European Geosciences Union General Assembly 2017
Vienna | Austria | 23–28 April 2017

Late Holocene depositional variability and provenance in the lower Ganges-Brahmaputra delta

Rory P. Flood[1,2,*], Iestyn D. Barr[2], G.J. Weltje[3], Sam Roberson[4], Mark I. Russell[2], John D. Meneely[2], Julian D. Orford[2]

(1) School of Natural Sciences, Trinity College Dublin, Ireland, (2) School of Natural and Built Environment, Queen's University Belfast, Northern Ireland, UK, (3) Department of Earth and Environmental Sciences, Geology Division, University of Leuven, Belgium, (4) Geological Survey of Northern Ireland, UK, (*) Present address: Department of Geography, Edge Hill University, UK. Email address: floodrp@tcd.ie

Abstract

The Sundarbans is one of the largest coastal wetland sites in the world, extending over an area of approximately one million hectares of the western delta of the Ganges and Brahmaputra (G-B) rivers. The western delta has not been directly fluvially sourced, due to the eastward shift of the Ganges. This western extent of the delta is considered abandoned with sediments derived from dominant estuary-tidal dynamics, with sediment source unknown. In this study, sediment cores from the Indian Sundarbans were examined for grain-size distributions (GSDs), mineralogy through X-ray diffraction (XRD), and geochemistry with X-ray fluorescence (XRF). Chemical weathering, transport, and hydrodynamic sorting processes all affect the internal facies composition. The West Bengal Sundarbans has been examined extensively and found to reveal intensively weathered, terrestrial sediment derived from the Ganges River. There is a predominance of quartz and mica with clay minerals, with quartz interpreted as G-B Rivers draining the Himalayas during low-relief tropical weathering. Kaolinite formation is derived from feldspar and muscovite mica with kaolinite the product of intense chemical weathering. Lithofacies through GSDs are indicative of a muddy tidal flat environment with aggradation and fining-up in sizes. Mineralogy and geochemistry has revealed that the thin mud facies (TMF) in the late Holocene is still considerably influenced by regional sedimentary provenance of the Ganges River.

Background

- The Indian Sundarbans comprise of c. 400,000 hectares of mangrove land cover in the western sector of the G-B delta, cross-cut by a number of approximately north-south estuarine channels; Mooriganga, Saptamukhi, Thakuran, Matla, Bidya, Gosaba, and Haribhanga (Fig. 1).
- This western part of the delta was fluvially abandoned prior to c. 5k cal yr BP, as the Ganges River migrated eastward towards its present position [1]. Over the last 4k yrs, the West Bengal Sundarbans area is considered to be dominated by estuary-tidal processes, leading to the deposition of the "Thin Mud Facies" (TMF: [1]).
- TMF represents the cap unit of coarser underlying facies units throughout the Bengal Basin and is a record of floodplain deposition for c. 5000 cal yr BP to present [1].

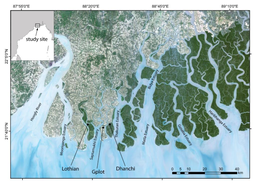

Fig. 1 Sundarbans and G-B delta

Methodology

- Coring was carried out using a motor driven percussion coring device in November 2010.
- 202 samples were collected from the three cores (Lothian, n=83, Gplot, n=46, and Dhanchi, n=73). Samples were divided into three groups for laboratory analysis (i.e., laser granulometry, XRD, and XRF).
- Grain size distributions (GSDs) were analyzed following [2] and [3], using a MalvernMastersizer 2000 instrument. Data were aggregated into quarter phi intervals (φ scale) over the range of 0.02 – 2000 µm, followed by multivariate data analysis [cf. 2,3].
- X-ray powder diffraction (XRPD) was performed using a 3 kW PANalytical X'pert Pro Powder Diffractometer (Almelo, The Netherlands) θ/θ goniometer with a CuKα1 electrode producing monochromatic radiation (λ = 1.54060 Å, 40 kV, 40 mA) between 3 and 63°2θ with a step size of 0.02° using an X'Celerator multichannel detector.
- Qualitative and quantitative analyses of XRD data was performed using the X'Pert HighScore Plus software with mineral identification performed with the JCPDS PDF-2 database from the International Centre for Diffraction Data® [4].
- ED-XRF was undertaken using a Bruker S1 TURBO SD portable X-ray fluorescence (PXRF) spectrometer (Bruker Corporation, Massachusetts, USA) consisting of a 10 mm X-Flash® SDD Peltier-cooled detector with a 4-W X-ray tube with an Ag target and a maximum voltage of 40 kV.
- The 10 elements that are generally listed as oxides in the major element chemical analysis, Al, Si, Ti, Fe, Mn, Mg, Ca, Na, K and P were determined in all samples. Trace elements Ba, V, Cr, Co, Ni, Cu, Zn, Rb, and Zr were also analysed.
- Maturity of sediments carried out following published approaches [5], [6].
- Chemical Index of Alteration (CIA) was carried out following [7], [8], [9].
- Element enrichment ratios and percentage change with respect to Al_2O_3 and TiO_2 was carried out following [10].
- Ternary diagrams of major element geochemistry and CIA [10].

