

Sandstone Petrology and Geochemistry of the Kolhan Basin, Eastern India: Implications for Basin Tectonics

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Abstract

The 2.2-2.1 Ga pear shaped Kolhan basin show the development of a time transgressive group in a passive rift setting caused due to the fragmentation of the Columbia supercontinent. The Kolhans while showing a variability in the thickening/thinning of the quartzo-feldspathic, quartzolitic, and quartzose sandstones, do also show a similarity in compositional and dispersal characteristics to both underlying and overlying strata, phenomenon termed here congruence.

A combined petrologic and geochemical analysis of sandstone suites (congruence suite) can be used to track changes in the sediment supply from adjacent areas if (1) a long-term record of the basin fill is available (2) the source signal is preserved by "proximal" depositional conditions and (3) diagenetic alteration of sediments is limited. Provenance-derived variations in sandstone compositions are therefore a key in unraveling regional tectonic histories. The basin axis controlled the progradation direction which was likely driven by climatically induced sediment influx, a eustatic fall, or both. In the case of the incongruent shift, increased sediment supply permitted the rivers to cross the basinal deep. Temporal association of the Kolhans with tectonic structures in the belt indicates that syntectonic thrust uplift, not isostatic uplift or climate, caused the influx of quartz.

The Kolhans display increasing textural and mineralogical maturity from base to top of its lithological succession. Continued regression and peneplanation heralded the deposition of supermature sandstone in the uppermost horizons of the Kolhans.

Keywords: Sandstone; Singhbhum Granite; Gazzi-Dickinson point

Introduction

The Kolhan basin in Singhbhum district is unique in many respects. Its narrow strip-like outcrop pattern, controlled by the NE-SW trend of the much older Iron-Ore Formation synclinorium abuts against the Singhbhum Granite in the east of a greater portion of its trend. A part of eastern and entire western boundary is in contact (fault) with the Iron-Ore Formation rocks. The Kolhan Shale Formation is of course definitely younger than the Iron-Ore Formation [1] and is also younger than the Singhbhum Granite as is clear from the field relations. The Kolhan Basin is set in a diversified lithological provenance, so that it exhibits the development of a rudaceous, arenaceous, calcareous and an argillaceous facies within only a few hundred feet of thickness. The various members of the Formation of the formation dip in general uniformly low to the west away from the contact with the Singhbhum Granite.

Geological Setting of the Area

The area is easily accessible from the nearby railway stations Chaibasa, Jhinkpani and Noamundi on the Tata-Barbil line of South-Eastern Railway. These stations are also well connected by roadways. Different sections around Chaibasa (85°48'-22°23')-Jagannathpur (85°36'-22°15') are Matgamburu, Gangabasa, Rajanka, Rajanbasa, Arjunbasa, Bistampur and Gumua Gara river section near Kudduhatu. The area represents an undulating topography with an average height of 350m and is bounded by hills towards the west and south; the peaks attain an average height of 470 m. The most important rivers are the Roro Gara and Gumua Gara, flowing towards northeast, while the river Deo has south easterly drainage. All sections of the Kolhans are exposed along the river and river sections. The western and southern regions are comparatively densely forested with many tropical trees. The Kolhan group unconformably overlies Singhbhum granite and show a faulted contact with Iron ore group of rocks. The Kolhans are shale dominated succession, and consists of gently westerly dipping, unmetamorphosed

and undeformed strata of sandstones at the base overlain by extensive occurrences of shale. The shale succession in its basal part often laterally grades to calcareous shale and encloses lenticular bodies of limestone, interbedded limestone-shale sequence and thin interval of manganese oxide interbedded with shale. The widespread occurrence of thin sandstone overlain by thick shale represents an asymmetry in vertical basin-fill architecture. The upper part of the lithostratigraphy exhibits widespread and monotonous occurrence of shale. The general stratigraphy of the Kolhan Group of rocks is shown in Figures 1 and 2 shows the Generalized tectonic map of the Indian subcontinent, (b) Singhbhum Iron Ore Craton map and (c) Longitudinal and transverse section of Kolhan Basin.

