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Cross-Association Analysis of Barren Measures Lithologies and Microfacies, Talcher Coalfield, Odisha

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ABSTRACT

Cross-association analysis of lithologies and microfacies of two borehole sections of the Barren Measures Formation, Talcher coalfield situated 12 km apart show strikingly dissimilar results. In case of lithologies, one-to-one correlation becomes significant, which suggests continuity of the formation throughout the Barren Measures Formation and prevalence of braided stream depositional environment. However, lack of significant correlation of microfacies suggests existence of different sub-environments at different parts of the Barren Measures Formation during each stage of sedimentation. When channel facies were laid down at one place, homotaxial leeve, floodplain and swamp facies were deposited elsewhere.

INTRODUCTION

The stratigraphic correlation is the demonstration of equivalency of stratigraphic units in terms of chrono-, bio- and litho-stratigraphic criteria (Krumbein and Sloss, 1963). The Gondwana sediments of the peninsular India (Fig.1A) have been correlated lithostratigraphically using the coal seams as marker horizons. However, their repetitive occurrences pose problems in inter- and intra-basinal correlation of strata. The present day coalfields were parts of master basins, which were in existence in geologic past (Hota et al. 2006), and their present day disconnected disposition is due to erosion of a thick pile of sediments. This study presents the cross-association analysis of two borehole sections of the Barren Measures Formation of Talcher coalfield located about 12 km apart in strike direction. This method has been used for correlation of measured and borehole sections (Rao et al. 1985; Hota, 2000; Saqqa and Al Salah, 2006 and Khan and Tewari, 2012). Further, the cross-association analysis attributes reconstruction of a sedimentation model for the Barren Measures Formation of the Talcher coalfield.

GEOLOGY OF THE BARREN MEASURES FORMATION

The Barren Measures Formation is coordinated in the southeastern part of the Talcher coalfield (Fig.1B) (toposheets NF45S13 and NF45T1 in 1:50,000 scale). The Talchir Formation in the south is succeeded by coal bearing Damuda Group in the north. The Talchir Formation is composed of tillite, glacial outwash deposits, varves, rhythmites, turbidites and characteristic needle shale (Maejima et al. 2004). The Gondwana strata strike east-west and dips 4 - 10° towards north (Fig.1C). Three formations of the Damuda Group are composed of repetitive occurrence of sandstone, shale and coal. The Karharbari Formation contains one high grade coal seam that splits into lower, middle and upper sections, where as the Barakar Formation contains ten coal seams, some of which split into two to five sections. Workable coal seams are lacking in the Barren Measures Formation, however, it contains streaks of carbonaceous shale and shaly coal.

On the basis of geometry, texture, gross lithology and sedimentary structures, eleven lithofacies have been identified in the Barren Measures Formation (Hota and Das, 2010). These are conglomerate, flat- and cross-bedded, pebbly, coarse-, medium- and fine-grained sandstones, interbeded sandstone-shale, gray-, ferruginous-shales, interbanded carbonaceous shale and shaly coal. Carbonaceous shale and shaly coal are the products of peat swamps, but could not develop into workable coal seams due to uncongenial environmental conditions prevailing during Barren Measures sedimentation. The sandstones are invariably ferruginous with iron oxide cement. These lithofacies are conspicuously arranged forming fining upward cycles, which are characteristic of fluvial environment.

METHODOLOGY

The gross lithologies of the Barren Measures Formation are sandstone, shale and coal. The conglomerate beds, due to their insignificant occurrences have been included within coarse-grained sandstone. However, in conformity with the borehole record and to keep the number of facies within workable limit, the above mentioned lithofacies have been grouped under five microfacies, viz. coarse-, medium- and fine-grained sandstones, shale and coal.