Results

The results from the laser granulometry, XRD, and XRF are shown in Fig. 2–7.

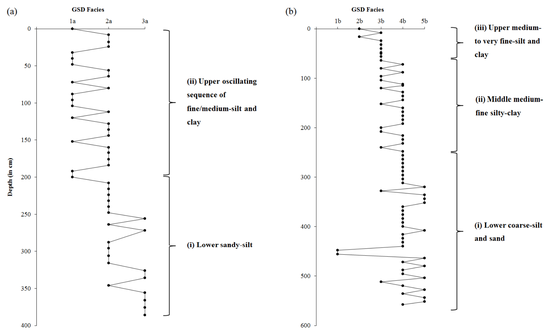

Fig. 2 Vertical disposition broad stratigraphical facies of the TMF of the Gplot Island (a) and Dhanchi Island (b) cores

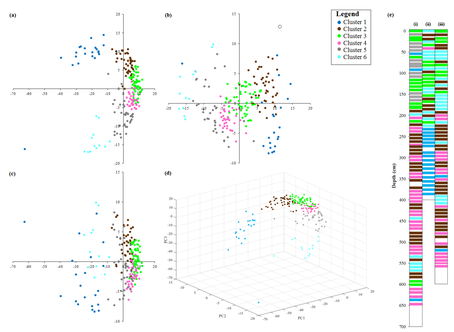

Fig. 3 (a) biplot of the first and second principal components, (b) biplot of the second and third principal components, (c) biplot of the first and third principal components, (d) triplot of the first, second, and third principal components, (e) distribution of XRD cluster groups throughout the cores, with Lothian Island (i), Gplot Island (ii), and Dhanchi Island (iii)

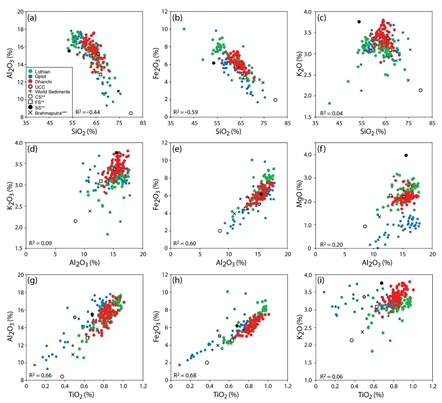

Fig. 4 Variation diagrams of major elements in West Bengal Sundarbans sediments, data are plotted against Al_2O_3, SiO_2 and TiO_2. For reference, UCC and World Sediments were also plotted as grey circle and cross, respectively, with **average data points from [10], ***average data points from [15]

Discussion

Dhanchi Island GSDs are interpreted as muddy tidal flat environments (cf. [11], [12], [3]). Dominance of silt and clay suggest a muddy depositional environment (e.g., Fig. 2). Mineralogy from the West Bengal Sundarbans reveals variability between the islands. Terrigenous minerals are abundant in the all cores, principally quartz, feldspars, and muscovite mica. Quartz in these sediments reflects detrital deposition of weather-resistant sediment. Increased erosion and sorting, the ratio of feldspar to quartz is diminished in sand composition with higher proportion of quartz indicative of coarse grain-size sediments [9].

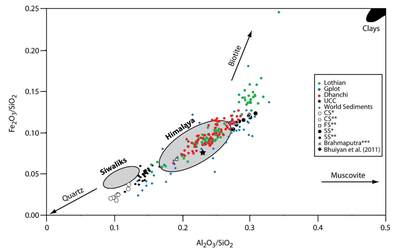

Fig. 5 Al_2O_3/SiO_2 versus Fe_2O_3/SiO_2 for river sediments of the West Bengal Sundarbans, Ganga alluvial plain, Siwaliks and the Himalayan sources, and data from [10] and [15]. Lower and higher ratios are indicative of the quartz dominance moving towards enrichment of phyllosilicates, respectively. Linear trend in mineralogical sorting is indicative of transportation. Gray ellipses indicate composition of source area: the Himalaya and the Siwaliks [16]. Star corresponds to average UCC [17]. *Data points from [10], **average data points from [10], ***average data points from [15]

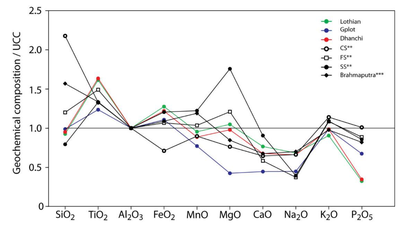

Fig. 6 Element ratio of West Bengal Sundarbans sediments calculated from average major element concentrations normalised to UCC [17] with respect to Al_2O_3. **Average data points from [10], ***average data points from [15]