Methods of Study

Thin section petrography and modal analysis of thin sections of sandstones, collected from Matgamburu, Gumua gara river section-Kudduhatu, Rajanbasa, Bistampur, ITI Chaibasa, Kondwa, Lisy, Baramirglindi, Gangabasa and Pungsiya were done following standard procedure of Gazzi-Dickinson point counting method with the count of a minimum of 300 framework grains per thin section. Matrix problems were minimized during counting by tabulating only those masses of the matrix that displayed obvious grain boundaries or other criteria of

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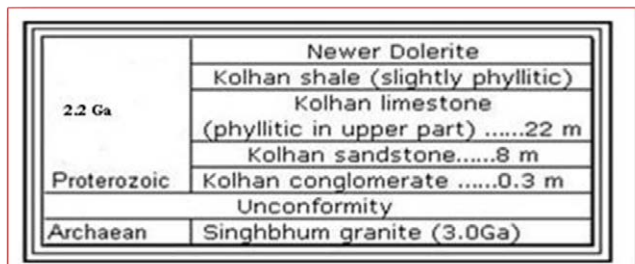


Figure 1: Stratigraphy of Kolhan Group of Rocks.

rock fragments like granite, Banded Haematite Jasper, chert, phyllite, recycled pebbles of quartzite and conglomerate.

Modal analyses of sandstone samples (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%) are the main constituents of those rocks. Quartz is the dominant constituent framework grain, and monocrystalline quartz predominates over polycrystalline quartz. Well rounded recycled plutonic quartz grains with long and concavo-convex contacts are frequently seen (Figures 3-5) [3].

Quartz

Three quartz types are easily recognizable namely non-undulatory quartz, undulatory quartz and polycrystalline quartz grains.

Feldspar

Both fresh and unaltered feldspar are observed in thin sections and

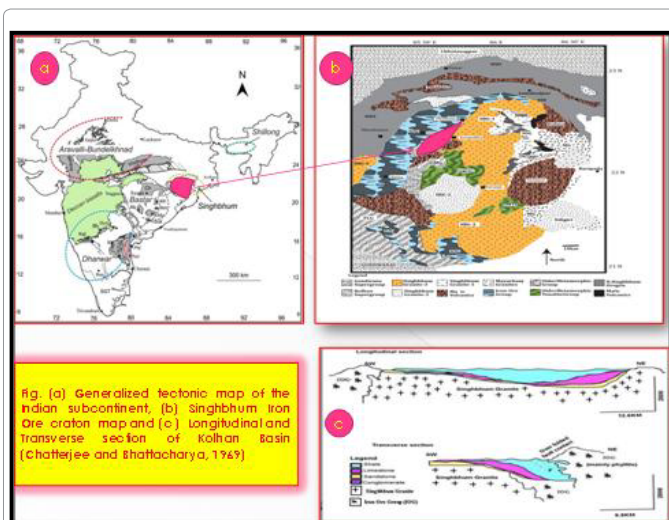


Figure 2: (a) Generalized tectonic map of the Indian subcontinent, (b) Singhbhum Iron Ore Craton map and (c) Longitudinal and Transverse section of Kolhan Basin.

pseudomatrix. The Gazzi-Dickinson point counting method minimizes compositional variation due to grain size differences by assigning sand sized grains within rock fragments to their own category rather than to that of the rock fragments. All calculations for determining the volume percentages of minerals were done following standard method outlined by Dickinson and Suczek (1979) [2]. Heavy mineral analyses were done by point counting method and respective ZTR index values were calculated.

Petrographic Studies of Sandstone

This gives a petrographical account of the siliciclastic rocks of the Kolhan Group of the area of investigation. The rocks are mainly sandstone, conglomerate and shale. The minerals are mainly quartz, feldspar, (lithic fragments) rock fragments, muscovite in minor amount, and heavy minerals like zircon, rutile, tourmaline and opaques. The effects of weathering, sedimentary processes, and compositional characteristics of the source rocks are preserved in the sedimentary rocks. The detrital sedimentary rocks provide information on the provenance and tectonic setting. The sedimentary provenance has been considered to be a direct reflection of the tectonic activities [2].

