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Kolhan Sedimentation in Chaibasa - Noamundi Basin, Jharkhand, India: A Critical Observation through Lithofacies Analysis

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Abstract: The Paleoproterozoic Kolhan Group (2100-2200 Ma) in the Chaibasa-Noamundi basin consists of interbedded conglomerate, sandstone and shale with lenticular patches of limestone. This assemblage is divided into six lithofacies {granular lag (GLA), granular sandstone (GSD), sheet sandstone (SSD), plane laminated sandstone (PLSD), rippled sandstone (RSD) and thinly laminated siltstone-sandstone (TLSD) facies}. The line of evidences adopted to determine the complex high energy fluvial environment for the Kolhan sedimentation were lithofacies assemblages, the directional attributes of sedimentary structures, petrography, modal analysis, paleocurrent and paleohydraulic studies. The sedimentological and petrofacies salients were plotted in Q-F-R and Q-F-Lt diagrams. The plots show the sandstones are mineralogically submatured sub-arkose to quartz arenite and derivatives of a craton interior. Presences of such lithofacies assemblages are indicative of a paleolacustrine fan-delta complex. High Qm/Qp ratio shows that the grains are mostly matured monocrystalline quartz grains and derived from either adjoining granitoid terrain or the Iron Ore Group. The shallowness of the basin is indicated by the development of thin sequences of rocks.

Keywords: *Petrography, Lithofacies analysis, Kolhan basin*

1. Introduction

Studies of petrofacies evolution are based on the assumption that the composition of detrital sediments records the composition of the source rocks from which those sediments were derived [8]. This theoretical relationship enables interpretation of paleogeography, paleoclimate, paleotectonic settings, and rock-uplift and exhumation histories from the sedimentary record. Sometimes sedimentary rocks may provide the only source of this information particularly in cases of deeply denuded source terranes. The validity of this assumption has been demonstrated for numerous samples detrital sediments and sedimentary rocks [8][9]. However, interpretation of provenance from sediment compositional data also requires consideration of other controlling factors such as transport distance, time, energy, and climate.

The Proterozoic Kolhan Group is the youngest unit in the Pre-Cambrian Singhbhum – Iron Ore stratigraphy. The Kolhans were deposited in the intracratonic basins that developed within the Singbhum-Orissa Iron Ore craton. The Kolhans unconformably overlie the Singhbum granite at the eastern margin and shows a faulted contact with Iron Ore Group of rocks at the western margin [23] (Fig.1). The Kolhans are shale dominated succession, and consists of northeast trending and gently westerly dipping, unmetamorphosed and undeformed strata of conglomerate and sandstones at the base overlain by extensive occurrences of shale with lenticular patches of limestone. The strata encompass dome and basin structure in westward part and show low dip near Singhbhum granite. Tectonically the Kolhan basin represents an epicontinental type with a NNE-SSW alignment, controlled by the similar trend of the Iron Ore Group. It is remarkable however that major part of the Kolhans does not show any appreciable effect of the younger Singhbhum Orogeny (905-934 Ma) [22]. This is probably partly due to the distance of these rocks from the Singhbhum shear zone and partly due to the blanketing effect of the basement granite which acted as a shield to absorb the southwards directed tectonic movements. Earlier studies reported the detailed stratigraphy, structure and partly the sedimentology of the Chaibasa-Noamundi basin [2][3][5][6] [16] [19][20][24][25] [29]. As the detailed sedimentation history covering comprehensive aspects of lithofacies analysis, sedimentological studies and basin modeling are virtually lacking. The present investigation is an attempt on some aspects of the sedimentological studies of the Proterozoic rocks for reconstruction of the depositional history.

2. Lithofacies

Lithofacies studies have been done following standard technique [9]. The various sections have been shown in fig.2a with a composite log (Fig.2b). All the seventeen logs show the Kolhans rest unconformably on the Singhbhum granite. Six lithofacies have been recorded and are described individually as Granular lag conglomerate facies (GLA), Granular-pebbly sandstone-facies (GSD), Cross-stratified coarse grained sandstone facies (SSD), Planar stratified sandstone facies (PLSD), and Wavy- ripple laminated sandstone facies (RSD) and Thin laminated sandstone facies (TLSD) (Fig.2c). The details of lithofacies characteristics and their interpretation from facies assemblages have been described below.

