayan rocks in the footwall of the main central thrust shed blue green amphibole and garnet. Metasedimentary Klippen shed dominated by epidote assemblages including blue green amphibole, garnet and staurolite. Garnet, staurolite and kyanite recycled from sub Himalayan molasses are associated with ultra-stables (ZTR), garnet and staurolite in accreted turbidites of Indo-Burman ranges. Blue green to green brown hornblendes were also derived from Shillong Plateau. The Kopili River flowing between the Mikir hills and Shillong Plateau carries dominant zircon and other ultrastables (Garzanti *et al.* 2004). Triangular plots of heavy mineral suites (Fig. 8) show the lower Jamuna River sands were influenced by mixed sources, mainly Inner Lesser Himalayan tributaries, with the influence of Lhasa Block and Indo Burma Ranges.

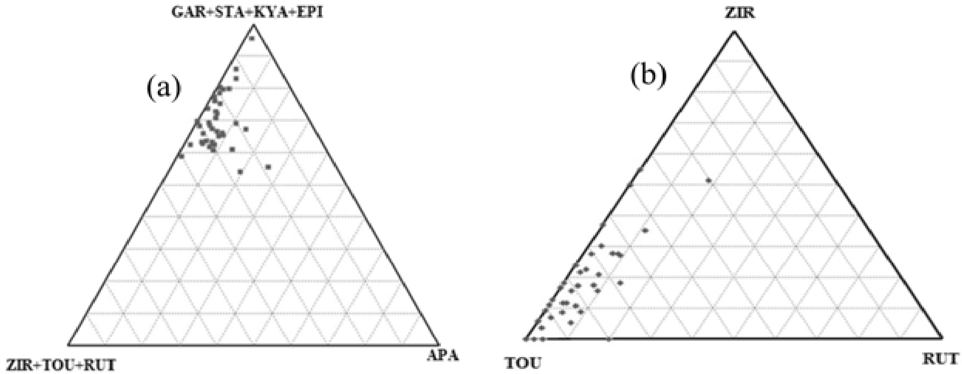


Fig. 8. Triangular plot of: (a)(GAR+STA+KYA+EPI)-(ZIR+ TOU+RUT)-APA and (b) ZIR-TOU-RUT (ZTR index) of the lower Jamuna River sands. (Here, ZIR- Zircon, TOU-Tourmaline, RUT-Rutile. GAR-Garnet, EPI-Epidote, STA-Staurolite, KYA- Kyanite, APA-Apatite).

From the heavy mineral concentration study of the lower Jamuna river sands it can be postulated that there are several types of source rock complexes that exist in the specific source area. These are: Lhasa Block, south of Lhasa Block, from arc batholiths, Mid Crustal rocks exposed in the eastern Himalayan syntaxes, high-grade, high-relief northern part of the Greater Himalaya, the Tethyan Zone, lower amphibole-facies Lesser Himalayan rocks in the footwall of the Main Central Thrust, sub-Himalayan molasses, Shilong Plateau and the Mikir Hills.

Conclusions

A detailed field work has been carried out along the lower reaches of the Jamuna River sand deposits. Lower Jamuna River sands are characterized by six prominent facies. These are: large-scale trough cross-stratified sands (St), planar to low-angle cross-stratified sands (Sp), parallel laminated sands (Sh), climbing ripple laminated (Sr_1), ripple cross-laminated (Sr_2) and massive sands (Sm). Facies St, Sp and Sm are generally medium to fine grained, whereas Sh and Sr facies are fine to very fine grained in size. The textural behaviors of the sandy facies support a river–link deposit. The nature of the lower Jamuna River lithofacies suggests sediments were deposited in fluvial channel bars.

In lower Jamuna River, the average heavy mineral concentration is around ~6.25%, where the concentration of epidote (~31.4%), amphibole (~17.9%), tourmaline (12.3%), garnet (8.6%), pyroxene (5.0%), apatite (3.5%), zircon (~2.7%), silimanite (~2.7%), kyanite (~2.7%) and staurolite (~1.6%) are occurred as significant amount. Facies St, Sp, Sh and Sr_2 show higher abundance of garnet and opaque minerals. All the lithofacies are dominated by the presence of SiO_2 and Al_2O_3 which indicate a high proportion of quartz and/or aluminosilicates. The sands are also revealed relatively higher concentration of Fe_2O_3 (3.70%-5.28%) which is in accordance with the presence of heavy aluminosilicate mineral phases such as amphiboles, garnet and epidote. The provenance study of the lower Jamuna river sands postulated several types of source rock complexes were including Lhasa Block, eastern Himalayan syntaxes, northern part of the Greater Himalaya, the Tethyan Zone, Lesser Himalayan, Main Central Thrust, sub-Himalayan molasses, Shilong Plateau and the Mikir Hills.

