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Author	Hota, R. N. / Pandya, K. L. / Maejima, Wataru
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Palaeocurrent and Palaeohydrologic Analysis of a Part of the Permian Barakar Formation, Talchir Basin, Orissa, India

R. N. HOTA[1], K. L. PANDYA[2] and Wataru MAEJIMA[3]

1 Department of Geology, Ravenshaw College, Cuttack-753 003, Orissa, India
2 P. G. Department of Geology, Utkal University, Bhubaneswar-751 004, Orissa, India
3 Department of Geosciences, Osaka City University, Sumiyoshi-ku, Osaka 558-8585, Japan

Abstract

Palaeocurrent analysis indicates that the Permian Barakar streams of the Talchir basin emerged from the highlands located in the south and south-eastern side of the basin and flowed in a north-westerly direction, filling the basin longitudinally during Barakar sedimentation. The streams were 88 m wide, 1.95 m deep and they discharged 51 m^3/sec water at a velocity of 1.52 m/sec. During periodic floods, the velocity of water increased to 1.89 m/sec, with consequent increase in discharge to 441 m^3/sec and bankful depth to 2.66 m. The streams were moderately sinuous, with sinuosity of 1.31 to 1.36 and meander wavelength of 1,016 m. They swept over the depositional surface that was sloping towards north-west at an average rate of 59 cm/km.

Key words : Barakar Formation, palaeocurrent, palaeohydrology, Talchir basin, Orissa.

Introduction

The Permian Barakar Formation of the Talchir basin (Figs. 1, 2), due to its huge coal resources, has been the attraction of geoscientists during recent years. As a result, much work has been done on such aspects as regional geology, stratigraphy, paleontology and coal resources of this Gondwana succession (Das and Rath, 1974; Raja Rao, 1982, Patra and Swain, 1992; Singh and Singh, 1993). However, the palaeocurrent and palaeohydrologic studies, which are essential for a proper understanding of the palaeogeography, have not been adequately investigated. Ghosh and Mitra (1972), Casshyap (1973), Raja Rao and Mitra (1978), Casshyap and Tewari (1984) and Das and Pandya (1997) have indicated a northwesterly palaeoflow during Barakar sedimentation and computed a few palaeohydrological parameters, but such features as local palaeocurrents, their variability, and computation of stream parameters like channel slope, meander wavelength, discharge, and flow velocity have not been worked out. In view of this, a segment of the Barakar

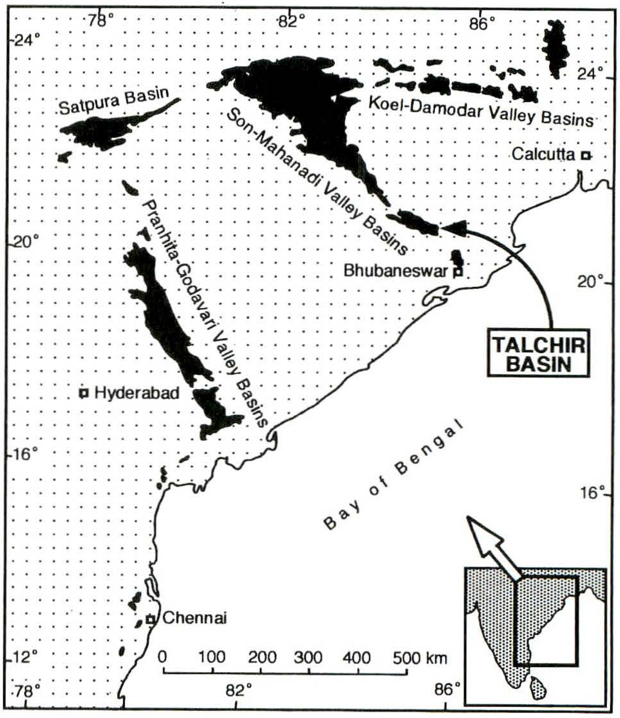

Fig. 1 Distribution of Gondwana basins in the eastern part of Peninsular India and location of the Talchir basin.

