CHAPTER-VIII

SEDIMENTATION HISTORY

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No evidence was found in any part of the Gondwana sequence of the present area to indicate other than continental sedimentation in a fault bounded basin. The sedimentation was initiated in a glacial climate as indicated by the presence of diamictite and dropstones in the lake sediments of the basal part of the succession. Sediment dispersal pattern, stratigraphic relationships, lithofacies and sedimentary structures indicate deposition of the Talchir Group in a predominantly lake environment and the Damuda Group in a fluvial environment by the streams draining a high land to the south. The sedimentary basin may be interpreted as a fault bounded basin bordering a high land to the south, which supplied large volume clastic detritus to the basin.

The lithofacies of Unit-A reveals glaciolacustrine and post-glacial lacustrine fan delta sedimentation (Fig.8.1). In the initial stage of deposition of Unit-A, the basin was occupied by a glacial lake. The complex of diamictite and interbedded sandstones and mudstones probably reflect the fluctuation in glacial activity. The diamictites represent deposition in an ice contact lake in the active stage of glaciation. At the terminus of lake margin, ice blocks floated onto the lake as icebergs, which yielded abundant clastic detritus transported by glaciers. The icebergs dropped various sized detritus into the lake basin mud depositing very poorly sorted, highly disorganized mud-matrix diamictites. On the other hand, when the glaciers retreated, the sandstones and mudstones were deposited in a non-ice contact lake by discrete-event turbidity currents derived from ice-melt streams. The drop stones in the interbedded sandstones and mudstones were originated from the seasonal ice-rafts.

Overlying the glacial lake deposits, the major part of Unit-A was originated in a fan delta environment. The vertical progression from pro-delta and fan delta toe through high gradient fan delta slope to alluvial fan (Fig.8.1) indicates that the alluvial fan prograded into the lake and built the fan delta on the margin of the lake. The development of a fan delta system following glacial lake sedimentation was possibly related to the climatic warming and the fan was fed by northeasterly flowing melt-water streams emerging from the receding glaciers. During glacial recession, collapse of glaciers would have frequently occurred and given rise to highly sediment-laden debris flow and flood flow. Such flows were primarily responsible for the deposition of the conglomerates and sandstones of the alluvial fan. The coarseness of the conglomerates and sandstones of the succession suggests moderate to high relief of the source area while the heavy minerals suggest derivation of the sediments from metamorphosed acid and basic igneous rocks (Fig.7.4). Coarse-grained sediment supply to the offshore slope by the northeasterly flowing streams would have resulted in the development of high gradient fan delta slope. The conglomerates with variety of facies were deposited on the steep fan delta slope reflecting deposition in the different stages of evolution of sediment gravity flows.

Continued sediment input into the steep lake margin led to the aggradation and progradation of the fan delta and reduced the gradient of fan delta slope resulting in outgrowth of an alluvial fan onto the fan delta slope. Occurrence of large scale trough and flat to low angle cross-stratification in the sandstones is suggestive of fluvial activity as well as generation of powerful sheet flood, which spread over the fan surface. Associated matrix-supported conglomerates suggest intermittent debris flow activity on the depositional surface.

The building up of the fan delta as peripheral accretion in a lake environment might have pushed the lake margin further north and the sedimentation of Unit-B was initiated in the new lake level. Change of palaeoslope brought about a change in palaeoflow and sediment dispersal pattern from northeast of Unit-A to a dominant northerly radiating type during the sedimentation of Unit-B (Fig.8.1). Unit-B represents two phases of delta advance in a lake basin (Fig.8.1). Further climatic warming caused considerable retreat or disappearance of the glaciers and the sedimentation in the new lake level was initiated by shallow and narrow, northerly flowing distributary streams, which debouched into the lake. Denudation of the source area caused a decline in the relief and consequent decrease in the competency of the northward flowing distributary streams for which the grain size of the sandstones decreased considerably. Unroofing of low rank metamorphic rocks and pegmatites due to denudation contributed such heavy minerals as biotite, chlorite, brown tourmaline and indicolite in the sediments of Unit-B (Fig.7.4) in addition to the heavy minerals observed in Unit-A.

During the first phase of delta advance the lake basin appears to be very shallow as indicated by the absence of pro-delta or lake floor sediments in the basal part of the succession and the delta building took place on a shallow lake shelf of moderate to high slope. The coarse to fine-grained sediments brought by the distributary streams in a number of phases were spread radially on the lake shelf. The coarser sediments remained confined to the distributary channels which prograded basin ward and formed amalgamated channel sandstones while the fine-grained sediments moved into the interdistributary areas and formed interbedded sheet sandstones and mudstones on the subaqueous delta platform. Wide lateral persistency and internal stratification sequences identical to turbidite model of Bouma suggest deposition of the sheet sandstones from the unconfined sheet flow of turbidity currents which spread widely onto the subaqueous interchannel areas. Such turbidity currents possibly were triggered due to debouching of sediment-laden distributary channels into the stagnant pool of lake water.

