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Statistical approach to study the lithostratigraphic sequence in the Proterozoic Kolhans

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ABSTRACT

Lithofacies succession in the Proterozoic Kolhan Group has been studied statistically using modified Cross-Association Analysis, Markov chain model, and Entropy function. The lithofacies analysis based on the field descriptions and their vertical packaging has been done for assessing the sediment depositional framework and the environment of deposition. Six lithofacies arranged, in two genetic sequences, have been recognized within the succession. The result of Markov chain and cross-association analysis indicates that the deposition of the lithofacies is in NonMarkovian and non-cyclic process and represents asymmetric fining-upward. The chi-square test has been done to test for randomness in hypotheses for lithofacies transition at a confidence level of 95%. The entropy analysis has been done to evaluate the randomness of occurrence of lithofacies in a succession. Two types of entropies are related to every state; one is relevant to the Markov matrix expressing the upward transitions (entropy after deposition), and the other, relevant to the matrix expressing the downward transitions (entropy before deposition). The total energy regime calculated from the entropy analysis showing maximum randomness, suggests that changing pattern in a deposition has been a result of rapid to a steady flow. This results in a change in the depositional pattern from deltaic to lacustrine deposit and sediment bypassing that finally generated non-cyclicity in the sequence.

Keywords: *Cyclicity, Asymmetricity, Fan-delta, 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[6]. Interpreting the depositional environment of the Proterozoic Kolhan sequence was difficult because of (a) the absence of body fossils which could provide telltale evidence of the depositional environment and (b) the absence of land vegetation, which has a profound influence on the precipitation, run-off, and sediment yield (c) scarcity of exposures.

Vertical variations of lithofacies within a given sequence play an important role in the recognition of depositional environment and their lateral dispersal[10]. In order to determine the depositional architecture and its regional variations, a check of the results obtained so far (Tewari and Singh, 2008) by mathematical means seemed desirable. Markov chain is one of the statistical methods that can be used to study the possibility of occurrence and repeat of different rock units at the time of deposition and based on proposed and interpreted the depositional model. This method have been used to provide an ideal sedimentary [2].

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 with the Iron Ore Group of rocks to the west (Saha, 1994). A pyrophyllitic shale layer (10 m thickness) is locally present in between the Singhbhum granite and the Kolhans (Saha, 1994). The Chaibasa-Noamundi basin extends from Chaibasa (850 48' – 220 33') in the north to Noamundi (850 28′ – 220 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).

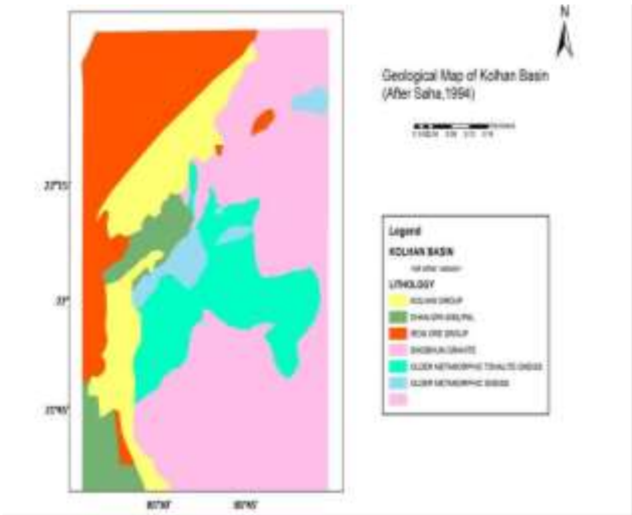

Fig 1.The geological map of Kolhan basin showing the two sub-basins (After Saha, 1994).

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 [7,8].Software packages used for the statistical analyses and graphical representations were MS Excel 2007, SPSS 12.0 and STATISTICA 8.0. Adobe-Photoshop 8.0, Corel-DRAW 11.6, and MS-Paint 5.1 were the drawing toolkits used for drawing maps, log sections, and field sketches. Programming of algorithm for Markov chain analysis and entropy analysis is carried out in Matlab and R.

3. CROSS ASSOCIATION ANALYSIS

Cross association detects the similarity between correlated geological columnar sections. Cross association is used to compare several geological columnar sections which are arbitrarily selected from different localities. Tracing the beds from section to section finally leads to what is known as lithological correlation. This type of correlation basically demonstrates the equivalency of rock units across an area the lithological correlation meets with difficulties due to the fact of 1) Lateral change in bed thickness, 2) Lithology and 3) Missing of strata by erosion, lack of fossils, and tilting of stratahe present chapter includes the validity of the geostatistical cross association method in facilitating the exact lining-up of stratified rocks and the correlation between different geological sections having great variation in litholog, thickness and obscurity in exact boundary between superimposed formation of rock units that may appear from one geologic exposure to another.