Petrographic Characteristics and Modal Analysis

The Kolhan sandstones are composed mainly of an aggregate of sub-angular to sub-rounded quartz embedded in siliceous-ferruginous matrix, with subordinate amounts of feldspar, jasper, muscovite,

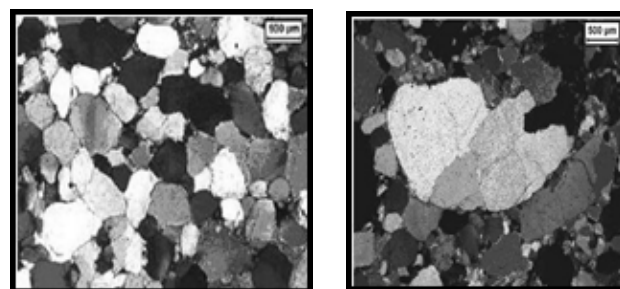


Figure 3: Polycrystalline quartz grains in quartz arenite (cross nicols, 50X).

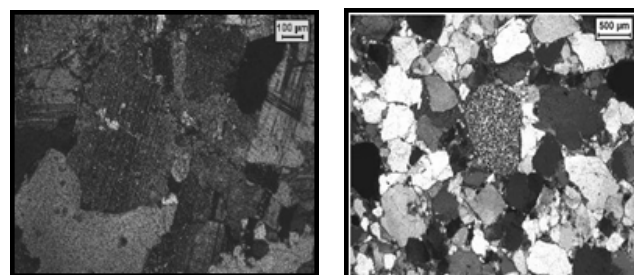


Figure 4: Feldspar grains in arkosic arenite (left figure), Subrounded rock fragments (right figure, in the central portion of the photomicrograph) (cross nicols, 50X).

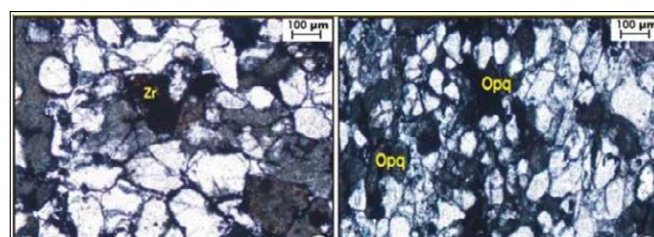


Figure 5: Zircon grains in Kolhan sandstone (plane polarized light, 50X), Opaque grains in quartz arenite (plane polarized light, 50X).

constitute about 1.5% or less. The grain size varies from 0.1 to 0.8 mm while the grains are subangular in shape coated with iron oxide. The feldspars include sodic plagioclase, microcline and untwined varieties.

Feldspar grains in arkosic arenite showing good lamellar and cross-hatched twinning (cross nicols, 50X)

Muscovite

Flakes of detrital muscovite measuring about 0.5 mm. are not commonly seen in these sections. The flakes however show degradation to sericite mica and replacement of their detrital outline by hematite cement.

Rock fragments

The rock fragments are usually identified by compositional and textural criteria.

Chert

The size varies between 0.12 and 0.5 mm. the grains the mostly sub-rounded to rounded with haematite coating. They contain fine sericite flakes as inclusion and show occasional recrystallization.

Other minor detrital components

These include biotite, chlorite and kyanite. Biotite is mostly altered to colourless chlorite with liberation of iron oxide and titanium oxide which form dusty hematite and minute rutile grains in the vicinity. Chlorite is greenish, feebly anisotropic to colourless and almost isotropic and is rarely found as pellets. It is mostly a prochlorite variety. Authigenic chlorite is also present. The kyanite is found as a single big crystal in only one thin section, with one set of prismatic cleavage and extinction angle of nearly 35°. It shows characters of replacement by muscovite flakes and by authigenic silica along the borders.