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বাংলাদেশের যমুনা নদীর নিম্ন অববাহিকায় সঞ্চিত বালিতে ভারী মনিকের বিস্তৃতি

মো: জয়নাল আবেদীন, এম. জুল্লে জালালুর রহমান,
আবু সাদাত মো: সায়েম ও রাশেদ আব্দুল্লাহ্

সারসংক্ষেপ

বর্তমান গবেষণায় যমুনা নদীর নিম্ন অববাহিকায় সঞ্চিত বালিতে ভারী মনিকের সমারোহ ও ধরণ সম্পর্কে আলোচনা করা হয়েছে। সঞ্চিত বালি স্তরসমূহে বৃহদায়তন আড়াআড়ি স্তরিত ফেসিস, সমান্তরাল হতে স্বল্পকৌনিক আড়াআড়ি স্তরিত ফেসিস, সমান্তরাল স্তরিত ফেসিস, আরোহিত ক্ষুদ্রতরঙ্গ ও ক্ষুদ্রতরঙ্গ স্তরিত ফেসিস এবং নির্দিষ্ট স্তরহীন ফেসিস বৈশিষ্ট্য দ্বারা চিহ্নিত করা হয়। বৃহদায়তন আড়াআড়ি স্তরিত ফেসিস, সমান্তরাল হতে স্বল্পকৌনিক আড়াআড়ি স্তরিত ফেসিস এবং নির্দিষ্ট স্তরহীন ফেসিসগুলির কণার আকার সাধারণত মাঝারি থেকে ক্ষুদ্রাকৃতির, পক্ষান্তরে স্বল্পকৌনিক আড়াআড়ি স্তরিত ফেসিস ও সমান্তরাল স্তরিত ফেসিস এবং ক্ষুদ্রতরঙ্গ স্তরিত ফেসিসগুলির আকার ক্ষুদ্র থেকে অতি ক্ষুদ্রাকৃতির। যমুনা নদীর নিম্ন অববাহিকায় সঞ্চিত বালিতে ভারী মনিকের গড় পরিমান প্রায় ৬.২৫%, যেখানে এপিডোট (৩১.৪%), অ্যাম্ফিবল (১৭.৯%), টুরমালিন (১২.৩%), অস্বচ্ছ খনিজ (৯.৮%), গারনেট (৮.৬%), পাইরক্সিন (৫%), অ্যাপাটাইট (৩.৫%), জিরকন (২.৭%), সিলিমেনাইট (২.৭%), কায়ানাইট (২.৭%), স্টেরোলাইট (১.৬%), রিউটাইল (০.৬%), এন্ডেলুসাইট (০.৫%), স্ফিন (০.২%) এবং মোনাজাইট (০.১%) চিহ্নিত করা হয়েছে। স্থায়ী ভারী মনিক, যেমন জিরকন, টুরমালিন এবং রিউটাইলের পরিমান প্রায় ১৫.৬%। আড়াআড়ি, সমান্তরাল এবং ক্ষুদ্রতরঙ্গায়িত ফেসিসসমূহে গারনেট ও অস্বচ্ছ খনিজের আধিক্য দেখা যায়। সকল লিথোফেসিসে সিলিকন ডাই অক্সাইড (৬৮.৭৫%-৭৬.৪১%) ও অ্যালুমিনিয়াম অক্সাইডের (১০.২৩%-১৩.৩৫%) আধিক্য কোয়ার্টজ এবং/অথবা অ্যালুমিনোসিলিকেটের উচ্চ অনুপাতকে নির্দেশ করে। যমুনা নদীতে সঞ্চিত বালিসমূহ তুলনামূলক অধিক আয়রন অক্সাইড (৩.০৫%-৫.৮৬%) দ্বারা চিহ্নিত, যা ভারী অ্যালুমিনোসিলিকেট মনিক যেমন অ্যাম্ফিবল, গারনেট ও এপিডোট এর উপস্থিতির সঙ্গে সামঞ্জস্যপূর্ণ।