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Evolution of Palaeo-Proterozoic Kolhan as a Half Graben

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Abstract: ***The Kolhan Group is preserved in the sub-basins of Chaibasa–Noamundi and Chamakpur-Keonjhar and is usually represented by a sequence of clastic (±carbonate) association alongwith development of thin and discontinuous patches of basal conglomerates draped by sandstone beds. Six lithofacies have been observed in the area. The IOG-fault marks the western 'distal' margin of the Kolhan basin showing evidence of passive subsidence subsequent to the initial rifting stage. The basin is thought to evolve as a half-graben under the influence of an extensional stress regime. This assumption of a tectonic setting for the NE-SW trending Kolhan basin can be related to the basin opening as a consequence of E-W extensional stress system that prevailed during the development of the Newer Dolerite dyke. The Paleoproterozoic age of the Kolhan basin is based on the consideration of the conformable stress pattern responsible both for the basin opening, and on the development of the conjugate fracture system along which the Newer Dolerite dykes intruded the Singhbhum Archaean craton. The half-graben development and fault growth evolve differently through time and produce different basin-filling patterns. In the initial stage the basin evolution can be explained by detachment type half-graben filling model that incorporates a basin-bounding fault soling into a sub-horizontal detachment fault. Two types of genetic sequences reflecting variations in the generated accommodation space have been recognized within the sub-basins of Chamakpur-Keonjhar and Chaibasa-Noamundi. The lower sequence in Chamakpur-Keonjhar is characterised by shallow braided river deposits that lack repetitive facies patterns and were deposited during a period of the slower rate of fault growth and generated accommodation space. An upward increase in the generated accommodation space is recorded by sheet sandstones encased in sand-streaked siltstones representing ephemeral flood deposits. During the fault growth stage the Kolhan basin grew both wider and longer through time as the basin-bounding faults lengthen and displacement accumulated as evident in the sub-basin of Chaibasa –Noamundi. Younger strata consistently pinch out against older syn-rift strata rather than pre-rift rocks in the later fault-growth stage. The basin fill thus commonly forms a fanning wedge during fluvial sedimentation, whereas lacustrine strata tend to pinch out against older syn-rift strata. The fluvial strata progressively onlap the hanging wall block, whereas the lacustrine strata pinch out against older fluvial strata at the centre of the basin but onlap along the lateral edges. The transition from fluvial to lacustrine deposition and hanging wall onlap relationships are thoroughly observed in the sub-basins of Kolhans. The pronounced variations in thickness of the fan delta succession and the stacking pattern in different measured profiles reflect the overriding tectonic controls on fan-delta evolution. A strong asymmetry in vertical basin architecture and the linearity in the outcrop pattern of the preserved sedimentary sequence are presumed to have developed in an elongated trough during the initial basinal rifting stage, while the later stage is marked by the progressive overlaps and coalesce of the facies built-up. The basin axis controlled the progradation direction which was likely driven by climatically induced sediment influx, a eustatic fall, or both.***

Keywords: half-graben, fan-delta lacustrine,braided-ephemeral

1. Introduction

The Kolhan Group is preserved as linear belt extending for 80-100 km with an average width of 10-12 km revealing deposition of Kolhan sediments in narrow and elongated troughs. The Kolhan Group lying unconformably above the Singhbhum granite is bounded by the Jagannathpur lavas on the southeast & south and the Iron Ore Group on the west. The western contact of the basin is faulted against the Iron Ore Group. The Kolhan Group of sediments into four detached sub-basins - Chaibasa-Noamundi basin, Chamakpur- Keonjhargarh basin, Mankarchua basin and Sarapalli-Kamakhyanagar basin[11]. The Kolhan basin is a time transgressive shale dominated supracrustal succession (shallow epicontinental) set in a passive continental rift setting, and caused due to the fragmentation of the Columbia supercontinent. The succession is represented by a sequence of subarkose-quartz arenite with lenses of conglomerate overlain by extensive thick shale-limestone package and show a non-cyclicity in the sedimentation history.

