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Review Article
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Insoluble Residue Analysis of Limestone in Kolhan Group: Tectonic Implications

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Abstract

The data from the insoluble residue analysis of nearly ninety eight samples collected from different horizons fully corroborate the petrogenetic evidences obtained from the petrographic and field features of the Kolhan Limestone. High grade limestones containing nearly 10% of insolubles constitute about half of the limestone samples. Only in ten samples, the silt-clay portion dominates over the sand portion and such very high grade pockets (containing at times about 95% $CaCO_3$) on chemical analysis should show almost equal distribution of SiO_3 and Al_2O_3, both together totaling to 5 to 10%. In the remaining forty samples the sand fraction clearly outweighs the silt-clay fraction and these varieties of equally high grade pockets should analyze SiO_2 content distinctly greater than the percentage of Al_2O_3 [1]. 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 [2]. The controls of source rock lithology or climate were of secondary importance to tectonic effects. Such a retrograding fan delta are rarely reported and may be a stratigraphic response of connected rift basins at the early stage of extension.

Keywords: Kolhan; Limestone; Insoluble; Tectonic

Introduction

The 2.2-2.1 Ga pear shaped 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 [3]. The succession is 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 Kolhans were deposited in an intracratonic basin that had a westward slope and were subsequently deformed into a synclinal structure. The depositories of this basin unconformably overlie the older rocks like the granitoids of different types and ages, and the members of the Iron Ore Group (including the shales and mafic lava flows) [4]. Representing a typical sandstone-carbonate-shale sequence, the Kolhan sedimentation (without any volcanic input) is marked by the development of thin and discontinuous patches of basal conglomerates draped by sheets of sandstones. A strong asymmetry in the 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 builtup [5]. The fining upward sequence, the vertical and lateral facies variation in the Kolhan implies superimposition of retrograding fan delta complex (Chaibasa basin) on an earlier prograding alluvial fan sand complex (Keonjhar basin). The Kolhan Group, traditionally considered as Palaeoproterozoic (Purana) ensemble, constitute the youngest lithostratigraphic 'outlier' formation in the Singhbhum Archaean craton. Successive deposition of carbonate and shale at a later stage (with thin interbeds of clay in the former and carbonates in the latter) took place under much quieter stable shelf condition. The fault-marked the western 'distal' margin of the Kolhan basin showing evidence of passive subsidence subsequent to the initial rifting stage [6]. This leaves little doubt that the basin evolved as a half-graben under the influence of an extensional stress regime. The west-boundary fault is recognised as the distal basin margin dislocation surface.

The regional stratigraphic framework and the gradational facies relationships between the clastic-carbonate members, compels one to interpret the entire Kolhan sequence as non-marine [7]. The pattern of sedimentation associated with the basin floor reflects a sequence of emergence, submergence and re-emergence of the land surface related to the development of an extensive ephemeral lake. The early emergence of the Kolhan land surface, led to the development of the erosional topography and also involved considerable lowering of the local base level of at least few metres. This suggests a tectonic uplift of rather limited areal extent because of the apparent restriction of marked palaeotopography [8]. The flanking sandstones and conglomerates are possibly the products of subaerial erosion. The larger blocks of sandstone on flanking conglomerates were probably not transported far and may be delta fed material [9]. The sandstone matrix of the conglomerates and the generally sandy nature of the flanking beds suggest that the early lithification was not particularly strong or complete and that disaggregation was fairly readily achieved. Some of the flanking beds are clearly subaqueous in origin, showing evidence of fluvio-lacustrine reworking [10]. The subaqueous reworking probably resulted from the earliest phase of submergence as a lake developed in the area. The lake appeared to have been relatively starved of clastic input in its earliest

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stages when a thin layer of carbonate sediment was deposited as a drape over the topography [11]. Such an early carbonate phase is not uncommon in other ancient lake-margin settings. It probably results from a combination of carbonate precipitated due to change in water chemistry caused by eruption of basic lavas (Jaganathpur lava). The fact that these deposits drape palaeotopography argues for considerable fluctuations in lake level even during the (relatively) submerged phase. Given such conditions, it is tempting to speculate upon the thicker development of carbonates in deeper parts of the lake (south western part of the basin) [12]. Deposition of shale-siltstone above the carbonate layer records the onset of clastic supply from the distant source area rather than from local reworking of the underlying sandstone. The silts were deposited primarily from suspension so that the topography was gradually draped. The lake was episodically inundated by floods some of which introduced sand sheets, and others brought silt clasts. This led to the gradual burial and elimination of the palaeotopography [13]. The upwards passage into progressively silt rich sediments is thought to record the building out of a sandy alluvial system across the featureless ephemeral lake.