The geochemistry of the Holocene sediment from the West Bengal Sundarbans can be described as intensively weathered, terrestrial sediment derived from the Ganges River, principally the Ganges Alluvial Plain (GAP). Sediments of the TMF are derived from the weathering and transport of Himalayan derived sediments, with geochemical data supporting the two stage weathering model proposed by [10], with initial weathering in the Himalaya and subsequent weathering under a humid sub-tropical climate [10]. Illite-smectite variability was not found in this study, several aspects of the geochemical data validate both the source and processes in the TMF of the West Bengal Sundarbans. Enrichment ratios found illustrate dissolution during chemical weathering, whereby SiO_2, Na_2O, and K_2O depletion may be attributed to the dissolution of feldspars [10]. Increased distance from sediment source, coupled with increased weathering, indicate depletion of SiO_2 and K_2O in sediments. Inter-element relationships found in the major element geochemistry show a generally negative trend with SiO_2, indicating a grain-size control on the geochemistry of weathering products [10]. Titanium and Fe_2O_3 were attributed to enrichment of heavy minerals in sediments and a common source of ferromagnesium minerals. Correlation for TiO_2 with Al_2O_3 and K_2O indicates that Ti was derived from mica in fluvial sediments [10]. Correlation for K_2O was poor (R^2 = 0.06), with correlation of Al_2O_3 relatively strong (R^2 = 0.66). Poor correlation with K_2O may be attributed to the substitution effect of K with Rb [13]. A–CN–K ternary diagram and CIA reveal a trend of increasing weathering throughout sediments. Progressive chemical weathering, an increase in clay mineral composition is found with a concomitant decrease in feldspars and other minerals [10]. The Sundarbans sediments follow a predicted weathering trend along the A–CN apex of the ternary diagram. A–CN–K ternary diagram shows higher intensity chemical weathering, with increased weathering of fine-grained material (winnowing effect of Fe-oxyhdroxides and biotite) [10]. The S/10–CM–NK ternary diagram show that data plot parallel to the S/10–CM apex, indicative of Na and K mobility during weathering [10]. The proximity of Sundarbans samples to Na and K illustrates the higher degree of weathering (cf. [10]).

Conclusion

The Holocene sediments of the Ganges-Brahmaputra delta have been examined and found to reveal intensively weathered, terrestrial sediment derived from the Ganges River, principally the GAP. This study presents a first-order approximation of lithofacies and geochemistry of the TMF on the lower Ganges–Brahmaputra delta and demonstrates that:

1. Geochemical data enhances the weathering model proposed by [10], with sediments of the TMF having undergone at least two cycles of weathering.
2. Mineralogy of the cores collected shows a predominance of quartz and mica with clay minerals. Quartz supply is interpreted as indicative of G-B Rivers draining the Himalayas with low-relief tropical weathering.
3. Kaolinite formation is derived from feldspar and muscovite mica with kaolinite the product of intense chemical weathering.
4. Dhanchi and Lothian Island lithofacies are considered to be muddy tidal flats with Gplot Island indicating an intertidal to shallow subtidal environment with possible channel-mouth and channel-side bar deposits.
5. Geochemical, mineralogical and lithofacies composition of the TMF suggest it is locally heterogeneous with sediment derived from the Ganges and deposited tidally in a low-energy system following existing models [10], [14].

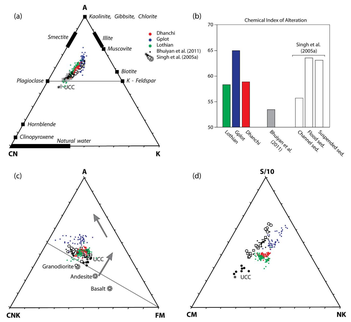

Fig. 7 (a) A–CN–K ternary diagram of molecular proportions showing sediment suites from the West Bengal Sundarbans. A = Al_2O_3; C = CaO; N = Na_2O and K = K_2O. Also plotted is the UCC [17] in a grey cross, along with idealised mineral compositions. Shown are the predicted weathering trends exhibited by the Ganga alluvial plain with arrows, which had experienced incipient to moderate chemical weathering. (b) Bar plot of average Chemical Index of Alteration values of the West Bengal Sundarbans sediments along with [10] and [15] for comparative purposes. (c) A–CNK–FM and (d) S/10–CM–NK ternary diagrams showing sediment suites from the West Bengal Sundarbans. A = Al_2O_3; C = CaO; N = Na_2O; K = K_2O; F = Total Fe; M = MgO; S = SiO_2.

