Journal of Indian Geomorphology
Volume 8, 2020 ● ISSN 2320-0731
Indian Institute of Geomorphologists (IGI)

Reconstruction of the Depositional Milieu during Pleistocene-Holocene Transition: A Preliminary Study at Eastern Subarnarekha Coastal Region Based on Borehole Samples

Pritam Kumar Santra[1], Abhijit Chakraborty[2] and Sunando Bandyopadhyay[1]
[1]*Department of Geography, University of Calcutta, Kolkata 700019*
[2]*Department of Geology, Jogamaya Devi College, Kolkata 700026*
E-mail: santrapritam11@gmail.com (Corresponding author)

Abstract: *Facies characterisation and granulometric studies on 28 borehole sediment samples retrieved from a 56m sediment succession at Eastern Subarnarekha Coastal Region (ESCR) indicates a reversal in the paleo-depositional milieu at a depth of 30 m below ground level (bgl). Multiple gravel beds alternating with occasional coarse sand interlayer in the basal part of the section are interpreted as fluvial deposits. The upper sandy intervals are undeniably marine with some aeolian inputs in the topmost intervals as interpreted from their grain size distribution and preserved marine shells in the former. An unconformity is predicted from the observed depositional hiatus at 30 m (bgl) at ESCR. This lithological break appears to mark the transition between end Pleistocene fluvial deposition followed by early Holocene marine deposition at ESCR as evident from age data reported for the similar facies transition in the region.*

Keywords: *Pleistocene-Holocene boundary, granulometry, borehole data, depositional environment.*

Introduction

Eastern Subarnarekha Coastal Region (ESCR) extending from Subarnarekha river in the west to the Rasulpur river in the east (Fig. 1), lies on the continental shelf of Indian plate, between Basin Margin Fault and Eocene hinge zone (Nandy, 2001; Bandyopadhyay, 2007; Hossain *et al.*, 2020). Tidal inlet and estuaries divide ESCR into five sectors, from west to east they are; Talsari, Digha, Chandpur, Dadanpatra and Junput (Bandyopadhyay *et al.*, 2009). The present study area at Talsari sector covers beach ridges and swales, barrier bars and spits, coastal dunes and deltaic flat (Niyogi, 1968).

Seven palaeo-strandline demarcates six stages of shoreline development in this region (Niyogi, 1968), which is also clear from the alternate formation of beach ridges and offshore bars in Talsari sector (Niyogi, 1970). Sub-parallel ridges of sand dunes with intervening mud flats, commonly known as chenier plains in this mesotidal (2–4m) region develop due to punctuations of the Holocene sea regressions (Chakrabarti, 1995). Chenier plains receive fine sediment supply under low to moderate wave energy from the neighbouring mud-dominated deltas and their rate of supply depends on delta lobe switching (Reading, 1996). This switching of delta lobes is related to changes in sediment supply (Penland and Suter, 1989; Reading, 1996); similar switching of four paradeltaic lobes in ESCR may be recognised from the drainage pattern and topographic characteristics evident in historical maps and topographic images (Paul, 2002). Three of them were by Subarnarekha river and another one by Kaliaghai-Rasulpur river. The fluvio-tidal flat on the both sides of distal-most dune ridges is dated 5760±140 years BP in its north and 2920±160 years BP in is south. This clearly indicates the timeframe of dune ridge development (Chakrabarti, 1995). While genetically reinterpreting four (out of six) palaeo-shorelines, Banerjee *et al.* (1997) were unable to find a single shell fragment in the deposits and stated them as compound aeolian-capped fluviatile deposits.