Details Texture Observation

The grains are mostly subangular to subrounded. The quartz is dominantly a common unit, slightly undulose. Polycrystalline, vein quartz and strongly undulose quartz are very subordinate in occurrence. The grains are mostly coated with iron oxide and exhibit authigenic overgrowths which produce euhedral out line in rare cases. Such overgrowths have occasionally replaced the primary hematite coating

living behind scattered relics of the latter. It is further observed that these overgrowths are rare on that side of the grain which is in contact with the "clay pellets". Recycled quartz grains with abraded outgrowths are occasionally formed. The contacts between the grains are generally plane and rarely sutured and stylolitic. Inclusions of minute apatite, zircon and rutile are rare. They sometimes show gas vacuoles rarely arranged in trails. There is no obvious preferred orientation of the grains, which are embedded in a clay matrix of ten times replaced by hematite and rarely by calcite cement. The detrital mineral grain next in order of abundance is feldspar which varies in modal proportions from practically nil to about 3%. The grain size variation is from 0.09 to 1 mm and the grains are mostly sub angular and coated with hematite. The feldspars and microcline are both fresh and altered and show all stages from nearly fresh to almost completely, seriticized in which few fresh relics are present, give cloudy appearance, sub-angular, feldspars are sodic plagioclase, perthite, microcline and untwined varieties [4].

Micro faulting and bending of the twin lamellae are other features rarely observed in thin sections. Such detrital feldspars show evidence of having been replaced by the slightly recrystallized illite-clay matrix. In other cases all stages of replacement by muscovite along cleavages are also observed. Authigenic overgrowths on detrital plagioclase are extremely rare.

The low content of feldspar could be due to (a) the removal of feldspar during transport or (b) diagenetic removal of feldspar.

Heavy Minerals

The non-opaque heavy minerals are generally poor in the Kolhan sandstone. Minerals like tourmaline, zircon and rutile are present in decreasing order of abundance. The opaque heavy minerals are dominantly hematite, pyrolusite.

The implication of Figures 6-10 are given. Figure 6(A) shows QFR plots [5] with the clastics that are mainly quartz arenite-subarkose and (B) shows QFL plots with most of the samples falling in the zone of craton interior and few in the transitional continental zone. (Modal analysis of the Kolhan Sandstone data given in Table 1). Figure 7 shows the compositional fields in the triangular diagrams indicating the sandstone samples which falls in the cratonic interior zone. (Qt=Quartz total; F=Feldspar; L=Lithic Fragments; Lt=Lithic fragments total). The blue dots indicates the sandstone samples. Figure 8 shows the sandstone

