International Journal of Geology, Earth & Environmental Sciences ISSN: 2277-2081 (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jgee.htm
2014 Vol. 4 (3) September-December, pp. 81-100/Ghosh
Research Article

PALAEOGEOGRAPHIC SIGNIFICANCE OF FERRUGINOUS GRAVEL LITHOFACIES IN THE AJAY – DAMODAR INTERFLUVE, WEST BENGAL, INDIA

***Sandipan Ghosh**
Department of Geography, The University of Burdwan, P.O. Rajbati, Barddhaman – 713 104, West Bengal, India
**Author for Correspondence*

ABSTRACT
Distribution of lithofacies in vertical sequence, lateral extent and association of lithofacies characterize the basin fill sediments through alluvial fan to fan-delta sequence, exposed in the eastern parts of Ranjganj Coalfield (*i.e.* Ajay – Damodar Interfluve of West Bengal). The occurrences of Gci, Gcm and Gcg facies reflect clast-rich debris to pseudoplastic flow in hot and arid climatic condition on the faulted basal slope, situated at western shelf zone of Bengal Basin. Towards the proximal part, the sedimentary sequences of Gh, Gt, Gp, Fm, Sm and Gmg signify the progradation of fan-delta in hot and humid climatic condition under shallow marine environment. These facies of gravels were probably deposited in between Oligocene and Miocene when the monsoon climate was gradually established in this part of Peninsular India. This event was followed by intensive lateritization process, giving birth of autochthonous and allochthonous ferruginous materials since Late Miocene when the shoreline was finally receded from this part. The ferruginous beds of clast-rich Tertiary gravels (fan lobes) are identified as a signature of earliest coarse deposits in the north-west Bengal Basin, carrying proxies of palaeomonsoon.

Keywords: *Fan-delta; Laterite; Palaeomonsoon; Gravels; Climate Proxy; Facies; Bengal Basin*

INTRODUCTION
An overall parallel drainage system flowing west to east is a significant geomorphic feature of the plateau fringe of West Bengal, reflecting structural control on drainage pattern and fluvial sedimentation since Early Tertiary (Niyogi *et al.*, 1970; Singh *et al.*, 1998). An emblematic north – south lateritic belt (geographically recognized as *Rarh Plain*) with the patches of gravel deposits (from Rajmahal Hills to Subarnarekha Basin) borders this province to make the transitional landforms and distinct sedimentation pattern in between Archaean – Gondwana Formation (west) and Quaternary Formation of Bengal Basin (east) (Biswas, 2002; Das and Mukherjee, 2006). The Bengal Basin lies in the north-eastern part of Indian subcontinent, between Indian Shield to the west and north and Indo-Burma Ranges to the east, covers Bangladesh, parts of West Bengal and Tripura states of India and the Bay of Bengal (Bandyopadhyay, 2007). The shelf zone of Bengal Basin is still tectonically active and since Late Eocene, tectonic upliftment and subsidence initiated marine transgression and regression to this region, developing different fluvio-deltaic sedimentary units wherein the ferruginous profiles are one of oldest formations of the Bengal Basin. It is assumed that since Tertiary Period the sedimentation of Bengal Basin was very much influenced by the strength of palaeomonsoon, the palaeofloods of peninsular rivers (e.g. Brahmani, Dwarka, Mayurakhshi, Ajay, Damodar, Dwarkeswar, Silai etc.), intensive lateritization of sediments and neo-tectonic movements (Sengupta, 1966). The occurrence of Late Tertiary grits and gravel deposits with ferruginous concretions and kaolinite clay bears a distinct depositional history, palaeopedogenesis and palaeoclimate in the early processes of filling up the Bengal Basin with coarse sediments (Hunday and Banerjee, 1967; Mahadevan, 2002). It has been recognized that the fluvial systems are the most sensitive elements of earth's surface and any shift in climate, tectonic and environmental conditions instigates a rapid response from the fluvial systems (Sridhar, 2008). The fluvial facies analysis of gravel and pebble deposits with ferruginous concretions can reflect a clue to typical fan-delta or braided deposition in the east-marginal fault-scarp region of Chotanagpur Plateau (Singh *et al.*, 1998) which compels to imagine

the palaeo-depositional mechanism and palaeoclimatic inference of earliest fan-deltaic deposits in the Bengal Basin, passing through the faulted Gondwana Formation. The lobes of semi-consolidated gravel beds (underlain by thick alluvium and laterite) exposed in the northern part of Durgapur City (Barddhaman district, West Bengal) is the main spatial unit of present study to analyze Tertiary deposits of debris flow, grain flow, inertia flow, turbidity current, channel and non-channel in a fan-deltaic sequence and post-depositional lateritic pedogenesis (Mahapatra and Dana, 2009). The proximity of this area to the Raniganj Coal-fields and the Bengal Basin, many marine transgressions – regressions in this part since Cretaceous (Sengupta, 1966; Singh *et al.,* 1998) and occurrence of ferruginous concretions (Das, 1972) suggest that this area may bear the imprints of Post-Gondwana tectonic sedimentation, Tertiary – Quaternary sea level changes and intensification of palaeomonsoon associated with lateritization of sediments in the eastern India. So the prime objectives of this study are as follows.

1. Analyzing the fan-deltaic facies of gravel deposits with their individuality, to understand the depositional processes in details,
2. Elucidating the sequences of depositional history with the roles of geological structure, neo-tectonic movements and sea level changes in the study area as a part of the Bengal Basin., and
3. Investigating the occurrences of ferruginous materials in relation to onset of strong palaeomonsoon climate in India.

Previous Works

The existence of Tertiary gravel beds was first recognized by Dunn and Dey (1942) in the vicinity of lower Subarnarekha Basin, close to the Bengal Basin. Sengupta (1966), Das and Biswas (1969) have studied the sedimentary geology of the western part of Bengal Basin, adjoining the Gondwana Formation of West Bengal in details. Hundy and Banerjee (1967) had found few patches of lateritic gravels and grits in the plateau fringes of West Medinipur, Bankura, Burdwan and Birbhum districts of West Bengal. In the East Singhbhum of Jharkhand the Tertiary gravels and pebbles are associated with low-level laterites which are studied by Ghosh (1970), Mukhopadhyay (1980), Satpathi (1981) and Mahadevan (2002). They suggest that these beds are the remnants of shelf deposits of the Bengal Basin and it demarcates the earliest shoreline running approximately north – south parallel to Rarh Plain of West Bengal. Mukhopadhyay (1970) and Niyogi *et al.,* (1970) have noticed the patches of laterites which cover the beds of unconsolidated gravels and pebbles in the faulted western margin of Bengal Basin, influenced by marine incursion. Das (1972) has precisely studied the sedimentation profile of Ajay – Damodar interfluve on the eastern margin of Raniganj Coal-field (rifted Gondwana Basin) and recognized the fluvial depositions since Early Cretaceous. The fluvial dominated shelf zone of western Bengal Basin is studied precisely by Vaidyanadhan and Ghosh (1993) who have focused on the depositional history and age of lateritic formations. Ghosh and Ghosh (2003) have analyzed the surrounding geology of Durgapur City and recognize the secondary formation of laterites on the gravel beds which may be derived from the conglomerate bed of Mahadeva Group. The gravity anomaly of Durgapur Depression is examined by Kumar (2006) to denote fault controlled sedimentation. Above all Mahapatra and Dana (2009) have been analyzed the gravelly sediments of northern parts of Durgapur City in details to find out the sedimentation processes in an alluvial fan to fan delta formation, including the identification of gravel facies association.

MATERIALS AND METHODS

The stratigraphic exposures, fluvial archives and borehole data have been allowed to reconstruct the alluvial history of Tertiary to Quaternary Period and palaeoclimate changes in the present monsoonal wet – dry region of western Bengal Basin. The term ‘facies’ is used here to refer the individual characteristics of each sedimentary unit of lithosection and by recognizing associations of facies it is possible to establish the combinations of processes that are present (Nichols, 2009). Assuming that the laws that govern physical and chemical processes have not changed through time, detailed measurements of fluvial sediments can be used to make estimates of the physical, chemical and biological conditions that existed at the time of sedimentation and post-depositional environment (Nichols, 2009). To know the sub-surface sediment characters of the lithosections we have studied the truncated and excavated profiles (3 to 6 metre depth) in the quarries using auger, trimming hammer, 30 m tape, 30 cm metal scale and Garmin GPS (Global Positioning System) receiver for the location. Depositional environment and the channel configuration have been deduced on the basis of sedimentological characters of fluvial deposits. So, a lithofacies classification similar to that developed by Miall (1985, 1996) and Einsele (1992) have been adopted for the present purpose. Miall's (2006) architectural elements of fluvial deposits (gravelly bedforms and channel deposits), viz., Gp, Gt, Gh, Gmm, Gmg, Gci, Gcm, Gh, Sm and Fm etc., are applied here to annotate the lithofacies of gravel deposits. Miall (2006) has designated the dominant grain size (i.e. gravels in the study area) as the capital letter G to indicate gravels, followed by the lower case letters m or c for matrix-supported or clast-supported, respectively. A second lowercase letter, m, i or g, is added for massive, inverse or normally graded structures (Miall, 2006). The graphic sedimentary logs (1: 100 scale) are prepared following Tucker (1996) formats to present sub-surface data in a way which is easy to recognize and interpret using symbols and abbreviations prepared by Nichols (2009). The interpretation of the lithofacies is provided here on the basis of (1) clast size, (2) texture, (3) colour, (4) depositional mechanism and grading, (5) flow types and (6) pedogenic characteristics. We have used GLCF (Global Land Cover Facility) Landsat TM image (2005), GSI (Geological Survey of India) District resource Map of Barddhaman district, SOI (Survey of India) toposheets of 73 M (RF – 1: 250,000,000) and 73 M/6 (RF – 1:50,000) as the secondary information. The thematic maps are prepared using ArcGis 9.3 and MapInfo Professional 9.0 software.