Structuring Data for Cross Association Analysis

Table 1: Main lithofacies and the corresponding numerical values

Sheet sandstone (SSD)	1
Rhythmite (TLSD)	2
Plane laminated sandstone (PLSD)	3
Wavy laminated sandstone (RSD)	4
Granular sandstone and Crossbedded sandstone (GSD)	5
Granular Lag and Pebbly sandstone (GLA)	6

Table 2: Logs of studied geological sections with numerical values

Name of the Location	Numerical value of lithofacies present											
Gangabasha	6	3	5	3	5	3	4	3					
Behind IT college	5	2	3	4	3	2							
Rajanbasha	5	3	2	4									
Gumaagara	2	3	5	3	5	3	5	2	5	3			
Arjunbasha	2	3	1	4	1	5	2	6	3	6	3	2	3
Tunglai	3	5	3	5	4	5	4	3					
Gutuhatu	5	2	4	2									
Bingtopang	3	2	3	2	4	1	2	3	2	1			
Bistampur	2	5	2	5	3	6	3	1					
Diliamarcha	4	5	4	5	4	5	4						
Matgamburu	6	4	3	4	5								
Rajanka	6	5	3	4	3	5	3	4					

Table 3: Summary Statistics of different lithounits present in the study area

Lithounits	GLA	GSD	RSD	SSD	TLSD	PLSD
Gangabasha	1	2	1	0	0	4
Behind IT college	0	1	1	0	2	2
Rajanbasha	0	1	1	0	1	1
Gumaagara	0	4	0	0	2	4
Arjunbasha	2	1	1	2	3	4
Tunglai	0	3	2	0	0	3
Gutuhatu	0	1	1	0	2	0
Bingtopang	0	0	1	2	4	3
Bistampur	1	2	0	1	2	2
Diliamarcha	0	3	4	0	0	0
Matgamburu	1	1	2	0	0	1
Rajanka	1	2	2	0	0	3

Analytical Procedure

To assess the degree of similarity between two sequences (sections), The nominal values in a given sequence are moved stepwise past the nominal values of a second sequence.

Δ = Number of comparisons (the length of the overlapped segments) and

t= The number of matches

The Cross Association Index (CAI) = the ratio of the number of matches to the length of the two overlapping segments.

Assuming that the number of matches at position I, then CAI is CAI(i) = t/Δ, The results of cross-association analysis are described in Table.4.

X= Number of observation in the kth state of the chain

Y=Number of observation in the kth state of the chain.

XY=Product of X and Y.

M=Match position

P=Probability of the match at any position of comparison

for any two random sequences of the same composition.

1- P= Probability of mismatch at any position of comparison for any two random sequences of the same composition.

E= Expected number of matches =PΔ

E'=Expected number of mismatches =Δ-E

O=Observed number of matches = t

O' = an Observed number of mismatches =Δ -O Let the values of 1st sequence be a1,a2,a3,...., ak.

then ∑ai=n where ai denotes the total number of occurrences of state i. similarly, for a 2nd sequence of values are denoted by b1,b2,b3,......., bk then ∑bi=m where bi denotes the total number of occurrences of state i. Using some counting method, the total number of possible ways of filling any match position is m*n, with 2 different values of k. While the same is ∑aibi for identical values of k.

Thus the probability of match position of comparison for any two random sequences of the same composition is P = ∑aibi /mn. The chi-square test used as an approximation test

$$\chi^2=\{ (O-E)^2 /E \}+ \{(O'-E')^2/E' \}$$

Yates correction may be applied in statistics especially when the expected number of matches is small. This correction calls for subtraction of 0.05 from the absolute difference between expected and observed number of matches for a given significant level of 5%.. the corresponding critical value is 3.84. Thus, the equation 1 becomes, $\chi^2 =\{ (O-E-0.05)^2 /E \}+ \{(O'-E'-0.05)^2/E' \}$ When Gangabasha section is moved by the Behind ITI college section one position at a time and it is compared at each match position, we can see that the best match position is at **10th** with **3** matches and **Δ=3/5**. When the last state of Gangabasha section (plane laminated sandstone) matches with 5th state of Behind ITI college section (plane laminated sandstone).

Null hypotesis,

H0 : 2 sequence are not similar

H1 : H0 is not true The passion approximation for the p values is 0.007 which also strongly support that H0 is not true ,

P value =p(O>0/Δ,H0) = 1 - ∑{(λre-λ)/r!} =1-{(.3050)+(.2149396)+(.025245)+(.08505)}

{as the value of r varies from 0 to 4 and λ=E=Δp} =1-.9923306 =.007

Match position 1 : 6 3 5 3 5 3 4 3 5 2 3 4 3 2 In this case t = 0 and CAI(1) = 0,

Match position 2: 6 3 5 3 5 3 4 3 5 2 3 4 3 2 In this case t = 0 and CAI(2) = 0,

Match position 3: 6 3 5 3 5 3 4 3 5 2 3 4 3 2 In this case t = 1 and CAI(3) = 1/3.