The depositional environment of the Kolhans varied from braided fluvial-ephemeral pattern to a fan-deta-lacustrine type. The channel geometries and the climate exerted a major control on the processes of sediment transfer. Repeated upliftment of the source area due to fault-controlled activity followed by subsidence and forced regression generated multiple sediment cyclicity that led to the fluvial-fan delta sedimentation pattern .Moreover, no such inference about the tectonic evolution of the basin has been yet drawn. Few workers from like [6] has suggested the half-graben model for Kolhan supported by [1,10] Our aim will be to find out whether Kolhan fits this model.

1.1Study Area

The Kolhans in general(Fig.1) displays low (5˚-10˚) westerly dip, and it is unconformably overlying the Singhbhum granite to the east with a faulted contact(Fig.2) with the Iron Ore Group of rocks to the west [11]. A pyrophyllitic shale layer (10 m thickness) is locally present in between the Singhbhum granite and the Kolhans[11]. The Chaibasa-Noamundi basin extends from Chaibasa (85^0 48’ – 22^0 33’) in the north to Noamundi (85^0 28′ – 22^0 09′) in the south (length : 60-80 km ; width : 8-10 km). The Chamakpur - Keonjhargarh (Long. 85°20’-85°35’ E **;** Lat. 21°35’-22°10’ N) (Fig. 1.2a) on other hand covers an area approximately 375 km2 (length : 50-55 km ; width : 6-8 km).

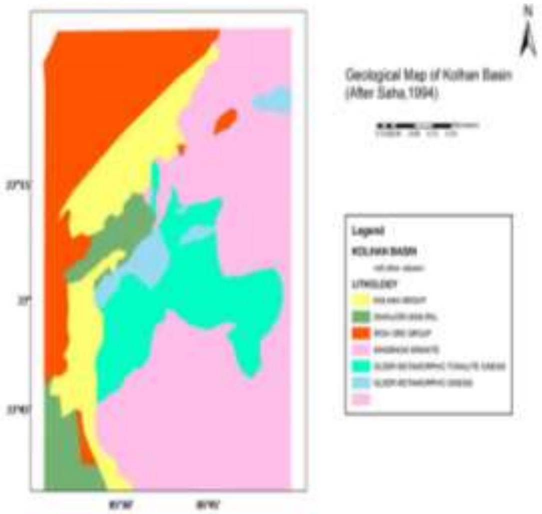

Figure 1: The geological map of Kolhan basin showing the two sub-basins (After Saha,1994).

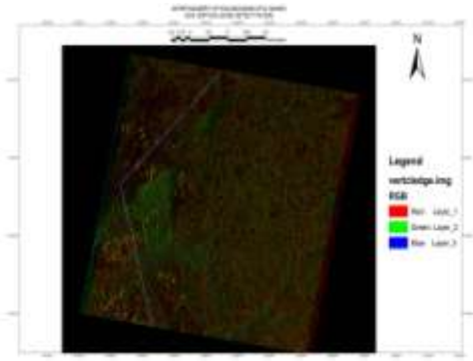

Figure 2: ASTER Satellite imagery (FCC) Image after 3x3 Vertical Edge Detect Filter to identify the detachment fault .

2. Methodology

Fieldworks were carried out to describe and characterize the lithounits of the Kolhan basin from Chaiabasa to Chamkpur. At each exposure, the different lithounits were studied and were identified on the basis of their bed geometries, gross lithologies, and sedimentary structures. The textural and the structural aspects of the lithounits observed in the outcrops were then clubbed into six lithofacies for better representation. The identity of each lithofacies was based on the presence of a set of primary textures and structures [15,16]. Fence diagram was prepared based on the litho-log data using ROCKWORKS16 for the two-sub-basins. A predicted Depositional Model correlating the two sub-basins sedimentation history was prepared using CANVAS 8 software.