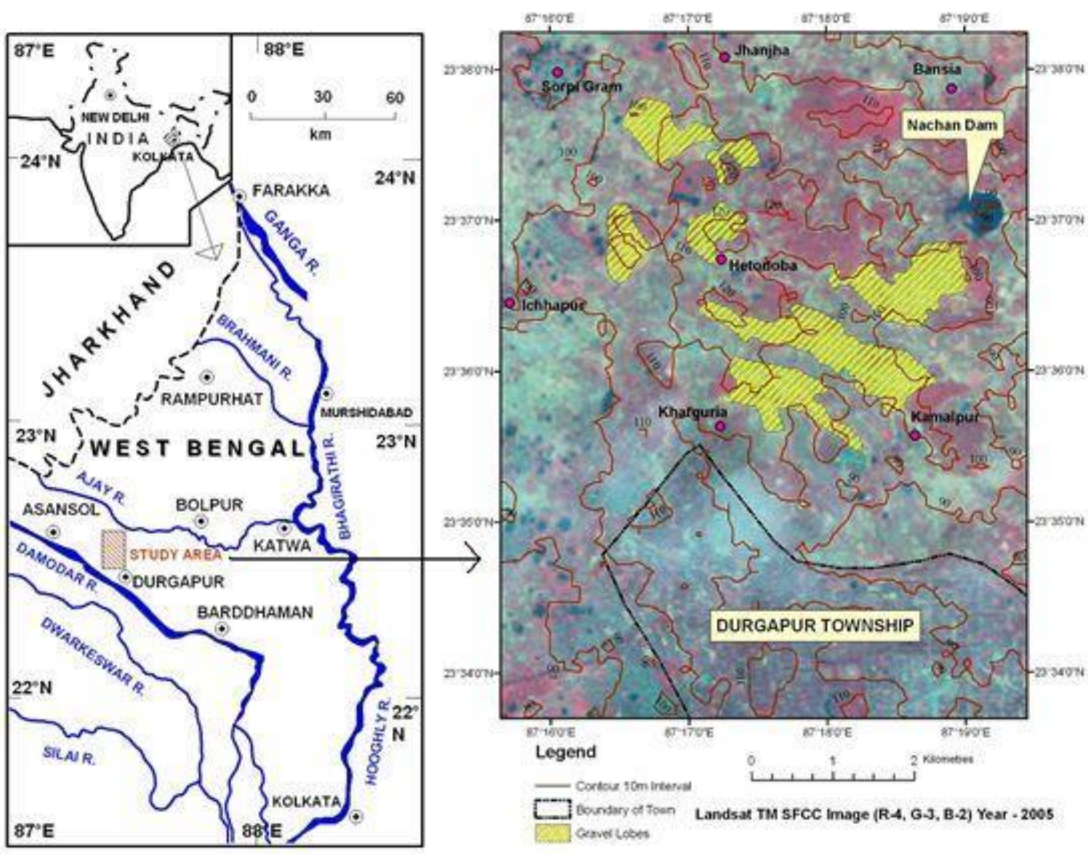

Figure 1: Location map of study area

Geological Setting of Study Area

The area under study (bounded by latitude 23° 34´ to 23° 38´ N and longitude 87° 16´ to 87° 19´ E) covers the upland terrain of the Ajay – Damodar interfluve (mean elevation of 90 to 120 metres from mean sea level), fringing the Peninsular Shield on the eastern margin of the Raniganj Coal-field and western part of lateritic Rarh Plain. The parallel gravel lobes (west – east oriented) of Kamalpur, Bansia, Hetodoba, Bansgara and Dhoadanga villages are the main spatial unit of study (figure 1) which are underlain by older alluvium (Early Pleistocene to Late Holocene) and low-level laterites (Miocene to Late Pleistocene). The dissected area is geomorphologically included into the upper catchments of Kunur (tributary of Ajay River) and Tamla (tributary of Damodar River). This geological museum is significant as the alluvial sediments (Tertiary to Recent Formation) of the Bengal Basin are juxtaposed with the Older Gondwana sedimentary rocks (Durgapur beds, Panchet sandstone and Raniganj Formation) on the west (figure 2) (Ghosh and Ghosh, 2003). The Gondwana sediments of the Raniganj sub-basin (coal-rich graben) are bounded to the north, south and west by Pre-Cambrian rocks (Granite and Gneiss) whereas the eastern boundary is concealed beneath a thick succession of unconsolidated recent sediments, gravels and laterite beyond and extends in the faulted Durgapur Depression up to Domra-Panagarh area (Kumar, 2006). The exposed and excavated semi-consolidated gravel beds have Tertiary age (Oligocene to Miocene), preserved at north of Durgapur City under the blanket of low-level laterites (Das and Biswas, 1969; Mahapatra and Dana, 2009). The Gondwana Basin Margin Fault Scarp Zone (Ghosh and Ghosh, 2003) or Chotanagpur Foot-hill Fault (Singh *et al.*, 1998) runs almost N-S about near Durgapur and it directly influenced the sedimentation on the Durgapur Bed and Panchet Formation in an alluvial fan to fan-delta sequences (Mahapatra and Dana, 2009). Based on the important geological studies done by Das and Biswas (1969), Niyogi *et al.*, (1970), Das (1972), Ghosh and Ghosh (2003) and Mahapatra and Dana (2009), the sub-surface stratigraphic succession of study area is prepared as follow (table 1). The depositional facies of Kuldiha, Alinagar and Bistupur Formations (Das, 1970) are getting main focus in this analysis.

Table 1: Stratigraphic succession near north of Durgapur City (after Das, 1970)

Formation Litho-unit	**Lithological Character**	**Thickness Range (metre)**	**Age**
Ajay-Damodar	sand, ferruginous, yellow, coarse to fine; silt; greyish yellow clay	–	Late Holocene to Recent
Bishtupur	sand, ferruginous, yellow; lithomargic clay; laterite; calcareous nodules	26 – 45	Pliocene to Pleistocene
Alinagar	sand and pebbles, greyish white; grey, sticky clay	21 – 82	Miocene
Khatpukur	Carbonaceous shale, claystones grey and greyish black, with thin bands of lignite and layers of sand	1 – 20	Oligocene to Miocene
Kuldiha	coarse sand and pebbles; kaolinitic and ochreous sandstone; red, green and white clays	2 – 45	Cretaceous to Oligocene
Durgapur	coarse felspathic sandstone; grits and pebbles	0.35 – 129	Middle Triassic to Jurassic
Panchet	felspathic sandstone, greyish green, greenish grey, medium to fine; red and green shale	51	Lower Triassic
Raniganj	felspathic sandstone, greyish white, medium to fine; carbonaceous shale; grey shale; a thin lens of coal	4.5	Permian

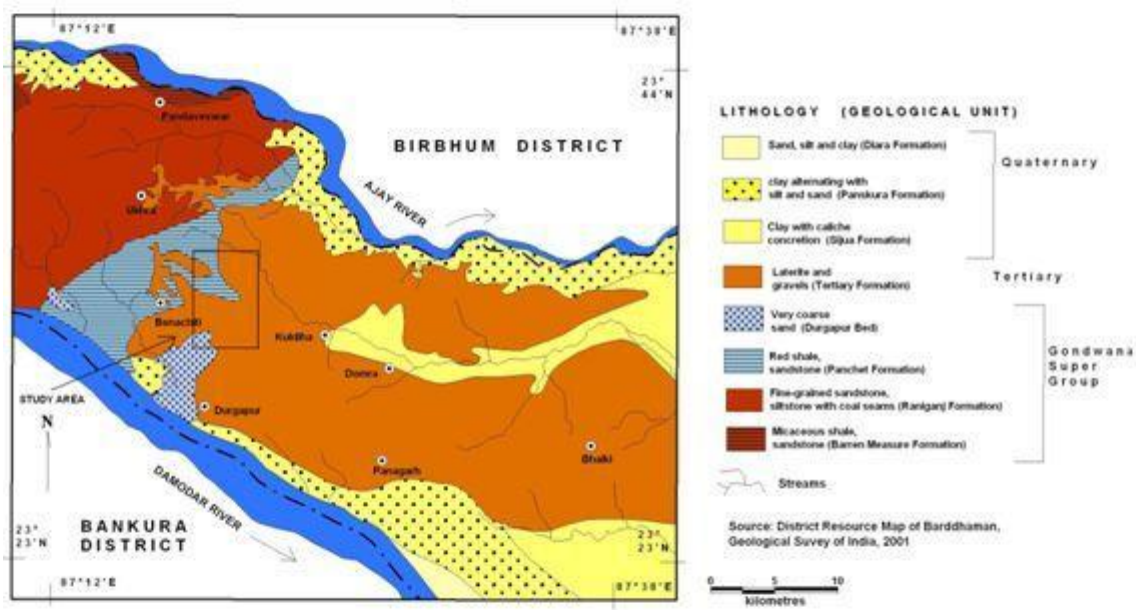

Figure 2: Surface geological map of western-central Barddhaman district (including study area), focusing Gondwana Super Group, Tertiary Formation and Quaternary Formation

RESULTS AND DISCUSSION

Association of Gravel Lithofacies as Alluvial Fan to Fan-Deltaic Sedimentation

The associations of gravel facies reflect a natural separation of depositional processes and sorting of the sediment load, controlling by traction currents, fluid flows, sediment gravity flows, grain flows, waning flow etc. (Miall, 2006). These flows are integral part of fan deposits (mostly fluvial origin) which has prograded into a standing body of water (Mahapatra and Dana, 2009). Fan delta is a prism of sediments delivered by an alluvial fan and deposited, mainly or entirely subaqueously at the interface between the active fan and standing body of water (Postma, 1984; Mahapatra and Dana, 2009). The identified major gravel lithofacies that occur in the study area are differentiated initially on the basis of texture, sorting and types of mass flows, and secondly on the basis of their internal structure and degree of mottling (figure 3). The sedimentary details of lithofacies (from apex to proximal part) are depicted in the following subheads from base to top of the each lithosections (table 2).

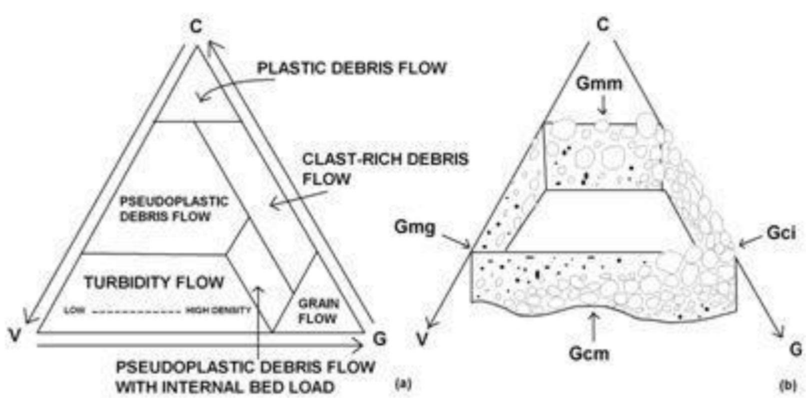

Figure 3: (a) Ternary diagram of sediment gravity flow classification; poles of triangle represent cohesive – plastic behaviour with increasing clay content (C), viscous – fluid behaviour with increasing water content (V) and granular – collisional behaviour with increasing clast content and shear rate (G); and (b) development of four main gravel lithofacies (found in the study area) under different debris flows (modified from Shanmugam, 1996; Miall, 2006).