Granular lag conglomerate facies, which directly overlies Singhbhum granite, is reddish brown in color and consists of moderately to poorly sorted, subrounded to rounded pebbles of chert, vein quartz, phyllite, jasper and granite. It is characterized by the occurrence of laterally impersistent, massive, ungraded and fine matrix supported conglomerate which is oligomict in character towards south and polymictic towards north. These conglomerates are mostly immature to sub-mature, and quite similar to the overlying sandstone. This fine matrix-supported GLA facies can be characterized as a more or less laminar, cohesive flow of relatively dense, sediment–fluid mixture of plastic behavior.

The GLA facies is overlain by reddish brown to brown color granular sandstone (GSD) facies .This facies is characterized by moderately to well sorted, moderate clast:matrix ratio, textural bimodality and development of normal grading with fining upward sequence. Planar cross-stratification is more commonly found in compare to trough cross- stratification.

The SSD facies is defined by sheets of subarkose-quartz arenite, sometimes intercalated with thin laminated siltstone. The facies shows profuse development of planar cross bedding and locally developed herringbone cross-bedding.

The PLSD facies is defined by thick amalgamated well sorted subarkose-quartz arenite, with a moderate - high grain: matrix ratio. The sandstone is medium to fine grained. The prominent structures are planar cross bedding, wavy lamination, washed out/flat top ripples, and herringbone cross-bedding. The wavy lamination beds occur with thin ripple laminated shale parting between two successive beds .Sandstone beds in this facies tend to be sheet like with almost constant bed thickness.

The RSD facies is defined by predominance of packages of rippled sandstone with prolific development of both symmetrical and asymmetrical ripples, herringbone cross-bedding, hummocky cross-stratification and multiple toe scour like structures. It is very commonly associated with thinly laminated sandstone facies and plane laminated sandstone facies.

The TLSD facies is defined by the rhythmic alternation of sandstone and shale units in which sandy layers are thicker than shale layers. Prominent structures are thinly laminated sandstone, convolute lamination, planar cross bedding and asymmetrical ripples.

3. Interpretation of Facies Assemblages

The poorly sorted texture of conglomerate in GLA facies is the result of freezing, as the shear stresses can no longer overcome internal shear strength. Large clasts may floats in a finer matrix and overall the deposit shows little or no internal bedding or lamination. The poor sorting is indicative of a deposition of Kolhan sediments through short transport close to the basin margin. The massive conglomerate with poor sorting and a fine matrix-supported character are regarded as products of debris flow. The composition of the GLA facies indicates the source to be both Singhbhum granite and Iron Ore Group. Chatterjee and Bhattacharya (1969) have also suggested a source area with complex lithology and more than one provenance type presumably a granitic to the east and northeast and an Iron-ore Formation type to the southwest and northwest of the basin [5]. The reddish brown color of GLA and GSD facies indicates oxidized state of iron suggesting humid environment. Fining upward sequence probably reflect lesser violently fluctuating with changing climatic conditions of the source area [7]. The sheet like morphology interbedded with wavy laminated sandstone represents high energy dominated shoreface depositional setting and marks a transgression period. The fine-grained clastic material of wavy laminated sandstone is sourced from river mouths and is carried in suspension by geostrophic and wind-driven currents and storms also rework a lot of fine sediments from the sea floor and carry it in suspension across the shelf. Wavy laminted sandstone indicated deposition under wave-current combined flow regime. Occurrence of antidune can be described from beaches and sea shore [17]. Antidunes along with washed out/flat topped ripples are the common bedforms developed on the emerged surface of the foreshore. The ripple like forms with straight and occasionally bifurcated crests developed in plane stratified sandstone facies is possibly replicate shore parallel swash ripples commonly present in wave dominated shore face. Presence of chevron cross-stratification indicates dominance of oscillatory flow. Occurrence of small scale wave ripples and associated plane lamination bears clue for deposition above fair weather wave base. The majority of parallel bedded sandstone with sheet like geometry of the sandstone beds and rare channel-form structures imply that much of the sediments are a product of sheet floods. Evenly laminated sandstone bodies are generally abundantly distributed on beaches or other sandy areas exposed to wave action. Besides this, evenly laminated sand can be produced in the plane-bed phase of high flow regime. Middleton and Hampton (1973) suggest that some of the parallel lamination may be related to migration of long wavelength antidunes, where lamination is diffused [15]. Evenly laminated sand of storm-sand layers in the shelf area are formed as a result of sedimentation of suspension clouds [21]. Horizontally laminated sand is also a dominant bedding structure of the backshore, where it accompanied with small scale cross bedding produced by small-current ripples and low-angle cross bedded units. Rhythmic sandstone with sharp contact between sand and mud is commonly described from tidal environment [21]. A strong asymmetry in vertical basin-fill architecture and the linear outcrop pattern of the preserved sedimentary sequence presumed to have formed in an elongated trough, collectively convey presence of a rift setting. The shallowness of the basin is indicated by the general development of thin sequences of rocks. The preliminary observation suggests lower shore face depositional set up.