Match position 4: 6 3 5 3 5 3 4 3 5 2 3 4 3 2 In this case t = 0 and CAI(4) = O

Match position 5 : 6 3 5 3 5 3 4 3

5 2 3 4 3 2 In this case t = 2 and CAI(5) =2/5,

Match position 6: 6 3 5 3 5 3 4 3

5 2 3 4 3 2 In this case t = 0and CAI(6) = 0,

Match position 7: 6 3 5 3 5 3 4 3

5 2 3 4 3 2 In this case t = 2and CAI(7) = 2/6=1/3.

Match position 8: 6 3 5 3 5 3 4 3

5 2 3 4 3 2 In this case t = 1 and CAI(8) = 1/6

Match position 9: 6 3 5 3 5 3 4 3

5 2 3 4 3 2 In this case t = 3 and CAI(9) = 3/5,

Match position 10: 6 3 5 3 5 3 4 3

5 2 3 4 3 2 In this case t = 1 and CAI(10) = 1/4,

Match position 11: 6 3 5 3 5 3 4 3

5 2 3 4 3 2 In this case t = 1 and CAI(11) = 1/3.

Match position 12: 6 3 5 3 5 3 4 3

5 2 3 4 3 2 In this case t = 0 and CAI(12) = 0.

Match position 13: 6 3 5 3 5 3 4 3

5 2 3 4 3 2 In this case t = 0 and CAI(12) = 0.

m*n= ∑Xi∑Yi =6*8 =48

∑XiYi =2+1+8=11

Thus, p= (∑XiYi /m*n) =11/48=.2291

E=Δp=.2291*5=1.145 {asΔ= 5 from match num 10}

E'=Δ-E=5-1.1872=3.855 And O=t=3

O'=Δ-O=5-3=2

χ 2Y ={ (O-E-0.5) 2 /E }+ {(O'-E'-0.5)2/E' } ={(3-1.145-0.5)2/1.145}+{(2-3.855-0.5)2/3.855}

= 1.5+1.44 =2.9 < 3.84 Hence null hypothesis can't be rejected.

Correlation is not significant

3.1.Markov Chain Analysis

Lithofacies studies have been done following standard technique (Miall, 1984). Six lithofacies have been recorded and are 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)

In the field it is observed that there is gross lithological asymmetricity present between various lithofacies. There is marked difference in the sandstone and shale thickness, with shale thickness very high as compared to sandstone. It is difficult to prove in the field time independent depositional relational, if any, between the two faices as there is absence of unconformity. The study is Compared with other Proterozoic basin where in same short depositional time period there is at least 3-4 vertical lithofacies cyclic arrangement are presents. To prove similar cyclic arrangement in the lithofacies in the study area, the Markov property was applied. Cyclic sedimentation defines cyclic or rhythmic sedimentation as a series of lithologic elements repeated through a succession (Duff, Hallam, and Walton, 1967). Alternatively, two types of observable cyclicity may be noteworthy: one in which there exists an order of sequence only, and another in which there is a certain order of repetition along the vertical scale of the sedimentary succession. In this study it is considered to ignore thickness altogether. In stochastic process, a Markov process, named after the Russian mathematician Andrey Markov, is a stochastic process that satisfies the Markovian property. It can be used to model a random system that changes states according to a transition rule that only depends on the current state. In a first-order Markov process, a lithologic unit or a facies state, Fj observed at a point n depends upon the facies state Fi observed at point (n-1). In other words, the geologic situation at point (n-1) governs the event that will happen at n. The transition probability of a facies being in the state Fj at n given that the facies is in state Fi at (n-1) is denoted by Pij(n-1, n), i.e. for discrete-time Markov chains,

$$Pij(n-1, n) = P[(Fnj)|(F(n-1)i)]$$

Structuring Data for Markov Chain Analysis

The data used in the study is vertical sedimentary log successions of lithological members coded into a limited number of states for the Markov chain and Entropy analysis (Fig. 2). No account has been taken of the thickness of each member and no multistory lithologies are recognized. Thus, it is not considered possible for a given lithological state to pass upward into the same lithological state. In the present study only discrete lithofacies transitions regardless of individual bed thickness are counted, therefore, focus is on the evolution of the depositional process. In order to prevent transition tendencies from being too diffused throughout the count matrix, only six lithofacies, which are distinctly marked in each sedimentary log as well as in outcrop sections, are used in this study. To analyze cyclic characters through space and time, the lithofacies transitions are analyzed together in all sedimentary logs, and by pooling the data for four sectors as well as for the entire area. Seventeen lithological sections (Fig. 2) were considered for studying the vertical and areal distributions of the lithofacies within the Kolhan basin. Vertical sedimentary logs are prepared using software sedlog. Since in the present study the type of lithofacies required for Markov chain and Entropy analysis, it is only shown in the sedimentary logs.