The present study addresses major change in the paleo-depositional environment from the depositional attributes of older layers retrieved from the borehole section. We also attempt to distinguish Holocene sediments from older Pleistocene sediments based on petrographic and granulometric studies. Stanley and Hait (2000) marked a depositional hiatus at 28 m depth at Diamond Harbour represented by a gravel bed, marking the boundary between Pleistocene and Holocene. A Pleistocene age (14460±350 yrs. BP) is assigned for an organic rich layer sandwiched between gravel layers. Similar gravel beds are reported (Chakrabarti, 1995; Hait *et al.*, 1996a, b) from varying depths at Negua (67 m), Digha (98 m), Kolaghat (7 m) and also from Kakdwip, Namkhana and Gangasagar areas (between 147 and 179 m). Similar gravel bed also identified by Mukherjee *et al.*, (2001) at Digha (73 m and 85 m), Kolaghat (7 m), Namkhana (91.4 m and 140 m) and Kolkata (10 m). These gravel beds (popularly known as 'kankar') are characterised as poorly sorted, leptokurtic, biologically barren deposits (Hait *et al.*, 1996b). This clay impregnated kankar were interpreted as deposition in fluvial environment under a prolonged arid period. Sample from peat layer just above this kankar layer was radiometrically dated 6,900±70 years BP, whereas 26.6 m depth sample from the same log is 31,750±2030 years BP. Thickness of Holocene unit were recorded (Stanley and Hait, 2000) from comparable depths at Kolaghat (11m), Digha (13.2m), Junput (16.5m), Sagar Island (23m) and Diamond Harbour (26.5m). Dated shell

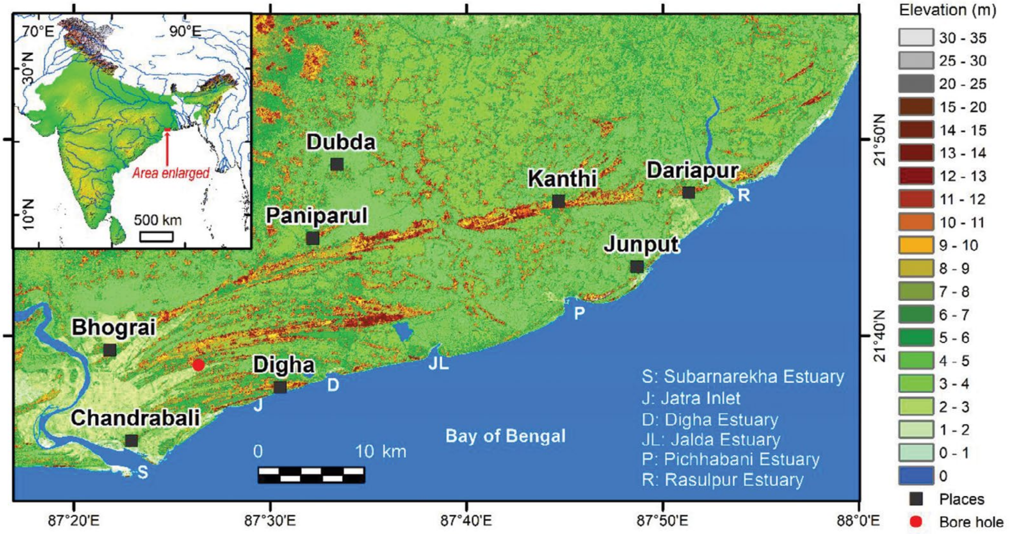

Figure 1. Location map of the study area indicating location of the borehole.

fragment at 11.8 m and organic-rich mud at 24.5 m depth at Digha shows 9,150±400 years BP and 22,360±450 years BP respectively. However, 70 m, 72 m and 64 m thick successions respectively at Digha estuary, Shankarpur backshore and Shankarpur beachfront were reported to reveal no gravel layer (Paul, 2002). Gravel layers recorded at depths between 45 m–195 m in the blocks of Bhagabanpur–I, Pataspur (I and II), Ramnagar, Tamluk (I and II), Egra and Panskura were considered as older Tertiary sediments of 'Kanthi formation' (Paul, 2002). However, detailed facies analysis for these different gravel beds and associated depositional units is necessary to establish their correlatability. Gravel beds have been reported from a number of borehole sections over a large region of Ganga–Brahmaputra delta, marking the transition between Pleistocene and Holocene (Chakrabarti, 1995; Hait *et al.*, 1996a, b; Stanley and Hait, 2000; Mukherjee *et al.*, 2001). The lateral continuity of this gravel beds indicates a major shift in the environment gradient in the region delimited within a small, time window (Stanley and Hait, 2000). Repetition of gravel beds in some sections (Chatterji *et al.*, 1964; Chakrabarti, 1995; Mukherjee *et al.*,2001) further indicate temporal perpetuality in the shift of environment.