Table 2: Details of facies used in the analysis (Modified from Miall, 2006)

Facies Code	Sedimentary Structure	Interpretation
Gmm	Matrix-supported massive gravels; weak grading	Plastic debris flow (high-strength, viscous)
Gmg	Matrix-supported massive gravels; inverse to normal grading	Pseudoplastic debris flow (low-strength, viscous)
Gci	Clast-supported gravel; inverse grading	Clast-rich debris flow (high-strength) or pseudoplastic debris flow (low-strength, viscous)
Gcm	Clast-supported massive gravel; out-sized clasts	Pseudoplastic debris flow (inertial bedload, turbulent flow)
Gcg	Clast-supported gravel; normal grading	Subaqueous mass flow deposits (intake of water); least viscous and partly turbulent flow
Gh	Clast-supported, crudely bedded gravel; imbrication	longitudinal bedforms, lag deposits, sieve deposits
Gt	Gravel stratified; trough cross-beds	Minor channel fills
Sm	Sand, fine to coarse; massive or faint wavy lamination	Sediment-gravity flow deposits
Fm	Mud, silt; massive, desiccation cracks	Overbank or waning flood deposits

Lithosection G1

The first identified lithosection G1 (23° 35.888´ N and 87° 17.324´ E) of Hetodoba Mouza carries four distinct lithofacies with ferruginous concretion and kaolinte clay which are exposed due to pebble quarrying (figure 4). At base of the section the inversely graded (upward coarsening of clasts) and clast-supported large gravels (Gci) of 2.45 – 2.71 metres depth reflect a high-strength subaerial debris flow with predominance of inertia flow which is self-sustained debris flow having entrained turbulent flow at top of the Gci facies (Shanmugam, 1996; Mahapatra and Dana, 2009). The clasts' longest axes are parallel to flow and imbricated, dipping upflow. In Gci facies the dispersive pressure (caused by grain collision) and buoyant lift (caused by mixture of water and fine grains), may force large pebbles and cobbles towards the surface of slip force leading to inverse grading (Postma *et al.*, 1988; Shanmugam, 1996; Sengupta, 2012). This facies signifies a 'sieve texture' (Sengupta, 2012) with scanty supply of sands and muds in the gravel lobes of proximal fan delta at west and cohensionless subareal debris flows dominated by the frictional effects at base (Lowe, 1982). This facies was later affected by lateritic pedogeneis and the presence of mottles (white to purple colour) reflects an acidic medium of deposition. Then the normally graded (upward fining of clasts) ferruginous clast-supported gravel deposits (Gcg) of 1.25 – 2.45 metres depth occur due to intake of water by the turbidly flow at its top, that decreased the effective flow viscosity and thus increase the possibility of vertical clast-size segregation (Mahapatra and Dana, 2009). Following lower Gci facies, the Gcg facies reveals a least viscous and partly turbulent flow, interpreted as subaqueous mass flow deposits. The brown to grey coloured clayey Fm facies (0.3 – 1.25 metres depth) reflects upper turbidite fine-grained deposits which was deposited from suspension after the turbidity current (occasionally occurred in sheetfloods) has come to rest (waning flow) and it is therefore recognized as hemipelagic deposits (Nichols, 2009). For a long time this massive clayey deposit was pedognized with ferruginous clays (dominance of goethite) which became hard and black on exposure. The top Gmg facies of heterogeneous coarse materials (coarse sand to large pebbles) are strongly cemented by derived ferruginous oxides (matrix-supported). It is also affected by recent pedogenesis and a few centimeter layer of sandy loam soil is developed over it, supporting grasses and bushes. Following lower Fm facies, it was formed by last high-density debris flow with the development of internal friction due to water loss. The occasional occurrences of out-sized clasts at the top of facies reveal a rheological interface between the slow moving inertia-flow layer (laminar flow) below and the faster moving turbulent suspension (turbulent flow) above (Shanmugam, 1996). The sedimentary sequence of this lithosection (clast-supported gravel base to matrix- supported gravel top) is recognized as *Gci – Gcg – Fm – Gmg.*

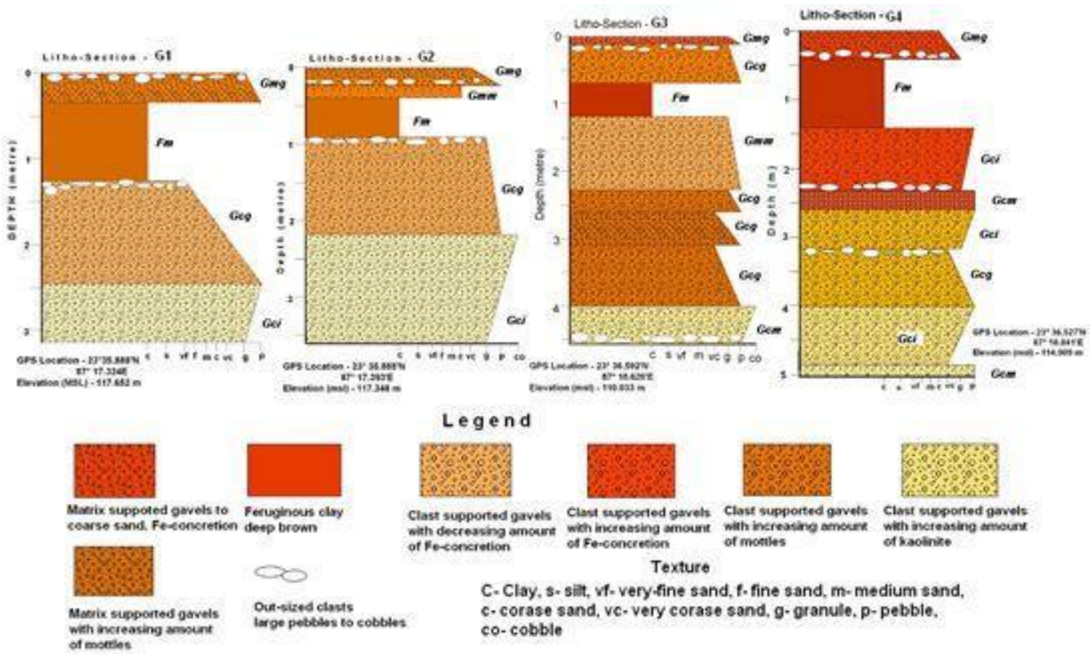

Figure 4: Four lithologs (G1 to G4) of gravel facies show vertical gradation of debris flow deposits (Gci), pseudoplastic debris flow (Gcm), subaqueous mass flow (Gcg), inertia flow (out-sized clasts), waning turbidity flow (Fm) and plastic debris flow (Gmg) in alluvial fan to fan-delta setting; lithosection G1 situated in the fan apex and others towards distal part of fan; clasts and matrix are coated with red – brown ferruginous oxides (top set) and white – pale yellow kaolinte (bottom set).

Lithosection G2

Carrying five distinct lithofacies, the lithosection G2 (23° 35.887´ N and 87° 17.292´ E) of Hetodoba Mouza significantly is dominated by clast-supported gravel beds at base and ferruginous mottles at top (figure 4). The base of the section is formed by clast-supported and inversely graded gravels (Gci) with coatings of mottles and kaolinte at a depth of 2.2 – 3.6 metres. The Gci facies reflects low-viscosity debris flow with inertia flow at top. Then normally graded gravels deposits (Gcg) of 0.9 – 2.2 metres depth signify a decreased flow velocity due to intake of water, having lower flow regime. Yellowish brown mottles with iron concretions provide a thin layer of matrix supported small sized gravels at the top of Gcg facies, signifying low strength wanning flow. Following this facies, brown to grey coloured Fm facies is found at a depth of 0.37 – 0.90 metres, signifying hemipelagic deposits and palaeopedogenesis. Then highly ferruginous matrix supported gravels and coarse sands (Gmm) of 0.25 – 0.37 metres depth carries the sign of poorly sorted deposits of debris flow and transported ferruginous materials from upper catchment. It is composed of subaqueously resedimented (gravity winnowed) materials derived from unstable portion of already frozen gravelly bed further upslope and then it is laterized with iron oxides. At the top of the profile (up to 0.25 metres depth) the irregular to sub-rounded upward fining gravel deposits (Gmg) are weakly cemented by derived ferruginous materials. It reflects a low strength debris flow with the development of internal friction due to water loss (Miall, 2006). The lack of imbrications of Gmg facies indicates the fully turbulent flow at the top, not allowing clast imbrications but a clast alignment parallel to flow (Mahapatra and Dana, 2009). The presence of out-sized clasts is the results of occasional dominance of inertia flow. According to Postma *et al.,* (1988) the occasional large out-sized clasts are found to float along the rheological interface between the grain flow and the overlying turbidity current. The overall sedimentary sequence of this lithosection is recognized as *Gci – Gcg – Fm – Gmm – Gmg*.