Following the first phase of delta advance on a shallow lake shelf the basin shows gradual deepening and second phase of delta advance with the development of all the four constructional phases of delta viz. pro-delta or lake basin floor, delta slope, subaqueous delta platform and deltaic distributary channel sand from the base to top. Such deepening of the lacustrine regime may be a consequence of rapid climatic warming which led to the recession and disappearance of glaciers and resulted in supply of abundant melt water into the graben. Climatic warming is indicated by extensive carbonate sedimentation, presence of red beds, stromatolitic algal limestones, growth of fibrous calcite along the bedding plane fractures of the mudstones and the mud cracks at the top of the succession.

Thick mudstones with varve like rhythmites at the basal part of the succession are lake basin floor or pro-delta sediments deposited in deep lake basinal environment. The varve like deposits may be of multiple origins. The millimeter thick, regularly alternating layers of fine and coarse sediments may represent annual rhythms of sediment accumulation. On the other hand, the coarse layers (10 - 30 mm thick) showing grading and internal stratification sequences comparable to Bouma's model, indicate deposition from low density, dilute turbidity currents spreading over the lake basin floor. Occurrence of 5 - 10 cm thick, laterally persistent beds of marlstones within the mudstones suggests climatic warming and precipitation of $CaCO_3$ at regular interval against a constant background of clay deposition.

The basin floor or pro-delta mudstones grade upward into the coarsening and thickening upward sandstone and mudstone sequence which was deposited on the base of slope environment. High density turbidity currents flowed down slope into the lake basin via channels dissecting the slope. The sediments delivered from the mouth of the channels were deposited at the base of slope forming sublacustrine fan lobe which prograded onto the lake basin floor. The thick pile of sediments deposited on the slope, slumped frequently due to gravity slumping and triggered turbidity currents. A number of slump features and penecontemporaneous deformation features attest to such slumping along the slope.

Deposition of sublacustrine fan lobe sequence at the base caused significant shallowing of the slope. Temporary cessation of sediment supply from the source favoured sedimentation from suspension and chemical precipitation resulting in accumulation of a thick sequence of interbedded mudstone and marlstone on the shallow lake shelf. The reduction of slope favoured growth of algae in localized areas. Since the algae require sunlight for photosynthesis, a maximum depth of 45 - 60 m can be suggested for the slope. In addition to trapping the lime-mud drift, the algae extracted CO_2 from the surrounding lake water resulting in the precipitation of $CaCO_3$ and formed stromatolitic algal limestones.

The lake slope sediments in their upward progression pass into distributary channels associated with over bank and interdistributary levee sediments deposited on the subaqueous and subaerial part of the delta (Fig.8.1). The channel sandstones, ripple cross laminations and asymmetric current ripples in the sheet sandstones (levee deposit) suggest incoming of sediments in pulses, increase in the current velocity and decrease in the water depth. The distributary channels were small in scale and were filled rapidly with frequent lateral shifting as revealed by relatively thin channel fill sequences and multistory and multilateral nature of the channel sandstones. Well developed over bank levee deposits closely associated with the distributary channels are indicative of frequent spill over of the sediments from the distributary channels onto the interdistributary areas. Rhythmic interbedding of sheet sandstones and mudstones of levee deposits, absence of deep scours on the bases of the sandstones and internal stratification sequences identical to Bouma's turbidite model suggest deposition of the sheet sandstones from the unconfined sheet flow of turbidity currents generated by spill over sediments. Wide lateral persistency of the sheet sandstones and mudstones suggests that the turbidity currents spread widely onto the subaqueous interchannel areas. The thick amalgamated channel sandstones displaying Ta and Tab turbidite sequences were formed by high density turbidity currents.

The second phase of delta advance in the lake basin was followed by emergence and desiccation of the basin as indicated by the red colour of the sandstones (acquired by the bleeding of the opaque minerals), mud cracks and growth of fibrous calcite along the bedding plane fractures of the mudstones.

Unit-B, therefore, represents two phases of delta advance in a lake basin under widely varying physical conditions like depth, palaeoslope, rate of sediment supply etc. Since the entire succession was deposited by turbidity current mechanism, the succession may be regarded as a high slope turbidite delta with two phases of delta advance in a lake basin.