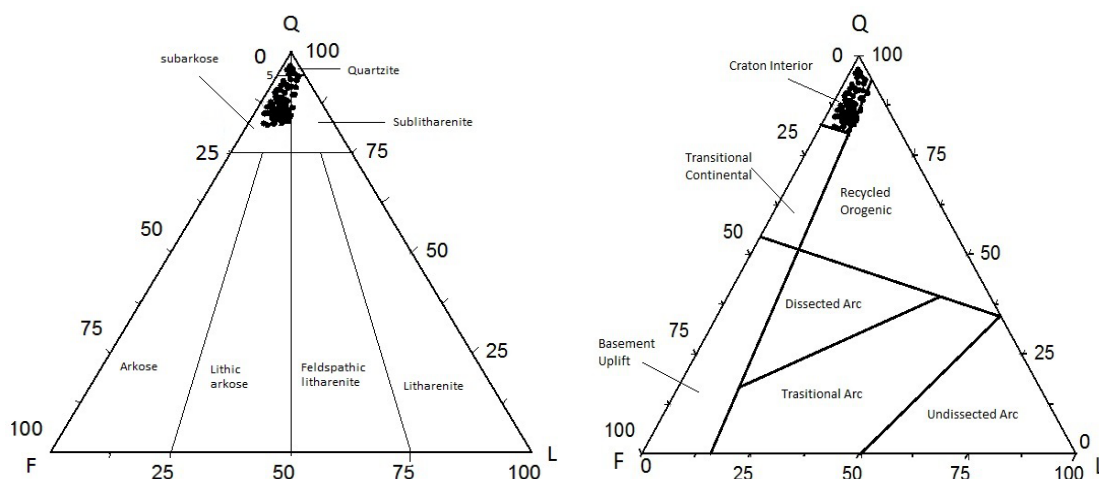


Figure 6: (A) QFR plots [5]: the clastics are mainly quartz arenite-subarkose, (B) QFL plots: show that most of the samples fall in the zone of craton interior and few in the transitional continental zone. (Modal analysis of the Kolhan Sandstone data given in Table 1).

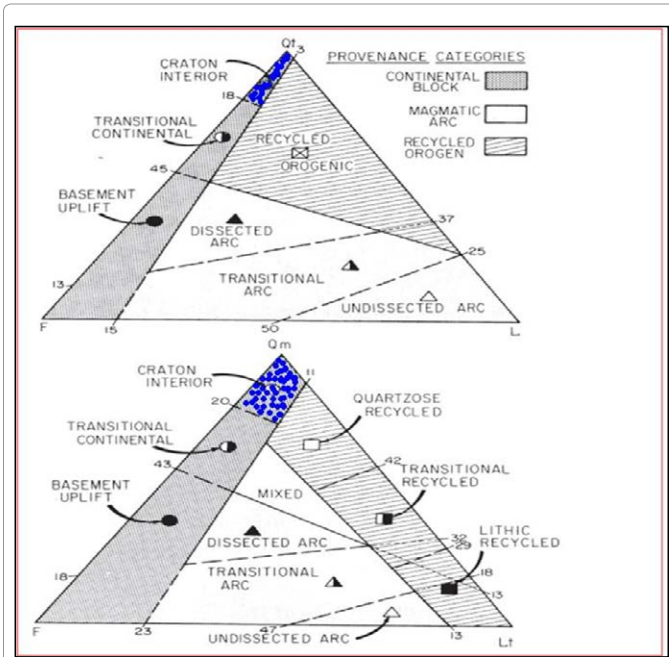


Figure 7: The compositional fields in the triangular diagrams indicate the sandstone samples fall in the cratonic interior zone. (Qt: Quartz total; F: Feldspar; L: Lithic fragments total). The blue dots indicates the samples.

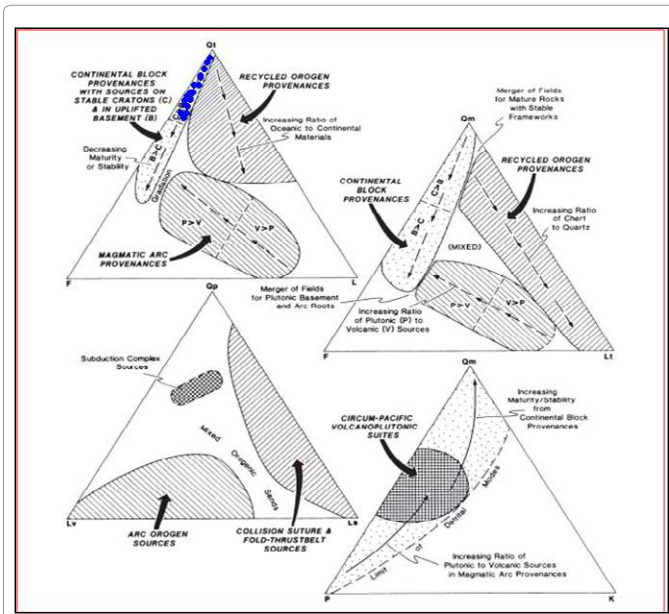


Figure 8: The sandstone samples plot in the stable craton field. The blue dots indicates the samples. (Qt: Quartz total=Qm+Qp; F: Feldspar; P+K (P=Plagioclase, K=potash feldspar); Qm: Quartz monocrystalline; L =total unstable Lithic fragments=Lv+Ls; Lt=Lithic fragments total=Qp+L; Lv=volcanic lithic fragments; Ls=Sedimentary lithic fragments; Qp: Quartz polycrystalline).