Analytical procedure

Frequency count matrix (F): Frequency count matrix is calculated from the vertical sequence profile of sedimentary logs shown in Fig. 2. Since we are using markov chain which has memory less property i.e the Geologic situation at point (n-1) governs the event that will happen at n. That"s why all seventeen sedimentary logs can be used to calculate matrix F without loss of information. Subsequently, data for all logs are added and a bulk matrix is structured at Basin level. No of transition from facies I to j is represented in row I and column j of matrix F, which signifies a number of times state j followed immediately after state I in the sedimentary logs. The frequency count matrix is structured into embedded Markov chain considering only transition lithologies and not their thickness as stated elsewhere. Since a transition is supposed to occur only when it results in a different lithology, the diagonal elements are all zeros in the resulting tally matrix.

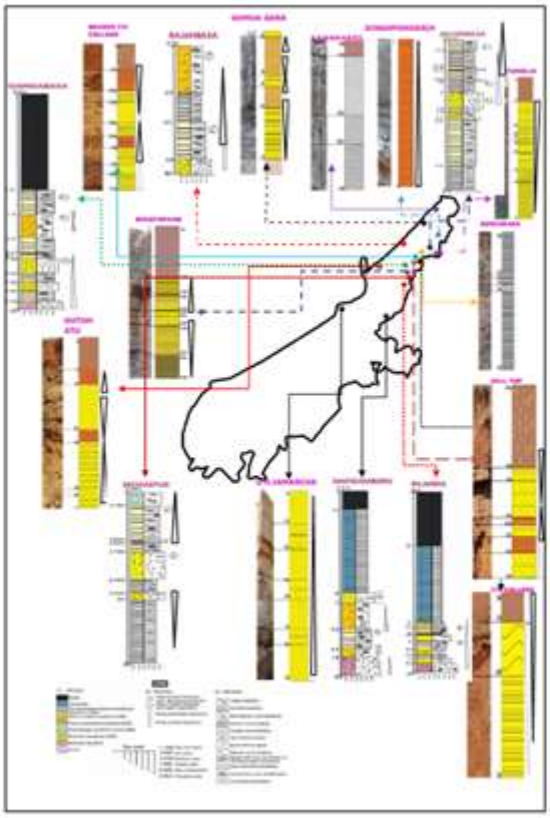

Fig. 2. Lithologs showing the vertical distribution of the lithofacies in the study area

The modified Markov process model [5]used in this study incorporates structuring of one step embedded tally count matrix (fij), where i, j corresponds to row and column number. It will be noticed that where i = j, zeros are present in the matrix, i.e., probability of moving from one state to another state has only been recorded where the lithofacies shows an abrupt change in character, regardless of the thickness of the individual bed.

Transition Frequency Matrix (F) As mentioned above, a first order embedded chain matrix is structured by counting transition from one facies to another, and the resulting frequency matrix will contain zeros along the principal diagonal (Fij =0). This is a two-dimensional array which records the frequency of the vertical transitions that occur between the different lithofacies in a given stratigraphic succession. The lower bed / facies of each transition couplet are given by the row numbers of the matrix, and the upper bed / facies by the column numbers. Each lithofacies is coded with column numbers or capital letters. The transition count matrix is expressed as Fij, where i = row number and j = column number. When i=j, the transition between same lithofacies are denoted by zeros. In other words, transitions are only recorded when the lithofacies shows abrupt changes in character in spite of the thickness of the individual lithofacies.

Upward Transition Probability Matrix (P) The upward transition probability matrix pertains to the upward ordering of lithologies in a succession and is calculated in the following manner: Pij = Fij / SRi Where, SRi is the corresponding row total. The transition probability matrix represents the actual probabilities of the transition between one lithofacies to another in a vertical section. This array is obtained by taking the number of transitions of one facies to another and dividing by the total number of transitions involving the first facies.

Downward Transition Probability Matrix (Q) Similar to the upward transition probability of lithologies a downward transition probability (Q matrix) can also be determined by dividing each element of the transition frequency matrix by the corresponding column total, i.e., Qji = Fij / SCj Where, SCj is the column total.

Independent Random Matrix (R) Assuming that the sequence of rock types was determined randomly an independent trials matrix can be prepared in the following manner: Rij = Cj / (T – Ci) Where, Ci is the column total of facies state Fi, Cj is the column total of facies state Fj, N is the total number of transitions in the system. The diagonal cells are filled with zeros. This matrix represents the probability of the given transition that occur in a random manner. If t=total number of lithofacies, n=rank of the matrix (the total number of rows and columns used), T= n k=0 Fij, where Fij =number of transition from facies A to facies A-F.