Sedimentation of Unit-C was marked by continued deepening of the basin, further decrease in the source area relief and a dominant northerly palaeoflow with a slight swing towards northwest (Fig. 8.1). Accumulation of thick mudstones interbedded with marlstones in the lower part of the succession suggests cessation of supply of coarser clastics from the source and sedimentation from suspension and chemical precipitation in a deep and quiet lake basin. The bedded marlstones were formed by the precipitation of $CaCO_3$ at regular interval because of rise of temperature of the lake water. The thick mudstones become heterolithic upward by the addition of discrete beds of ripple-drift cross-laminated fine-grained sandstones, which increase in frequency, bed thickness and grain size. In the later part of sedimentation, the source area supplied very fine sand to depositional site through streams flowing in a northerly direction. The streams carrying fine-grained sediments debouched into the quiet lake basin and triggered density underflows, which carried the fine detritus into the deep lake basin and deposited ripple-drift cross-laminated sandstones. The upward increase in frequency, bed thickness and grain size of the sandstones suggests increasing bed load sedimentation. Consequently, the lake basin was rapidly filled by the fine-grained sediments and eventually turned to a fluvial depositional environment in which the sediments of Damuda Group were laid down.

The lithofacies association and sedimentary cycles of the Karharbari and Barakar Formation of Damuda Group suggest sedimentation in a fluvial regime under humid tropical climatic condition. The palaeocurrent and sediment dispersal pattern indicate a northwesterly palaeoflow with the dispersal of coarse to fine clastics from the source terrain that was located towards the southeastern side of the basin (Fig.8.1). The relief of the source area and subsidence of the basin floor played an important role in shaping the sedimentary distributive mechanism and consequent sedimentary cycles of the Karharbari and Barakar Formation of the present area.

The Karharbari Formation is characterised by wide variation in grain size from boulder conglomerate to fine sandstone deposited by stream flow, debris flow and sheet flood processes. The coarsening upward nature of the sedimentary cycles, absence of thick and laterally extensive coal seams (Fig.8.1) and proximity of the succession to the southern faulted boundary of the basin suggest deposition in an alluvial fan environment (Fig.8.1).

Reactivation of the boundary faults caused source area uplift, basin subsidence and steepening of the alluvial surface as indicated by the coarsening upward nature of the sedimentary cycles and the drainage deflection towards northwest. The Karharbari succession, thus, represents a syntectonic phase of sedimentation. Tectonism in the source area upraised the igneous and metamorphic complex of the Easternghat Group and exposed for the first time the high rank metamorphic rocks as evidenced by the first appearance of staurolite and sillimanite in these sediments (Fig.7.4). Prolonged weathering under a humid tropical climate produced large volume of clastic detritus at the source. An increase in the relief and gradient and consequent increase in the competency of northwesterly flowing streams brought large volume of clastics to the basin which were distributed radially and formed an alluvial fan or a series of laterally coalescing alluvial fans along the faulted margin of the basin. Increased gradient caused frequent bifurcation of the streams resulting in an interlaced network of braided channels and bars on the depositional surface. Frequent lateral shifting of the channels and bars produced multistory and multilateral sandstone bodies without extensive development of over bank flood plain and swamp deposits.

The lower part of the succession is dominantly composed of stream flow and sheet flood sandstones and suggests deposition in a more distal part of the alluvial fan. The trough and planar cross-stratified sandstones attest stream flow sedimentation. The multistory and multilateral sandstone bodies are suggestive of infilling of rapidly shifting channels. The associated ripple-drift cross-laminated sandstones are interpreted as sheet flood deposits. Sheet like geometry and ripple-drift cross-laminations are suggestive of rapid deposition from heavily sediment-laden flows, which spread over the depositional surface as unchannellised, laterally extensive sheet floods. An expansion of braided channels resulted in multistory and multilateral sandstone bodies. As the channels became poorly defined, unchannellised sheet floods became a dominant process on the distal part of the fan.

The upper part of the succession is characterised by coarsening upward cycles composed of trough and planar cross-stratified pebbly sandstones, unstratified boulder conglomerate and matrix-supported boulder conglomerate. These are deposited in a proximal and mid-fan environment by stream flow and debris flow processes. The vertical progression from distal fan to mid- and proximal fan indicates that the alluvial fan prograded towards the basin. Such progradation is of tectonic origin resulting from the tectonic rise of the source area. Intense tectonic uplift in the source area caused a steep gradient when large volume of boulders, cobbles and pebbles were transported by high velocity braided streams and were deposited on the mid fan depositional surface as gravelly channel and bar deposit. Frequent supply of large volume of coarse clastics caused progradation of the mid- and proximal fan over the distal fan segment depositing a thick blanket of unstratified boulder conglomerate at the top of the succession (Fig.8.1). The matrix-supported conglomerates were formed by intermittent debris flow which extended into the mid fan environment.

The thin and impersistent coal seams occurring as pods, ribbons, dendroids and belts within the thick succession of sandstones and conglomerates were formed in abandoned channels, irregular depressions on the fan surface and in the interlobe and lobe front depressions which formed stagnant pool of water and were converted to swamps.

