



Research Paper

THE PALEOPROTEROZOIC SUPRACRUSTAL KOLHAN BASIN: PROVENANCE, TECTONIC AND PALAEOWEATHERING HISTORIES

Smruti Rekha Sahoo^{1*} and S Das¹

*Corresponding Author: **Smruti Rekha Sahoo** ✉ smruti@iitkgp.ac.in

The 2.2-2.1 Ga supracrustal Kolhan Group is a shale dominated fluvio-deltaic succession set in a continental rift setting. The succession is a sequence of subarkose-quartz arenite with lenses of conglomerate overlain by extensive thick shale-limestone package and show a non-cyclicality in the sedimentation history. 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. A general north-west directed palaeoslope is inferred from the areal disposition of the lithofacies, vertical thickness distribution and variations of the sediment textures. The size-roundness relationship, the mineralogy, the bimodal distribution, textural inversion and palaeocurrent studies are suggestive of complex lithologies and multiprovenance - presumably a granitic to the east and northeast and an Iron Ore Group to the southwest and northwest of the basin.

Keywords: Provenance, Tectonic setting, Paleoweathering history

INTRODUCTION

Sandstone compositional studies are very important in tracing sediment provenance (Dickinson and Suczek, 1979). Sandstone compositional analyses, in which proportions of detrital framework grains within a sand (stone) sample are plotted on various ternary plots (QFR, QFL, etc.), can distinguish various tectonic settings of source areas (Ingersoll *et al.*, 1995). Composition of detrital sediments is controlled by various factors, including source rocks, modes of transportation, depositional environments, climate, and diagenesis (Suttner, 1974, Valdiya, 2010). Provenance studies that focus on key

attributes of detrital mineralogy provide important constraints on basin evolution and unroofing history of orogenic belts.

The study area Proterozoic Kolhan Group is the youngest unit in the Pre-Cambrian Singhbhum – Iron Ore stratigraphy and was deposited in the intracratonic basins that developed within the Singhbhum-Orissa Iron Ore craton. The basin shows a general NNE-SSW alignment and controlled by the trend of the Iron Ore synclinorium. The metasedimentary rocks comprising of basal conglomerate, sandstone, and shale with impersistent limestone and unconformably overlies the Singhbhum granite

¹ Department of Geology and Geophysics, Indian Institute of Technology Kharagpur, 721302.

in the east and partly over, folded and thrust-faulted, Iron-Ore Group to the west. The geological map of the Chaibasa-Noamundi basin is documented by Chatterjee and Bhattacharya, 1969 and GSI, 2006 (Figure 1). The Kolhan basin represents a shallow pear-shaped epicontinental basin with a low westerly 5-10° dip.

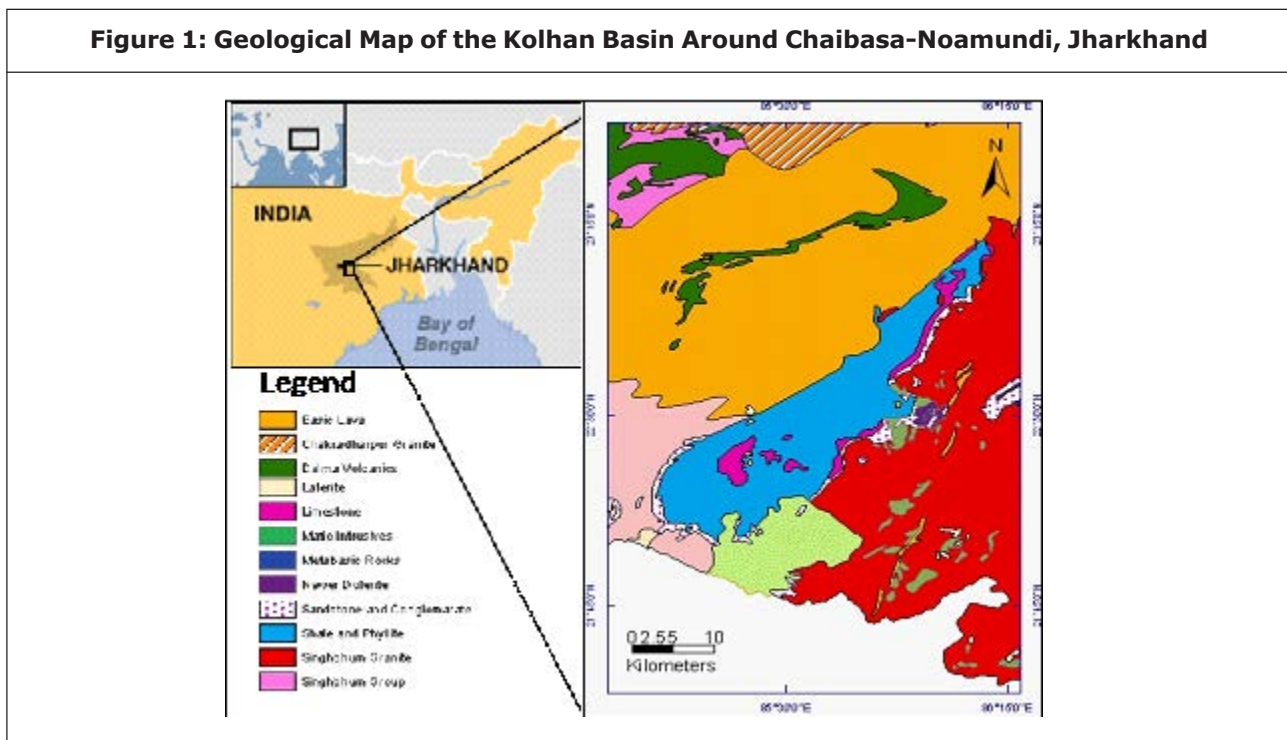
Jones (1934) included members of the Kolhan Group as part of his Iron Ore Series. Dunn (1940) used the term 'Kolhan Group' for a sequence of unmetamorphosed sedimentary formation overlying the Singhbhum granite and later Dunn and Dey (1942) correlated the Kolhan Group with the Dhanjoris of eastern Singhbhum. Earlier studies reported the detailed stratigraphy, structure and partly the sedimentology of the basin (Saha, 1948a-b; Ray and Bose, 1959, 1964; Bhattacharya and Chatterjee, 1964; Chatterjee and Bhattacharya, 1969; Bandopadhyay and Sengupta, 2004; Chakraborty et.al., 2005; Mukhopadhyay *et al.* 2006). As the detailed