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is granite in this case. The blue dots indicate the sandstone samples. Figure 10(A) shows K₂O-Na₂O diagram classifying Kolhan siliciclastics as quartz rich type, (B) CaO-Na₂O- K₂O triangular diagram showing Kolhan siliciclastics in the passive margin (PM) field and also shown are the fields of different tectonic settings, (ACM-Active Continental Margin, OIA-Oceanic Island Arc, CIA-Continental Island Arc). The blue dots indicate the sandstone samples and the red dots indicate the shale samples.

Matrix and Cement

The matrix material in sandstone consists of sericite or reconstituted complex aggregates of chert and sericite. Chlorite determined by its green colour and low birefringence is also present in small amount. This usually occurs as fibrous or finer laths in the pore spaces and on average constitutes about 9%.

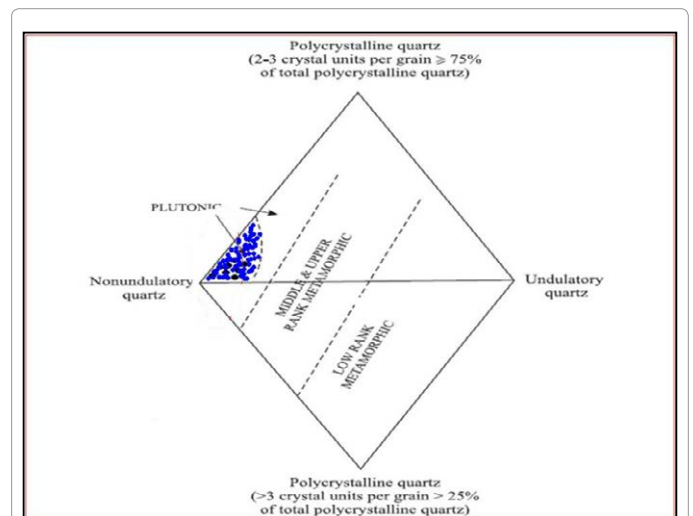


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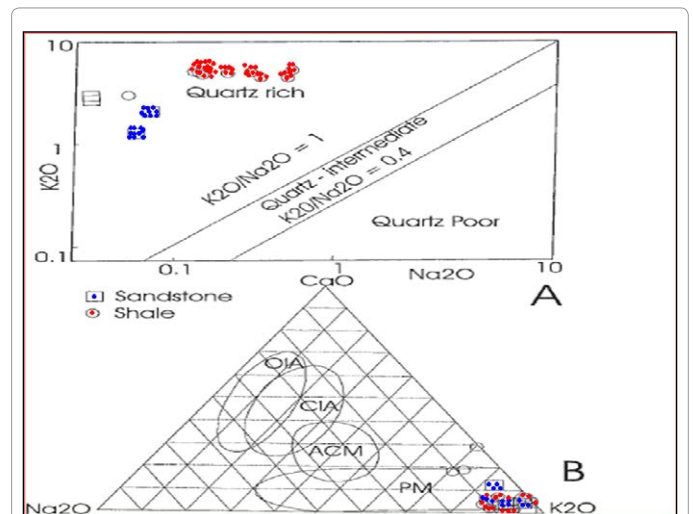


Figure 10: (A) K₂O-Na₂O diagram classifying Kolhan siliciclastics as quartz rich type. (B) CaO-Na₂O- K₂O triangular diagram showing Kolhan siliciclastics in the passive margin (PM) field; also shown are the fields of different tectonic settings, ACM-Active Continental Margin, OIA-Oceanic Island Arc, CIA-Continental Island Arc. The blue dots indicate the sandstone samples and the red dots indicates the shale samples.