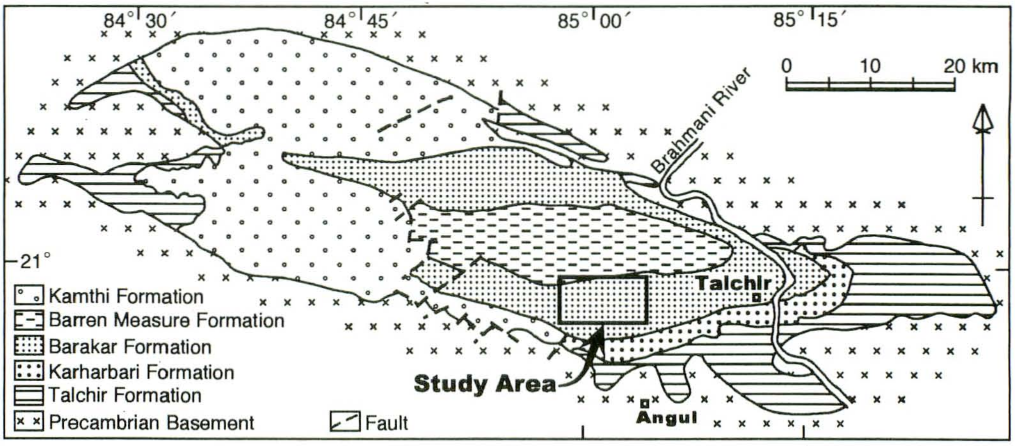

Fig. 2 Geologic sketch map of the Talchir basin and location of the study area (modified from Raja Rao, 1982).