sedimentation history covering comprehensive aspects of tectonic setting, and paleoweathering histories 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 at the early stage of basin formation.

MATERIALS AND METHODS

Fieldworks were carried out to describe and characterize the lithounits of the Kolhan basin. Different lithounits were identified on the basis of bed geometries, gross lithologies, and sedimentary structures from 17 different locations viz. Gangabasa, ITI College (two sections), Rajanka, Gumuagara, Kamarhatu, Singpokharia, Arjunbasa, Tunglei, Gutuhatu, Bringtopang, Bistampur, Dyliamarcha, Matgamburu, Rajanka, ITI hill top and Surjabasa. The textural and the structural aspects of the lithounits observed in the outcrops were then

Figure 1: Geological Map of the Kolhan Basin Around Chaibasa-Noamundi, Jharkhand



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 (Selley, 1970, 1976). Sampling has been done from selected sections for further petrographic and geochemical analysis.

RESULTS AND DISCUSSION

Facies Analysis

Lithofacies studies have been done following standard technique (Miall, 1984) and various sections studied have been shown in Figure 2a. Six lithofacies are described individually as, (a) Granular lag facies (GLA), (b) Granular sandstone facies (GSD), (c) Sheet sandstone facies (SSD), (d) Plane laminated sandstone facies (PLSD), (e) Rippled sandstone facies (RSD) and (f) Thin laminated sandstone facies (TLSD). The field photographs of six lithofacies are shown in Figure 2b.

Paleocurrent Analysis

Circular histograms (with vector azimuth) showing paleocurrents have been shown in Figure 3A,a-f (a. Gangabasa section, b. Pungsiya section, c. Bistampur section, d. Gumua Gara rivers section, e. Matgamburu section, f. Rajanbasa section). The computed vector mean suggests northwesterly and northeasterly paleoflow. The sector level paleocurrents also show wide variation ranging from 357° to 14°. Statistical analyses of the paleocurrent data is shown in Table 1. Higher value of vector strength, with unimodal distribution for most of the sectors suggests predominantly unidirectional sediment transport (Selley, 1968).

The percentage frequency distribution of azimuths of detrital quartz in thin section cut parallel to bedding plane, in which the azimuth is grouped into twelve class intervals. The statistical operation carried out on the above data includes

Figure 2: (a) Lithologs Showing the Vertical Distribution of the Lithofacies in the Study Area (b) Field Photographs of six Lithofacies

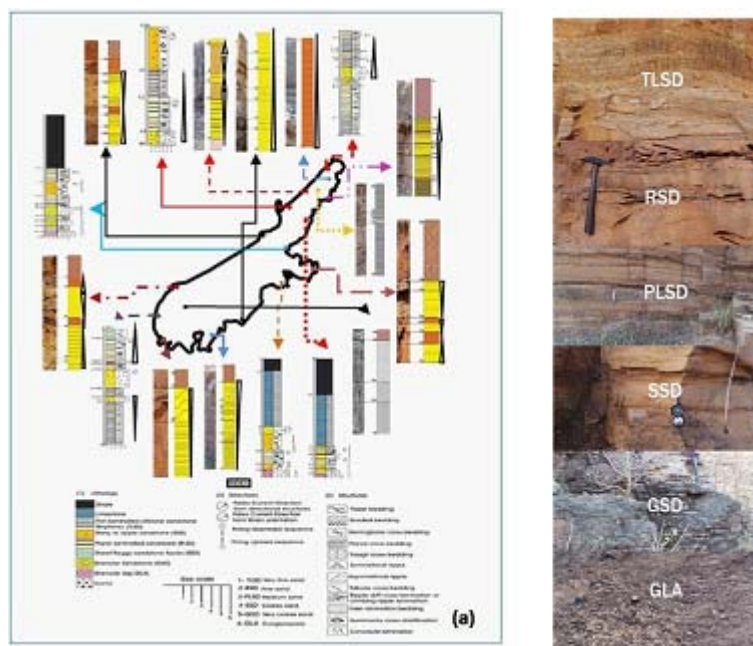
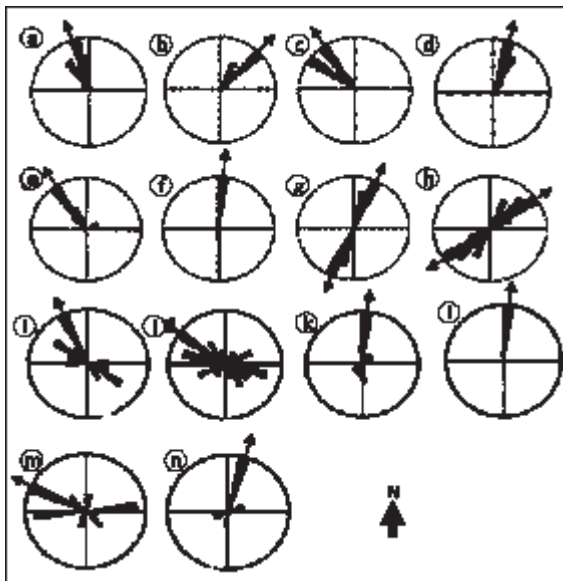