An interplay between several intrabasinal and extrabasinal controls probably determined the fan delta evolution [14]. This is suggested by the occurrence of traction deposits, tectono-depositional intervals and their textural characteristics, and by the evidence of synsedimentary extensional tectonism. The shallow water settings are highly sensitive to subsidence, and the presence of fine-grained sedimentation above coarse-grained deposits in a tectonically controlled sedimentary succession is the best indicator of renewed tectonic activity [15]. As the rifting processes compartmentalized the basin into fault blocks and grabens were consequently separated, subsidence lowered the floor of these grabens below base level, and lakes were formed as an immediate response to tectonics. A large volume of sediment was then available for erosion due to the differential relief between the uplifted source area and the subsided basin, and the fan-delta systems began to prograde into the lakes. In some compartments of the basin, where the lakes were probably relatively deeper due to a greater subsidence rate, the initial clastic progradation took place through sandy flows, formed when heavily sediment-laden, sandy gravity flows or stream flows were introduced into the lakes [16].

The abundance of shale itself poses another problem as because it is commonly assumed that the mud formation is very limited under conditions that favour arenites-arkoses. Apart from the fact that the Chemical Index Alteration (CIA) (CIA=Al_2O_3/Al_2O_3+CaO+Na_2O+K_2O) × 100 as used to determine the weathering intensity in the source areas of shales is in need of reassessment and refinement, the conflict climate signals between sandstones and shales of the Kolhans may also be inherent in the way sandstones and shales are produced [17]. For example, sediment transport can, via hydraulic sorting, lead to compositional fractionation of sediment-size fractions. The unaltered feldspars and well-rounded quartz and feldspar grains in conjunction with low latitude suggest that the Kolhans were deposited in a arid to semi-arid climate. In such a climatic setting, unaltered feldspars would become concentrated in sandy deposits of braided streams and may also undergo inland reworking, whereas fine detritus and clay (from feldspar weathering) would be carried to the basin as suspended load, thus leading to a separation between intensely (clay fraction) and incompletely weathered (sand fraction) material [18]. Therefore intensities of chemical weathering indicated by shales will tend to be higher than those indicated by sandstones. It appears therefore that for realistic estimates of source area weathering conditions the data from shales and sandstones should be considered in conjunction. The estimate of weathering intensity that is obtained from sandstone petrology is notably different from that derived from shale geochemistry. The reason for this discrepancy deserves further investigation.

The variability in the sand-silt ratio even in the high grade pockets of the Kolhan Limestone is thus very well brought out by the insoluble residue analysis (Table 1).

Sample Nos.	Soluble carbonate (mainly $CaCO_3$)	Total insoluble residue	Sandy insoluble residue	Silt-Clay insoluble residue
1	95.10	4.90	1.57	3.33
1a	73.68	26.32	17.30	9.02
2	93.62	6.38	1.26	5.12
3	95.19	4.80	1.53	3.27
4	94.46	5.54	2.21	3.33
4a	60.24	39.76	32.03	7.73
5	94.67	5.33	0.92	4.41
6	95.18	4.92	1.33	3.49
7	87.09	12.91	5.69	7.22
8	94.24	5.76	1.85	3.91
9	90.71	9.29	1.59	7.70
10	92.99	7.01	4.32	2.69
11	89.78	10.22	7.84	2.38
12	93.35	6.65	4.05	2.60
13	95.74	4.26	2.09	2.16
14	93.36	6.64	3.68	2.96
14a	80.53	19.47	12.23	7.24
15	90.64	9.16	5.52	3.64
16	94.73	5.27	2.48	2.79
17	87.81	12.19	6.82	5.37
18	89.91	10.09	6.93	3.16
19	89.20	10.30	6.81	3.99
20	88.03	11.97	8.02	3.95
21	93.09	6.91	3.71	3.20
22	90.12	9.96	7.16	2.80
23	93.78	6.22	3.03	3.19
24	89.54	10.46	6.96	3.50
25	91.38	8.62	4.83	3.79
26	94.07	5.93	2.72	3.21
27	89.20	10.79	7.19	3.60
28	90.43	9.57	6.21	3.36
29	87.31	12.69	9.47	3.22
30	87.57	12.43	9.32	3.11
31	89.53	10.47	7.11	3.36
32	91.63	8.32	5.37	2.95
33	89.71	10.28	6.66	3.62
34	90.44	9.56	5.79	3.77
35	85.99	10.01	7.64	6.37
36	92.88	7.12	3.15	3.97
37	93.15	6.85	3.78	3.06
38	95.55	4.45	1.73	2.72
38a	89.77	10.23	5,35	4.88