Quantitative stratigraphic correlation by cross-association analysis (CAA) is appropriate to compare vertical sequences of nominal data (Davis, 2002). In this analysis, the CAA data consists of a string of lithologies or microfacies states, which are mutually exclusive. The analysis involves movement of one sequence against another, from bottom to top, one step at a time, and the degree of matching between the overlapped segments is calculated. At each position, the matching ratio, defined as number of matches divided by number of comparisons, is computed. The matching ratio is an index of similarity of the two sequences at the overlapping position. An "associatogram" is prepared by plotting the match position v/s matching ratio. The significance of the matching ratio is determined by χ^2 test that involves comparison of the number of matches and mismatches of the overlapping segments with those between two totally random sequences comprising same number of observations in each state as the two strings of data under consideration.

Let two sequences with 'm' possible categories be designated as string-1 and string-2. If the number of observations in the 'k^{th}' state of string -1 is denoted as X_{1k}, the total length of string-1 is $n_1 = \Sigma_{k=1}^{m} X_{1k}$. In string-2, there are also 'm' categories each with X_{2k} observations giving a total length of string-2 as $n_2 = \Sigma_{k=1}^{m} X_{2k}$. The probability of match is the sum of the products of each of the 'm' categories in two strings divided by the product of string lengths i.e.

$$P = \frac{\sum_{k=1}^{m} X_{1k} X_{2k}}{n_1 n_2} \quad \text{and} \quad \chi^2 = \frac{(O - E)^2}{E} + \frac{(O' - E')^2}{E'}$$

Where, P = probability of matches; O = observed number of matches; E = expected number of matches; O' = observed number of mismatches; E' = expected number of mismatches. The χ^2 test statistic has one degree of freedom.

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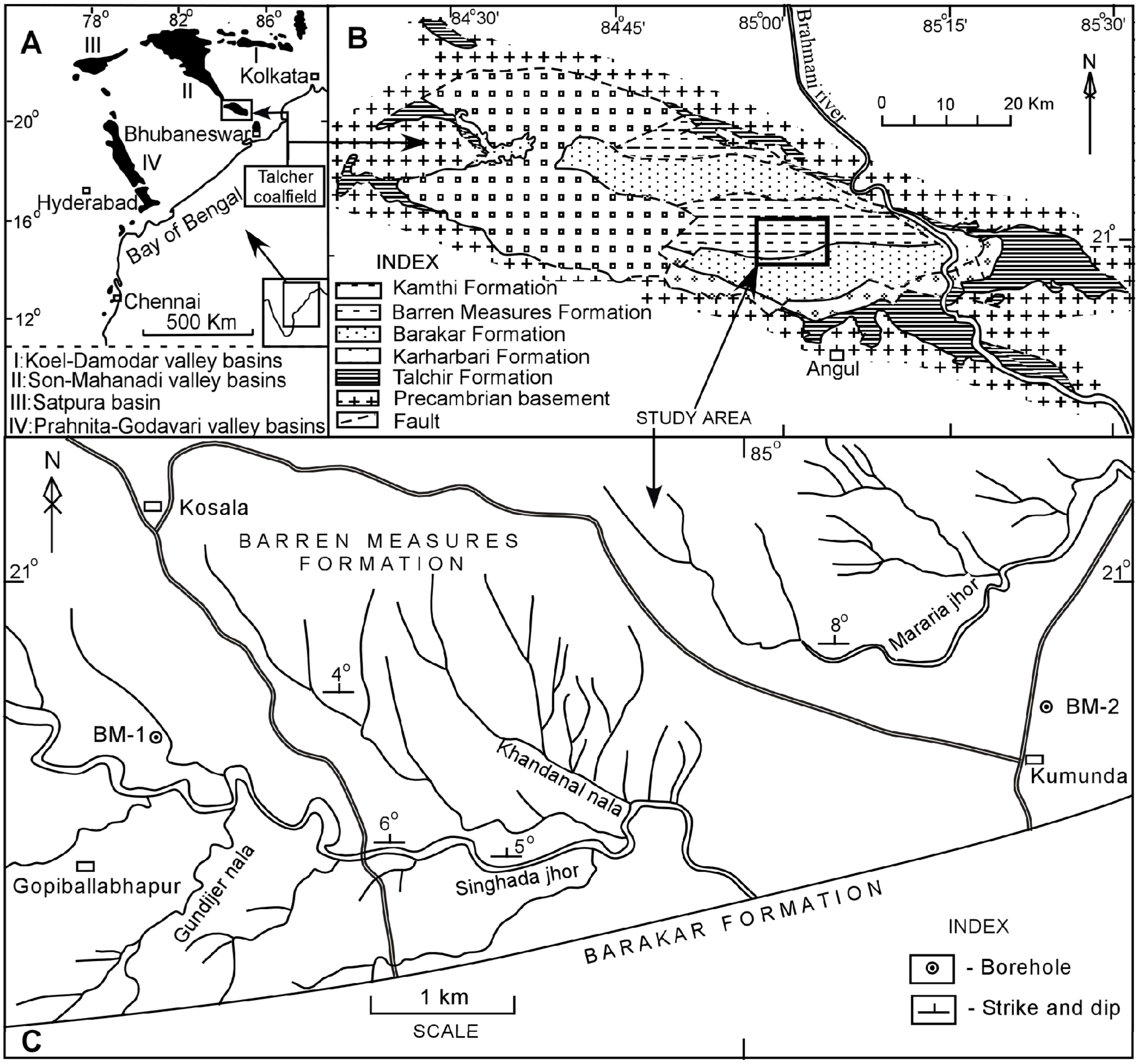