Sample No.	Quartz	Feldspar	Lithic fragments (RF+Chert)	Recalculated to 100		
				Q	F	L
1	72.06		2.51	96.63	0	3.36
2	67.79		1.68	97.58	0	2.42
3	69.05		3.9	94.65	0	5.35
4	70.18	2.17	0.42	96.44	2.98	0.58
5	63.16		4.48	93.38	0	6.62
6	70.51		2.3	96.84	0	3.16
7	70.49		1.67	97.68	0	2.31
8	71.92		1.54	97.90	0	2.09
9	60.63	1.1	1	96.65	1.75	1.59
10	82.31		1.63	98.06	0	1.94
11	63.72		2.69	95.95	0	4.05
12	71.93	2.55	2.61	93.31	3.30	3.38
13	69.43		2.02	97.17	0	2.83
14	62.03		1.84	97.12	0	2.88
15	65.81	1.14	1.62	95.97	1.66	2.36
16	67.43	1.23	0.39	97.65	1.78	0.56
17	65.43		0.49	99.26	0	0.74
18	69.68		1.81	97.47	0	2.53
19	63.71	0.52	2.01	96.18	0.78	3.03
20	70.9		5.24	93.18	0	6.88
21	68.37		3.28	95.42	0	4.58
22	72.59		1.04	98.59	0	1.41
23	72.33	1	3.68	93.92	1.29	4.78
24	61.14	0.25	2.48	95.72	0.39	3.88
25	67.44		4.66	93.54	0	6.46
26	78.05		0.99	98.75	0	1.25
27	81.3	0.4	5.21	93.54	0.46	5.99
28	52.31		0.83	98.44	0	1.56
29	48.77		2.19	95.70	0	4.29
30	79.11		8.6	90.19	0	9.80
31	82.56		0.57	99.31	0	0.68
32	68.24	0.44	1.45	97.30	0.63	2.07
33	79.87		2.16	97.37	0	2.63
34	70.19		1.41	98.03	0	1.97
35	67.46		5.46	92.51	0	7.49
36	67.11		3.01	95.71	0	4.29
37	71.93		2.11	97.15	0	2.85
38	50.94		1	98.07	0	1.92
39	70.43		0.33	99.53	0	0.47
40	72.94		4.51	94.17	0	5.82
41	63.56		5.88	91.53	0	8.47
42	63.65		1.6	97.55	0	2.45
43	79.64		0.42	99.47	0	0.52
44	68.64		2.29	96.77	0	3.23
45	73.9		4.65	94.08	0	5.92
46	78.31		1.9	97.63	0	2.37
47	72.94		3.23	95.75	0	4.24
48	79.48		3.6	95.67	0	4.33
49	60.59	0.22	3.5	94.21	0.34	5.44
50	73.94	1.19	5.46	91.75	1.48	6.77
51	70.45	1.52	6.15	90.18	1.94	7.87
52	71.11		2.35	96.80	0	3.19
53	71.31		4.81	93.68	0	6.32
54	77.28		2.43	96.95	0	3.05
55	76.027	0.735	5.882	91.99	0.89	7.12
56	65.996	0.4	20.498	75.95	0.46	23.59
57	69.501	2.84	8.7927	85.66	3.50	10.84

58	64.8		10.04	86.58	0	13.41
59	65.344	0.266	26.21	71.16	0.28	28.54
60	65.239		5.865	91.75	0	8.25
61	72	0.2	11.8	85.75	0.24	14.04
62	45.97	0.364	0.182	98.83	0.78	0.39
63	48.29	2.23	11.766	77.53	3.58	18.89
64	69.65	0.66	7.59	89.40	0.85	9.74
65	54.658	Total Fld	9.285	85.48	0	14.52

Table 1: Generalized modal compositions of sandstones of the Kolhan Group. Quartz (Q), feldspar (F) and lithic fragment (L) proportions in sandstones of the Kolhan Group used in the QFL plot for sandstone classification.

The amount of sericite matrix however, decreases with an increase in grain size of the sandstone in some cases. Fine 'white mica' or sericite flakes commonly appear as intergrowths with detrital grains along their boundaries or intermixed cherts and sericite matrix.