Lithosection G3

Eight massive lithofacies are encountered in the lithosection G3 (23° 36.592´ N and 87° 18.626´ E) having greater percentage of ferruginous concretion at top and kaolinte clay at base (figure 4). Below 4.0 metres of depth the imbrications of large clasts (Gcm) with mottles and kaolinte suggest low-strength, pseudo-plastic debris flows, deposited from viscous, laminar and turbulent flows (Miall, 2006). Following this massive facies three similar upward fining gravel layers (Gcg) are found at the depths of 3.1 – 4.0 metres, 2.6 – 3.1 metres and 2.3 – 2.6 metres respectively. The decreasing concentration of ferruginous concretions in these lithofacies of Gcg reflects free movement of clasts in a subaqueous mass flow deposits with vertical and lateral segregation of gravels (Mahapatra and Dana, 2009). Therefore, three similar depositional episodes occurred with weak post-depositional lateritic pedogenesis. Interestingly the mid-layer of oxidized coarse sands and gravels (deep reddish brown in colour) was deposited as subaqueous resedimented (gravity winnowed) materials in between 2.6 – 3.1 metres depth. Then the matrix supported upward fining gravels with iron concretions (Gmm) of 1.2 – 2.3 metres depth implies a high density debris flow, forming lobate with convex-up margin (Miall, 2006). The massive (0.72 – 1.2 metres depth) light brown coloured Fm facies reflects again very fine hemipelagic deposits in a stable suspension flow condition. Normally graded imbrication of gravels (Gcg) reflects again subaqueous mass flow at a depth of 0.15 – 0.72 metres with out-sized clasts at top (inertia flow). The topmost facies (up to 0.15 metres depth) of Gmg is the result of turbulent mass flow with weak matrix formation and it is turned into lateritic crust with heterogeneous materials. Therefore we have recognized here a new sedimentary sequence as *Gcm – Gcg – Gcg – Gcg – Gmm – Fm – Gcg – Gmg.*

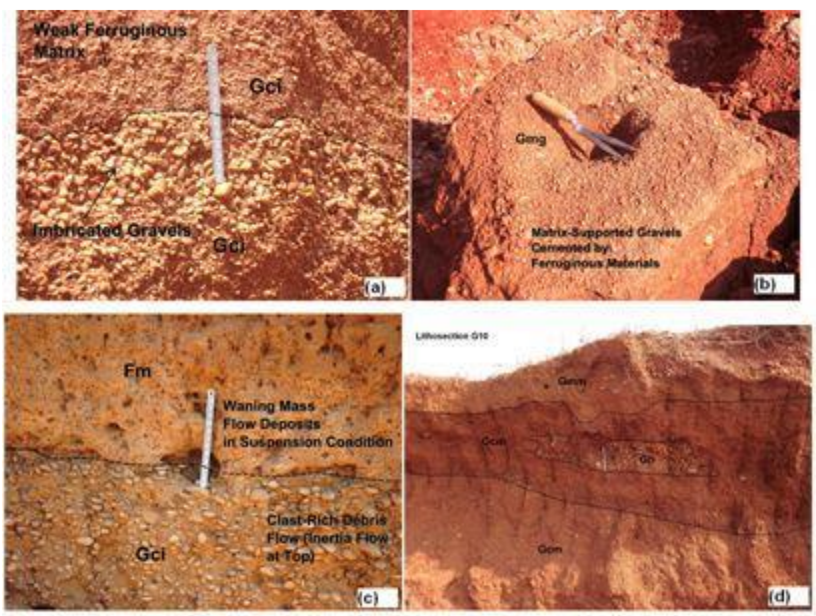

Figure 5: (a) Inversely graded clast-supported gravels (Gci) at Kamalpur (note: length of metal scale is 30 cm); (b) broken block of weak matrix-supported gravels (Gmg) with high percentage of cemented iron oxides at Hetodoba (note: length of auger is 21 cm); (c) bottom Gci facies is overlain by grey – light brown clayey Fm facies which signifies brackish estuarine condition at Kamalpur (note: length of metal scale is 30 cm); and (d) association of Gcm (clast-supported) and Gmg (matrix-supported) facies are influenced by the fluvial facies Gh as lag or sieve deposits with erosional unconformity at Hetodoba (note: length of pen is 14.5 cm).

Lithosection G4

Consisting of nine distinct lithofacies, the lithosection G4 (23° 36.527´ N and 87° 18.841´ E) has both normal graded and inverse graded clast-supported gravels beds with high percentage of ferruginous materials and kaolinite (figure 4). Below 5.8 metres depth, an imbrication of upward coarsening of large clasts (Gci) is strongly coated by kaolinite clay, reflecting cohesionless subaerial debris flow and inertia flow at top (Mahapatra and Dana, 2009). Then clast-supported massive gravels (Gcm) of a depth of 4.8 – 5.8 metres represent low-strength, pseudo-plastic debris flows, deposited from viscous, laminar or turbulent flows (Miall, 2006). Then again Gci facies dominates in between 4.0 and 4.8 metres depth. In between 3.2 and 4.0 metres depth a layer of upward fining of clasts (Gcg) is observed having coating of mottles. Again the presence of Gci facies is observed at depths of 2.6 – 3.2 metres and 1.4 – 2.3 metres respectively. In between these facies Gcm facies is encountered at a depth of 2.3 – 2.6 metres. Wavy ferruginous clayey Fm facies (0.4 – 1.4 metres depth) signifies wanning flow in suspension condition. Cementation of heterogeneous gravel deposits (Gmg) is observed up to depth of 0.4 metres, reflecting last subaerial debris flow, developing lobate. The out-sized clasts are found at depth of 0.4, 2.35 and 3.2 metres depth respectively, reflecting an interface between the grain flows and the overlying turbidity current. This lithosection has revealed few repeated episodes of same sedimentary deposition as *Gci – Gcm – Gci – Gcg – Gci – Gcm – Gci – Fm – Gmg*.

Lithosection G5

This excavated profile (23° 36.224´ N and 87° 17.957´ E) is consisted of seven facies, dipping upslope and imbricated (figure 6). Up to depth of 1.88 – 2.35 metres Gci facies dominates the base, with high percentage of mottles and limonite. Normally graded massive Gcg facies is observed in between 1.55 – 1.88 metres and 0.75 – 1.25 metres depth respectively, showing subaqueous mass flow deposits and inertia flow at the top of facies (presence of imbricated out-sized clasts). Inversely graded Gci facies is found again at a depth of 1.25 – 1.55 metres and 0.53 – 0.75 metres, signifies counter cohesionless subaerial debris flow (Mahapatra and Dana, 2009). Waning flow deposits (Fm) are found at a depth of 0.12 – 0.53 metres. The top of this lithosection is dominated by the matrix-supported gravels (Gmg) and ferruginous concretion. It is observed that lower gravel facies are associated with erosional unconformity and wavy in appearance. The resultant sedimentary sequence is recognized as *Gci – Gcg – Gci – Gcg – Gci – Fm – Gmg*.

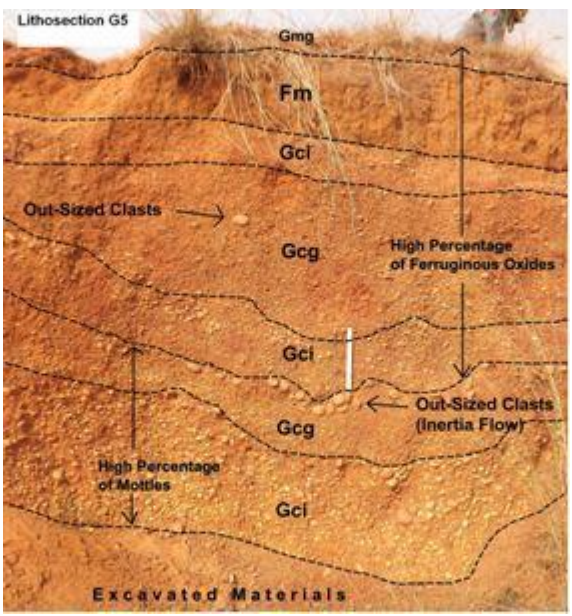

Figure 6: Lithosection G5 shows repeated dominance of ferruginous clast-supported gravel facies (Gci and Gcg) at base with occurrence of imbricated out-sized clasts (inertia flow deposits) and cemented Fm and Gmg facies at top (note: length of metal scale is 30 cm).

International Journal of Geology, Earth & Environmental Sciences ISSN: 2277-2081 (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jgee.htm
2014 Vol. 4 (3) September-December, pp. 81-100/Ghosh
Research Article

Lithosection G6

Seven facies are identified in the lithosection G6 (23° 36.686´ N and 87° 18.928´ E), having faint lamination of coarse sands and gravels (figure 7). Up to depth of 1.45 – 1.90 metres normally graded clast-supported gravels (Gcg) reflects least viscous mass flow deposits with coatings of iron oxides. Unoxidized Gcm facies is found at a depth of 0.55 – 0.90 metres, 0.90 – 1.20 metres and 1.20 – 1.45 metres respectively, having oxidized crudely bedded gravels (Gh) as lag deposits. The absence of iron oxides and mottles may be attributed to relatively dry climate and rapid channel fills. Laminated massive fine to coarse sands (Sm) with high percentage of hematite is found at a depth of 0.25 – 0.55 metres, showing sluggish sediment gravity flow deposits (Miall, 2006). Again the presence of unoxidized Gcg facies reflects counter least viscous mass flow deposits at a depth of 0.15 – 0.25 metres. Though the Fm facies is absent here but Gmg facies again dominates the top of lithosection. The overall sedimentary sequence signifies an estuarine deposits, minor channel fills and progradation of fan-delta as *Gcg – Gcm – Gcm – Gcm – Sm – Gcg – Gmg.*

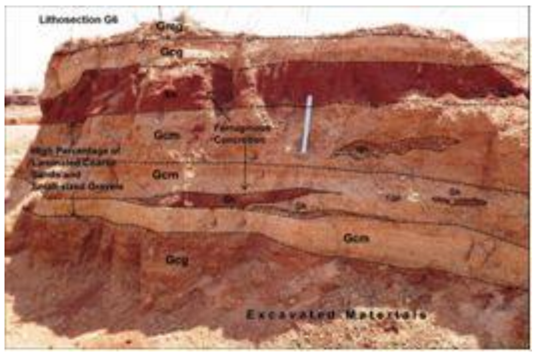

Figure 7: Lithosection G6 shows deposition at distal part of fan-delta setting with unoxidized thick Gcm facies, inter-bedded oxidized Gh facies (lag deposits) and highly oxidized Sm facies (post-depositional lateritization); high percentage of laminated coarse sands in Gcm facies indicates minor channel fills and progradation of delta from shallow marine to fluvial condition (note: length of metal scale is 30 cm).

Lithosection G7

Eight prograded facies are indentified in the lithosection G7 (23° 26.592´ N and 87° 18.626´ E) showing differential alignment with flow types at distal part of fan-delta. Gci dominates base, reflecting low-viscosity debris flow with inertia flow at top (figure 8). Trough cross-bedded gravel (Gt) signifies minor channel fills at the distal part of gravel lobe, following lag deposits of coarse grains and post-depositional lateritization since Late Tertiary.