4. Sandstone petrography

Detailed petrographic studies of 105 sandstones samples were done for modal composition and a variety of other petrographical features. For each thin section 300 points were counted using the Gazzi-Dickinson method [13]. The sandstones are coarse-grained and show considerable compositional variability, ranging from subarkose to quartz arenite [10]. The grains of all types are typically subrounded-rounded and moderately well sorted [18]. The quartz grains are mainly monocrystalline with weak or absent undulatory extinction. Polycrystalline quartz occurs in two varieties: (a) grains with a polygonal fabric of interlocking grains and (b) grains with elongate, lenticular, interlocking, sutured crystals (Fig.3a). The feldspars are K-feldspars, microcline, and albite-rich plagioclase (in descending order of abundance). K-feldspars are commonly clouded with alteration products and also show microperthitic intergrowth with Na-plagioclase. Matrix quartz shows feeble recrystallization and fused contacts with the framework grains (Fig.3b). Quartz grains show bimodal distribution in quartz arenite (Fig.3c). A microscopic photograph of rhythmic sandstone is shown in fig.3d. The feldspar grains show rounded inclusions of quartz (Fig.3 e-f). Sedimentary rock fragments are intrabasinal, intraformational and extraformational. During point-counting all efforts were made to identify replaced feldspar grains and to record them as feldspars. Because of the considerable influence of feldspar alteration, orthoclase and plagioclase are not reported separately. Partial replacement of feldspars by calcite has been observed, but is less common.

5. Provenance information from sandstones

5.1. Source rocks

The detrital quartz is the most abundant component in Kolhan sandsone. The average quartz content is 62 % but may be as small as 25 % and as large as 90 %. The feldspar content ranges from 1.46 to 13.54 %, and rock fragments (0.49 to 7.82 %) (Fig. 4a), embedded in ferruginous-siliceous cement (0.00-7.97%) and cherty-sericitic matrix (1.41-10.21%) are the main constituents of those rocks. As because the interest is more in the source area and the tectonic setting, only extrabasinal components have been considered [30].

Quartz is the dominant constituent framework grain, and monocrystalline quartz predominates over polycrystalline quartz (Fig. 4b).Well rounded recycled plutonic quartz grains with long and concavo-convex contacts are frequently seen.

5.2. Tectonic setting

The QFR and QFLt plots (Fig. 5a and b) show the distribution of detrital modes for Kolhans. The sandstones were primarily derived from the cratonic interior (Fig. 5a). From the disproportionate in the angularity distributions, it is clear that the cratonic margin was to the south (Fig. 5b).