Figure 3: Circular Histograms Showing The Paleocurrent Dispersal Patterns At Seven Lithologs (From Cross Bed), (A) Behind ITI Section, (B) Surjabasa Section, (C) Bingtopang Section, (D) Gumuagara River Section, (E) Dylamarcha Section 1st, (F) Hill Top, (G) Tunglai Section, (H) Dylamarcha Section 2nd, (I) Gangabasa Section, (J) Pungsiya Section, (K) Bistampur Section, (L) Gumua Gara Rivers Section, (M) Matgamburu Section, (N) Rajanbasa Section



Tukey chi-square test for preferred grain orientation data (Harrison, 1957; Middleton, 1965) and circular arithmetic means (Wood and Wood, 1966). The paleocurrent data from grain orientation shows that the direction varies from NE to SW (Table 2). Such directions should roughly correspond to the paleocurrent directions from cross bedding and ripple marks.

Petrographic Characteristics and Modal Analysis

Modal analyses of fifty-one fine to medium-grained texturally mature to submature samples from the six different lithofacies were performed. The different lithofacies do not show appreciable mineralogical differences. Quartz (60.37 % - 89.21 %), feldspars (1.46 - 13.54%), and rock fragments (0.49 to 7.82 %), embedded in ferruginous-siliceous cement (0.00-7.97%) and cherty-sericitic matrix (1.41-10.21%) (Fig. 4a) are the main constituents of those rocks. Quartz is the dominant constituent framework grain, and monocrystalline quartz predominates over polycrystalline quartz (Figure 4b).

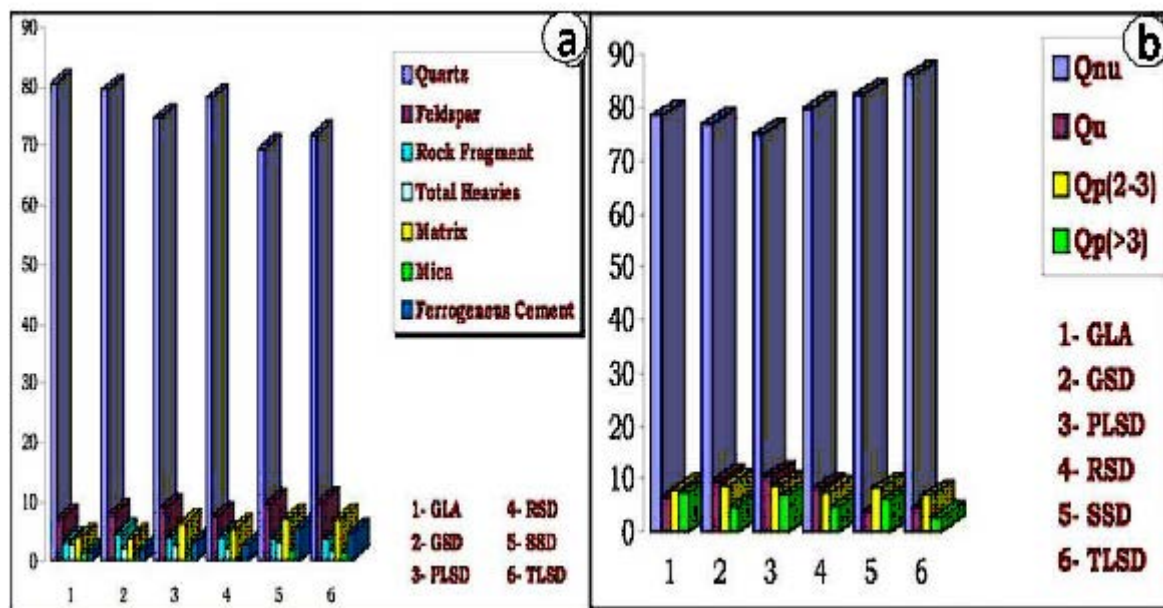
Table 1: Statistical Analyses of Paleocurrent Data

Location	No. of data	Class intervals	Vector mean in Degrees	95% confidence intervals in Degrees
A	70	10	338	7.2
B	55	10	36.2	4.1
C	40	10	311	10.2
D	78	10	23	5.6
E	50	10	339	10.2
F	68	10	3	29.9
G	54	10	19 and 199	4.3
H	47	10	46 and 226	13.7
I	48	10	318	36
J	51	10	294	38
K	58	10	12.2	12
L	44	10	06.2	6
M	50	10	291	19
N	47	10	28.2	33

Table 2: Data for Preferred Grain Orientation Direction

Sample Nos.	Value of χ^2	Level upto which significant (2.d.f)	Preferred orientation direction	Linear arithmetic mean \bar{y} (in degrees)	Circular arithmetic means (\bar{y}) in degrees
1	5.93	90 th	245°49'	201.80	255.88
2	5.76	90 th	163°46'	176.62	193.35
3	5.60	90 th	288°17'	205.56	300.26
4	12.47	99.5 th	236°13'	169.89	285.95
5	6.82	95 th	259°28'	171.00	275.41
6	6.54	95 th	227°23'	192.48	305.04
7	9.09	97.5 th	156°12'	169.48	302.05
8	8.86	97.5 th	210°24'	193.44	290.24
9	6.57	95 th	130°24'	159.61	253.54
10	9.33	99 th	338°02'	207.41	317.40
11	6.25	95 th	194°20'	185.64	145.84
12	6.38	95 th	348°14'	180.43	315.00