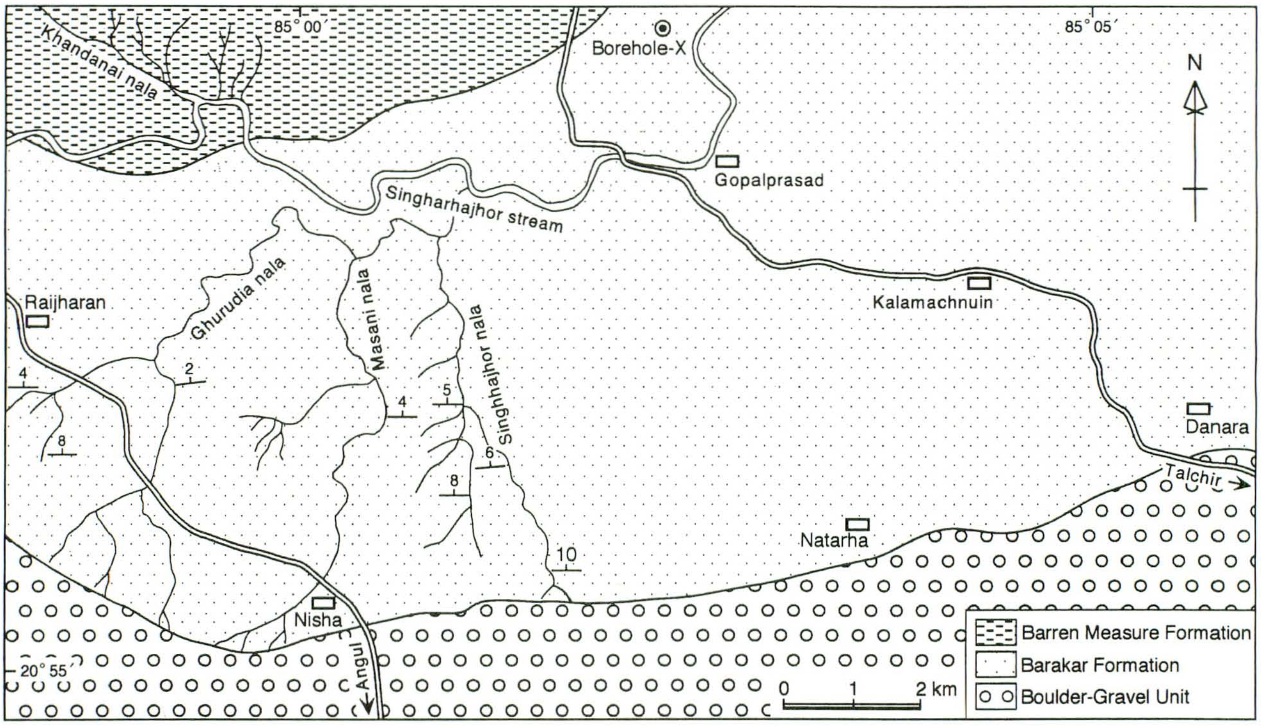

Fig. 3 Geologic map of the study area and stream sections from which palaeoflow data were collected.

Formation exposed in the southeastern part of the Talchir basin (Fig. 2) has been selected for detailed investigation in order to deduce the local as well as the regional palaeoflow pattern, and to understand the nature and competency of Barakar streams.

Study Area

The area investigated (Figs. 2, 3) is located in the southeastern part of the Talchir basin which is the southeasternmost end member of the Son-Mahandi valley basins. It is bounded by latitudes 20° 55' N and 20° 59′ 28″ N, and longitudes 84° 58′ 09″ E and 85° 06′ 19″ E, and forms a part of survey of India Toposheet No 73 $^{D}/_{13}$ and 73 $^{H}/_{I}$. The area is located 12 km west of Talchir township. Singarhajhor stream is the main drainage in the area, and it flows in an easterly direction for some distance and then takes a sharp northerly turn (Fig. 3). It is fed by a system of northerly and northeasterly flowing ephemeral streams which rise from the Boulder-Gravel Unit in the south.

Geologic Setting

The Barakar Formation of the study area represents a fairly continuous succession of strata, attaining a thickness of 275 m. The formation is underlain by the Boulder-Gravel Unit in the south and overlain by the Barren Measure Formation in the northwest (Fig. 3). It strikes east-west and dips towards the north at low angles, ranging from 2 to 10 degrees, forming a homoclinal structure It is chiefly constituted of cyclothemic sequences of sandstone, shale and coal seams, which are vertically arranged in a distinctive pattern, giving rise to a number of well-defined, fining upward cycles (Fig. 4) The lithologic makeup compares well with the fining upward cycles of meandering stream alluvium, and a fluvial origin has been assigned to the Barakar Formation of the present area (Hota, 1999).

Methodology

Due to the thick alluvial cover over the greater part of the area, palaeocurrent and palaeohydrologic data collection was largely confined to the sandstones exposed along the stream sections in the western part of the present area (Fig. 3). Data were obtained from the trough cross bedding, which have been regarded as reliable palaeocurrent indicators. Sixty-two locations were studied and a total number of 600 directional (direction of concavity of trough axes) and 180 hydrologic (cross-bedding thickness) data were collected. To reveal both local and regional palaeoflow patterns, the area was segmented into a number of 1 km² sectors (Fig. 5) and the data collected from each sector as well as the bulk data for the entire area were grouped at 30° class intervals to construct rose diagrams by the nonlinear frequency net, devised by Nemec (1988). The resultant palaeocurrent vector ($\bar{\theta}V$), vector strength ($\bar{R}$), 95% confidence interval, circular standard deviation (S), variance (S^2) and probability of randomness (p) were calculated for each sector and for the entire study area by following formulae (cfr. Curray, 1956; Batschelet, 1981; Davis, 1986):

$$\bar{\theta}V=\tan^{-1}\sqrt{\Sigma\sin\theta/\Sigma\cos\theta} \qquad \text{(Davis, 1986)}$$

$$\bar{R}=\frac{1}{n}\sqrt{(\Sigma\sin\theta)^2+(\Sigma\cos\theta)^2} \qquad \text{(Davis, 1986)}$$

$$95\%\ \text{confidence level}=\pm\frac{180}{\pi}\times 1.96\times\frac{1}{\sqrt{n\bar{R}k}}$$