Fig.1. (A) Distribution of Gondwana coalfields in Peninsular India. **(B).** Geological map of the Talcher coalfield (after Raja Rao, 1982). **(C)** Location of the boreholes (BM-1 and BM-2).

The χ^2 test is used to test the null hypothesis (H_0) that the two strings of data form random sequences of states and the observed number of matches and mismatches are not greater than that expected from two random strings of equivalent composition.

RESULT AND DISCUSSION

The cross-association analysis has been applied to two borehole sections of the Barren Measures Formation of Talcher coalfield, which are situated 12 km apart in strike direction (Fig.1C). This distance seems sufficient to represent the homotaxial channel, leeve, flood-plain and swamp sediments of freely migrating braided rivers. The borehole BM-1 in the west comprising 45.99 m of strata is composed of 15 lithologies and 23 microfacies. The borehole BM-2 in the east with 64.26 m of strata constitutes 15 lithologies and 22 microfacies (Table 1). The thickness of the lithologic and microfacies illustrates wide variation ranging from 0.04 to 12.21 m. The lithologic data string of borehole BM-2 moved past the data string of borehole BM-1 from the bottom, one step at a time, and the degree of correspondence between the overlapped segments at each position was calculated. In case of lithologic states, maximum match is attained at 15th match position with 13 matches and 2 mismatches with 15 comparisons (Table 2, Fig.2). The probability of matches under condition of randomness of lithologic states comprising similar number of data is computed to be 0.44 and the expected number of matches and mismatches are 7 and 8 respectively (Table 3). The computed value of χ^2 (9.64) exceeds the critical value (3.84) for one degree of freedom at 0.05 significance level (Table 3). This leads to the rejection of the null hypothesis (H_0) and acceptance of the alternative hypothesis (H_1) that the two strings of lithologic states compare with each other significantly more than expected from matching two strings having random sequence of lithologic states of same composition. Thus, the vertical sequences of lithologies in borehole sections BM-1 and BM-2 are statistically correlatable. Fig.2 displays the lithologic sequences at the match position along with the associatogram. Thus, the vertical sequences of lithology (sandstone – shale – coal) continue uninterrupted from west to east of the Barren Measures Formation.