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



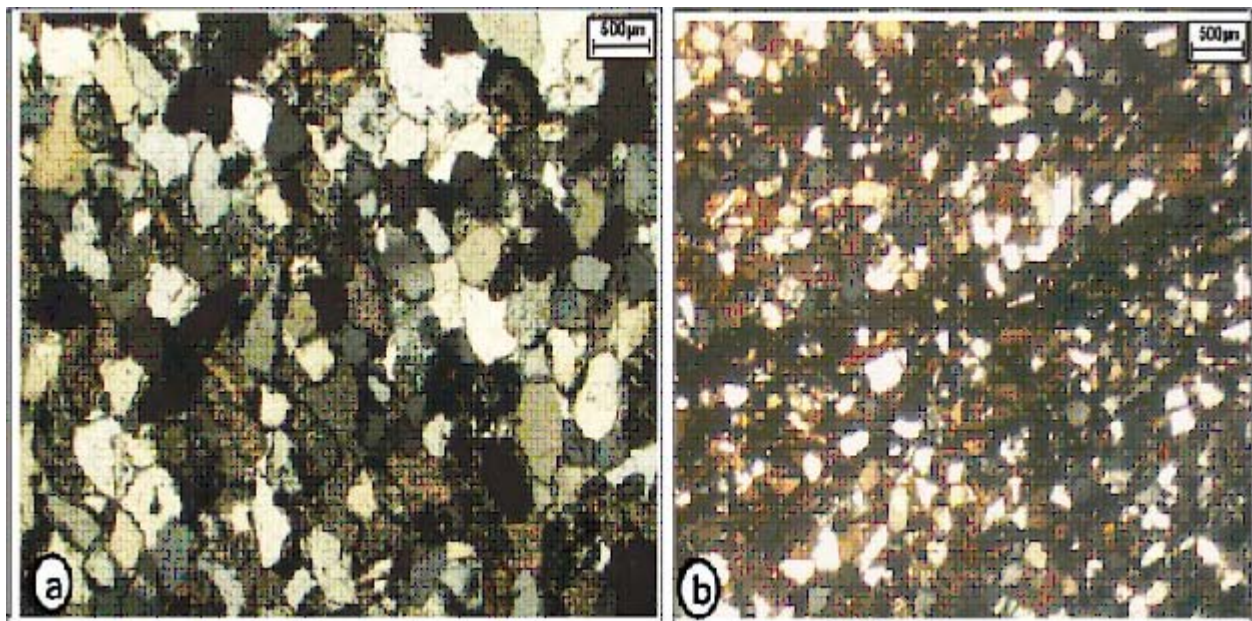
Clast-Matrix Ratio, Cement and Pre and Post depositional alteration

The matrix material consists of sericite or reconstituted complex aggregates of chert and sericite (Figure 5a). The amount of sericitic matrix decreases with an increase in the grain size of sandstones. The relationship between total quartz and matrix percentage has been shown in Fig. 4.4c. In the study area, the matrix is derived from both weathered profile over the Singhbhum granite as well as from the post-depositional alteration of sand sized detrital feldspar grains. Such clay matrix may have been later recrystallized into sericitic mica flakes. The ferruginous cement (Figure 5b) may have been derived from the alteration of ferromagnesian minerals. The silica cement is mainly derived by the alteration of unstable mineral such as feldspars, clayey aggregates and unstable forms of silica (Pye, 1944; Towe, 1962). These constituents are present in Kolhan Sandstones

and could well have contributed to the silica cements.

The Kolhan sandstones show both compositional and textural alterations. Early diagenetic alterations include precipitation and deposition of silica around detrital quartz grains, detrital clay-aggregates and rarely on detrital feldspars. Such silica overgrowths are conspicuously absent on those quartz grains which are embedded in sericite-clay matrix. The sericite-clay matrix seems to have acted as a barrier for the secondary solutions to reach the quartz grains and form overgrowths. The other more probable alternative appears to be that the clay matrix has completely replaced the overgrowths, leaving no relict whatsoever. With increasing intensity of diagenesis, the matrix becomes recrystallized and reconstituted with partial dissolution of detrital outlines. Feldspar is a subordinate constituent in the Kolhan Sandstone and occurs mostly in a slightly sericitized or

Figure 5 (a) Sericite Matrix Or Reconstituted Complex Aggregates Of Chert and Sericite Matrix (b) Silica and Ferruginous Cement



muscovitized condition in detrital subangular grains. The other type of feldspar of much smaller size, clean and quite fresh is authigenic in origin and includes mostly anhedral crystals of twinned microcline and finely lamellar twinned albite. The sericitization and muscovitization of the plagioclase feldspar must have taken place prior to deposition during the transport or in source rock itself.

Plots of Q-F-L (quartz–feldspar–lithics, $L=L_t$), Q_m/Q (ratio of monocrystalline quartz to total quartz), Q_m/Q_p (ratio of monocrystalline quartz to polycrystalline quartz), TFG (total framework grains), L_s/L (ratio of sedimentary lithics to total lithics), and feldspar percent vs. $Q_m/(Q_m+L_t)$ have been shown in Figure 6, a-f and the triangular plots have been shown in Fig. 7, a-b. The observations are detailed below.