39	89.38	10.62	6.44	4.18
40	88.43	11.57	7.32	4.25
41	93.29	6.71	4.34	2.37
42	89.41	10.59	5.43	5.16
43	87.14	12.86	8.51	4.35
44	85.30	14.70	9.71	4.99
45	84.14	15.86	7.49	8.37
45a	84.27	15.73	13.85	1.88
46	86.85	13.15	5.81	7.34
47	86.11	13.89	10.04	3.85
48	84.28	15.72	5.67	10.05
49	82.71	17.28	9.09	8.19
50	86.49	13.51	6.03	7.48
51	86.26	13.74	3.21	10.53
52	85.60	14.40	6.09	8.31
53	82.15	17.85	10.21	7.64
54	84.23	15.77	5.97	9.80
55	85.80	14.19	8.89	5.30
56	84.94	15.06	10.03	5.03
57	77.56	22.44	14.73	7.71
57a	66.55	33.45	22.76	10.69
58	74.81	25.19	18.04	7.15
59	81.12	18.88	11.31	7.57
60	78.44	21.56	13.53	8.03
61	75.28	24.72	19.37	5.35
62	79.44	20.56	13.60	6.96
63	78.19	21.80	10.46	11.34
64	81.49	18.51	13.32	5.19
65	81.48	18.52	6.57	11.95
66	81.24	18.76	13.36	5.40
67	75.70	24.29	10.13	14.16
68	75.53	24.47	6.85	17.62
69	71.43	28.57	6.12	22.45
70	75.45	24.55	3.82	20.73
71	73.06	26.94	6.35	20.59
72	70.06	29.94	7.48	22.46
73	70.59	29.41	10.46	18.95
74	73.03	26.97	18.83	8.14
75	72.32	27.68	19.82	7.86
76	74.67	25.33	15.17	10.16
77	60.13	39.86	26.49	13.37
78	69.05	30.95	9.82	21.13
79	69.07	30.93	25.37	5.56
80	59.22	40.78	24.15	16.63
81	59.04	40.96	23.48	17.48
82	67.75	32.25	15.15	17.10
83	66.24	33.76	9.78	23.98
84	60.59	39.41	8.57	30.84
85	61.28	38.72	11.46	27.26
86	69.42	30.58	6.38	24.20
87	62.65	37.35	8.63	23.72
88	69.19	30.81	16.62	14.18
89	57.49	42.51	15.49	27.02
90	68.32	31.68	17.25	14.48
91	53.23	46.77	33.37	13.40
92	65.32	34.68	25.36	9.32
93	60.32	39.68	20.63	19.05
94	69.66	30.34	14.42	15.92
95	66.11	33.89	8.02	25.87
96	52.17	47.83	43.19	4.64
97	48.59	51.41	20.15	31.26
98	25.60	74.40	42.88	31.52

Table 1: Percentage of soluble carbonate and insoluble residue in the Kolhan Limestone.

In the average high grade limestone which forms the bulk of the main horizon, the picture looks apparently more consistent. Of the fifteen samples analyzed, (insoluble residue content nearly 15%), as many as ten exhibit a dominance of sand over silt-clay and only four show a positive reverse relation [19]. What is more interesting is the fact that the reverse relationship is shown by specimens collected adjacently from the same locality which provides the usual samples (sand dominant over silt), thus confirming again the somewhat erratic nature of the sand-silt-clay distribution in the insoluble residue. However, the dominant trend of the very high pockets (sand-silt ratio >1) is maintained in the average high grade samples [20]. Chemical analyses of such high grade samples are available and all show a dominance of SiO_2 percentage over $Al_2O_3 + Fe_2O_3 \pm MnO$ as is clear from the following: (Table 2).