3. Lithofacies Analysis

Lithofacies studies have been done following standard technique [8]. Six lithofacies have been recorded and are described individually as, 1. Granular lag facies (GLA) 2. Granular sandstone facies (GSD) 3. Sheet sandstone facies (SSD) 4. Plane laminated sandstone facies (PLSD) 5. Rippled sandstone facies (RSD) 6. Thin laminated sandstone facies (TLSD)

3.1 Chamakpur-Keonjhar Sub-Basin Depositional Environment

Braided fluvial plain facies association(Fig.3 and Fig 5) The granular lag (GLA) and granular sandstone (GSD) facies are a part of shallow braided fluvial plain facies association. These two facies were formed in fluvial channels and bars in braided streams that gradually fanned outwards. This led to the gradual avulsion of thebraided streams. The nature, lateral-vertical transition, and the geometry of the facies association are indicative of the development in a humid and subtropical environment. The braided stream deposits gave way to the deposition of sheet-like deposits, where the process of recycling of sediments started in conjunction with the related hydrodynamic factors. The evidences in support of the braided stream are as follows.

- Presence of lenticular or wedge shaped bed geometry (wedge thickness increases downslope) showing a transition from orthoconglomerates to granular sandstones and oriented approximately parallel to the paleostrike of the basin.
- Presence of upcurrent imbrications. Elliptical pebbles oriented normal to the paleocurrent directions are rare. Presence of angular grains and abundance of rock fragments suggest a short transport from the source area.
- Overall fining upward cycles together with a decrease in the scale of cross-bedded units. The coarsest deposits at the base of the channel are those carried in the thalweg [2] in between the sand bars. Local coarsening upwards sequence indicates a rapid shifting of the braided streams (channel avulsion) during deposition [4].
- Where the bar is gravelly, the deposits consist of cross-stratified granules, pebbles or rarely cobbles in a single set. Where the bar is sandy, stacked sets of subaqueous dune deposits have been observed, that form a succession of cross-bedded sands whose top surface is occupied by finer sands and silts, representing the abandonment of the bar.
- Presence of local fining and coarsening upward sequence that reflect a low fluctuation in the basin tectonism and a changing scenario in the climatic condition at the time of deposition.
- Presence of unidirectional (with occasional cross-paleocurrent) patterns and channel scours that suggest braided fluvial sedimentation.
- Presence of laterally intercalated, well sorted, coarse - medium - fine grained, trough cross-bedded, planar cross-bedded, and flat-bedded units suggest a rapid fluctuation in sediment supply.
- Presence of irregular boundary between the coarse and the fine grained sediment layers frequently marked by channel scours.Presence of GLA and the GSD facies as the basal layer in the stratigraphic sequence. Trough and planar cross-beddings are common structures developed as a result of the lateral and downstream advance of a mid-channel bar that finally coalesced into the adjacent branch channel.
- Ephemeral Sheet Flood Facies Association The association of sheet sandstone (SSD), plane laminated sandstone (PLSD), rippled sandstone (RSD), and thin laminated siltstone-sandstone (TLSD) facies are typical ephemeral sheet flood facies (Miall, 1996). Some of the

characteristic features of this facies observed in the study area have been highlighted below.

- The lower part of the sheet sandstone facies is characterized by trough and large scale high angle (foreset dip 20-28 degree) planar cross-bedding almost at right angles to the elongation of sand bodies.
- The upper parts of the sheet sandstone and the plane laminated sandstone facies are characterized by both low angle frontward and high angle backward crosslaminations, asymmetrical ripples, isolated lunate and linguid megaripples, and antidune cross-stratifications. Reactivations of erosional surfaces are often marked by thin granules and pebble layers. Subhorizontal parallel laminations with occasional shale chips and landward climbing-ripple laminations are also prevalent in the plane laminated sandstone facies.
- Presence of antidune cross-stratification and climbing-ripple laminations are indicative of rapid sedimentation under high suspended load [3]. A possibility is there of the existence of a crosschannel and transverse movement of sand bodies as transgressive sheet sands [17,9].