In case of microfacies, maximum match is reached at 25th match position with 8 matches and 12 mismatches in 20 comparisons (Table

Table 1. Barren Measures lithologs of boreholes

Lithology/ Microfacies	Code		Thickness (in m)
	Lithology	Microfacies	
Borehole BM-1			
WZ	—	—	6.00
Sst. Cr.	A	A_1	10.75
Sst. Fn.	A	A_3	1.56
Gray shale	B	B	0.30
Sst. Md.	A	A_2	1.39
Gray shale	B	B	3.47
Sst. Cr.	A	A_1	0.71
Sst. Fn.	A	A_3	0.48
Sst. Md.	A	A_2	0.39
Sst. Fn.	A	A_3	1.89
Sst. Cr.	A	A_1	5.31
Gray shale	B	B	0.88
Coal	C	C	0.10
Gray shale	B	B	3.32
Sst. Cr.	A	A_1	1.73
Sst. Md.	A	A_2	0.53
Sst. Cr.	A	A_1	2.09
Int. Sst. Sh	B	B	3.41
Sst. Fn.	A	A_3	0.47
Sst. Cr.	A	A_1	0.58
Gray shale	B	B	0.82
Sst. Fn.	A	A_3	5.10
Gray shale	B	B	0.43
Sst. Md.	A	A_2	0.28
Borehole BM-2			
WZ	—-	—-	4.65
Sst. Fn.	A	A_3	2.70
Sst. Md.	A	A_2	12.05
Sst. Fn.	A	A_3	9.75
Sst. Md.	A	A_2	1.34
Gray shale	B	B	1.99
Sst. Fn.	A	A_3	5.04
Gray shale	B	B	2.88
Sst. Fn.	A	A_3	6.20
Coal	C	C	0.18
Sst. Fn.	A	A_3	1.71
Gray shale	B	B	0.63
Sst. Fn.	A	A_3	0.44
Int. Sst. Sh	B	B	1.15
Sst. Md.	A	A_2	0.44
Gray shale	B	B	0.25
Sst. Fn.	A	A_3	2.66
Sst. Md.	A	A_2	0.81
Sst. Cr.	A	A_1	12.21
Gray shale	B	B	0.42
Sst. Fn.	A	A_3	1.05
Sst. Md.	A	A_2	0.32
Sst. Fn.	A	A_3	0.04

Legend: WZ – Weathered zone; Lithology: Sandstone (A), Shale (B) and Coal (C) Microfacies: Sst. Cr.: Coarse-grained sandstone (A_1); Sst. Md.: Medium-grained sandstone (A_2); Sst. Fn.: Fine-grained sandstone (A_3), Int. Sst. Sh.: Interbanded sandstone – shale and shale (B); Coal (C).

4, Fig.3). The probability of matches under condition of randomness of microfacies states with similar number of data is computed to be 0.23 and the expected number of matches and mismatches are 5 and 15 respectively. The computed value of χ^2 (2.40) is less than the critical value (3.84) for one degree of freedom at 0.05 significance level (Table 5). This leads to the acceptance of the null hypothesis (H_0) that two strings of microfacies are random sequences of states and the observed number of matches and mismatches are not significantly greater than that expected from two random sequences of similar composition.

Table 2. Comparison of Barren Measures lithologies

Match position	No. of matches	No. of comparisons	Matching ratio	Match position	No. of matches	No. of comparisons	Matching ratio
1	1	1	1.00	16	0	14	0.00
2	0	2	0.00	17	11	13	0.85
3	3	3	1.00	18	0	12	0.00
4	0	4	0.00	19	9	11	0.82
5	5	5	1.00	20	0	10	0.00
6	0	6	0.00	21	8	9	0.89
7	6	7	0.86	22	0	8	0.00
8	0	8	0.00	23	6	7	0.86
9	7	9	0.78	24	0	6	0.00
10	0	10	0.00	25	5	5	1.00
11	9	11	0.82	26	0	4	0.00
12	0	12	0.00	27	3	3	1.00
13	11	13	0.85	28	0	2	0.00
14	1	14	0.07	29	1	1	1.00
15	**13**	**15**	**0.87**				

Table 3. Cross-association analysis of the Barren Measures lithologies

Lithologies	X_{1k}	X_{2k}	$X_{1k}.X_{2k}$
Sandstone	7	8	56
Shale	7	6	42
Coal	1	1	1
Total	15	15	99
Match position			15
Number of comparisons			15
Probability of matches (P)			0.44
Probability of mismatches (1-P)			0.56
Observed number of matches (O)			13
Expected number of matches (E)			7
Observed number of mismatches (O')			2
Expected number of mismatches (E')			8
Computed value of χ^2			9.64
Critical value of $\chi^2_{(\alpha = 0.05, n = 1)}$			3.84
Conclusion			Correlation is significant