5.3. Relief, climate, transport history

The well-rounded feldspar and quartz grains (Fig. 3.a and f) are indicative of an extrabasinal component of the texturally matured - submatured sandstones. Folk (1980) suggests that the latter indicates tectonic quiescence, peneplanation of the hinterland, a dry climate (climatic arkose), and rounding of sand in lacustrine-deltaic environment [10]. Even though the lack of chemically decomposed feldspars in the Kolhans suggests a dry climate, the sandstone petrography provides no clues regarding the prevailing temperature regime (arid v. semi-arid climate). The observation that feldspars are quite fresh and of similar average grain size than the quartz grains, suggests that the extrabasinal component of the Kolhan is at least in part first-cycle material. For that reason, and because it seems unlikely that inland reworking caused significant rounding of sand grains, it appears most likely that quartz and feldspar grains in the Kolhans experienced an episode of inland transport.

6. Paleocurrent Analysis

The most prevalent current direction during the deposition of GLA and GSD facies is towards NW and NNW. The current rose diagram commonly exhibit unimodal character, but sometimes that show polymodal characters too [27]. The SSD, PLSD and RSD facies show conspicuous influence of NNE, NE and NW directed paleocurrents with some local variations. The influence of northeasterly trend of paleocurrent is comparatively more as revealed from the magnitude of the resultant vector. These facies are well sorted with occasional granule layer. The north-westerly fluvial currents down the paleo-slope are also persistent during the deposition. The current directions remain almost towards NE in TLSD facies.

A synoptic view of the paleocurrent dispersal pattern has been shown in fig. 6. The dispersal of sediments was from the southwest and southeast directions, and the Iron Ore Group and Singhbhum granitoid terrains may be the source rock for the Kolhans.

7. Paleohydraulics

The channel width (W), meander wavelength (lm), channel depth (d), flow velocity (v), mean sediment discharge (Q) and Froude number (F) have been calculated following standard methods [1][4][12][14][26][28]. Estimates of the paleohydraulic parameters were made to assess the hydrodynamic conditions that prevailed during the Kolhan sedimentation (fig.7). The paleohydraulic values obtained for the individual lithofacies and the average paleohydraulic estimates of the study area is shown in Table.1.

8. Discussion-Paleoproterozoic Kolhan sedimentation history

The ultimate aim of sedimentary petrological investigations is to discover the characteristics of the provenance, to discuss the probable mode of dispersal of the clastic constituents and finally to specify the various parameters of the environment of deposition [13]. Reliance is given in such studies on the sedimentary characteristics of clastic particles deposited in known environments. The conclusions derived are necessarily limited due to various factors which among others have been discussed [11][27]. The diagnostic features of the Kolhan Group of Rocks in the study area are briefed in Table 2.

Six lithofacies have been erected on the basis of the lithologies, grain size, sedimentary structures, and bed geometries. Presence of herringbone cross-bedding washed out ripples and occurrences of rhythmic sandstone (tidal bedding) are the evidences of tidal activity. Parallel lamination and antidune represent sedimentation in upper flow regime conditions. A general NW–NE directed paleoslope is inferred from the areal disposition of the lithofacies, its vertical thickness distribution, variations of the sediment textures.

A close observation of these vertical successions states that the GSD and GLA facies occur as lenticular or lens shaped bodies sandwiched frequently between SSD and PLSD and more pronounced towards northern and southern part of the basin. SSD facies is widely distributed with large scale cross-bedding and attain a maximum thickness near the central part. The thickness of bed set of PLSD is almost uniform, where RSD facies is more pronounced towards southern. The average bed thickness of TLSD is very less in all sections. The variability of the azimuthal directions of cross-bedding and grain orientation are more pronounced towards southern part as compared to central and northern portions of the basin. The paleocurrent direction seems to be frequently towards NE and NW indicating a dual source, may be from Iron Ore Group and Singhbhum granite. Fig. 8 shows the schematic summarized stage model of Kolhan sedimentation.