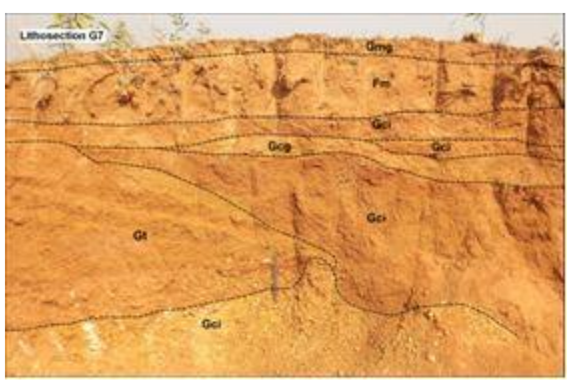

Figure 8: Lithosection G7 shows dominance of Gci facies at base with minor channel fill deposits (Gt) and massive Fm facies at top (note: length of metal scale is 30 cm).

The initiations of repeated Gci and Gcg facies (0.35 – 1.20 metres depth) reflect again clast-rich debris flow and subaqueous mass flow. Similarly Fm and Gmg facies dominate the top set of lithosection. The sedimentary sequence is identified as *Gci – Gt – Gci – Gcg – Gci – Gci – Fm – Gmg.* ***Fan-deltaic Origin of Gravel Facies***

Analyzing the seven facies it is recognized that upper flow regime (mainly Gci facies) dominated the base, and then lower flow regime (Fm facies) and at last again upper flow regime (mainly Gmg facies) made upward coarser gravel sequence in this fan delta setting (figure 9). The lack of imbrication of most of the clasts indicates the fully turbulent flow at the top and the turbidity currents have waning flows, developing massive clayey facies at top of lithosections. The clast-rich high debris flow predominated the basal slope of alluvial fan (at apex), and then the pseudoplastic debris flow to turbulent flow prevailed on the fan-delta slope (distal part) to deposit as much as gravels and coarse sands with ferruginous materials in the Bengal Basin (figure 9). The event that followed mudflows, sheetfloods and back swamp gave rise to Fm (Tamrakar *et al.,* 2009). On the proximal fan-delta in this case has been affected by the wandering river gravels that were fed by the alluvial system further upstream. The system covers subareal delta and fan fringe. Absence of preferred orientation of clasts, organization of clasts, poor modification of shape, poor sorting and matrix-supported fabric of dominant lithofacies Gmm and Gmg suggests that wandering river gravel perhaps deposited with frequent sediment gravity flows (Tamrakar *et al.,* 2009).

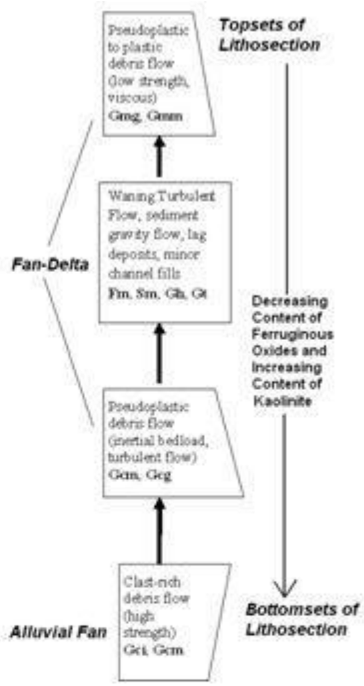

Figure 9: Schematic model indicates sequence in sediment gravity flows, fan deposits and fluvial deposits in alluvial fan to fan-delta setting in the study area; clast-rich debris flow transforms into pseudoplastic debris flow - waning turbidity flow and ends into low strength plastic debris flow

We have observed six principal facies of lateritized gravels which are summarized as follows.

1. The inversely graded and chaotic clast-supported gravels, i.e. Gci, were deposited under subaerial condition by clast-rich debris flow (high strength) and by occasionally low strength pseudoplastic debris flow. This facies (at the base of lithosections) represents the alluvial fan portion of the deposit at apex of fan-delta.
2. The facies of Gcg and Gcm were deposited in subaqueous condition when the Bay of Bengal touched the fan-delta slope. These gravel facies represent pseudoplastic debris flow, inertia flow, turbulent flow due to intake of shallow water at depressed Bengal Basin.

3. According to Mahapatra and Dana (2009) the stratified gravels and coarse sands (figure 7) developed further downslope (distal part of fan-delta), reflects a subaqueously resedimented material derived from the unstable portion of the fan-delta. It is observed that the depositional couplets of sheetflood (i.e. coarse gravel) were deposited as bedload (unoxidized) when standing waves were forming, overlain by finer gravel, sand and mud (oxidized Sm and Fm) deposited from suspension as the wave is washed out (Mahadevan, 2002; Nichols, 2009).
4. The early developed gravelly sediments are crossed cut by small channel fills (Gt) formed due to later surges. Towards the distal part of each lobe the depositional environment was transformed from alluvial fan to fan-delta setting (Mahapatra and Dana, 2009) because gradual increase in finer sediments, inter connectedness of the channels and number of spill over channels are observed in the distal part.
5. The common occurrence of massive Fm facies signifies relatively stable condition and waning turbidity flow when the lithofacies was under shallow water and very finer clay and silt were deposited in a suspension condition.
6. The last depositional facies (Gmg and Gmm) is matrix-supported gravels of different sizes, reflecting high strength viscous plastic debris flow. But this facies thickness is decreased with distance from apex of lobe because this type of material does not travel far due to higher friction at basal part of the flow.

Examining the grain sizes of gravels by the slide-calipers the deposition of bedload at critical flow velocity is determined to understand the power of palaeocurrent (critical depostional velocity of mass flows) in this fan delta (table 3). According to Hjulstorm diagram (Nichols, 2009) a pebble will come to rest at round 20 – 30 cm s^{-1}, a medium sand grain at 2 – 3 cm s^{-1} and a clay particle when the flow velocity is effectively zero (Nichols, 2009). The maximum size of coarser gravels ranges from 453 to 523 mm (except large out-sized clasts) and minimum size of gravels varies from 32 to 45 mm in the identified lithosections. The estimated palaeoflow velocity of Gci (clast-supported) facies varies from 135 to 205 cm s^{-1} and Gmg (matrix-supported) facies varies from 100 to 70 cm s^{-1} in the depositional lithounits of western Bengal Basin. According to Middleton (1967) the low density turbidity current includes 23 per cent solids by volume and the high density turbidity current includes 44 per cent solids by volume. High density turbidity current has a bulk density of at least 1.1 g cm^{-3} and the tubidites deposited by the flows have a thicker coarse unit at their base (Nichols, 2009). It has been found that 5 per cent clay (including water) matrix by volume provides buoyant lift (Rodine and Johnson, 1976) and 19 per cent clay by weight provides strength to coarse-grained sandy debris flow (Hampton, 1975).

Table 3: Estimating depositional critical palaeoflow velocity of gravels in the study area

Average grain size of gravels (mm)	**Deposition of bedload at critical flow velocity (cm s^{-1})**
>500	>205
400	190
200	135
100	100
80	90
60	78
40	70

Evolution of Tertiary Gravel Deposits

The date of separation of the Indian segment of the Gondwanaland from the Antarctic – Australia segment may be placed in Early Cretaceous (127 million years) (Vaidyanadhan and Ghosh, 1993; Meert *et al.*, 2010). As rifting widen a new sea floor was created up on which the Indian Ocean entered as Bay of Bengal (Vaidyanadhan and Ghosh, 1993). A Permian palaeo-shelf was present intervening between Peninsular India and a landmass that lay to its east (Vaidyanadhan and Ghosh, 1993). The Rajmahal Volcanics were the earliest manifestation of volcanic activity (Late Jurassic) which bordered the sea from the peninsular landmass. During Early Tertiary Period (Palaeogene) the Bay of Bengal was reached northwards up to the Garo – Rajmahal Saddle (Vaidyanadhan and Ghosh, 1993). The whole of the present day Bengal Basin (including Ganga – Brahmaputra Delta) was under water until the Mio – Pliocene Epoch and then the strandline grazed the eastern margin of the Peninsular Shield, i.e. much inland (towards west) from the present day Orissa – Bengal Coastline (Vaidyanadhan and Ghosh, 1993; Das Gupta and Mukherjee, 2006).

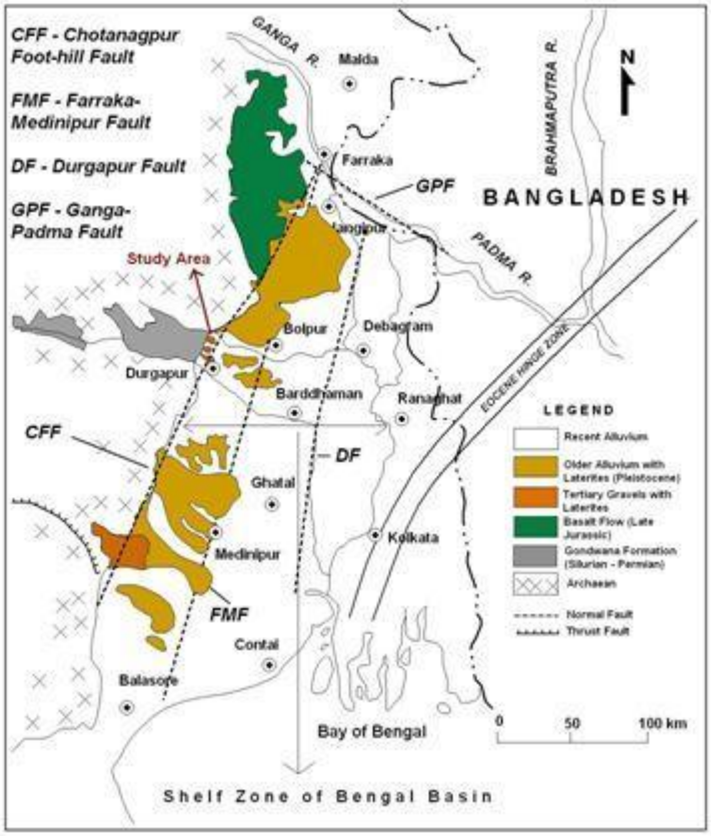

Figure 10: Geological setup of western part of Bengal Basin (shelf zone) linking Tertiary deposits with fault controlled structure (Modified from Sengupta, 1970; Singh *et al.*, 1998)