An attempt to reconstruct the paleo-depositional environment at ESCR is based largely on granulometry and associated facies attributes (including the faunal data) of the depositional units recognised in a borehole section. Prediction on the time connotation of the depositional units is also attempted comparing the dated sediment successions in the region.

Materials and methods

Sample collection

Borehole grab samples used in the present study were collected from Kukudia village (21°38′30.77′′N, 87°26′21.23′′E) of Bhograi block, Baleswar district, in the state of Odisha during field survey between 25 and 27 January 2017 (Source: Barbatia Gram Panchayat, Baleswar district). Surface elevation of the drilling locality was determined to be 5 m from Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) sensor of Advanced Land

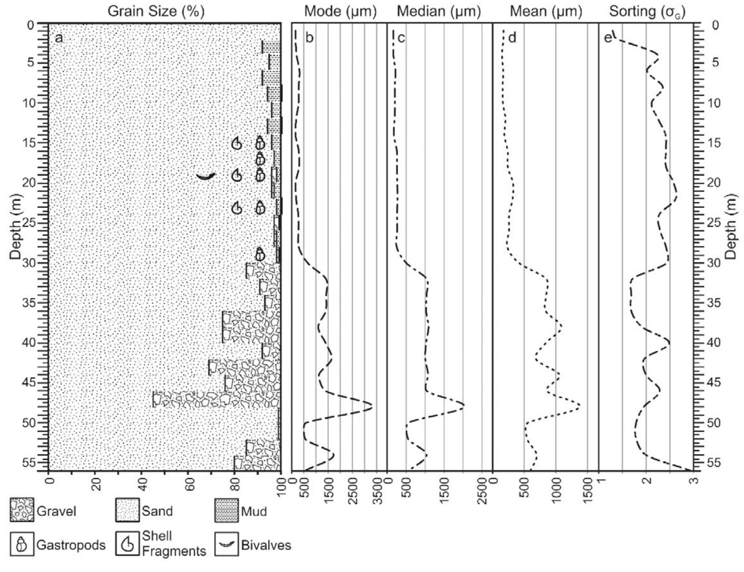

Figure 2. Litholog of the studied boreholes (a) along with variation of mode (b), median (c), 287 mean (d) and sorting (e) with depth.

Observing Satellite (ALOS) elevation model (Fig. 1).

Rotary drilling with flush method was used to collect samples at 2 m intervals. A 56 m thick sediment succession was studied in the present study (Fig. 2). It is apparent that internal layers will be homogenised in the grab samples making it difficult (if not impossible) to identify actual compositional layers. However, a triangular diagram (Fig. 3) is prepared with gravel-sand and mud percent (recalculated to 100) as end members to get an empirical lithological status for these grab samples from their plots in specified field in the diagram. Fields for sediment types (gravel, sand and mud) were assigned following the common definition of respective sedimentary rocks, viz. conglomerate, sandstone and shale. For example, gravels are considered as precursor sediment of conglomerate. Accordingly, gravel field was fixed for sediment comprising >10% gravel. Subsequently, sand field was fixed for sediments having >25% sand content. Each grab samples thus plotted in respective fields were assigned empirical lithological identity as 'gravel', 'sand' or 'mud'. Accordingly, the borehole log is transformed into a litholog or sediment succession.

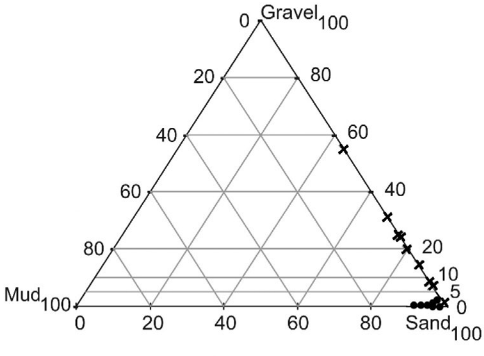

Figure 3. Ternary diagram showing proportion of gravel, sand and mud within the samples.