9. Conclusions

The Kolhan sandstone is typically subarkose at the base that quickly changes to quartz arenite at the top of the stratigraphic sequence. This increase in the mineralogical maturity towards the top is due to the recycling of grains through tidal-wave activities. The Kolhan sandstone is overlain by thick occurrence of shale which suggests strong asymmetry in vertical basin-fill succession and rapid lateral lithofacies variations. These attributes and the linear outcrop pattern of the preserved sedimentary sequence presumed to have formed in an elongated trough, collectively convey presence of a rift setting. The source rock lithology, warm humid climate, absence of vegetation and wave-tide processes in the shelf environment had strong influence on sedimentation processes and the mode of sediment transfer from the feeder system to the basin, as well as on basinal processes. However, their functions were of secondary importance to tectonic effects. Kolhan sandstone is characterized by low matrix, lower feldspar and rock fragment content and compositionally is subarkose and quartz arenite, which typifies paleolacustrine fan-delta sandstone.

10. Acknowledgement

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Figures and Tables

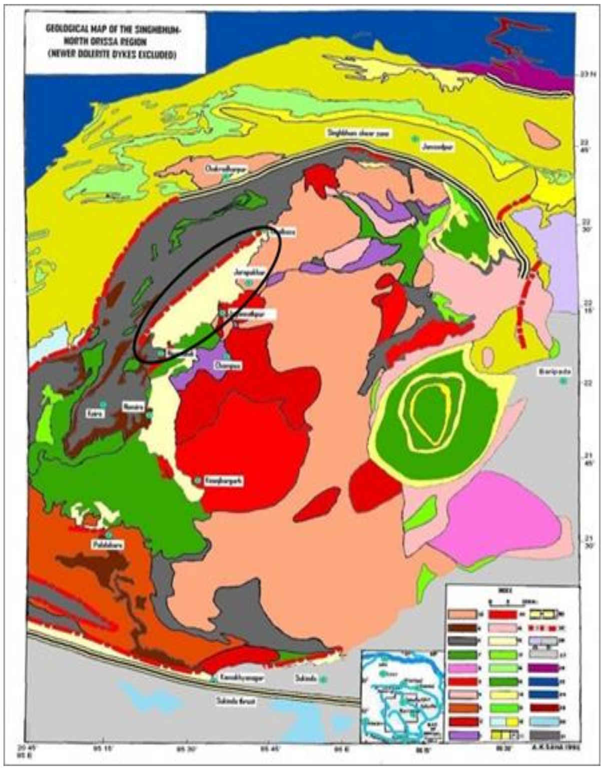

Figure 1 *Generalized geological map of the Singhbhum-North Orissa region [23]*

Legend: 1-Older Metamorphic Group; 2-Older Metamorphic Tonalite-gneiss; 3-Pala Lahara gneiss; 4-Singhbum granite-phase I; 5-Singhbum granite-phase II and xenolith dominated areas of Bonai granite; 6-Nilgiri granite; 7-Iron Ore Group lavas, ultramafics; 8-Iron Ore Group shales, tuffs, phyllites; 9-BHJ, BHQ and sandstone-conglomerate of Iron Ore Group; 10-Singhbhum granite-phase III; Bonai granite; Chakradharpur granite; 11-Singhbhum Group (a) pelites, psammipelites (b) mafic bodies (c) carbon phyllite; 12-Singhbhum Group quartzites; (a) quartzites-pelites; 13-Dhanjori Group (unclassified); 14-Quartzite-conglomerate-pelite of Dhanjori Group; 15-Dhanjori-Similipal-Jagannathpur-Malangtoli lavas; 16-Dalma lavas; 17-Proterozoic gabbro-anorthosite-ultramafics; 18-Kolhan Group and equivalents (a. Chaibasa-Noamundi basin, b. Chamakpur-Keonjhargarh basin, c. Mankarchua basin, d. Sarapalli-Kamakhyanagar basin); 19-Mayurbhanj granite; 20-Soda granite, Arkasani granophyre, Kuilapal granite, Alkaline granite; 21-Charnockite; 22-Khondalite; 23-Amphibolite enclaves (within CGG); 24-Pelitic enclaves within CGG; 25-Chhotanagpur granite gneiss (CGG); 26-Porphyritic member of CGG; 27-Gondwana sediments; 28-Alluvium, Tertiaries; 29-Fault; 30-Thrust fault