The zone (i.e. *Rarh Plain*) between the Raniganj Coalfield (west) and the Bhagirathi – Hooghly River (east) is recognized as the north-western delta shelf zone of Bengal Basin which is stretched from Farakka in the north to Digha – Haldia coastline in the south (figure 10) (Vaidyanadhan and Ghosh, 1993). The faults of western margin of Bengal Basin are arranged in an en echelon pattern (Sengupta, 1970) and it is possible that this structural zone along the Basin margin behaved as a tectonic hinge (Eocene Hinge Zone) and controlled the depositional conditions throughout the Tertiary (Mukhopadhyay, 1970). After formation of rifted Upper Gondwana Super Group (i.e. Barren Measure Formation, Raniganj Formation) and creation of the Basin Margin Chotanagpur Foot-hill Fault (Singh *et al.*, 1998) the coarse sediments were started to deposit since Late Cretaceous as the Panchet Formation and Dugrapur Formation. The Durgapur Beds (felspathic sandstone), grits and mottled clays are considered as Upper Tertiary age (Neogene) (Hundy and Banerjee, 1967). As a result of faulting the uplifted Gondwana Formation was behave as a closure to shallow marine condition and the derived fluvial gravelly sediments were deposited as fan-delta on the subsided eastern block where the Bay of Bengal encroached to Gondwana Formation in Early to Middle Miocene (Hundy and Banerjee, 1967).
The imaginary line joining the point of initiation of each gravel lobe may signify the trace of fault plane (Mahapatra and Dana, 2009). According to Satpathi (1981) during the Tertiary Period the peneplained surfaces were uplifted to different elevations during Oligocene, Mid-Miocene and Pliocene – Pleistocene in which periods in sympathy with the violent Himalayan orogenic movement this region experienced

International Journal of Geology, Earth & Environmental Sciences ISSN: 2277-2081 (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jgee.htm
2014 Vol. 4 (3) September-December, pp. 81-100/Ghosh
Research Article

regional uplifts, creating few faults in the western shelf region, viz., Medinipur – Farakka fault and Damodar fault respectively (Singh *et al.,* 1998). The Raniganj Coalfield (Damodar rift graben) was further faulted down in the eastern parts in between Late Jurassic and Early Cretaceous and the depositions of Bengal Basin started under fluvial conditions in this area in Late Cretaceous (Das, 1972). This was interrupted by the marine incursions in between Oligocene and Miocene, forming the fan-deltaic depositions (Das, 1972). As the sea regressed in the Miocene, the fluviatile conditions were reestablished along the present day courses of Ajay and Damodar rivers, developing the Sijua, Panskura and Diara Formations (Das, 1972). The depth of basement increases from 35 metres in the west around Arra to more than 150 metres in the east (Das, 1972). There is an abrupt steeping of the gradient of the basement between Molangdighi and Rakshitpur, bearing evidences of jointed and fractured sandstones with mineralization and silicification at Kuldiha (Das, 1972). This post-Gondwana and pre-Cretaceous – Tertiary remnant topography influenced the sedimentation of gravels in this region (Das, 1972).

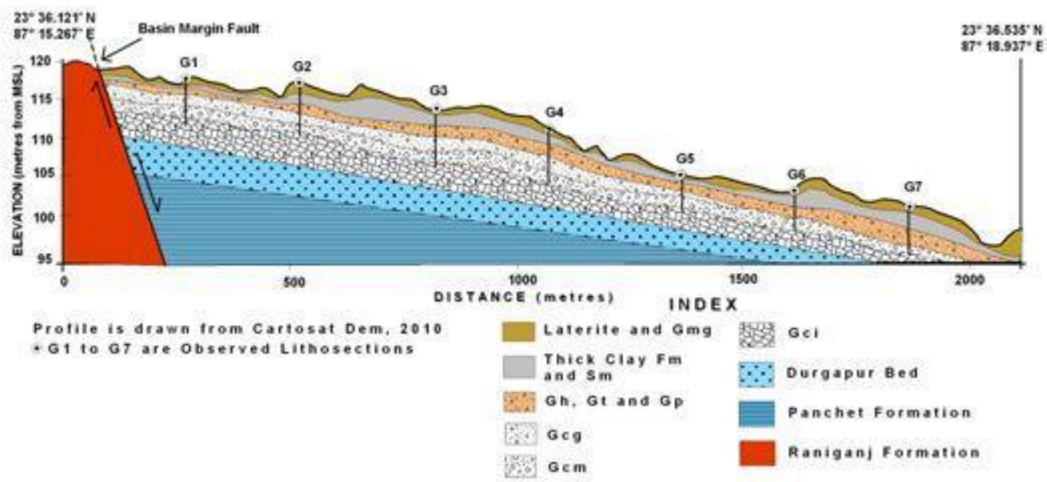

Figure 11: Subsurface long profile shows progradation of alluvial delta to fan-delta on the subsided faulted scarp where Gci, Gcg and Gcm facies indicate alluvial fan deposits above sea level where Gh, Gt, Gp, Fm, Gmg and Gmm (fan-delta deposits) deposited in shallow marine to fluvial condition when the shoreline regressed from this region since the end of Miocene Epoch

Here the debris flow fan developed its proximal area in steepest depositional fault plane where the fan form radiates, developing few lobes of gravels in connection with sea level. The initial process of deposition was started as alluvial fan but due to Miocene transgression of sea level the fan-deltaic sediments were deposited on the subsided faulted block under estuarine condition. The gravel lobes of Dhoadanga, Kamalpur, Bansia, Hetodoba and Bansgara villages (Mahapatra and Dana, 2009) were formed due to transport and deposition by debris flows (i.e. viscous slurry of material), coming from the Gondwana upland. In this fan-delta setting five types of flows are dominated from base to top of the lithosections (figure 9). The identified lithofacies with kaolinite and ochreous are recognized as Kuldiha Formation by Das (1972), comprising unconsolidated to semi-consolidated gravels, coarse sands and ferruginous materials which was derived from Raniganj Formation. The marine incursion started in Oligocene and continued up to Miocene (Das, 1972). Most of the fan-delta deposits were occurred in this period and east of the fault line was influenced by brackish water lagoonal conditions (Khatpukur Formation). At the close of Miocene, the uplift and erosion occurred in this part of Bengal Basin, developing Bishtupur Formation in Early Pleistocene Epoch (Das, 1972). It is assumed that since Miocene Epoch the shoreline moved away from the western part of Bengal Basin and the coarse sediments with ferruginous materials and kaolinite exceeds the space available for its accommodation, an upward change to a shallower facies takes place within the Bengal Basin, as a process of progradation of fan-delta.

International Journal of Geology, Earth & Environmental Sciences ISSN: 2277-2081 (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jgee.htm
2014 Vol. 4 (3) September-December, pp. 81-100/Ghosh
Research Article

Ferruginous Concretion as Indicator of Palaeomonsoon

Reconstruction of past climate needs a 'climate proxy' which is a physical, chemical or biological attribute or property of the natural system enabling us to understand the change in climate in the past (Singhvi and Kale, 2009). Terrestrial palaeoclimatic proxies of western India include riverine deposits and flood sediments (fluvial archives) which indicate distinct periods of erosion, incision and aggradation associated with changes in the monsoon conditions and sediment supply (Rajaguru *et al.*, 1993; Singhvi and Kale, 2009). The main fluvial responses to the climate changes in India are (Rajaguru *et al.*, 1993; Mishra *et al.*, 2003; Thomas *et al.*, 2007; Singhvi and Kale, 2009):

(1) Periods of aggradation are linked to periods of weaker monsoon, reduced sediment supply and caliches formation (semi-arid climate), and

(2) Periods of stronger monsoon are associated with erosion and incision, increased sediment supply and iron nodules formation (humid monsoon climate).

Climatologically the study area is most tropical, as the Tropic of Cancer (23° 30´ N) passes through Durgapur City. The strong seasonal contrast (permanent wet – dry period) and mean monsoonal rainfall (June – September) of 985 mm make the region perfect for lateritization process (Ghosh and Ghosh, 2003). It is clear that a high proportion of elongate concretions lying horizontally, as well as high proportion of sub-rounded to rounded clasts indicate a transported origin for the concretions investigated here. So here occurrences of ferruginous materials and kaolinite are considered as the climate proxy for palaeomonsoon in this region as palaeopedogenesis of gravel deposits. Ferricretes or laterites are typical of hot, humid tropical climates (mean annual rainfall of 1200 – 1700 mm; mean atmospheric relative humidity smaller than 80 %; mean annual temperature around 28° C) but with long dry season (at least 4 months) which is analogous with Indian monsoon climate (Tardy *et al.*, 1991).

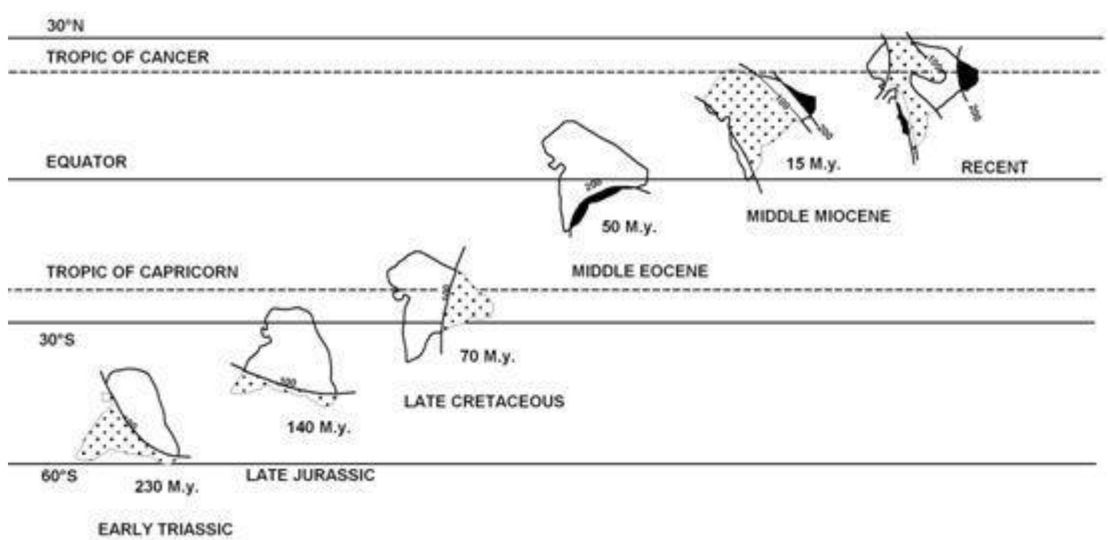

Figure 12: Drifting of Indian plate from the southern hemisphere to present position and establishment of tropical climate favourable for lateritization since Late Cretaceous (after Tardy *et al.*, 1991).