- (a) An overall increase in QFL percentage from 80-90 is observed in all the lithofacies, with the QFL percentage maximum in the GSD facies (Figure 6a).
- (b) The ratio Q_m/Q shows a considerable fluctuation in the values, with the maximum value in the TLSD facies (Figure 6b).
- (c) An overall predominance of monocrystalline grains over polycrystalline grains (Q_m/Q_p) suggests maturity and stability of the basin (Figure 6c).
- (d) TFG percentage shows a wide fluctuation and eventually decreases towards TLSD. A fall in the TFG percentage is seen in the SSD facies (Figure 6d).
- (e) The ratio L_s/L shows fluctuation from GLA facies to TLSD facies with decrease at RSD facies. (Figure 6e).
- (f) Feldspar percentage vs. $Q_m/(Q_m+L_t)$. The

relatively high quartz content in the GLA and GSD facies compared to feldspar shows that the conglomerates must have been recycled and a part of the original matrix must have been removed (Fig. 6f).

- (g) QFR (quartz-feldspar-rock fragments) plots (Folk, 1980) shows that the clastics are mainly quartz arenite- subarkose (Fig. 7a).
- (h) QFL plot (Fig. 7b) show that most of the samples fall in the zone of craton interior and some in transitional continental zone (Dickinson, 1985).

These plots indicate the possibility of a dual source for these sediments and also focus on the grain stability including relief, weathering, maturity, and provenance.

Provenance history and tectonics

Both the mineralogical and chemical compositions of the sedimentary and metasedimentary rocks have been frequently used for the determination of provenance. The source rock has been identified from petrographic analysis and the reasons behind the identification are given below.

- (a) The presence of pebbles of jasper, white chert, sandstone, banded hematite jasper (BHJ), quartzite, volcanic and granitic rocks embedded in sandy-silty matrix indicates that the sediments have been derived both from the Iron Ore Group and the Singhbhum granite.
- (b) Evidence of dual provenance is also inferred from the sediment bimodality.
- (c) The presence of well rounded grains along with the subrounded and well sorted grains is indicative of sediment maturity and

Figure 6: (a) An overall percentage QFL ranging from 80 to 90 is observed in all the lithofacies, with the QFL percentage maximum in the GSD facies. (b) The ratio Q_m/Q_p , (c) An overall predominance of monocrystalline grains over polycrystalline grains (Q_m/Q_p), (d) The TFG percentage shows a wide fluctuation and eventually decreases towards TLSD. (e) The ratio L_s/L , (f) Feldspar percentage vs. $Q_m/(Q_m+L_t)$ plot

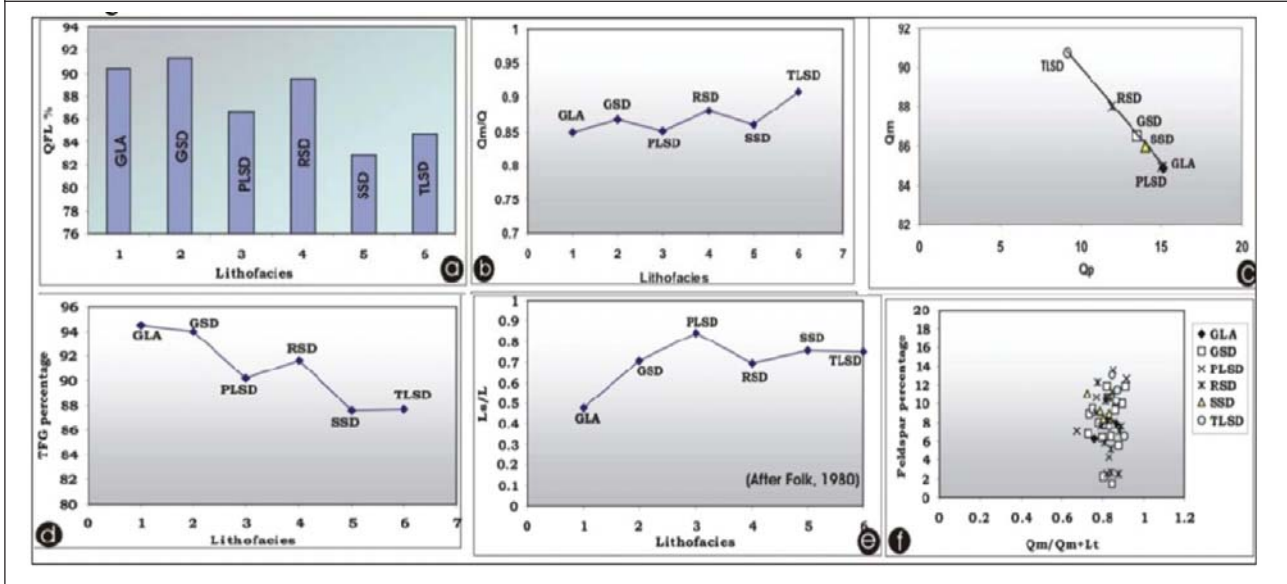
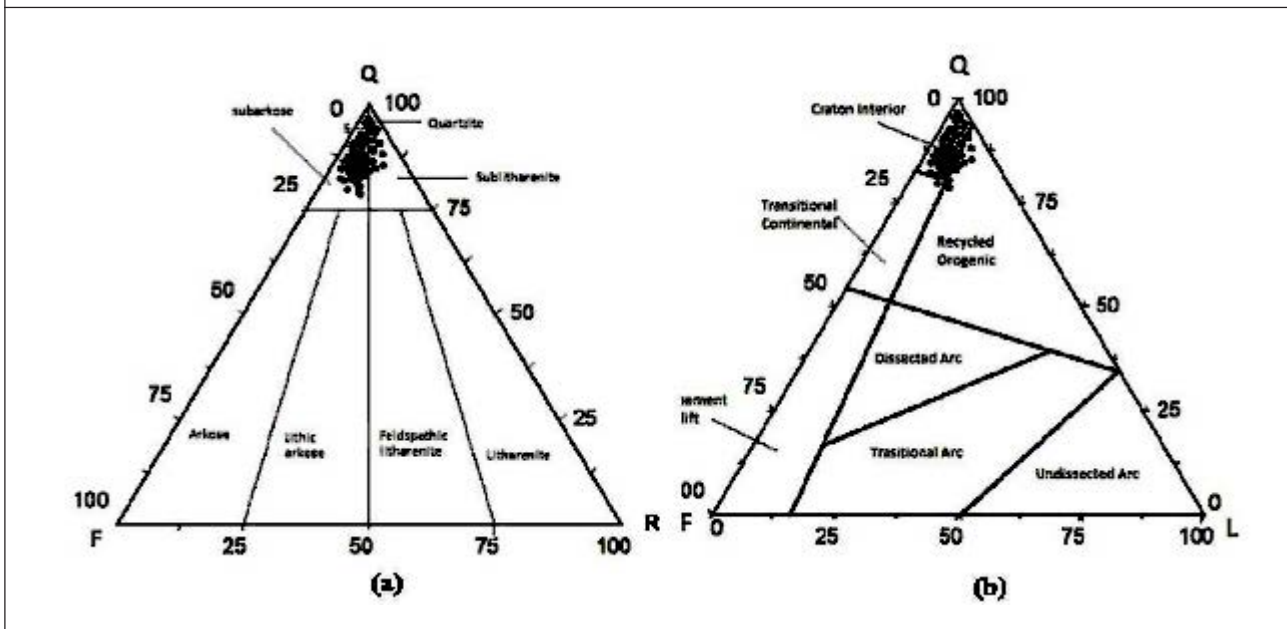