Difference Matrix (D) A difference matrix is calculated which highlights those transitions that have a probability of occurring greater than if the sequence were random. By linking positive values of the difference matrix, a preferred upward path of facies transitions can be constructed which can be interpreted in terms of depositional processes that led to this particular arrangement of facies (Miall, 1973). Dij = Pij – Rij A positive value in difference matrix indicates that a particular transition occurs more frequently and a negative value indicates that it occurs less frequently. In difference matrix the values in each row of the matrix sum to zero. If the values are close to zero, a vertical succession with little or no „memory" indicates independent nature of deposition of facies in a basin.

Expected Frequency Matrix (E) It is necessary to construct an expected frequency matrix since a statistician"s rule of thumb states that chi-square tests should only be applied when the minimum expected frequency in any cell not exceeds 5. The matrix of expected values is given by Eij = Rij*SRi.

Test of Significance Non-parametric chi-square ($\chi 2$) test has been applied to ascertain whether the given sequence has a Markovian „memory" or no memory. To test the null hypothesis, chi-square ($\chi 2$) values are calculated for vertical successions.

Fij = transition count matrix or observed frequency of elements in the transition count matrix; Eij = Expected frequency matrix

ν = degree of freedom given by the number of non-zero entries in the [rij] matrix minus the rank of the matrix=n2–2n, where n denotes rank of the matrix If he computed values of chi-square exceed the limiting values at the 0.5% significance level suggests the Markovity and cyclic arrangement of facies states.

3.2 Entropy Analysis

Hattori (1976) applied the concept of entropy to sedimentary successions possessing Markov property to determine the degree of random occurrence of lithologies in the succession. Methods of calculation of entropy as suggested by Hattori (1976) have been largely followed in the present study. Hattori (1976) recognized two types of entropies with respect to each lithological state; one is post-depositional entropy corresponding to matrix P and the other, pre– depositional entropy, corresponding to matrix Q. Hattori (1976) defined post-depositional entropy with respect to lithological state i as

$$Ei^{(post)} = -\sum_{j=0}^{n} Pij * \log(Pij) \quad \text{....eq1}$$

If Ei(post)= 0.0, state i is always succeeded by state j in the sequence. If Ei(post)>0, state i is likely to be overlain by different states. Hattori (1976) defined pre – depositional entropy with respect to state i as

$$Ei^{(pre)} = -\sum_{j=0}^{n} Qij * \log(Qij) \quad \text{...eq2}$$

LargeEi(pre) signifies that i occur independent of the preceding state. Ei(post) and Ei(pre) together form an entropy set for state i, and serves as indicators of the variety of lithological transitions immediately after and before the occurrence of i, respectively. Hattori (1976) used the interrelationships of Ei(post) and Ei(pre) to classify various cyclic patterns into asymmetric, symmetric and random cycles .The values of Ei(pre) and Ei(pre)calculated by equations (1) and (2) increases with the number of lithological states recognized. To eliminate this influence, Hattori (1976) normalized the entropies by the following equation:

$$R = E/Emax, \text{ where, } Emax = -\log 2 \frac{1}{n-1}$$

where R is the normalized entropy, E is either post-depositional entropy or pre–depositional entropy, and Emax is the maximum entropy possible in a system where n state variable operates Table6.

4. RESULTS

The results of cross-association analysis are

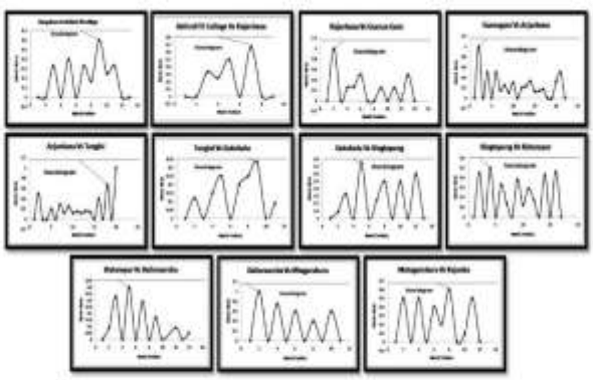

Fig3.Associatogram showing the position of maximum match between the widely separated strata associations of eleven litho section