Considering the plate movement model when going from wet – dry tropical climate to arid ones, the ferricretes are marked by decreasing goethite contents and by increasing hematite contents and by nodule formation (Tardy *et al.*, 1991). In contrast, a decrease in indurations together with a goethite development is evident when going from contrasted tropical zones to equatorial ones (Tardy *et al.*, 1991). From the end of the Triassic to the Cretaceous the Indian continent's climate evolved from hot and dry (Late Cretaceous) to hot and humid (since Middle Miocene) (Tardy *et al.*, 1991). The climatic conditions were favourable for lateritization from Cretaceous to Paleocene times and during that period the Indian plate crossed the zone between 30° S and 0° (Equator) (figure 12) (Kumar, 1986; Tardy *et al.,* 1991). After the collision of Indian plate against Eurasian plate at the end of the Miocene, peninsular climate became more tropical or monsoonal having distinct wet and dry phase in a year (Tardy *et al.,* 1991). So it is very interesting to note that the deposits of laterites or ferrecretes (high level or low level) of Peninsular India are vital indicator for the onset of monsoon climate in India as well as in the Bengal Basin. The development of ferruginous materials began at the end of the Cretaceous in eastern part of India and continued during the Tertiary. The occurrence of nodular ferruginous accumulations indicates a derived origin and secondary formation which was derived from the primary laterites of Raniganj Formation (Hundy and Banerjee 1967; Niyogi *et al.*, 1970) through the debris flows at the time of sheetfloods.

Laterites on Tertiary gravelly sediments bear a ploy-profile of low-level laterites with an intervening erosional surface, different mass flow deposits and original gravels (with iron staining) are present in this region (figure 13a). Three distinct zones are identified as (1) nodular ferruginous crust (0 – 1.5 metres depth), (2) mottle gravelly zone (1.5 – 2.5 metres depth) and (3) bleached kaolinte gravels (3.5 – 6.0 metres) (figure 13b). Greyish white to white, soft, porous kaolinitic layer with abundance of original gravels have red to brown spots of iron hydroxides (figure 13c). A series of depositional multiple laminar goethite rinds on concretions, with occasional gibbsite, incorporating individual quartz grains and gravels between them as evidence of their accretionary origin (Milnes *et al.,* 1987; Tardy *et al.,* 1991). So it is evidenced that source region of fan-delta (Gondwana Upland) was already rich with ferruginous materials as primary formation in Miocene Epoch. The deposition of laminar Fm facies with ferruginous clay indicates a succession of pedogenic environment with a long history of exposure and weathering. The ferruginous clay layer with goethite (brownish black in colour) becomes hard due to exposure in the pebble quarries (figure 13d). This layer is overlain by the ferruginous matrix-supported gravel layer, having high percentage of hematite (highly oxidized in humid condition). In this clast-rich porous system lateritization process was favoured by the following factors (Niyogi *et al.*, 1970) –

1. Onset of monsoonal rainfall with prolonged dry months (Mid Eocene – Late Miocene) accelerated subaerial chemical weathering in derived ferruginous matrix, followed by intermediate block upliftment;
2. Adequate permeability and drainage condition to permit deep percolation of silica and deposition of iron oxides as coating over gravels;
3. Warm and strong seasonal climate to hasten the chemical breakdown, hydration and dehydration of ferruginous and aluminous oxides; and
4. Prolonged quiescent phase of geological time with permanent regression of sea level (Late Miocene) from this area.

In this subsided faulted scarp the voluminous coarse sediments were deposited as the gravel facies of alluvial fan - fan-delta probably in Early Miocene when this area was under shallow marine condition. The rounded to sub-rounded shape of gravels indicates a second-cycle origin (Sengupta, 2012) and the increased strength of monsoon rainfall generated frequent sheetfloods and debris flows to transport these gravels from Gondwana upland. The presence of quartz wacke in matrix indicates the origin from sandstones (Sengupta, 2012) which belongs to the Barakar, Ironstone Shale and Raniganj Formations at west. In the Durgapur Depression (Kumar, 2006) the ferruginous materials (Pliocene) were formed over deposited gravels which is probably Oligocene to Miocene age (Mukhopadhyay, 1970; Das, 1972). Local occurrence of lateritic conglomerate (Gmg facies) is product of in-situ lateritization of debris flow deposits in Pliocene to Early Pleistocene and it is comparable to Pleistocene Lalgarh Formation (West Medinipur district, Baltora Formation (Bankura district), Illambazar Formation (Birbhum district), Kharagpur Formation (East Medinipur district) and Worgram Formation (Barddhaman district) (Vaidyanadhan and Ghosh, 1993). Increased precipitation during the ~15 – 5 ka period of monsoon recovery probably increased discharge and promoted incision and widespread badland (rills and gullies) formation (Sinha and Sarkar, 2009). The older flat-topped but dissected lateritized gravel beds appear as an 'inversion of relief topography' (Pain and Ollier, 1995) where the Quaternary Sijua and Panskura Formations are found at the river valleys (below 60 metre from msl) much below Tertiary Formation (90 – 120 metre from msl). In the eastern part the probable age of top lateritic upland has been assigned 350 –

International Journal of Geology, Earth & Environmental Sciences ISSN: 2277-2081 (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jgee.htm
2014 Vol. 4 (3) September-December, pp. 81-100/Ghosh
Research Article

1000 ka by Niyogi (1975). Singh *et al.,* (1998) suggest that the upland red soils of this region are the oldest ferruginous soils from the Indian part of these plains, bearing evidence of palaeomonsoon. The grits and sands (toe of each lobe) show red to brown colouration (staining) due to coating of iron-rich clay minerals (figure 7) mechanically infiltrated later from the muddy suspended load (Mahapatra and Dana, 2009). The red and brown coloured mud facies (Fm) were formed by either post-depositional oxidation process or emergence of land above sea level in Late Miocene – Early Pliocene. Present day formation of ferrecrete is reported to be restricted to Koppen's 'A' Climate Zone, extending from 30° N to 30° S latitude (Tardy *et al.,* 1991).

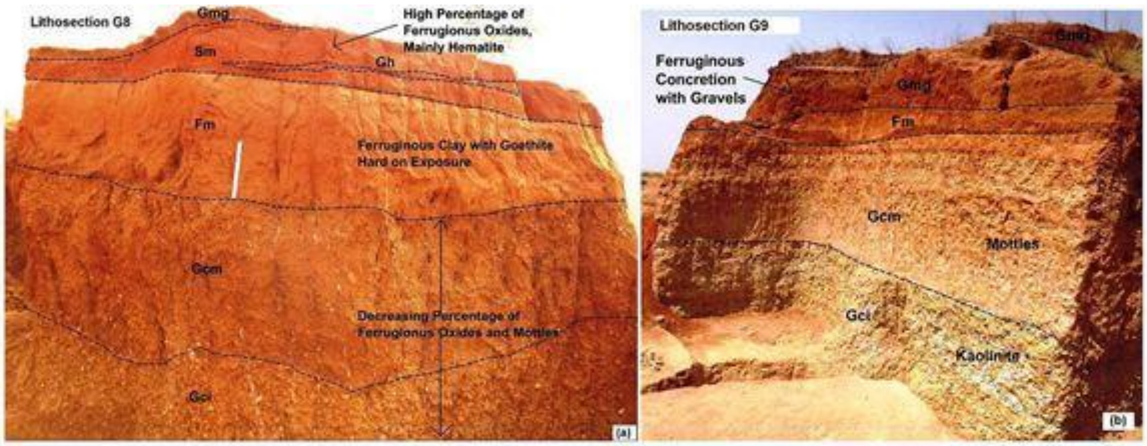

Figure 13: (a) Poly-profile of lateritized gravels signifying different mass flow deposits (Gmg, Sm, Fm, Gcm and Gci) at Hetodoba and (b) distinct appearance of ferruginous concretion, mottles and kolinite in the lithofacies of gravels (Gmg, Fm, Gcm and Gci) at Heodoba (note: length of metal scale is 30 cm)

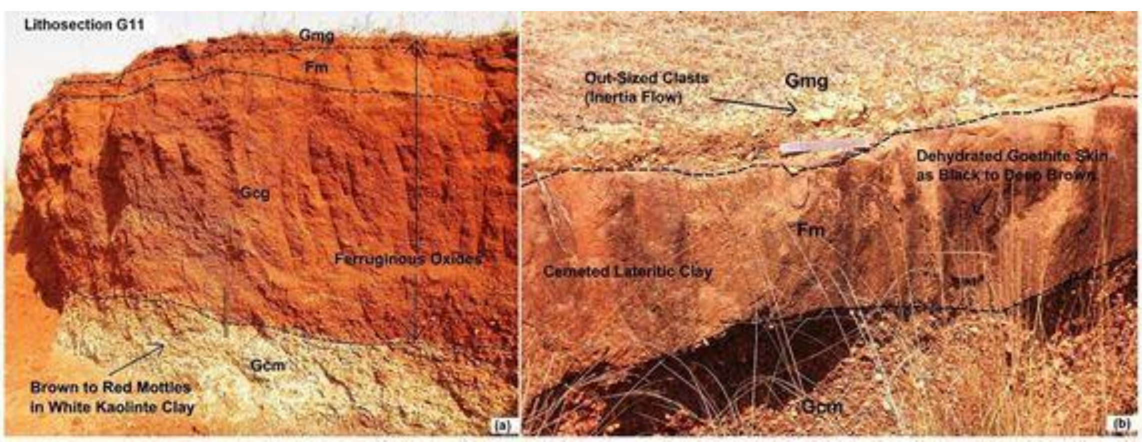

Figure 14: (a) Development of reddish-brown ferruginous oxides on the brown to red mottled layer and white kaolinite clay at Kamalpur and (b) goethite rich ferruginous hard clay (Fm) in between Gmg and Gcm facies at Kamalpur (note: length of metal scale is 30 cm).