Table 4. Comparison of Barren Measures microfacies

Match position	No. of matches	No. of comparisons	Matching ratio	Match position	No. of matches	No. of comparisons	Matching ratio
1	0	1	0.00	23	4	22	0.18
2	1	2	0.50	24	4	21	0.19
3	1	3	0.33	**25**	**8**	**20**	**0.40**
4	1	4	0.25	26	2	19	0.11
5	1	5	0.20	27	5	18	0.28
6	2	6	0.33	28	1	17	0.06
7	0	7	0.00	29	5	16	0.31
8	4	8	0.50	30	1	15	0.07
9	0	9	0.00	31	4	14	0.29
10	3	10	0.30	32	2	13	0.15
11	2	11	0.18	33	4	12	0.33
12	3	12	0.25	34	1	11	0.09
13	2	13	0.15	35	2	10	0.20
14	4	14	0.29	36	4	9	0.44
15	3	15	0.20	37	2	8	0.25
16	2	16	0.13	38	1	7	0.14
17	8	17	0.47	39	1	6	0.17
18	2	18	0.11	40	2	5	0.40
19	4	19	0.21	41	1	4	0.25
20	3	20	0.15	42	**0**	**3**	0.00
21	5	21	0.24	43	1	2	0.50
22	7	22	0.32	44	0	1	0.00

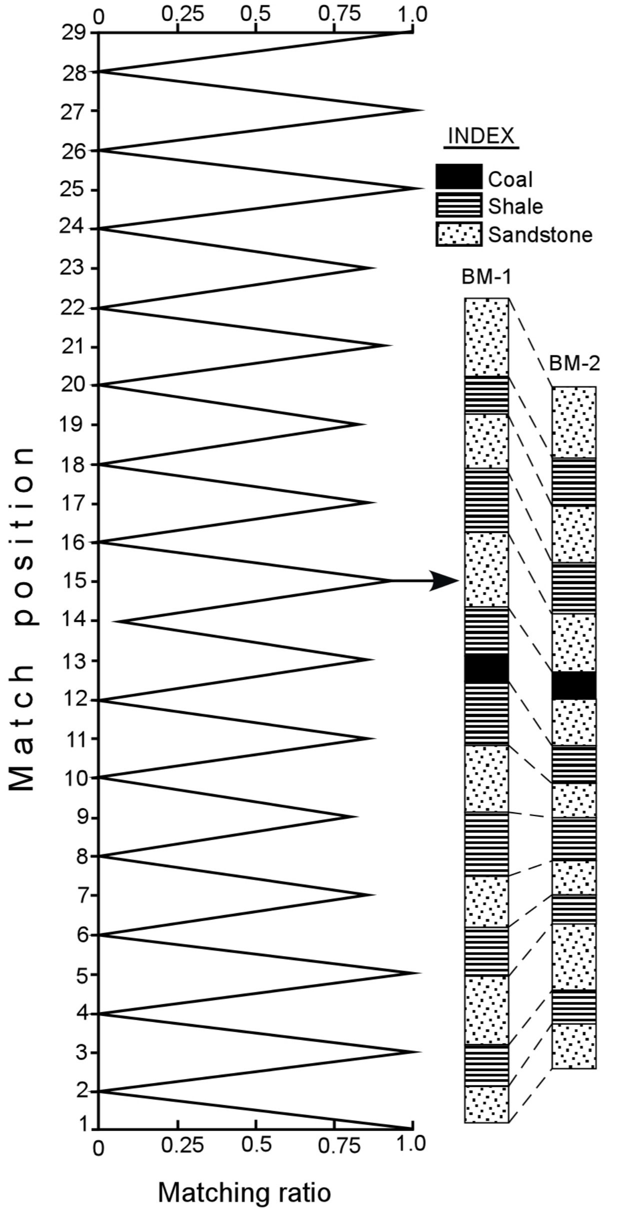

Fig.2. Comparison of the vertical sequences of lithologic states of the Barren Measures Formation, Talcher coalfield. The sequences (in log scale) are in maximum match position.