3.2 Chaibasa –Noamundi Sub-Basin Depositional Environment

- Fan Delta Lacustrine Type: Fan-deltas are deposited immediately adjacent to highland region, usually a fault-bounded margin, and occupy a relatively a narrow space between highland and a standing body of water of shallow depth[7] . The geological set-up of Chaibasa-Nomundi fits the definition. The evidences in support of this are as follows(Fig4 and Fig 6):
- Presence of fine - medium grained, well sorted quartz rich sandstones (RSD) frequently interbedded with thin laminated siltstone-sandstone (TLSD) resembling heterolithic facies. The variability of sedimentary structures in the facies associations reflects rapid fluctuations in the supply of sediments.
- Records of low energy suspension fallout in the TLSD facies, presence of asymmetric ripples on the top surface of the fine-grained sandstones, and mudcracks in the TLSD facies indicate a low energy, suspension fall out during the waning phase of the sedimentation.
- Cross-laminations, antidunes, and supermature quartz arenite indicate sedimentation recycling. The sediments have been transgressed by the continuous lateral and transverse shifting of longitudinal bars, that resulted in the development of sheet flats and transgressive sand sheets.
- Presence of scoured surfaces with granule layers in the GSD and PLSD facies, diffused nature of the contact between RSD and TLSD facies, and poor linkage between SSD, PLSD, and RSD facies indicate a rapid sedimentation in the upper reaches of the stream [2].
- The Kolhan succession starts with a basal conglomerate, which is thin, laterally impersistent and becomes more and more oligomictic to the South, with the dominance of chert and jasper pebbles. Pebbles of granite and quartz are common in the somewhat polymictic types developed towards the north.
- The Conglomerate are mostly sub mature to immature, devoid of structure, with a matrix very similar to the overlying sandstones with which they show a highly transitional contact and wedge shaped geometry.
- The dominance of iron and argillaceous matter is often observed and the rapid conversion of shale from calcareous to argillaceous to ferrugenous is an indicator of its non-marine nature.
- Presence of herringbone cross-bedding washed out ripples and occurrences of rhythmic sandstone (tidal bedding) are the evidences of tidal activity.
- The patches of limestone present confirms it to be of non-marine body.The sudden huge thickness of shale can be attributed to the landlocked nature of the basin.
- The shallowness of the basin is indicated by the general development of thin sequences of rocks, while the stability and generally subdued morphology of the source area is suggested by the slow transport of detritus containing very little fresh feldspar grains by the sluggish streams contributing sediments in moderate amount to the Kolhan sea of the epicontinental type.

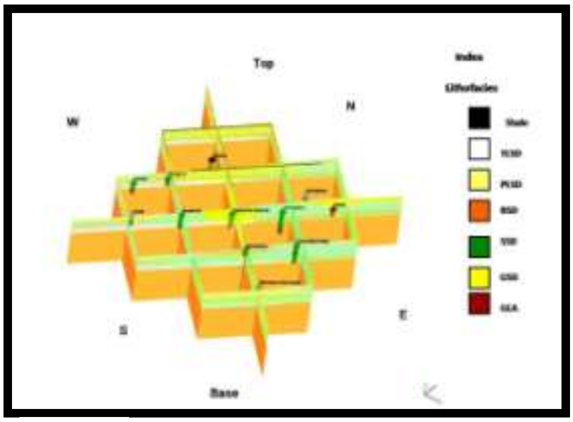

Figure 3: Fence diagram showing facies variation across the Chamakpur-Keonjhar sub-basin

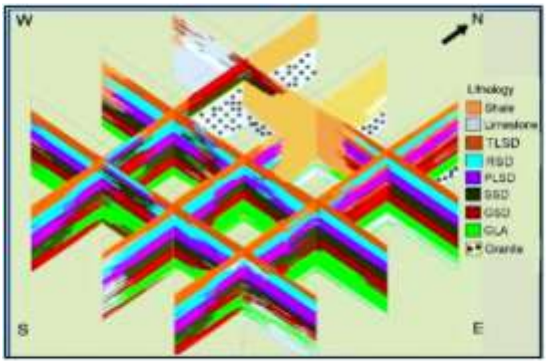

Figure 4: Fence diagram showing facies variation across the Chaibasa Noamundi sub-basin