Discussion

The insoluble residue analyses of the Kolhan Limestone would be of great economic significance in deciding the high or low grade character of the deposits, particularly in view of the uniformly low Mg content of these rocks [21]. The beneficiation process to be adopted for the upgrading of the limestones would be to a large extent controlled by the nature of the insolubles, whether silt-clay rich or sand-rich. The problem will ofcourse be rather complicated due to the somewhat erratic nature of the distribution. In the present state of our knowledge it is premature to assess the environmental and petrogenetic significance of the residue analysis.

The data on the residue analysis of the medium grade limestones (nearly 25% insolubles) are equally interesting and instructive (Table 1) of the twenty samples analyzed, more than half contain sandy fractions distinctly out-weighing the silt-clay fractions and thus follow the usual trend already noted. In the rest (mostly from Jagannathpur area) a reverse trend is observed, which is in agreement with the petrographical evidence regarding the dominantly argillaceous facies of the limestones in the southern part of the basin. Chemical analyses are not available to substantiate the above on the basis of the SiO_2 and Al_2O_3 percentages [22].

Deterioration in the quality of the limestones is on the basis of the above, mostly due to admixture of ciliceous particles, rather than clayey impurities except locally. Confirmation of the erratic nature of the quality of the limestones based on the haphazard distribution of insoluble residue is available of the above Table 2 which shows that the insolubles jump from 22.44 to 33.45%, from 4.90 to 26.32%, from 5.54

Components	Average of 60 samples (%)	High grade limestone (%)
SiO_2	7-8 (estimated by author from percentage insoluble)	11.4
Al_2O_3 + Fe_2O_3	0.88	2.1
CaO	50.58	47.3
MgO	0.53	0.6
Loss on ignition	39.78	37.0
Insoluble	8.29	16.0 (estimated by author from percentage $CaCO_3$ – 83.4)

Table 2: Chemical analyses of high grade limestones.

From Basakuti	Average of 60 samples (%)	Low grade limestones
SiO_2	22.10	26.9
Al_2O_3	8.51	5.2
Fe_2O_3	0.39	2.5
CaO	35.80	35.6
MgO	0.72	1.3
Na_2O	1.34	-
K_2O	0.32	-
MnO	0.84	Combined with Al_2O_3

Table 3: Chemical analyses of low grade limestones.

to 39.76% and from 6.64 to 19.47% in the two parts of the same sample (cf. Sample Nos. 1, 1a, 4, 4a, 14, 14a, and 57, 57a).

Chemical analyses of the low grade limestones reproduced below serve to confirm the high silica content of such rocks particularly in the northern part (Table 3).

A few specimens from the low grade limestone show an abnormally high content of insolubles, nearly 50% or above due to quartz admixture or clayey impurities. Such specimens represent highly silicified limestone (indistinguishable from calcareous arenite by insoluble only) or calcareous shale, the later particularly true of the southern part which shows a gradual transition from the calcareous to the argillaceous facies in the field.

Conclusion

The behaviour of the insolubles in the low grade limestones (Ca 35% insolubles) follows the same trend as discussed above. The deterioration of the limestone quality in the southern part of the basin is clearly due to the development of an argillaceous facies of limestone with practically no silicification in contrast with the northern half where the sand-silt ratio may be as high as 3 obviously due to quartz admixture, probably of metasomatic origin. Even the low grade phyllitic limestones show a marked dominance of sandy residue over silt-clay, signifying that contributon of quartz grains of sand grade from the phyllitic shale is greater than that of silt-clay. Alternatively this may be due to silica replacement which is a common feature in the northern part of the basin. The dominance of clayey material in the south attests to weak circulation equated with a shallow lagoonal basin of low current intensity.

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 [23]. Provenance-derived variations in sandstone compositions are therefore a key in undestanding 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 a retrograding fan delta are rarely reported and may be a stratigraphic response of connected rift basins at the early stage of extension.

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