(Davis, 1986)

$$S=\frac{180}{\pi}\sqrt{2\,(1-\bar{R})} \qquad \text{(Batschelet, 1981)}$$

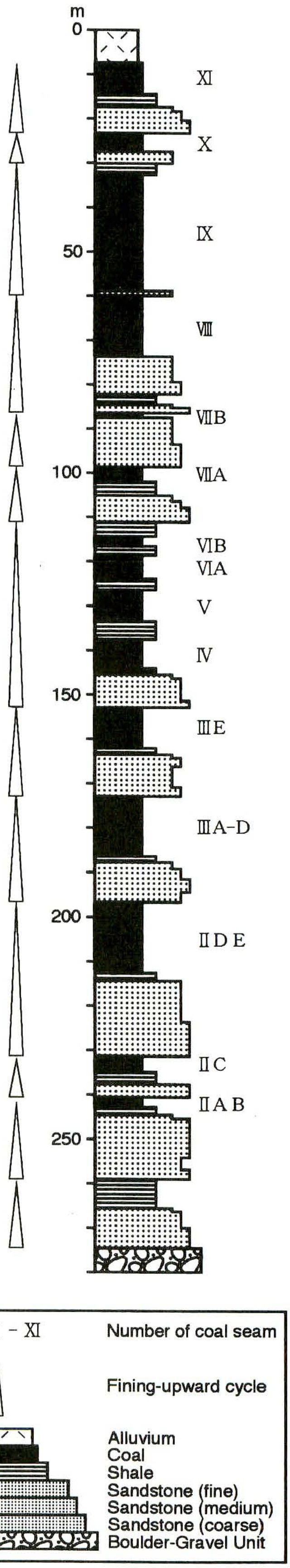

Fig. 4 Stratigraphic section of the Barakar Formation along the borehole-X.