Table 5. Cross-association analysis of the Barren Measures microfacies

Microfacies	X_{1k}	X_{2k}	$X_{1k} \cdot X_{2k}$
Coarse grained sandstone	6	1	6
Medium grained sandstone	4	5	20
Fine grained sandstone	5	9	45
Shale	7	6	42
Coal	1	1	1
Total	23	22	114
Match position			25
Number of comparisons			20
Probability of matches (P)			0.23
Probability of mismatches (1-P)			0.77
Observed number of matches (O)			8
Expected number of matches (E)			5
Observed number of mismatches (O’)			12
Expected number of mismatches (E’)			15
Computed value of χ^2			2.40
Critical value of $\chi^2_{(\alpha = 0.05,\ n = 1)}$			3.84
Conclusion	Correlation is not significant		

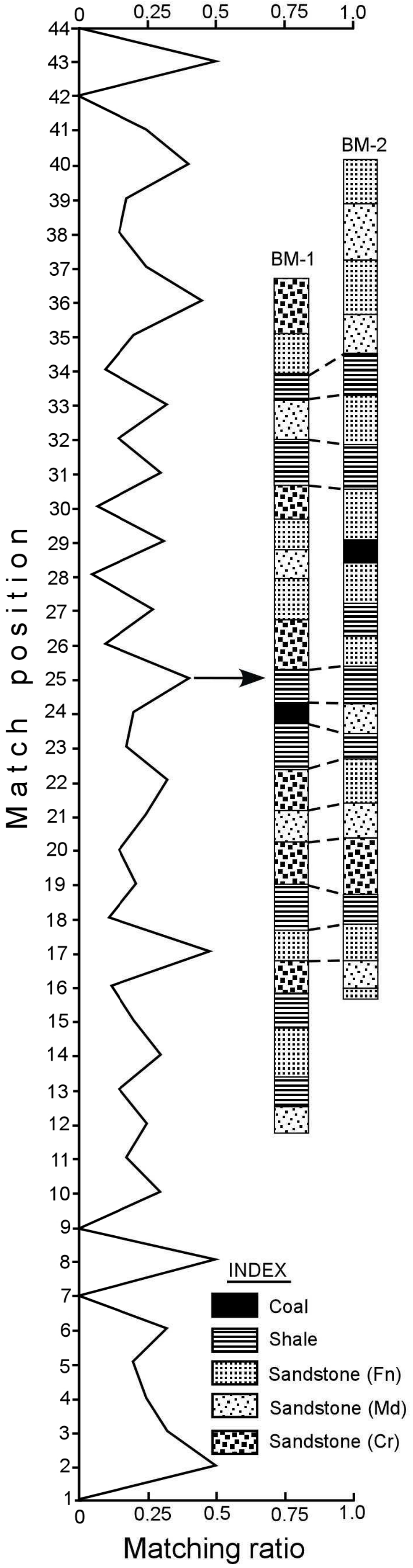

Fig. 3. Comparison of the vertical sequences of microfacies states of the Barren Measures Formation, Talcher coalfield. The sequences (in log scale) are in the maximum match position.

Thus, the vertical sequences of microfacies in both the borehole sections are statistically not correlatable. The associatogram along with the microfacies sequences in the maximum match position are presented in Fig.3. This suggests juxtaposition of dissimilar microfacies, which are characteristic of different sub-environments of braided stream depositional environment.

CONCLUSIONS

- Cross-association analysis of two widely spaced boreholes drilled in the Barren Measures Formation of Talcher coalfield suggests that two sections represent identical lithic assemblages and prevalence of similar (braided stream) depositional environment during Barren Measures sedimentation.
- Lack of correlation at microfacies level indicates lateral facies change and existence of different sub-environments at different places at any point of time.
- When the channel facies were deposited at one place, homotaxial leeve, floodplain and swamp facies were deposited elsewhere.

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