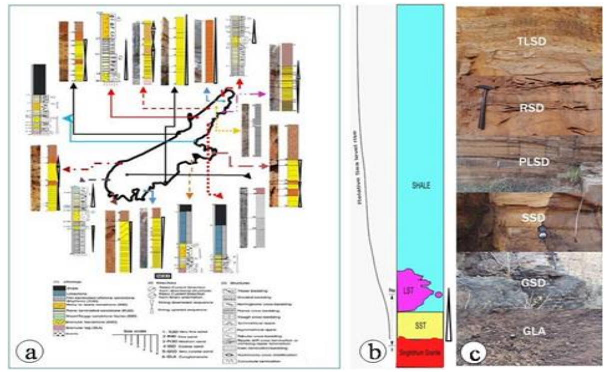

Figure 2 *(a) Lithologs showing the vertical distribution of the lithofacies in the study area (b) a composite log (scale in meters), (c) Six different facies photographs*

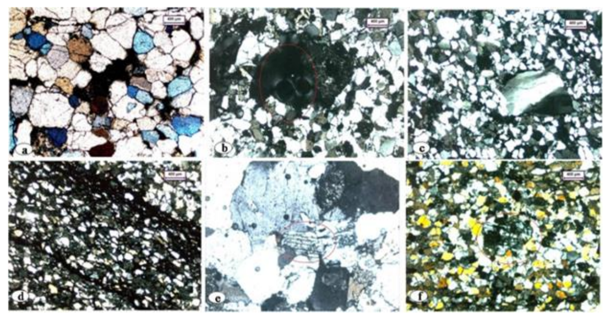

Figure 3 *(a) Moderately well sorted, medium-coarse grained sandstone, well rounded quartz grains with long and concavo-convex contact, (b) Rounded to sub-rounded monocrystalline framework quartz grains in quartz arenite, Matrix quartz shows feeble recrystallization and fused contacts with framework grains, (c) Quartz grains showing bimodal distribution in quartz arenite, (d) Rhythmic sandstone thin section (e and f); feldspar showing rounded grains*

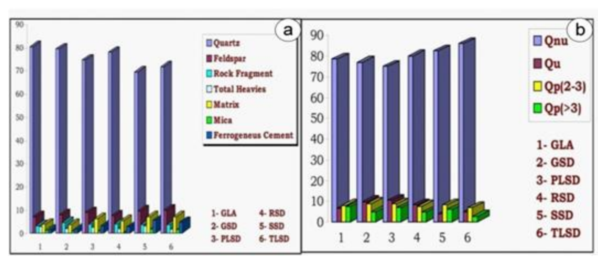

Figure 4 *(a) Modal analysis of fifty-one fine to medium-grained texturally mature to submature samples of six different lithofacies constitute monocrystalline quartz (60.25-76.88%), polycrystalline quartz (2.64-15.07%), feldspars (1.46 - 13.54%), and rock fragments (0.49 to 7.82 %), embedded in ferruginous-siliceous cement (0.00-7.97%) and sericitic matrix (1.41-10.21%) (b) Quartz type percentage for six lithofacies (Note: quartz is the dominant constituent framework grain, and monocrystalline quartz predominates over polycrystalline quartz*

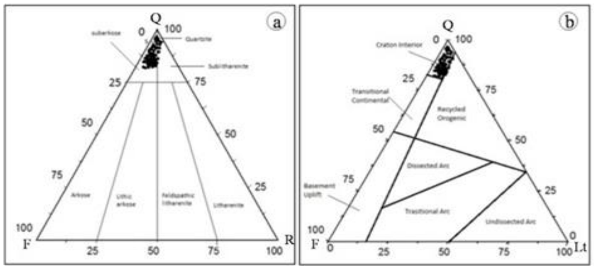

Figure 5 *(a) QFR plot [10]: the clastics are mainly quartz arenite-subarkose (b) QFLt plot [9]*