References

[1] Goodbred Jr., S.L., Kuehl, S.A., 2000b. The significance of large sediment supply, active tectonism and eustasy on margin sequence development: Late Quaternary stratigraphy and evolution of the Ganges-Brahmaputra delta. Sedimentary Geology 133, 227–248.
[2] Flood, R.P., Bloemsma, M.R., Weltje, G.J., Barr, I.D., O'Rourke, S.M., Turner, J.N. Orford, J.D., 2016. Compositional data analysis of Holocene sediments from the West Bengal Sundarbans, India: Geochemical proxies for grain-size variability in a delta environment. Applied Geochemistry 75, 222–235.
[3] Flood, R.P., Orford, J.D., McKinley, J.M., Roberson, S., 2015. Effective grain size distribution analysis for interpretation of tidal–deltaic facies: West Bengal Sundarbans. Sedimentary Geology 318, 58–74.
[4] ICDD, 2002. International Centre for Diffraction Data. Mineral Powder diffraction file data book. (941 p.).
[5] Pettijohn, F., Potter, P., Siever, R., 1972. Sand and Sandstone: New York, Springer-Verlag, 618 p.
[6] Herron, M.M., 1986. Geochemical classification of terrigeneous sands and shales from core or log data. Journal of Sedimentary Petrology, 58, 820–829.
[7] Nesbitt, H.W., Young, G.M., 1989. Formation and diagenesis of weathering profiles. The Journal of Geology, 129–147.
[8] Nesbitt, H.W., Young, G.M., 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. Nature, 299, 715–717.
[9] Nesbitt, H.W., Young, G.M., McLennan, S.M., Keays, R.R., 1996. Effects of chemical weathering and sorting on the petrogenesis of siliciclastic sediments, with implications for provenance studies. The Journal of Geology, 525–542.
[10] Singh, M., Sharma, M. and Tobschall, H.J., 2005a. Weathering of the Ganga alluvial plain, northern India: implications from fluvial geochemistry of the Gomati River. Applied Geochemistry, 20, 1–21.
[11] Allison, M.A., Khan, S.R., Goodbred Jr., S.L., Kuehl, S.A., 2003. Stratigraphic evolution of the late Holocene Ganges-Brahmaputra lower delta plain. Sedimentary Geology 155, 317–342.
[12] Goodbred, S.L., Saito, Y., 2011. Tide-dominated Deltas. In: Davis, R. Dalyrymple, R.W. (Eds.) Principles of Tidal Sedimentology. Springer, New York, pp. 129–149.
[13] El-Makky, A.M., Sediek, K.N., 2012. Stream sediments geochemical exploration in the northwestern part of Wadi Allaqi Area, South Eastern Desert, Egypt. Natural resources research, 21, 95–115.
[14] Rogers, K.G., Goodbred Jr., S.L., Mondal, D.R., 2013. Monsoon sedimentation on the 'abandoned' tide-influenced Ganges-Brahmaputra delta plain. Estuarine, Coastal and Shelf Science 131, 297–309.
[15] Bhuiyan, M.A.H., Rahman, M.J.J., Dampare, S.B., Suzuki, S., 2011. Provenance, tectonics and source weathering of modern fluvial sediments of the Brahmaputra–Jamuna River, Bangladesh: inference from geochemistry. Journal of Geochemical Exploration, 111, 113–137.
[16] Galy, A. and France-Lanord, C., 2001. Higher erosion rates in the Himalaya: Geochemical constraints on riverine fluxes. Geology, 29, 23–26.
[17] Taylor, S.R. and McLennan, S.M., 1985. The continental crust: its composition and evolution. Oxford, Blackwell, London.

Acknowledgements

RPF acknowledges the support provided by a Department for Employment and Learning (Northern Ireland) research studentship and the Department of Education and Science's Higher Education Grant Scheme (ROI) via Laois County Council (ROI). RPF also acknowledges the School of Natural and Built Environment (Formerly the School of Geography, Archaeology and Palaeoecology), Queen's University, Belfast (QUB) for the fieldwork support provided by their Soulby Research Fund. RPF acknowledges the assistance and technical support provided by Paul O'Meara (PANanalytical B.V.), Mike Dobby (MikeDobby Analytical Consultant), and Pat McBride (QUB), for their help and assistance with XRD, XRF, and laser granulometry, respectively. RPF and JDO would like to acknowledge the support and assistance of Vincent van Walt and Van Walt Environmental Ltd., in the core extraction, while logistical support in the Sundarbans provided through the Institute of Environmental Studies & Wetland Management (IESWM), Kolkata, West Bengal, India (S. Battachariyya and K. Sen Sarma) is gratefully acknowledged. RPF acknowledges the financial support and assistance for conference attendance provided by Edge Hill University (EHU), and support provided by Irene Delgado-Fernandez and Nigel Richardson (EHU).