Table4: Results of Cross Association Analysis in the Kolhan Group

Comparision Between logs	lithofacies	X	Y	$\sum X_i \sum Y_i$	M	P	1-P	O	O'	E	E'	$\chi^2 Y$	Conclution
Gangabasha Vs Behind IT college	GLA	1	0	0	10	.3	.7	3	2	1.15	3.86	2.9	Correlation is not significant
	GSD	2	1	2									
	SSD	1	1	1									
	PLSD	0	0	0									
	RSD	0	2	0									
	TLSD	4	2	8									
	TOTAL	8	6	11									
Behind IT college Vs Rajanbasha	GLA	0	0	0	7	.25	.75	2	1	.75	2.25	2.11	Correlation is not significant
	GSD	1	1	1									
	SSD	1	1	1									
	PLSD	0	0	0									
	RSD	2	1	2									
	TLSD	2	1	2									
	TOTAL	6	4	6									
Rajanbasha Vs Gumuagara	GLA	0	0	0	2	.25	.75	2	0	.50	1.50	4.6	Correlation is significant
	GSD	1	4	4									
	SSD	1	0	0									
	PLSD	0	0	0									
	RSD	1	2	2									
	TLSD	1	4	4									
	TOTAL	4	10	10									
Gumuagara Vs Arjunbasa	GLA	0	2	0	2	.2	.8	2	0	.4	1.6	5.75	Correlation is significant
	GSD	4	1	4									
	SSD	0	1	0									
	PLSD	0	2	0									
	RSD	2	3	6									
	TLSD	4	4	16									
	TOTAL	10	13	26									
Arjunbasha Vs Tunglai	GLA	2	0	0	20	.16	.84	1	0	.15	.85	2.94	Correlation not significant
	GSD	1	3	3									
	SSD	1	2	2									
	PLSD	2	0	0									
	RSD	3	0	0									
	TLSD	4	3	12									
	TOTAL	13	8	17									
Tunglai Vs Gutuhatu	GLA	0	0	0	9	.16	.84	1	2	.47	2.5	.42	Correlation not significant
	GSD	3	1	3									
	SSD	2	1	2									
	PLSD	0	0	0									
	RSD	0	2	0									
	TLSD	3	0	0									
	TOTAL	8	4	5									
Gutuhatu Vs Bingtopang	GLA	0	0	0	5	.25	.75	3	1	1	3	4.3	Correlation is significant
	GSD	1	0	0									
	SSD	1	1	1									
	PLSD	0	2	0									
	RSD	2	4	8									
	TLSD	0	3	0									
	TOTAL	4	10	9									
Bingtopang Vs Bistampur	GLA	0	1	0	2	.2	.8	1	1	.4	1.6	.75	Correlation is not significant
	GSD	0	2	0									
	SSD	1	0	0									
	PLSD	2	1	2									
	RSD	4	2	8									
	TLSD	3	2	6									
	TOTAL	10	8	16									
Bistampur Vs Daliamarcha	GLA	1	0	0	5	.14	.86	2	3	.71	4.29	1.61	Correlation is not significant
	GSD	2	3	6									
	SSD	0	4	4									
	PLSD	1	0	0									
	RSD	2	0	0									
	TLSD	2	0	0									
	TOTAL	8	7	10									
Matgamburu Vs Rajankaa	GLA	1	1	1	8	.23	.77	3	2	1.13	3.88	2.65	Correlation is not significant
	GSD	1	2	2									
	SSD	2	2	4									
	PLSD	0	0	0									
	RSD	0	0	0									
	TLSD	1	3	3									
	TOTAL	5	8	10									
Daliamarcha Vs Matgamburu	GLA	0	1	0	2	.31	.69	2	0	.63	1.37	3.75	Correlation not significant
	GSD	3	1	3									
	SSD	4	2	8									
	PLSD	0	0	0									
	RSD	0	0	0									
	TLSD	0	1	0									
	TOTAL	7	5	11									

Matrices used to analyze transitions of lithofacies in Kolhan Group is calculated using method and equations given in the previous chapter. A= GLA; B= GSD; C= SSD; D= PLSD; E= RSD; F= TLSD; SRi= Sum of ith row of the count matrix SCj= Sum of jth column of the count matrix T= Total number of transition

Table5: Matrices used to analyze transitions of lithofacies in the Kolhan Group

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a) Transition Count Matrix (F)

	A	B	C	D	E	F	SR_i	$T\text{-}SR_i$
A	0	1	1	3	0	1	6	33
B	3	0	1	1	1	1	7	32
C	0	1	0	0	0	1	2	37
D	1	2	0	0	1	1	5	34
E	0	2	0	0	0	0	2	37
F	2	1	0	1	0	0	4	35
SCj	6	7	2	5	2	4	Total=26	

b) Upward Transition Probability Matrix(P)

	A	B	C	D	E	F
A	0	0.35	0.1	0.25	0.1	0.2
B	0.316	0	0.105	0.263	0.105	0.21
C	0.25	0.292	0	0.208	0.083	0.167
D	0.286	0.333	0.095	0	0.095	0.19
E	0.25	0.292	0.083	0.208	0	0.166
F	0.273	0.318	0.091	0.227	0.091	0

c) Downward Transition Probability Matrix(Q)