Figure 7: (a) QFR plots (Folk, 1980): the clastics are mainly quartz arenite-subarkose (b) QFL plots (Dickinson, 1985)



recyclicity. The paucity of feldspar, abundance of fine grained sedimentary lithics, and evidence of sediment diagenesis are indicative of sediment recycling.

(d) The high ratio of the stable (quartz, chert) to unstable grains (feldspar, lithic fragments) indicates a compositional maturity of the sand-stones (Pettijohn, 2004).

- (e) Triangular plots are suggestive of sediment derivation from craton interior. Association of recycled sandstones and non-undulose quartz are also indicative of sediment derivation from the craton interior.
- (f) The climatic condition may be initially humid for the development of subarkose, which later differentiated into quartz arenite.
- (g) The orthogonal nature in the major paleocurrent patterns (NE and NW directions) is indicative of a dual source.

Geochemical Characteristics

The Kolhan shale are composed of 63.0-68.4 % SiO_2 , 14.8-18.0 % Al_2O_3 , 3.1-6.2 % K_2O , 0.03-0.5% Na_2O , 0.2-0.4 % CaO , 0.2-2.2 % MgO , 0.1-0.4 % P_2O_5 , 0.5-0.7 % TiO_2 , 0.07-0.1 % MnO , and 3.8-15.4 % Fe_2O_3 . Kolhan shale is characterized by high values of SiO_2 , K_2O , Fe_2O_3 and low values of CaO , TiO_2 , Na_2O , Al_2O_3 , MgO as compared with the average Proterozoic shale (APS). On comparing with the results of Bondopadhyay and Sengupta, 2004 Kolhan shale shows more or less the same values for SiO_2 , Al_2O_3 , Fe_2O_3 , MnO , MgO content.

Paleotectonic history

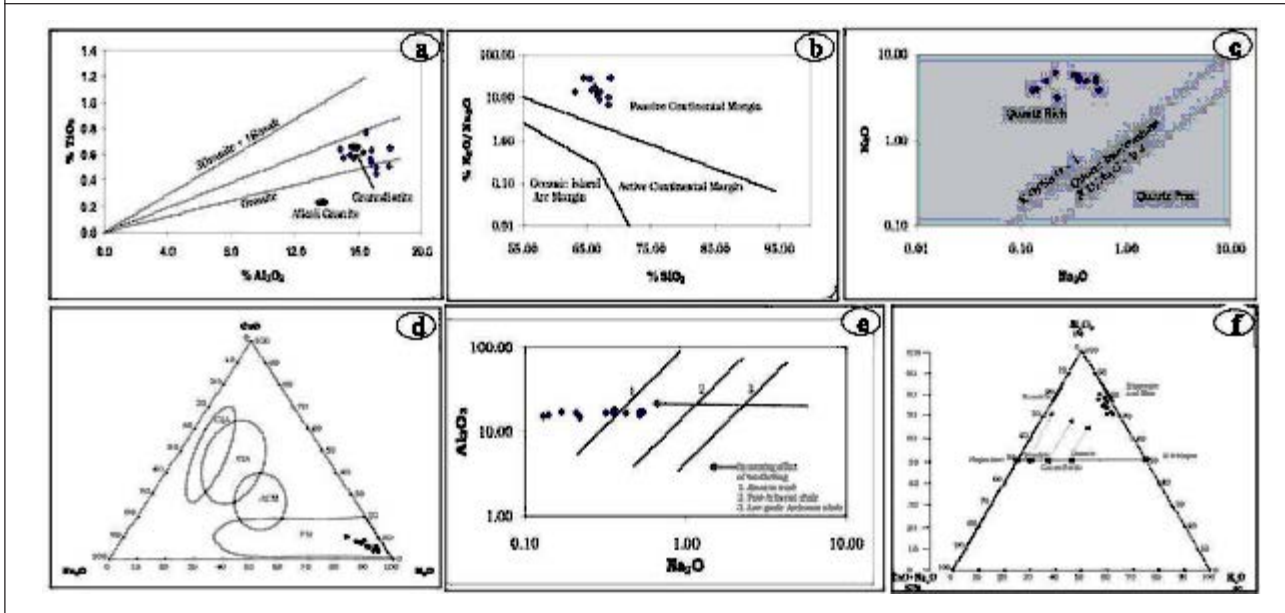
The K_2O vs. Na_2O (Crook, 1974), $\text{K}_2\text{O}/\text{Na}_2\text{O}$ vs. SiO_2 plot (Roser and Korsch, 1986) and $\text{CaO}-\text{K}_2\text{O}-\text{Na}_2\text{O}$ ternary plot (Bhatia, 1983) have been used successfully to determine the tectonic setting of shales. The bivariate plot between Al_2O_3 and TiO_2 indicates the source rock to be granitic composition (Figure 8a). The data points for the Kolhan shales plot in the passive margin/intracratonic set up (Figure 8b). In K_2O vs. Na_2O plot (Figure 8c), the Kolhan shale fall in quartz rich field of Crook, (1974) suggesting that these lithounits were deposited in plate interior either at