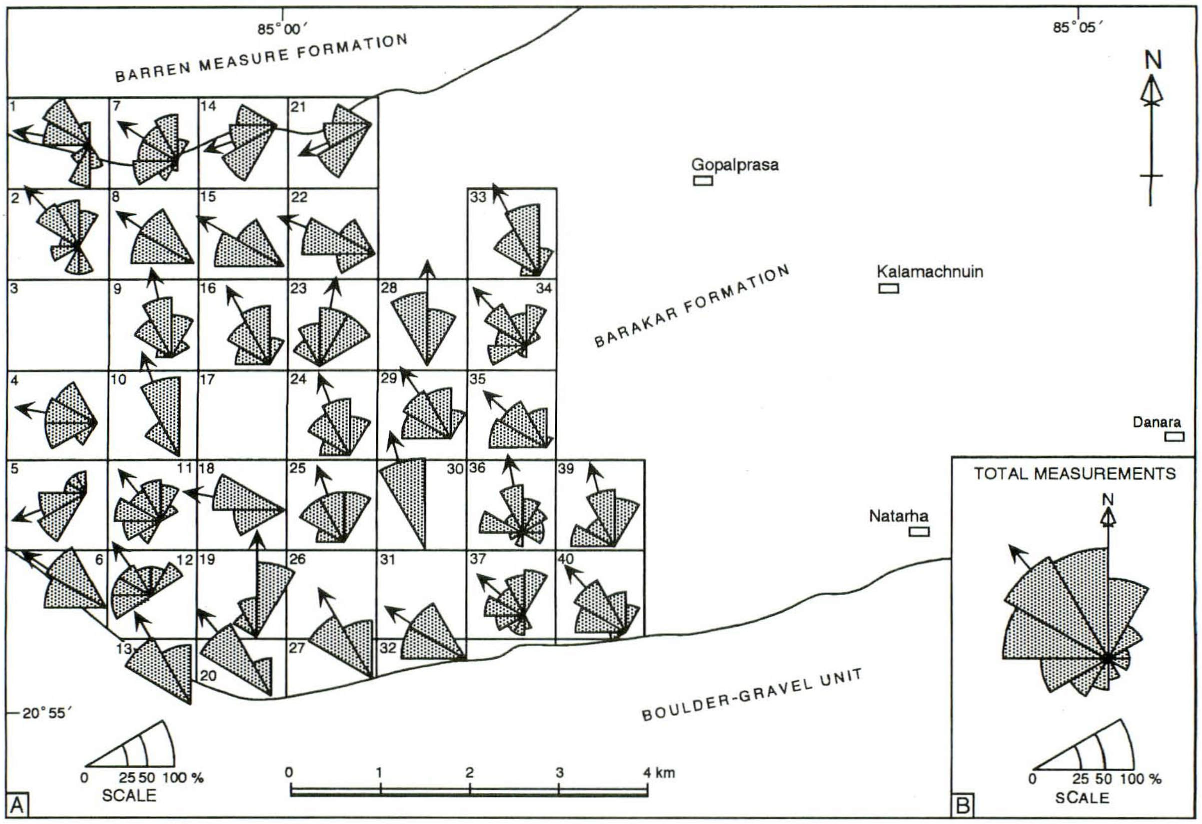

Fig. 5 A) Sector-level cross-bedding azimuth distribution. Number within each sector indicates sector number. B) Current-rose showing overall palaeocurrent pattern of the Barakar Formation of the study area.

$$p=e^{-(\bar{R})^2 n} \qquad \text{(Curray, 1956)}$$

where

n = number of observations

θ = direction of concavity of the trough axis in degrees from north

k = concentration parameter (Davis, 1986)

The results are presented in Table 1.

The palaeohydrologic parameters have been calculated by employing the following empirical formulae:

channel sinuosity

$$P=\frac{1}{1-(\theta/252)^2} \qquad \text{(Miall, 1976)}$$

$$P=\frac{1}{\bar{R}} \qquad \text{(Barrett and Fitzegerald, 1985)}$$

$$P=0.94\ M^{0.25} \qquad \text{(Schumm, 1963)}$$

mean crossbed set thickness (in meters)

$$H=0.086\ d_S^{1.19} \qquad \text{(Allen, 1968)}$$

channel width (in meters)

$$W=42\ d_S^{1.11} \qquad \text{(Allen, 1968)}$$

width/depth ratio

$$F=225\ M^{-1.08} \qquad \text{(Schumm , 1963)}$$

meander wavelength (in feet)

$$Lm=10.9\ W^{1.01} \qquad \text{(Leapold et al., 1964)}$$

$$Lm=106.1\ Q_m^{0.46} \qquad \text{(Carlston, 1965)}$$

channel slope (in feet/mile)

$$S_c=60\ M^{-0.38} Q_m^{-0.32} \qquad \text{(Schumm, 1968)}$$

bankful depth (in feet)

$$d_b=0.6\ M^{0.34} Q_m^{0.29} \qquad \text{(Schumm, 1969)}$$

$$=0.9\ M^{0.35} Q_{ma}^{0.42} \qquad \text{(Schumm, 1969)}$$

flow velocity (in m/sec)

$$v=\frac{R^{2/3} S_c^{1/2}}{n} \qquad \text{(Sengupta, 1994)}$$

flood stage velocity (in m/sec)

$$v_m=\frac{Q_{ma}}{W d_b} \qquad \text{(Schumm, 1972)}$$

clastflow velocity (in m/sec)

$$v_b=9\ d^{1/2} \qquad \text{(Malde, 1968)}$$

Froude number

$$Fr=\frac{v}{(g d_s)^{1/2}} \qquad \text{(Sengupta, 1994)}$$

where

θ = maximum angular range of the mean crossbed azimuth in degrees

d_s = mean water depth in river tract in meters

M = sediment load parameterpercentage of silt plus clay in stream channel perimeter

Q_m = mean annual discharge in feet^3/sec

Q_{ma} = mean annual flood discharge in feet^3/sec

R = hydraulic radius

Table 1 Statistical parameters of palaeocurrent data of the Barakar Formation of the study area.