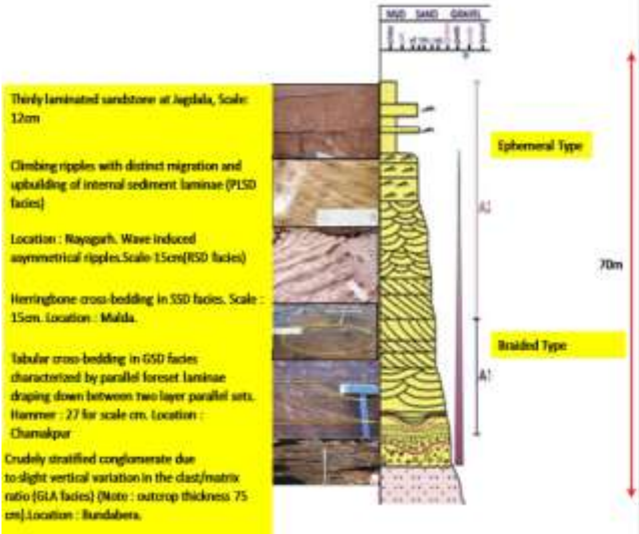

Figure 5: Composite log of the Chamakpur-Keonjharh Basin showing the sedimentary structures in each facies and the braided ephermal vertical succession

Figure 6: Composite log of the Chaibasa-Noamundi Basin showing the sedimentary structures in each facies and the fan-delta lacustrine vertical succession.

4. Tectonic Evolution of Kolhan

Active extension or stretching of continental lithosphere and high heat flow due to the effects of normal faulting and the resultant changes in crustal and mantle thickness, structure and state. The tectonic environment of stretching is controlled by regional plate motions. Extension may occur in a variety of geodynamic settings, including continental crust adjacent to back-arc basins, continental interiors and thickened crustal orogens. Rifting may be passive (i.e.closed system, where the input of asthenospheric mass from outside the stretched lithosphere occurs passively as a response to lithospheric thinning) or active (i.e. open system, where rifting is accompanied by the eruption of voluminous volcanics, and the initial rising of the asthenosphere is independent of the magnitude of lithospheric extension

4.1 Half-Graben Basin Filling Model

- In the initial stage the fault model incorporates an intrabasinal fault that soles into a sub-horizontal detachment fault; the change in the rate of increase in the volume of the basin during uniform fault displacement is zero.(detachment type).(Fig.7a)
- Both basin-bounding faults, intrabasinal faults and the intervening fault blocks rotate during extension and as a consequence, there is a change in the rate of increase of the volume of the basin.(domino type).(Fig.7 b)
- During the fault growth models, the Kolhan basin grew both wider and longer through time as the faults lengthen and displacement accumulates; the change in the rate of increase in basin volume is positive.(Fig.7c)
- Basin fill commonly forms a fanning wedge during fluvial sedimentation, whereas lacustrine strata tend to pinch out against older synrift strata.

The transition from fluvial to lacustrine deposition and hanging wall onlap relationships observed in the individual basins of Kolhans are best explained by these basin filling Models (Fig.8 and Fig 9) [5,12.13].

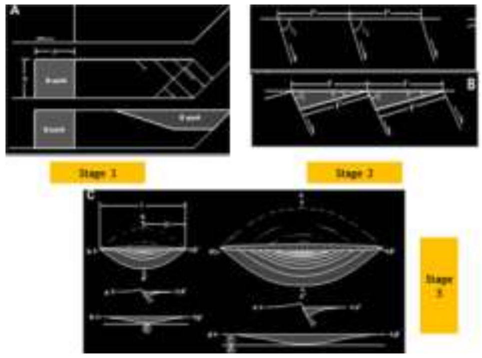

Figure 7: Illustration of half-graben basin-filling model.(A) Planar fault geometry (taken for simplicity) where there is horizontal displacement (h) on the detachment fault (B)domino fault block model in which both the faults and the intervening fault blocks rotate during extension. i is the initial dip angle of the faults; is the dip after extension; is the dip of a horizon that was horizontal before extension; F' is the initial fault spacing; F is the fault spacing after extension. (C) Essential elements of the fault growth model .All the 3 end member half-graben basin- filling models are applicable in various stages of the basin evolution.