stable continental margin or in the intracratonic basin. High $\text{SiO}_2/\text{Al}_2\text{O}_3$ and $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio of these shales suggest their derivation from a granite dominated upper continental crust (McLennan *et al.*, 1993). In the $\text{CaO}-\text{K}_2\text{O}-\text{Na}_2\text{O}$ ternary plot (Bhatia, 1983) the studied shale samples plot in passive margin field (Figure 8d). The rate of chemical weathering of source rock and the erosion rate of weathering profile are controlled by the prevailing climate as well as source rock composition and tectonics.

Paleoweathering and Paleoclimate

Warm humid climate and stable tectonic setting favor intense chemical weathering. A useful way to assess the paleoweathering and tectonic history of the rock is the Chemical Index of Alteration (CIA) = $\{ \text{Al}_2\text{O}_3 / (\text{Al}_2\text{O}_3 + \text{CaO} + \text{Na}_2\text{O}) \} \times 100$ (Nesbitt and Young, 1982) to monitor the progressive alteration of plagioclase and K-feldspar to clay minerals. CIA value increases with increasing weathering intensity, reaching 100 when all Ca, Na and K have been leached out from weathering residue. The CIA value for the Kolhan shale vary from 70.7-80.3, (av.75.2) indicating that the source rock underwent moderate to high degree of chemical weathering in humid tropical condition. The weathering intensity of sedimentary rock can be inferred from the concentration of Al_2O_3 and Na_2O (Taylor *et al.*, 1986). In the discriminative diagram of Al_2O_3 and Na_2O (Figure 8e), the plots are in the field of Amazon mud. This indicates a high intensity of chemical weathering (feldspars have been altered to clay minerals). The weathering history of igneous rocks and the source for various clastic sedimentary sequences have been evaluated by using the A-CN-K (A= Al_2O_3 ; CN= $\text{CaO}+\text{Na}_2\text{O}$; K= K_2O) triangular diagram (Nesbitt and Young, 1982). In A-CN-K plot (Figure 8f); the

Figure 8: (a) Bivariate plot between Al_2O_3 and TiO_2 , (b) Tectonic discrimination diagram for the Kolhan shale, (c) K_2O-Na_2O diagram (Crook, 1974), (d) $CaO-K_2O-Na_2O$ triangular diagram (Bhatia, 1983), (e) Discriminative diagram (Taylor et al., 1986), (f) A-CN-K compositional space showing weathering trends for the Kolhan shale



compositional trends of various rocks during initial stage of weathering would be almost parallel to A-CN line from their respective fresh unweathered points. These pathways of weathering for mafic and felsic igneous rocks are confirmed by weathering profile and thermodynamics/kinetic calculation (Nesbitt and Young, 1984a). The pathways are parallel to A-C-N line because in the initial stage of weathering Na and Ca are removed from plagioclase and as the degree of weathering increases, K-feldspar are destroyed releasing K in preference to Al. During this process the residual bulk composition is enriched with Al_2O_3 . All the samples of Kolhan shale plot parallel and close to the $Al_2O_3-K_2O$ boundary implied that their source area had undergone extensive weathering and produced shaly sedimentation.

CONCLUSION

The sandstone petrography and the shale

geochemistry clearly indicates that the Kolhans had both IOG and Singhbhum granite as the source rocks. However, a sandstone plots on a QFL diagram does not only depend on the tectonic setting of the source area (Dickinson, 1985), but also on the prevailing climate (Basu, 1985). In sandstones derived from low-to moderate relief source areas under humid climatic conditions there may be a depletion of feldspars and rock fragments and enrichment in quartz (Basu, 1985).

A general NW–NE directed paleoslope is inferred from the areal disposition of the lithofacies, its vertical thickness distribution, variations of the sediment textures. The paleocurrent studies (based on apposition fabric analysis and structures like ripple marks and cross beddings) suggest not only a source area with complex lithology but more than one provenance type-presumably a granitic to the east and northeast and an Iron Ore Group type to the southwest and northwest 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 basin. The provenance studies are indicative of a dual source and extensive sediment reworking during deposition. The sedimentation took place under a warm and humid tropical paleoclimate which is responsible for the intense weathering of the rocks. As a cause of deep chemical weathering and destruction of the labile framework grains within the basin, the quartz content in the sediments is high. The source rock lithology, warm humid climate, absence of vegetation and shallowness of the basin 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 renewed tectonic effects.

ACKNOWLEDGMENT

The authors express their gratefulness to several postgraduate and research scholars for their help and cooperation. Help and cooperation received from the Head of the Department, Geology and Geophysics are also acknowledged.