	A	B	C	D	E	F
A	0	0.142	0.5	0.6	0	0.25
B	0.5	0	0.5	0.2	0.5	0.25
C	0	0.142	0	0	0	0.25
D	0.1667	0.285	0	0	0.5	0.25
E	0	0.285	0	0	0	0
F	0.333	.145	0	0.2	0	0

d) Independent Trails Probability Matrix(R)

	A	B	C	D	E	F
A	0	0.167	0.167	0.5	0	0.167
B	0.428	0	0.143	0.143	0.143	0.143
C	0	0.5	0	0	0	0.5
D	0.2	0.4	0	0	0.2	0.2
E	0	1	0	0	0	0
F	0.5	0.25	0	0.25	0	0

e) Difference Matrix (D)

	A	B	C	D	E	F
A	0	-0.183	0.67	0.25	-0.1	-0.033
B	0.113	0	0.37	-0.12	0.037	0.067
C	-0.25	0.208	0	-0.208	-0.083	0.334
D	-0.086	0.067	-0.095	0	0.105	0.009
E	-0.25	0.708	-0.083	0.208	0	-0.167
F	0.227	-0.68	-0.091	0.023	-0.091	0

f) Expected Frequency Matrix (E)

	A	B	C	D	E	F
A	0	2.1	0.6	1.5	0.6	1.2
B	2.212	0	0.735	1.841	0.735	1.47
C	0.5	0.584	0	0.416	0.166	0.334
D	1.43	1.665	0.475	0	0.475	0.95
E	0.5	0.584	0.166	0.416	0	0.332
F	1.092	1.272	0.364	0.908	0.364	0

g)Test Of Significance

Test of Equation	Computed value of	Limiting value at 0.5% significance level	Degree of freedom
Billingslay	14.343	30.14	19

5. DISCUSSION

Markov Chain and Cross Association Analysis In the interpretation of significant facies transitions it is important to note that the calculated significant transitions represent the most probable facies transitions, but not their frequency in the studied sedimentary sequences. The real frequencies of facies transitions are written down in the matrix of observed facies transitions (Table 5). Therefore, when interpreting sedimentary successions it is useful to consider both statistically significant and real facies transitions in order to better understand their significance and real occurrence in the studied sedimentary record. The highest values of <P> and the positive entries of <D> were analyzed to determine the cyclic processes. The computed values of chi-square are lower than the limiting values at the 0.5% significance level (Tables 5g)) this means that the null hypothesis is false, suggesting the deposition of sediments is not by the Markovian process and non-cyclic arrangement of facies states in Kolhan Group. The facies relationship diagram (Fig. 4) is constructed from the difference matrix results (Table 5(e)). Relationship diagrams showing the upward transition of facies states of Kolhan group in Fig. 4.

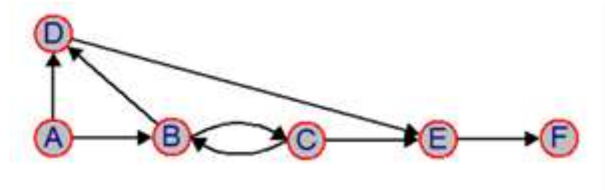

Fig 4. Facies relationship diagrams showing the upward transition of facies states of Kolhan group.A-GLA; B-GSD; C-SSD; D-PLSD; E-RDS; F-TLSD

The preferred upward transition path for the lithofacies is GLA GSD SSD PLSD RSD TLSD.

The transition between GLA GSD, GSD SSD, SSD PLSD and RSD TLSD is non-Markovian and the lineage is non-repetitive in nature. The obvious aim of such approach was to detect and define cyclic relationships if any. In the present case, the cyclicity is absent or very weak. This information can greatly assist in environmental interpretation.

Entropy Analysis Both Epre and Epost are larger than 0.0 implies all six lithofacies (GLA, GSD, SSD, PLSD, RSD, TLSD) overlies and also is overlain by more than one state [1]. Epre and Epost are larger in number for GSD (Table 6), and it is deduced that the influx of pebbly sandstone into the basin was the most random event. For RSD and PLSD, Epre > Epost. This relation indicates that rippled sandstone could accumulate in a wide variety of depositional environment and exerted a considerably strong influence upon the state selection of its successor. The large difference in Epre and Epost and with Epre < Epost relationship in case of facies F indicates its strong dependence on its precursor which is visualized from the Markov metrics (Table 6 and Fig. 4). The depositional pattern in the TSLD facies is indicative of a low energy, suspension falls out during the waning phase of the sedimentation. In other words, these facies accumulated in the environment was located in the distal part of the basin in preference to other areas. The E(pre) and E(post) plots for coarse to medium-grained sandstone, interbedded fine-grained sandstone/shale, shale fall almost linearly but far from the diagonal line (Fig.5).In Fig.6 comparing well with the type C cyclic pattern of Hattori, which signifies random lithologic series, as deduced independently by improved

Markov process model. The cycles Kolhan basin belongs to the maximum entropy indicated by a black dot (Fig. 6) [1].