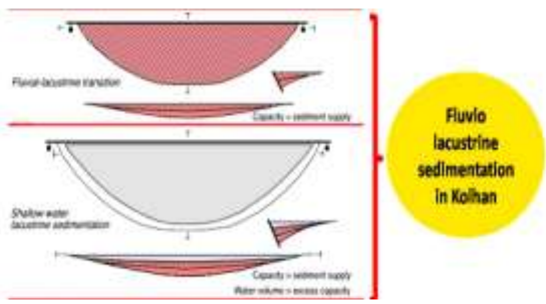

Figure 8: Filling of an evolving half-graben basin shown in map view alongwith longitudinal cross section , and transverse cross section . Dashed line represents lake level. The relationship between capacity and sediment supply determines whether sedimentation is fluvial or lacustrine. For lacustrine sedimentation, the relationship between water volume and excess capacity determines the lake depth. Modified from Schlische and Anders (1996).

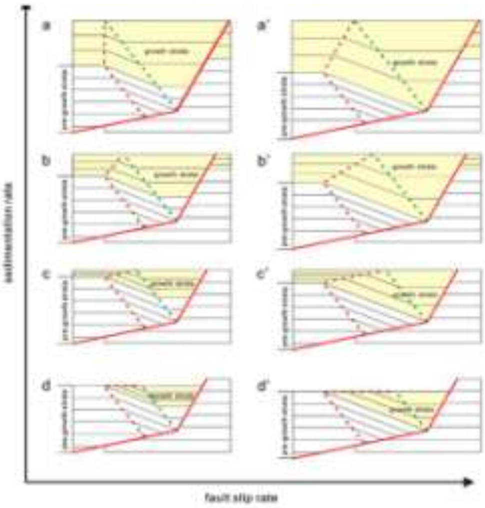

Figure 9: Variation of sedimentation and fault rate that occurs in a half-graben set-up [5]

4.2Flexural-rotation (rolling hinge) model

The second model that can be applied is that of a flexural-rotation (rolling hinge) model as proposed by [16] where an initially high-angle normal fault is progressively rotated to lower dips by isostatic uplifting resulting from tectonic denudation. Beneath these areas of extension, however, there is no upwarping of the Moho as would be anticipated if isostatic compensation of the extension occurred within the mantle. Thus, it is possible to find both heterogeneous upper crustal strain and uniform deep crustal structure across extensional domain boundaries resulting from the effects of intracrustal isostasy.

5. Discussion

General models for sedimentation in half-graben (Fig 10) set-up incorporate large-scale alluvial fans entering the half-graben from the low-gradient footwall. Significantly, the model predicts a contrasting facies change between the transverse alluvial fans and the major longitudinal trunk rivers flowing along the axis. The presence of lacustrine-related facies within the Kolhans proves significant development of lake sedimentation caused by interior drainage within the half-graben . The Kolhan serves as an example of sedimentary response to changing tectonic regimes associated with the SSZ. The tectonism responsible for sedimentation and deformation of the Kolhans may be related to a ca. 2.0-2.2 Ga tectonic event or by intra-cratonic reactivation of structures within a previously assembled greenstone belt. The Kolhans, which may have been deposited in a half-graben set-up, unconformably overlie the Singhbhum granite. This establishes a sequence of tectonic regimes of north–south orientated compression, tectonic quiescence, denudation and north–south orientated extension, following the 2.0 Ga event in the Singhbhum region. The syn north–south orientated extension in the region may have been related to orogenic collapse of the Singhbhum shear zone

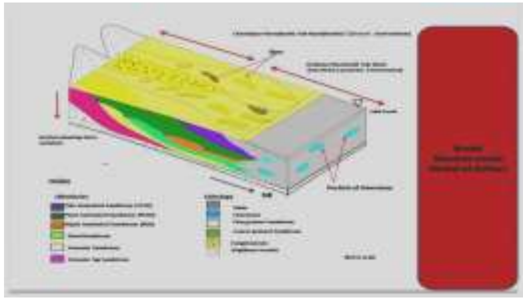

Figure 10: Predicted depositional model based on contrasting facies change in both the sub-basins

6. Acknowledgement

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