Table 1. List of identified gastropods and Bivalves with depth

Depth (m)	Identified species
16	*Oliva sp.* and *Nassarius stolatus*
18	*Polinices didyma*
20	*Cerithidea cingulate, Oliva sp., Theis sp.*, and oyster fragment
24	*Oliva sp.*
30	*Nassarius stolatus*

Sample processing

Samples were collected at a regular depth interval of 2 m. Hundred gram (100 g) of air-dried samples (50 g in case of certain depth intervals with less recovery of sediment) were homogenised through coning and quartering. Samples were then oven dried at 80°C for 6 hours and cooled in a desiccator to prevent samples from gathering moisture. Ready samples were subjected to mechanical sieving for 10 minutes at quarter ϕ interval.

Grain size statistics was calculated using GRADISTAT v.9 (Blott and Pye, 2001) in micron as well as in ϕ (Folk and Ward, 1957) for the sake of plotting them in different fields in the standardised diagrams.

Sediment log

Litholog or sediment log was prepared (Fig. 2) using the SedLog v3.1. Invertebrate shells in distinct layers were identified (Table 1) at generic level to understand their ecology.

Sample statistics

Both graphical and moment methods were considered for sediment analysis. First moment (mean) along with other two central tendency (viz, median, mode) and second moment (sorting) were plotted against the depth (using MS Excel v. 2019). Diagrams were digitally processed using CorelDRAW v.X7 for enhanced resolution and readability. Pearson's Correlation (Table 2) was used to evaluate the relationship between depth from surface and sediment size class and its granulometric parameters. To test the significance of the Pearson's correlation, we have calculated the t-test following R.A. Fisher and Student's t distribution with (n-2)

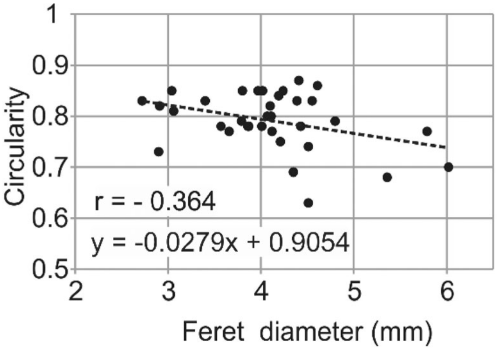

Figure 4. Relation betweenCircularity and Feret diameter of gravelliest sample at 48 m depth.

degrees of freedom (Das, 2013). Pearson's correlation and test of significance was done using XLSTAT v.2014.

Relationship between circularity and grain diameters were also observed (Fig. 4) from the digitised photographs of the gravelly fractions using Image thresholding to understand the depositional significance of these gravelly deposits.

Twenty eight sediment samples were analysed following conventional dry sieving method to characterise their grain size distributions (Folk and Ward, 1957). Size descriptors were plotted in CM diagram

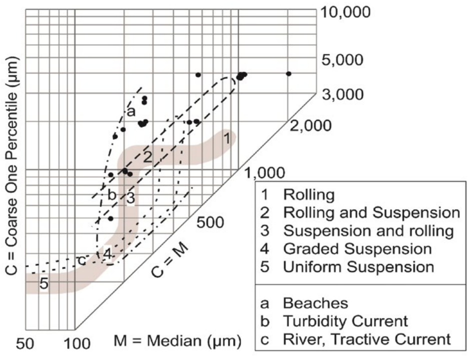

Figure 5. CM pattern of the 28 borehole samples.

(Passega, 1957 and 1964; Friedman, 1961) (Fig. 5) and several bivariate diagrams (Fig. 6 a–d) (Friedman, 1961; Tanner, 1991a, 1991b; Varghese *et al.*, 2016; Ghaznavi *et al.*, 2019) to understand their environment allegiance. Mean (M_z), variance (σ_1^2), skewness (Sk_1) and kurtosis (K_G) of samples were used in multivariate analyses to discriminate depositional environment with Linear Discriminant Function (Y) being defined as

$$Y=\lambda^1 X_1+\lambda^2 X_2+...+\lambda_p X_p \ldots \text{(Sahu, 1964)}$$

Where, X_1, X_2,…...,X_p are *p* normally distributed variables and λ^1, λ^2,…., λ^p are coefficients. We calculated four linear discriminant functions to distinguish; aeolian and littoral (beach), beach and shallow agitated marine environments, marine and fluvial processes, fluvial and turbidity current deposit respectively following Sahu (1964). Samples taken from sandy upper interval (0~30 m bgl) and those collected from lower intervals were tentatively held as two separate sediment genres from their apparent difference in gross texture. Accordingly, these were plotted as two separate series in the discriminant diagrams (Fig. 7 a–c).