Cement is silica and ferruginous. The most likely source for iron-oxide cement is the alteration of ferromagnesian minerals and solution of iron oxide from the provenance area (Banded Iron Formation)

Provenance History

The source rocks of the Kolhan clastics can be identified by integrating the petrological, sediment dispersal, and provenance data, assuming there has been no lateral displacement after the Proterozoic Kolhan basin stabilized. The presence of pebbles of jasper, white chert, sandstone, banded haematite jasper (BHJ), quartzite, volcanic and granitic rocks embedded in sandy-silty matrix indicates that the sediments have been derived from both the Iron Ore Group and the Singhbhum granite. Evidence of dual provenance is also inferred from the sediment bimodality, textural and mineralogic maturity, presence of rounded and well sorted grains, and presence of fresh feldspar grains. The high value of Qm/ Qp ratio indicates that the mature monocrystalline quartz grains have a higher chance of survival in the sedimentary cycle than the less mature polycrystalline quartz and lithic grains. The presence of well rounded grains along with the subrounded and well sorted grains is indicative of sediment maturity and recyclicity. The paucity of feldspar, abundance of fine grained sedimentary lithics, and evidence of sediment diagenesis are indicative of sediment recycling. The ratio of the stable (quartz, chert) to unstable grains (feldspar, lithic fragments) indicates a compositional maturity of the sandstones. The presence of clay-rich matrix, frequently replaced by silica and haematite, the reddish and grayish colour of the sandstones, low content of feldspar, and the presence of chert, sandstone and granites as lithic fragments are indicative of dual source. Triangular plots are suggestive of sediment derivation from craton interior. Association of the recycled sandstone and non-undulose quartz are also indicative of the sediment derivation from the craton interior.

Inference from Shale Geochemistry

The Kolhan shales are dominated by illite, quartz, and fine crystalline dolomite; the average chemical index of alteration (CIA) for Kolhan shale is 71.8, and indicative of a granitoid source with a modest amount of chemical weathering. High Al₂O₃/SiO₂ and K₂O/Na₂O ratios reflect a derivation of sediments from stable cratons during tectonic quiescences; the sandstones indicate an arid-semiarid climate with low chemical weathering, whereas the shales are indicative of a modest amount of chemical weathering. This discrepancy is due to transport segregation that accounts for the high percentage of shale in the basin. The Al₂O₃/SiO₂ and K₂O/Na₂O ratio do indicate that the clastics were deposited in a passive margin/cratonic margin. The petrographic features imply a source area dominated by granites and

granitoid gneisses, semi-arid to arid climate, tectonic quiescence and peneplain topography.

Conclusion

The 2.2-2.1 Ga Kolhan basin which is pear shaped show the development of a time transgressive group. This group developed in a passive rift setting caused due to the fragmentation of the Columbia supercontinent. A combined petrologic and geochemical analysis of sandstone suites is used to track changes in the sediment supply from adjacent areas. Provenance-derived variations in sandstone compositions are therefore a key in understanding regional tectonic histories. The basin axis controlled the progradation direction which was likely driven by climatically induced sediment influx. The influx of quartz is caused by syntectonic thrust uplift, not isostatic uplift or climate.

The sedimentation history in the Kolhans indicates a change from braided fluvial-ephemeral pattern to a fan delta lacustrine type. Repeated fault-controlled uplift of the source, followed by subsidence, generated multiple fining-upward cycles and a retrograding fan-delta system. The marked variations in thickness of the delta succession and the stacking pattern in different measured profiles reflect the overriding tectonic controls on fan-delta evolution. The accumulated

fault displacement in active sectors created higher accommodation and thicker delta sequences. Intermittent uplift of fault blocks exposed fresh bedrock to mechanical weathering, generated a large amount of detritus, and resulted in forced closure of the land locked basin, repeatedly disrupting the fining upward pattern. The controls of source rock lithology or climate were of secondary importance to tectonic effects. Such retrograding fan deltas are rarely reported and may be a stratigraphic response of connected rift basins at the early stage of extension.

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