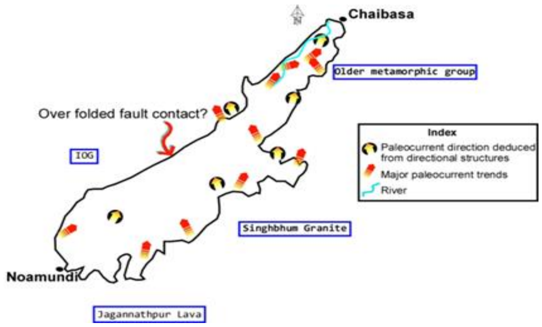

Figure 6 *A synoptic view of the paleocurrent dispersal pattern in the study area*

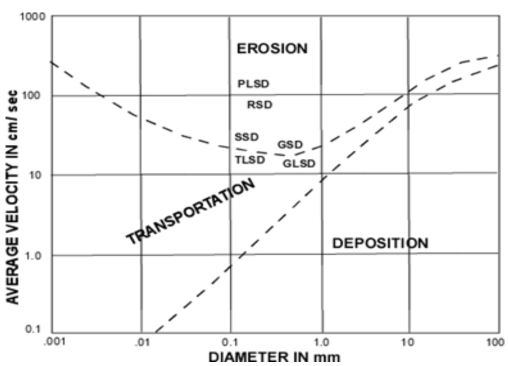

Figure 7 *Hjulstorm's diagram showing relationship among erosion, transportation and deposition of sedimentary particles (modified after Hjulstorm, 1939 [12])*

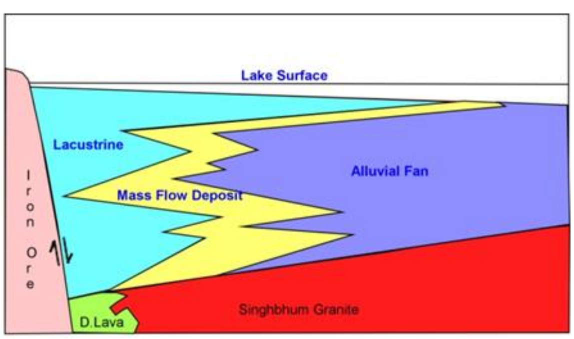

Figure 8 *Schematic model of Singhbhum granite, Kolhan group, Dangoaposi lava and Iron group of Rocks in the study area (not to scale)*

Table 1 *Estimate of Paleohydrologic Parameters of the Study Area*

Parameters	Mean Estimate
Mean cross-bed set thickness	0.13 m
Mean water depth (d_s)	1.38 m
Channel width (w)	61.59 m
Width/depth ratio (F)	42.97
Meander wavelength (L_m)	701.26 m
Mean annual discharge (Q_m)	94.34m^3/s
Channel slope (S_c)	0.00084
Flow velocity (v)	0.66m/s
Froude number (F_r)	0.20

Table 2 *Diagnostic Features of the Kolhan Group of Rocks in the Study Area*

Set thickness	Average around 50-65 cm, maximum being 160 cm; set thickness decreases (10-25 cm) towards the top
Succession	Fining upward sequence in general
Sandstone / shale ratio	Very high; local beds of laterally impersistent shale/siltsone (2-3 cm thickness)
Geometry of Sandstone bodies	Elongate, fairly straight – lenticular or sheet like sandstone bodies that grade laterally into fluvial plain deposits (sand sheet); tabular and laterally continuous for hundreds of metres
Sedimentary structures	Large scale trough cross-beds, filling channels with long low angle foresets that alternate with cosets of parallel-laminated sandstone and tabular cross-bed migrating across channels; rippled sandstone facies dominates towards the top of the formation
Erosional surfaces	Planar erosional surfaces, occasionally compound overlain by conglomerates; lenticular and impersistent sheets of coarser clastics; overall upward decrease in the size of the pebbles and granules; patches of moderately-poorly sorted sediment zones along the direction of paleoflow
Paleocurrent	Flow was dominantly to the NW and NE and occasionally towards NNW