Results and Discussions

Sediment log

Studied 56 m thick sediment section depicts a major textural and compositional change at 30 m depth (Fig. 2). Top 30 m of the section is comprised of sand and mud, in which sand proportion ranges between 91.56% and 99.73% and mud proportion ranges between 0.27% and 8.44%. Lower part of the section (from 30 m to 56 m) is dominantly gravelly, in which gravel proportion ranges between 0.98% and 54.62% while sand proportion ranges between 45.03% and 98.91% (Fig. 3).

Invertebrate shells (intact and fragmentary) in the basal part of upper sandy interval (0–30 m bgl) were identified as exclusive marine gastropods and bivalves (Table 1). Sandy interlayers, as well as, the coarser (granule to gravel) units of the lower interval (>30 m to 56 m) are totally devoid of shells.

Sediment statistics

Mean (µm) grain size is below 500 µm (1ϕ) up to 30 m depth which is mainly sandy in nature. Gravelly sand deposits show mean grain size more than 500 µm. Median is more persistent than other two central tendency and shows 165–250 µm range in upper portion and near 1000 µm (0ϕ) up to 46 m. The coarsest (gravelly) bed only shows median values more than 2000 µm (–1ϕ). After that median value trends back near 500 µm (1ϕ). Mode also shows similar nature like mean and median but reaches more than 3000 µm as it is more influenced by the maximum grain diameter (Fig. 2).

Sandy samples up to 30 m depth depicts poorer sorting (σ_G>2) with an exception of first 2 m depth sample, which is well sorted fine sand, that may be attributed to aeolian sorting in dune environment. Gravelly sand beds below 30 m showing better sorting than sandy mud samples probably indicates high energy and prolonged residence before final emplacement. Below 30 m sample shows moderately sorted sample with three exceptions at 40 m, 46 m and 56 m (Fig. 2).

Gravel beds depict moderately well rounded to very well-rounded grains in the coarse sediment populations. Pearson's correlation coefficient shows that, there is a poor but significant (p <0.05) negative correlation (r = –0.364) exists between grain size diameter and circularity (Fig. 4). Negative correlation is also observed between transport and grain size; while positive correlation is observed between transport and sphericity or roundness (Pettijohn, 1957). Moderately well-rounded to well-rounded clasts in the gravel beds perhaps imply longer (extent / duration) transport in this context. Similar range of roundness is reported from ephemeral channels (Tao *et al.*, 2017).

CM Diagram

All 28 samples plotted in CM diagram (Passega, 1957 and 1964; Passega and Byramjee, 1969) depicts transportation under varied mode. Substantial percentage of the samples (39%) fall under beach pattern

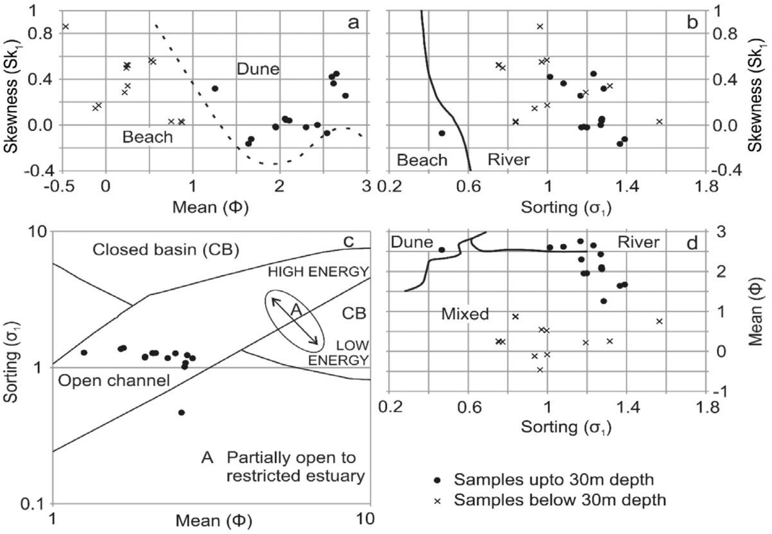

Figure 6. Bivariate plot of Mean and Skewness (a); Sorting and Skewness (b); Mean and Sorting in log-log scale (c); Sorting and Mean (d) to decipher the depositional environment.