The eastern part of Indian peninsula (including Bengal Basin) entered in this zone from Late Cretaceous (figure 12) and the strength of monsoon wind was getting more active since Middle Eocene with the upheaval of Himalayas. Increasing content of hematite (nodular ferruginous accumulations at top) in place of goethite at the toe of each lobe (figure 13 and 14) suggests that climate was going from wet-dry monsoonal climate (Late Tertiary) to semi-arid climate in Early – Middle Pleistocene. But the top reddish

Gmg facies with nodular laterite again signifies more humid condition in between Middle and Late Pleistocene.

Conclusion

The study of sedimentary facies and their vertical and horizontal architectures provide an idea about sedimentation pattern in alluvial fan to fan-delta setting as the earliest shelf deposits of Bengal Basin. Deposited in a subaerial condition Gci and Gcm facies reflect the initiation of sedimentary cycle with clast-rich debris flow (alluvial fan apex portion) on the basement slope of Durgapur Bed and Panchet Formation which was subsided by Chotanagpur Foot-hill Fault at east of Raniganj Coal-field. Deposited in subaqueous condition, the facies of Gcg, Gh, Gt, Sm and Fm reveal turbidity mass flow, inertia flow, sediment gravity flow and waning flow in progradation of fan-delta (distal part of lobe). The presence of low-strength pseudoplastic debris flow (Gmg) indicates the end of sedimentary cycle at the shelf zone of western Bengal Basin. The huge volume of gravels and occurrence of ferruginous materials are strongly correlated with the palaeomonsoon and sheetfloods began in Oligocene - Miocene. Increased seasonality of the climate increased sediment yield in upper catchment, because the vegetation cover was limited by the constraints of the log dry season, so that runoff was more flashy and therefore more competent in the wet season. This effect is particularly marked in monsoon climate which was established in the eastern part of Peninsular India in between Late Cretaceous and Paleocene. With the Tertiary upheavals of Himalayas the strength of monsoon was increased as well as the process of lateritization widely covered the Peninsular India. Typical clastic lithofacies of mass-flow deposits (Gci, Gcm, Gmm and Gmg) indicate a hot - arid system where fan lobe deflation surface overlaid debris-flow winnowed gravels. Occurrence of stream-flow facies (Gh, Gt, Gp) and ferruginous materials indicate an transformation into hot –humid systems with progradation – abandonment cycles of fan lobes. It is assumed that in between Oligocene and Miocene the shoreline of Bay of Bengal was running approximately eastern fringe of Gondwana Formation and due to faulting the derived gravels and channel sand facies deposited in shallow marine condition. After regression of shoreline (Late Miocene) the sedimentary facies were exposed at the surface upliftment and were lateritized under the influence of monsoon climatic regime. Ferrugination took place under overall well drained condition and the hematitic pisolites of Fm and Gmg facies suggests development of ferrisol subphase in which large amounts of red, dehydrated ferric iron are present. On the top of gravel lobes the presence of secondary ferruginous materials reflects an allochthonous origin. This oxidized -materials were derived from the primary laterites (autochthonous origin) developed due to in situ weathering of Raniganj Formation. This fact probes the simultaneous occurrences of gravel lobes and palaeomonsoon at the begging of Miocene in the western part of Bengal Basin.

ACKNOWLEDGEMENT

I sincerely thank to *Subhankar Bera* (Research Fellow, Department of Geography, The University of Burdwan) for his suggestions and field support to do this work in a fruitful manner. I am very much thankful to *Dr. Sanat Kumar Guchhait* (Associate Professor, Department of Geography, The University of Burdwan) for his suggestions to enrich the manuscript. I am also grateful to the Department of Geography, The University of Burdwan for providing me the necessary tools and academic support to conduct this work.

REFERENCES

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

Chamyal LS, Khadkikar AS, Malik JN and Maurya DM (1997). Sedimentology of the Narmada alluvial fan, western India. *Sedimentary Geology* **107** 263 – 279.

Das Gupta AB and Mukherjee B (2006). *Geology of NW Bengal Basin*. Geological Society of India, Bangalore.

Das S (1972). Sedimentation in the Ajay – Damodar Basin; In: *The Bhagirathi – Hooghly Basin*, edited by Bagchi KG (University of Calcutta, Calcutta) 9 – 17.

Das S and Biswas AB (1969). Geology and groundwater conditions of the alluvial tract, east of Durgapur, Burdwan district, West Bengal – a preliminary study. *Indian Geohydrology* **5**(1) 71 – 89.

Devaraju TC and Khanadali SD (1993). Lateritic bauxite profiles of south-western and southern India – characteristics and tectonic significance. *Current Science* **64** 919 – 921.

Ghosh AK (1970). The Paleolithic cultures of Singhbhum. *Transactions of the American Philosophical Society* **60**(1) 3 – 68.

Ghosh S and Ghosh S (2003). Land degradation due to indiscriminate 'murrum' extraction near Durgapur Town, West Bengal. In: *Land Degradation and Desertification*, edited by Jha VC (Rawat Publication, Jaipur) 255 – 267.

Hampton MA (1975). Competence of fine-grained debris flows. *Journal of Sedimentary Petrology* **45** 834 – 844.

Hundy A and Banerjee S (1967). Geology and mineral resources of West Bengal. *Memoirs of the Geological Society of India* **97** 44 – 51.

Kumar J (2006). Integrated modelling of Durgapur Depression (Damodar Basin). *6th International Conference & Exposition on Petroleum Geophysics* 26 – 29.

Lowe DR (1982). Grain flow deposits. *Journal of Sedimentary Petrology* **46** 188 – 199.

Mahadevan TM (2002). *Geology of Bihar and Jharkhand*. Geological Society of India, Bangalore.

Mahapatra S and Dana RK (2009). Lateral variation in gravelly sediments and process in an alluvial fan – fan-delta setting, north of Durgapur. *The Journal of Geological Society of India* **79** 480 – 486.

Meert JG, Pandit MK, Pradhan VR, Banks J, Sirianni R, Stroud M, Newstead B and Gifford J (2010). Precambrian crustal evolution of peninsular India: a 3.0 billion years odyssey. *Journal of Asian Earth Sciences* **39** 483 – 515.

Miall AD (1985). Architectural element analyses: a new method of analyses applied to fluvial deposits. *Earth Science Reviews* **22** 261 – 308.

Miall AD (2006). *The Geology of Fluvial Deposits* (Springer) New York.

Middleton GV (1967). Experiment of density and turbidity currents: III deposition of sediment. *Canadian Journal of Earth Sciences* **333** 350 – 352.

Mishra S, Naik S, Rajaguru SN, Deo S and Ghate S (2003). Fluvial response to Late Quaternary climatic change: case studies from upland western India. *Proceedings of Indian National Science Academy* **69A** 185 – 200.

Mukhopadhyay SC (1970). Tectonic landforms of the south – western fringe area of the Bhagirathi – Hooghly Basin; In: *The Bhagirathi – Hooghly Basin*, edited by Bagchi KG (University of Calcutta, Calcutta) 39 – 47.

Mukhopadhyay SC (1980). *Geomorphology of the Subarnarekha Basin*. The University of Burdwan, Burdwan.

Nichols G (2009). *Sedimentology and Stratigraphy* (Wiley-Blackwell) Chichester.

Niyogi D, Mallick S and Sarkar SK (1970). A preliminary study of laterites of West Bengal, India. In: *Selected papers of physical geography, 21st International Geographical Congress, India*, edited by Chatterjee SP and Das Gupta SP (National Committee for Geography, Calcutta) 443 – 449.

Pain CF and Ollier CD (1995). Inversion of relief – a component of landscape evolution. *Geomorphology* **12** 151 – 165.

Postma G (1984). Slumps and their deposits in fan delta front and slope. *Geology* **12** 27 – 30.

Postma G (1990). Depositional architecture and facies of river and fan delta: a synthesis. *Sedimentology* **10** 13 – 27.

Postma G (1995). Sea-level-related architectural trends in coarse-grained delta complexes. *Sedimentary Geology* **98** 3 – 12.

Postma, G Nemec W and Ronnert L (1988). Large floating clast in turbidities: a mechanism for their emplacement. *Sedimentary Geology* **58** 47 – 61.

Rajaguru SN Kale VS and Badam GL (1993). Quaternary fluvial systems in upland Maharastra. *Current Science* **64** 817 – 821.
Rhodine JD and Johnson AM (1976). The ability of debris, freighted with coarse debris clastic material to flow on gentle slopes. *Sedimentology* **23** 213 – 234.
Satpathi DPP (1981). *An Outline of Indian Geomorphology*. Classical Publishing Company, New Delhi.
Sengupta S (1966). Geological and geophysical studies in western part of Bengal Basin, India. *Bulletin of American Association Petroleum Geology* **50**(5) 1001 – 1017.
Sengupta SM (2012). *Introduction to Sedimentology* (CBS Publishers and Distribution Pvt. Ltd.) New Delhi.
Shanmugam S (1996). High-density turbidity currents: are they sandy debris flows? *Journal of Sedimentary Research* **66**(1) 2 – 10.
Singh LP, Parkash B and Singhvi AK (1998). Evolution of the Lower Gangetic Plain landforms and soils in West Bengal, India. *Catena* **33** 75 – 104.
Singhvi AK and Kale VS (2009). Palaeoclimatic studies in India: Last Ice Age to the Present. *IGBP-WCRP-SCOPE-Report Series* **4** 1 – 30.
Sinha R and Sarkar S (2009). Climate-induced variability in the Late Pleistocene-Holocene fluvial and fluvio-deltaic successions in the Ganga plains, India. *Geomorphology* **113**(3-4) 173 – 188.
Sridhar A (2008). Fluvial palaeohydrological studies in western India: a synthesis. *Earth Science India* **1**(1) 21 – 29.
Tamrakar NK, Shrestha P and Maharjan S (2009). Facies association and depositional environment of fan delta sequence in southwest Kathmandu Basin, Nepal. *Bulletin of the Department of Geology Tribhuvan University Kathmandu Nepal* **12** 1–16.
Tardy Y Kobilsek B and Paquet H (1991). Mineralogical composition and geographical distribution of African and Brazilian periatlantic laterites – the influence of continental drift and tropical palaeoclimates during the past 150 million years and implications for India and Australia. *Journal of African Earth Sciences* **12**(2) 283 – 295.
Vaidyanadhan R and Ghosh RN (1993). Quaternary of the East Coast of India. *Current Science* **64** 804 – 815.