REFERENCES

1. Bandopadhyay P C and Sengupta S (2004), "Paleoproterozoic supracrustal Kolhan Group in Singhbhum craton, India and the Indo-African Supercontinent", *Gondwana Res.*, Vol. 7, No. 4, pp. 1228-1235.
2. Basu A (1985), "Reading provenance from detrital quartz", In G G Zuffa (Ed.), *Provenance of Arenites*, Dordrecht D Reidal, pp. 231-247.
3. Bhatia M R (1983), "Plate tectonics and geochemical composition of sandstones", *Jour. Geol.*, Vol. 91, pp. 611-627.
4. Bhattacharya A K and Chatterjee B K (1964), "Petrology of Precambrian Kolhan formation of Jhinkpani, Singhbhum district, Bihar", *Geologische Rundschau*, Vol. 53, pp. 758-779.
5. Chatterjee B K and Bhattacharya A K (1969), "Tectonics and sedimentation in a Precambrian shallow epicontinental basin", *Jour. Sed. Petrol.*, Vol. 39, No. 4, pp. 1566-1572.
6. Crook K A W (1974), "Lithogenesis and geotectonics: the significance of compositional variations flysch arenites (greywakes)", In: Dott R H and Shaver R H (Eds.), *Modern and Ancient Geosynclinal Sedimentation. Soc. Econ. Paleo. Min. Spl. Publ.* Vol.19, pp. 304-310.
7. Dickinson W R and Suczek C A (1979), "Plate tectonics and sandstone compositions", *Bull. Amer. Assoc. Petrol. Geol.* Vol.63, pp.2164-2182
8. Dickinson W R (1985), "Interpreting provenance relation from detrital modes of sandstones", In: G G Zuffa (Ed.), *Provenance of Arenites*. Dordrecht D. Reidal. pp.333-363
9. Dunn J A and Dey A K (1942), "Geology and petrology of Eastern Singhbhum and surrounding areas", *Mem. Geol. Surv. Ind.* Vol. 69, No. 2, pp. 281-456
10. Dunn J A (1940), "The stratigraphy of North Singhbhum", *Mem. Geol. Surv. Ind.*, Vol. 63, No. 3, pp. 303-369.

11. Folk R L (1980), "Petrology of Sedimentary Rock", Hemphill Publ. Co., Austin, Texas.
12. Ingersoll R V, Graham S A and Dickinson W Rarrison, P W, Dickinson, W R (1995), "Remnant ocean basins", in Busby, C J and Ingersoll, R V (eds.), *Tectonics of sedimentary basins*: Blackwell Science, Cambridge. p. 363-391
13. Jones H C (1934), "The Iron ore deposits of Bihar and Orissa", *Mem. Geol. Surv. Ind.*, Vol. 63 No. 2, pp.167-302.
14. Mukhopaddhyay J, Ghosh G, Nandi A K and Chaudhuri A K (2006), "Depositional setting of the Kolhan Group: its implications for the development of a Meso to Neoproterozoic deep-water basin on the South Indian Craton", *South African Jour. of Geol.*, pp.183-192.
15. Nesbitt H W and Young G M (1982), "Early Proterozoic climates and plate motions inferred from major elements of lutites", *Nature*, Vol. 299, pp.715-717.
16. Nesbitt H W and Young G M (1984a), "Prediction of some weathering trends of plutonic and volcanic rocks based on thermodynamics and kinetic consideration", *Geochim. Cosmo. Acta*, Vol. 48, pp. 1523-1534.
17. Pettijohn F J (2004), *Sedimentary Rocks* (3rd Ed). CBS Publishers and Distributors, New Delhi, India
18. Pye W D (1944), "Petrology of Bethal sandstone of South-Central Illinois", *Bull. Amer. Assoc. Petrol. Geol*, Vol. 28, pp. 63-122.
19. Ray S and Bose M K (1959), "Fold patterns in the Kolhan Formation", 46th Indian Sci. Congr.Proc. pt.3, p. 202.
20. Ray S and Bose M K (1964), "Unique fold pattern in shallow basin", Rept. 22nd Session, *Int. Geol. Cong.*, Vol. 4, pp.163-170.
21. Roser B P and Korsch R J (1986), Determination of tectonic setting of sandstone- mudstone suites using SiO₂ content and K₂O/Na₂O ratio. *Jour. Geol.* Vol. 94, pp. 635–650.
22. Saha A K (1948a), "A study of limestone near Chaibasa", *Geol. Min. Met. Soc. India, Quart. Jour.*, Vol. 20, pp.49-58.
23. Saha A K (1948b), "The Kolhan Series-Iron –Ore Series boundary to the west and southwest of Chaibasa", *Bihar. Sci. and Culture*, Vol.14, pp.77-79.
24. Suttner L J (1974), "Sedimentary petrologic provinces: An evaluation", Ross C A (eds.), *Paleogeographic Provinces and Provinciality, Society of Economic Paleontologists and Mineralogists*, special publication, Vol. 21, p. 75-84.
25. Taylor S R, Rudnick R L, Mclennan S M and Erickson K A (1986), "Rare earth element patterns in Archean high grade metasediments and their tectonic significance", *Geochim. Cosmo. Acta.*, Vol. 50, pp. 2267-2279.
26. Towe K M (1962), "Clay mineral diagenesis as a possible source of silica cement in sedimentary rocks", *Jour. Sed. Petrol.*, Vol. 32, pp.26-28.
27. Valdiya K S (2010), *The Making of India Geodynamic Evolution*, Macmillan Publishers India Ltd, New Delhi.