Table 2. Karl Pearson's Coefficient of Correlation between depth and selected granulometric parameters in the borehole grab sample of ESCR. Medium sand, fine sand and very fine sand are represented as MS, FS, and VFS, respectively. Coarse one percentile is abbreviated as C. Using the Folk and Ward methods, the statistical parameters are determined geometrically (in metric units).

Variables	Depth (m)	Gravel %	Sand %	Mud %	MS %	FS %	VFS %	C (μm)
Gravel %	0.605[a]							
Sand %	–0.496[a]	–0.983[a]						
Mud %	–0.762[a]	–0.470[b]	0.301					
MS %	–0.434[b]	–0.662[a]	0.564[a]	0.731[a]				
FS %	–0.747[a]	–0.507[a]	0.468[b]	0.385[b]	0.245			
VFS %	–0.816[a]	–0.611[a]	0.485[a]	0.847[a]	0.632[a]	0.571[a]		
C (μm)	0.799[a]	0.741[a]	–0.652[a]	–0.720[a]	–0.700[a]	–0.747[a]	–0.779[a]	
Mode (μm)	0.638[a]	0.843[a]	–0.799[a]	–0.538[a]	–0.615[a]	–0.615[a]	–0.718[a]	0.753[a]
Median (μm)	0.717[a]	0.889[a]	–0.831[a]	–0.630[a]	–0.703[a]	–0.678[a]	–0.807[a]	0.836[a]
Mean (μm)	0.759[a]	0.886[a]	–0.815[a]	–0.689[a]	–0.753[a]	–0.705[a]	–0.853[a]	0.874[a]
Sorting (σG)	–0.076	–0.102	0.038	0.350	0.349	0.006	0.448[b]	–0.057
Skewness (SkG)	–0.272	–0.517[a]	0.542[a]	0.083	0.176	0.477[b]	0.406[b]	–0.412[b]
Kurtosis (KG)	0.063	0.280	–0.274	–0.142	–0.437[b]	–0.158	–0.227	0.256

[a] Correlation is significant at the 0.01 level (2-tailed).
[b] Correlation is significant at the 0.05 level (2-tailed).

(scattered near greater C values having lesser median), followed by turbidity current (21%) pattern (parallel with C=M line). Another 39% sample has much higher C values with 7–55% gravel component, falls closer to the maximum limit of turbidity current but does not coincide under any hydrodynamic condition (Fig. 5). This position is between turbidity current and fluvial gravel (Passega, 1957; Baiyegunhi, 2017; Ghaznavi *et al.*, 2019).

Bivariate analysis

Bivariate analyses of the samples do not indicate any perceivable and consistent trend as regards to their environment affinity. Sandy sediments (in the top 30 m) plots variously indicate deposition in dune field (Fig. 6a), river field (Fig. 6b), open channel (Fig. 6c) and mixed field (Fig. 6d). Coarser sediments in the basal part of the succession show affinity to both beach and fluvial environment.

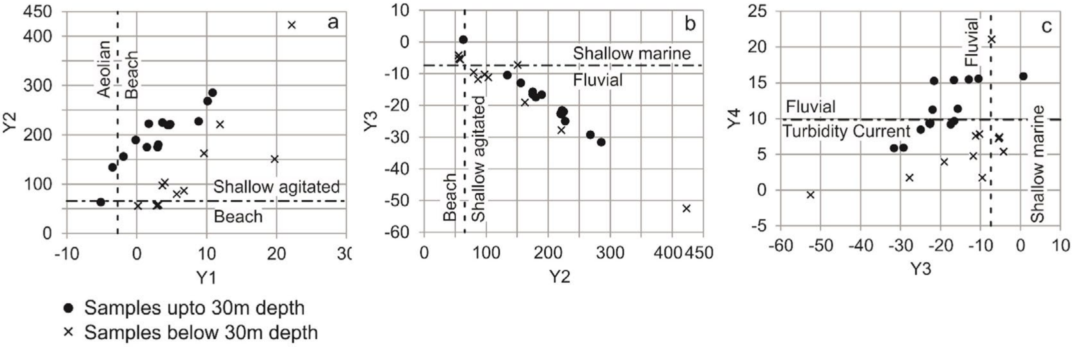

Figure 7. Linear Discriminant Function (LDF) plot on bivariate diagrams: Y1 and Y2 (a); Y2 and Y3 (b); Y3 and Y4 (c).