Sector number	Number of readings (n)	Vector mean (θv)	Vector strength in percent (R)	Circular standard deviation (S)	Variance (S^2)	Probability of randomness (p)	Nature of distribution
1	15	280° (±29°)*	61.5	50°	2528	$<10^{-2}$	bimodal
2	20	318° (±29°)	55.5	54°	2922	$<10^{-2}$	trimodal
3	-	-	-	-	-		-
4	15	281° (±15°)	88.2	28°	775	$<10^{-5}$	unimodal
5	15	249° (±19°)	80.6	36°	1274	$<10^{-4}$	unimodal
6	9	304° (±9°)	97.4	13°	177	$<10^{-3}$	unimodal
7	20	303° (±18°)	75.8	40°	1589	$<10^{-4}$	bimodal
8	10	303° (±9°)	96.5	15°	230	$<10^{-4}$	unimodal
9	25	347° (±10°)	91.2	25°	578	$<10^{-9}$	unimodal
10	10	340° (±5°)	98.9	8°	72	$<10^{-4}$	unimodal
11	50	321° (±13°)	70.8	44°	1917	$<10^{-10}$	bimodal
12	20	324° (±25°)	61.0	51°	2561	$<10^{-2}$	bimodal
13	6	329° (±6°)	99.2	7°	53	$<10^{-2}$	unimodal
14	10	250° (±14°)	92.8	22°	473	$<10^{-3}$	unimodal
15	6	300° (±9°)	98.4	10°	105	$<10^{-2}$	unimodal
16	12	331° (±13°)	92.2	23°	512	$<10^{-4}$	unimodal
17	-	-	-	-	-	-	-
18	6	281° (±15°)	97.4	13°	171	$<10^{-2}$	unimodal
19	10	360° (±7°)	98.2	11°	118	$<10^{-4}$	unimodal
20	6	320° (±9°)	98.4	10°	105	$<10^{-2}$	unimodal
21	10	250° (±14°)	93.0	21°	460	$<10^{-3}$	unimodal
22	6	290° (±13°)	97.5	13°	164	$<10^{-2}$	unimodal
23	18	12° (±13°)	87.8	28°	801	$<10^{-6}$	unimodal
24	10	339° (±14°)	92.5	22°	492	$<10^{-3}$	unimodal
25	10	340° (±14°)	92.2	23°	512	$<10^{-3}$	unimodal
26	-	-	-	-	-	-	-
27	6	330° (±9°)	98.4	10°	105	$<10^{-2}$	unimodal
28	6	360° (±9°)	97.9	12°	138	$<10^{-2}$	unimodal
29	42	322° (±8°)	89.2	27°	709	$<10^{-14}$	unimodal
30	6	345° (±7°)	99.4	6°	39	$<10^{-2}$	unimodal
31	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-
33	18	335° (±8°)	96.3	16°	243	$<10^{-7}$	unimodal
34	30	318° (±18°)	69.1	45°	2029	$<10^{-6}$	bimodal
35	50	312° (±8°)	91.2	24°	578	$<10^{-18}$	unimodal
36	43	347° (±19°)	57.7	53°	2778	$<10^{-6}$	trimodal
37	30	317° (±27°)	50.2	57°	3270	$<10^{-3}$	bimodal
38	10	303° (±9°)	97.2	14°	184	$<10^{-4}$	unimodal
39	10	344° (±19°)	87.4	29°	827	$<10^{-3}$	bimodal
40	30	318° (±10°)	88.3	28°	768	$<10^{-9}$	unimodal
Total	600	319° (±4°)	74.6	41°	1668	0	unimodal

* 95 % confidence limits of vector means are given in brackets.