Table 6: Matrices used to analyze ENTROPY VALUE of lithofacies

	E(Post)	E(Pre)	R(Post)	R(Pre)
A	1.793	1.643	0.772	0.707885
B	2.128	2.4643	0.9167	1.061741
C	1	0.9010	0.4306	0.388195
D	1.921	2.1474	0.8279	0.925205
E	0.009	0.5167	0.002	0.22262
F	1.5	0.6937	0.6423	0.250474

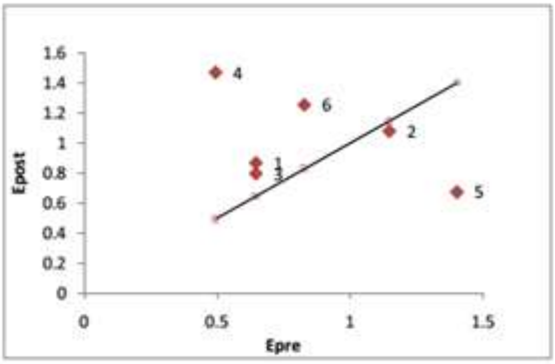

Fig. 5. Entropy set derived from Kolhan basin.1-GLA; 2-GSD; 3-SSD; 4-PLSD; 5-RDS; 6-TLSD

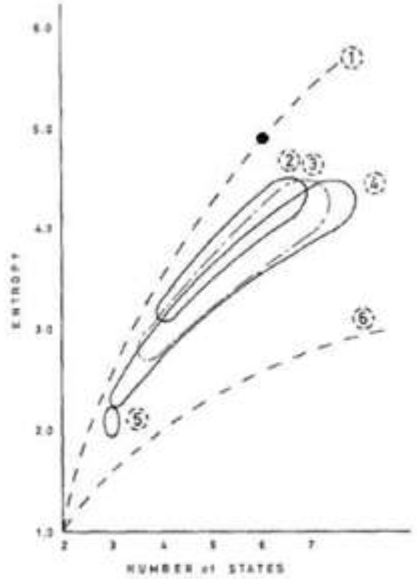

Fig. 6. The relationship between entropy and depositional environment of lithological sequences (after Hattori, 1976). 1-maximum entropy; 2-entropies for coal measure succession; 3-entropies for fluvial-alluvial successions; &entropies for neritic successions; 5-entropies for flyschsediments; 6-minimum entropy; Black dot indicate entropy of basin under study

6. CONCLUSION

The major findings of the study can be summarized as follows: The application of the Cross association analysis on the vertical sections shows¬ that there is no significant correlation in between different lithofacies. The energy level of the fluid during the entire process shows a considerable¬ fluctuation. Lack of correlation suggests lateral facies variation and existence of different¬ environment at different places. This suggests that the total number of matches is large enough to indicate that the section have degree of similarity greater than the degree of similarity when the two sections are any two randomly selected sections. The application of the first order Markov Chain analysis on the vertical¬ sections shows that there is a preferred fining upward transition path in the lithofacies. The operative geological processes were non-Markovian or independent in nature. The energy level of the fluid during the entire process shows a considerable¬ fluctuation reflected by the Entropy analysis. Entropy analysis also proves type “C” cyclic pattern of Hattori, which signifies random lithologic series, as deduced independently by improved Markov process model. The cycles of Kolhan basin belongs to the maximum entropy Asymmetric sequence can be well explained by sediment bypassing. The thinning upward sequences represent lacustrine deposits, while the thickening upward sequences represent point bar-sand flat deposits. Variation in layer thickness is suggestive of deposition by unsteady flow in a fluvial¬ regime within the channel. The flow was suddenly impeded, and as a result there was a quick fall in the energy of the solid-fluid system that resulted in rapid deposition. It appears that the GLA and the GSD facies represent the channel lag deposits of a braided river and the SSD, RSD, PLSD, and TLSD facies represent the portions of a fining upward sequence complex of a channel bar or possibly the longitudinal bartransverse bar-cross-channel bar complex in a fluvial environment. Energy regime related to the total entropy suggests that the shale in distal part of basin¬ is not a marine origin. The flow pattern overall changes from the deltaic environment to lacustrine environment. The result of this study described that the basin are non-cyclic, fining upward asymmetric sedimentary sequence of sandstone, shale with patches of carbonate.

7. ACKNOWLEDGEMENT

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