Linear discriminant analysis

Y1 vs. Y2 plots for finer (sandy) sediments in the upper section clearly indicates their deposition in beach environment except for the topmost layers, which on the other hand indicate deposition under aeolian processes (Fig. 7a). Similarly, Y3 vs. Y2 plots (Fig. 7b) of coarser sediments below 30 m shows dominant fluvial trend. Y4 against Y3 plots on the other hand (Fig. 7c) for all sediments do not indicate any perceptible trend.

Conclusions

Grain size descriptors, faunal contents and other facies attributes of the borehole sediments at ESCR help to mark a major reversal in the depositional regime at 30 m bgl as indicated by onshore marine (beach) deposition over fluvial deposits. Lower part of the succession is represented here by ephemeral coarser channel facies that alternate with finer, sandy interfluve deposits, defining a fluvial phase in the depositional milieu. Overlying beach deposits and aeolian deposits indicate shoreline retrogradation. Due to lack of robust age data in the studied part of ESCR, precise age cannot be provided for this event. However, similar facies association recorded in dated sediment successions in the region points towards a Pleistocene-Holocene transition for this depositional break. With all probability, these gravel beds mark the Last Glacial Maxima. Meticulous mapping and facies correlation of these gravel beds encountered at varying depths in different sections in the region might give a clearer picture of the Pleistocene-Holocene transition in ESCR.

Acknowledgement

Authors are thankful to Mr. Sanjit K. Mandal and Mr. Rakhohari of Kukudia village, Bhograi block, Baleshwar, Odisha for providing support to collect data. Dr. Subhronil Mondal, Department of Earth Sciences, IISER, Kolkata is acknowledged for the identification of gastropods. We thankfully acknowledge the anonymous reviewer(s) who kindly helped us to improve the manuscript.

References

Baiyegunhi, C., Liu, K., Gwavava, O. (2017) Grain size statistics and depositional pattern of the Ecca Group sandstones, Karoo Supergroup in the Eastern Cape Province, South Africa. *Open Geosciences*, 9: 554–576.

Bandyopadhyay, S. (2007) Evolution of the Ganga-Brahmaputra Delta: A Review. *Geographical Review of India*, 69(3): 235–268.

Bandyopadhyay, S., Mukherjee, D., Pahari, D. (2009) Coastal erosion and its management at Digha, Medinipur, West Bengal. In Sharma, H.S. and Kale, V.S. (eds.) *Geomorphology in India* (Prof. Savindra Singh Felicitation Volume), Prayag Pustak Bhavan, Allahabad: 124–132.

Banerjee, P.K., Goswami, S., Chatterjee, S. (1997) A Genetic re-interpretation of the shore parallel sand ridges on the Balasore-Contai floodplain, W. Bengal and Orissa. *Journal Geological Society of India*, 49: 687–692.

Blott, S.J., Pye, K. (2001) GRADISTAT: A grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms*, 26: 1237–1248.

Chakrabarti, P. (1995) Evolutionary history of coastal Quaternaries of Bengal plain, India. *Proceedings. Indian National Science Academy*, 61A(5): 343–354.

Chatterji, G.C., Biswas, A.B., Basu, S., Niyogi, B.N. (1964): Geology and Groundwater Resources of the Greater Calcutta Industrial Area, W. B. *Bulletin of Geological Survey of India*, B (21): 1–150.

Das, N.G. (2013) *Statistical Methods*, Combine Ed, McGraw Hill Education (India) Private Limited, New Delhi: 907p

Folk, R.L., Ward, W.C. (1957) Brazos River bar: A study in the significance of grain size parameters. *Journal of Sedimentary Petrology*, 27(1): 3–26.

Friedman, G.M. (1961) Distinction between Dune, Beach, and River sands from their textural characteristics. *Journal of Sedimentary Petrology*, 31(4): 514–529.

Ghaznavi, A.A., Quasim, M.A., Ahmad, A.H.M., Ghosh, S.K. (2019) Granulometric and facies analysis of Middle–Upper Jurassic rocks of Ler Dome, Kachchh, western India: an attempt to reconstruct the depositional environment. *Geologos*, 25(1): 51–73.