(for streams with $W > 3$ m, $R = d_s$)

n = Manning roughness coefficient

(for open channels, $n = 0.25$)

d = mean diameter of the pebble in meters

g = acceleration due to gravity (9.8 cm/sec)

These equations, though they have certain limitations (Ethridge and Schumm, 1978), nevertheless have been used to deduce the palaeochannel morphology and flow parameters of ancient fluvial channels (Miall, 1976), including those of Gondwana streams (Casshyap and Khan, 1982; Casshyap and Tewari, 1984; Reddy and Prasad, 1988; Sengupta et al., 1988). Keeping the above limitations in mind, an attempt has been made to assess the hydrologic parameters of the

Table 2 Estimates of palaeohydrologic parameters of the Barakar Formation of the study area.

Parameters	Mean estimate
Channel sinuosity (P)	1.31-1.36
Mean water depth (d_s)	1.95 m
Bankfuk water depth (d_b)	2.66 m
Channel width (w)	88 m
Width/depth ratio (F)	45.1
Sediment load parameter (M)	4.4
Meander wave length (L_m)	1016 m
Mean annual discharge (Q_m)	51 m^3/sec
Mean annual flood discharge (Q_{ma})	441 m^3/sec
Channel slope (S_c)	0.00059
Flow velocity (v)	1.52 m/s
Flood stage velocity (v_f)	1.89 m/s
Clast flow velocity (v_b)	2.2 m/s
Froude number (F_r)	0.412

fluvial systems responsible for the deposition of Barakar sediments. The Barakar succession is made up of ten sandstone horizons separated by laterally persistent coal seams (Fig. 4), and they represent independent events of fluvial sedimentation interrupted by coal-forming environments. Each sandstone horizon might have different palaeoflow and palaeohydrologlc characteristics. As all the sandstone horizons could not be mapped separately, the palaeohydrologic parameters deduced in the present work represent the average values for the entire Barakar succession (Table 2).

Results and Discussion

Palaeocurrent

The computed values of vector strength for the 35 sectors and that of the entire area exceed the critical value for Raleigh's test for the presence of a preferred trend at 1% significance level (Davis, 1986) and the probabilities of randomness are less than 10^{-2} (Table 1). This suggests a statistical significance of the resultant palaeocurrent vectors and an overall, northwesterly (319°±4°) palaeoflow paralleling the basin axis (Fig. 5) implying axial filling of the basin during Barakar sedimentation. The sector level palaeocurrents, on the otherhand, show wide variation, ranging from 249° to 12° (Table 1), which may be due to deposition of sediments by meandering streams (Sengupta. 1994). Higher values of vector strength, with unimodal distribution for most of the sectors, suggest predominantly unidirectional sediment transport in a fluvial environment (Selley, 1968); whereas polymodal distribution, with relatively lower values of vector strength in a few sectors, indicates dispersal of sediments by multidirectional currents (Akhtar and Ahmad, 1991), which might be in response to tributary/distributary channel system. Furthermore, dispersion within each sector, as indicated by standard deviation and variance, may be attributed to local meandering of stream channels and variation in the direction of sediment transport within meander bars (Sengupta, 1970). The northwesterly regional palaeoflow, deduced in this study, agrees well with the earlier palaeocurrent reconstructions (Casshyap and Tewari, 1984; Das and Pandya, 1997) for the Barakar Formation of the Talchir basin. Palaeocurrents are slope-controlled in a fluvial environment (Reddy and Prasad, 1988). The depositional slope, therefore, might have been northwesterly during Barakar sedimentation and the sediments were largely derived from an Easternghat source located to the south and southeast of the investigated area. This inference is supported by the composition of lithic fragments and the heavy mineral assemblages of the Barakar sandstones (Hota, 1999).