The Barakar Formation represents deposition in a meandering stream depositional environment as revealed by the fining upward sedimentary cycles. Stable, unidirectional, northwesterly palaeoflow and metamorphosis of the braided stream depositional environment to a low sinuosity meandering stream environment (Fig.8.1) suggest stable to substable condition of the source area as well as the depositional site and decrease in the stream gradient. Intense tectonic uplift of the source area during boulder gravel period was followed by a long period of stability and prolonged denudation which caused a decline in relief and consequent decrease in the stream gradient and competency of the northwesterly flowing streams. Deep and prolonged weathering also exposed the deeper part of the crust documented by the appearance of significant proportion of high rank metamorphic minerals like sillimanite, staurolite and blue-green hornblende in the Barakar sediments (Fig.7.4).

The clastic detritus formed at the source area was supplied to a system of northwesterly flowing sub parallel drainage that emerged from the source terrain and flowed in a northwesterly direction onto a broad, more gently sloping depositional surface. Due to decrease in the stream gradient, the channels were transformed into low sinuosity streams, which flowed along the northwesterly dipping palaeoslope. Frequent lateral shifting of the channels produced multilateral and multistory sandstones formed by lateral accretion of the shallow channels and bars. The fine-grained sediments were deposited from suspension in the flood plain and formed vertical accretion deposits completing the fining upward fluvial cycles.

The thickness and grain size of the sandstones of the successive sedimentary cycles decrease upward (Fig.8.1). The sandstones underlying seam II and III are very thick, coarse-grained and laterally extensive suggesting their multistory and multilateral nature. In contrast, the sandstones underlying seam

IV, V and VI are thin, fine-grained and associated with shale beds. The gradual decline in the relief of the source area and consequent decrease in the competency of the streams supplied less volume of clastics to the depositional site. The proportion of silt and clay dominated over sand and as a result, the sandstones became thin and relatively fine-grained containing much argillaceous material and occurred interbedded with shale (Fig.8.1).

The periods of clastic sedimentation were interrupted with phases of peat accumulation during which the entire alluvial plain was converted to swamp and subsided slowly keeping pace with peat accumulation. The peat accumulation, however, was periodically interrupted by clastic sedimentation that resulted in splitting of coal seams. The dominant arenaceous partings in seam III (Fig.8.1) suggest proximity of the swamp to the active fluvial sedimentation for which splay and levee encroached the swamp. In contrast, the thin shale and sandstone partings in seam II, IV, V and VI suggest deposition in the distal flood plain (swamp) where the influence of active fluvial sedimentation was negligible.

The Barakar succession, thus, records periods of extensive clastic sedimentation associated with meandering stream channels punctuated by phases of peat accumulation and these conditions recurred atleast six times during Barakar sedimentation. Relief of the source area and mild subsidence of the basin played an important role in triggering fluvial sedimentation and conversion of the flood plain into peat swamps.

The sediments of the Talchir and Damuda Group underwent diagenetic changes in form of cementation, mineral alteration, mineral replacement, recrystallisation etc. and ultimately gave rise to lithified rocks. The carbonate diagenesis in above forms is very prominent in the Talchir sediments. The vegetal debris of the Karharbari and Barakar Formation underwent coalification process and were converted to coal.

The palaeocurrent analysis and petrographic studies indicate that the sediments of the Gondwana sequence were derived from the metamorphic and igneous rocks of the Easternghat Group that were exposed and extended along the southern margin of the basin. Increasing complexity in the heavy mineral suite in upward progression is largely due to unroofing of new rocks at the source area in response to denudation and tectonism. The Talchir Group represents a denudation phase of the source area with declining relief manifested by decreasing mean grain size and increasing complexity in the heavy mineral suite due to unroofing of low rank metamorphic rocks at the source. In contrast, the Damuda Group represents a syn- and post-tectonic phase of sedimentation manifested by upward increase in grain size and increased complexity in the heavy minerals by the exposure of high rank metamorphic rocks at source due to tectonic uplift (Fig.8.1).

The regional palaeoflow and sediment dispersal pattern of Unit-A, Unit-B and Unit-C of Talchir Group was broadly towards north with a slight swing towards northeast and northwest (Fig.7.1, 8.1). This suggests a transverse filling of the basin with a radiating sediment dispersal pattern fanning out from the southern margin of the basin towards basin centre. In contrast, the Damuda Group is marked by a dominant northwesterly unidirectional palaeoflow and sediment dispersal pattern paralleling the basin axis implying an axial filling of the basin. A sinistral swing of the palaeoflow pattern from northeast during the sedimentation of Unit-A to a northerly radiating type during Unit-B and Unit-C followed by a unidirectional northwesterly flow during Karharbari and Barakar period has been considered due to change in palaeoslope because of gradual deepening of the basin during Talchir time and syn- and post-tectonic drainage deflection towards northwest due to source area uplift, basin subsidence and northwest steepening of the alluvial surface during Damuda period.