Hait, A.K., Das, H.K., Ghosh, S., Ray, A.K., Saha, A.K., Chanda, S. (1996a) New dates of Pleisto-Holocene subcrop samples from south Bengal, India. *Indian Journal of Earth sciences*, 23(1-2): 79–82.

Hait. A.K., Das, H.K., Ghosh, S., Ray, A.K., Chanda, S. (1996b) Environmental variations in late Quaternary sequence of Kolaghat, West Bengal, India. *Current Science*, 70: 1089–1093.

Hossain, Md.S., Xiao, W., Khan, Md.S.H., Chowdhury, K.R., Ao, S. (2020) Geodynamic model and tectono-structural framework of the Bengal Basin and its surroundings. *Journal of Maps*, 16(2): 445–458.

Mukherjee, B.B., Mitra, A., Chakrabarty, P. (2001) Quaternary coastal environment and shoreline change in the Bengal basin- A Review. In Rajamanickam, G.V. and Tooley, M.J. (ed) *Quaternary Sea-Level variation, Shoreline displacement and coastal environment*, New Academic Publishers, Delhi: 223–229.

Nandy, D.R. (2001) *Geodynamics of Northeastern India and the Adjoining Region*, ACB Publications, Kolkata: 209p.

Niyogi, D. (1968) Morphology and Evolution of the Subarnarekha Delta, India. *Saertrykaf Geografisk Tidsskrift*, 67 Bind: 230–241

Niyogi, D. (1970) Geological background of beach erosional Digha, West Bengal. *Bulletin of the Geological Mining and Metallurgical Society of India*, 43: 1–36.

Passega, R. (1957) Texture as characteristic of clastic deposition. *Bulletin of the American Association of Petroleum Geologists*, 41(9): 1952–1984.

Passega, R. (1964) Grain size representation by CM patterns as a geological tool. *Journal of Sedimentary Petrology*, 34(4): 830–847.

Passega, R., Byramjee, R. (1969) Grain-size image of Clastic deposits. *Sedimentology*, 13: 233–252.

Paul, A.K. (2002) *Coastal Geomorphology and Environment: Sundarban Coastal plain, Kanthi Coastal Plain, Subarnarekha Delta Plain*. ACB Publications, Kolkata: 582p.

Penland, S., Suter, J.R. (1989) The geomorphology of the Mississippi River chenier plain. *Marine Geology*, 90(4): 231–258.

Pettijohn, F.J. (1957) *Sedimentary rocks*, 2nd Ed, Harper & Brothers, New York: 718p.

Reading, H.G. (1996) *Sedimentary Environments: Processes, Facies and Stratigraphy*, 3rd Ed, Blackwell Publishing, New Delhi: 688p.

Sahu, B.K. (1964) Depositional mechanisms from the size analysis of Clastic sediments. *Journal of Sedimentary Petrology*, 34(1): 73–83.

Stanley, D.J., Hait. A.K. (2000) Holocene Depositional Patterns, Neotectonics and Sundarban Mangroves in the Western Ganges-Brahmaputra Delta. *Journal of Coastal Research*, 16(1): 16–39.

Tanner, W.F. (1991a) Application of suite statistics to stratigraphy and sea-level changes. In: Syvitski, J.P.M. (ed.) *Principles, methods and application of particle size analysis*, Cambridge University Press, Cambridge: 283–292.

Tanner, W.F. (1991b) Suite statistics: The hydrodynamic evolution of the sediment pool. In: Syvitski, J.P.M. (ed.) *Principles, methods and application of particle size analysis*, Cambridge University Press, Cambridge: 225–236.

Tao, J., Zhang, C., Qu, J., Zhu, R., Yuan, R., Pan, J. (2017) Application of gravel roundness quantitative description in Conglomerates reservoirs. *Chemical Engineering Transactions*, 62: 457–462.

Varghese, T.I., Prakash, T.N., Nagendra, R. (2016) Depositional history of coastal plain sediments, Southern Kerala, South West India. *Journal of Earth Science & Climatic Change*, 7(6): 1–8

Date received : 23 December 2020
Date accepted after revision : 30 December 2020