Palaeohydrology

The sinuosity of Barakar streams, computed from the variation of mean palaeocurrent azimuth from 35 sectors (249° to 12°, Table 1), is 1.31, which is very close to the sinuosity calculated from vector magnitude (1.34) and sediment-load parameters (1.36). The mean, cross-bed thickness computed from 180 measurements is found to be 0.19 m and that yields a value of 1.95 m for the mean water depth and 88 m for the channel width of Barakar streams. This estimated value of channel width corresponds to the width of a single channel. However, the actual channel width would be much greater due to multichannel behavior of low to moderate sinuous streams (Casshyap and Tewari, 1984). The width/depth ratio of 45.1 and the sediment-load parameter of 4.4 are suggestive of the bedload nature of the Barakar streams of the present area. The average water depth in stream channels was 1.95 m, which rose to 2.66 m during periodic floods. The mean annual discharge of 51 m^3/sec increased to 441 m^3/sec during periodic floods. Similarly the water velocity in stream channels was 1.52 m/sec during normal periods and rose to 1.89 m/sec during periodic floods and to 2.2 m/sec during clast flow. The streams were meandering, with meander wavelengths of 1,016 m, and they swept over a depositional surface that was sloping at the rate of 59 cm/km in a north to northwesterly direction. The Froud number of 0.412 suggests that the water flow in the stream channel was tranquil and of a low-flow regime, which, in turn, accounts for the profuse development of cross-bedded units in sandstones. The various palaeohydrologic parameters computed in the present work are in close agreement with those computed by Casshyap and Khan (1982), Casshyap and Tewari (1984) and Sengupta et al. (1988) for their study on the Barakar succession elsewhere.

The tectonic rise of the source area during the underlying Boulder Gravel period possibly caused a steep gradient and, consequently, large volumes of boulders, cobbles and pebbles were spread as a thick alluvial fan on the depositional surface (Das and Pandya, 1997). The Barakar Formation, on the other hand, represents a post-tectonic stable phase of sedimentation, characterized by a change in stream regime and deposition of thick coal seams. However, differential subsidence of the depositional surface during Barakar sedimentation resulted in drainage deflection, which is indicated by swing of the sector level palaeocurrent direction towards southwest. The Barakar Formation in the present area is characterized by ten coal seams, separated by a similar number of sandstone horizons (Fig.4). Thus it is evident that periods of clastic sedimentation were punctuated by phases of peat accumulation, during which the entire area was converted into peat-swamp, resulting in cessation of fluvial sedimentation. The Barakar streams at various phases of sedimentation migrated laterally at varying rates and in some instances were confined to certain linear zones that subsided at a faster rate than the adjoining areas. This is documented by variable thickness and lateral continuity of the sandstones (Fig. 4). During each phase of clastic sedimentation, a new system of streams appeared in the area. Metamorphosis of these streams occurred in vertical progression in response to the provenance, stream gradient and competency, which can only be revealed by a close examination of the inter- and intra-seam sandbody geometry of the Barakar Formation of the present area.

Conclusions

The Barakar succession of the Talchir basin was deposited in river basins, interrupted by phases of peat accumulation. The river systems which appeared in the area in successive phases of sedimentation migrated laterally at varying rates, and at times they were confined to certain linear zones that subsided at a relatively faster rate, resulting in greater thickness of sandstones The flow direction and hydrologic parameters of these streams might have been different, but on average they were 88 m wide, 1.95 to 2.66 m deep, with sinuosity of 1.31 to 1.36 and meander wavelength of 1,016 m. These rivers discharged 51 m^3/sec to 441 m^3/sec of water at a variable velocity of 1.52 m/sec to 2.2 m/sec, and they swept over a depositional surface that was sloping at the average rate of 59 cm/km in a northwesterly direction. The sediments of the study area were largely derived from Easternghat sources located along the southern boundary of the basin.

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