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# Depositional Record of Tidal-Flat Sedimentation in the Permian Coal Measures of Central India: Barakar Formation, Mohpani Coalfield, Satpura Gondwana Basin

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**Abstract**

The Permian Barakar Formation in the Mohpani coalfield, Satpura Gondwana basin, is composed of three broad lithologies that occur repetitively and are iterdigitated: (1) several metres thick coarse- to medium-grained sandstone bodies with scoured bases, (2) 5-20 m thick medium- to fine-grained sandstone bodies and (3) 5-20 m thick mudstone-dominated packages with variable proportions of centimetre- to decimetre-scale, fine- to medium-grained sandstone, carbonaceous shale and coal. The Barakar strata were previously interpreted as deposits of braided rivers and associated inter-channel flood basin in a continental setting. However, this study recognizes signatures of tidal current from the mudstone-dominated packages implying marine influence during Barakar sedimentation.

The mudstone-dominated sediment bodies are the focus of this paper and comprise of three lithofacies that bear imprints of tidal processes during Barakar sedimentation: (1) heterolith, (2) sandstone, and (3) coal-carbonaceous shale, which alternate with one another within individual bodies. The heterolithic facies show interlayering of sandstone and claystone resembling flaser, wavy and lenticular bedding, as well as pinstripe stratification. Successive sandstone-mudstone couplets indicate periodic waxing and waning of flows. Within individual heterolithic packages, the sandstone:claystone ratio along with the bedding style, varies cyclically upwards giving rise to alternate sandstone-dominated and claystone-dominated intervals suggesting tidal velocity fluctuation reflective of spring-neap lunar cycle. Thickness plots of successive sand-mud couplets also reveal cyclic variation with a conspicuous periodicity of around 12 couplets per cycle, which corroborates the spring-neap-spring (or neap-spring-neap) lunar cycle. Presence of abundant desiccation cracks indicates periodic emergence and points towards an intertidal setting. The sandstone facies is characterized by a variety of wave-generated features such as bundled and chevron upbuilding of lamina, bi-directional foreset orientations, offshooting and draping laminae, scour-and-drape feature, swollen lens-like geometries suggesting their emplacement under storm-induced combined-flow on the tidal-flat. The coal-carbonaceous shale facies represent supratidal marsh environment.

**Key words:** Gondwana basin, Permian coal measure, Central India, fluvial, tidal rhythmites, tidal flat.

## Introduction

The Gondwana strata of India record resumption of sedimentation in peninsular India during the Permo-Carboniferous period followin.g a long depositional hiatus since the Proterozoic. Gondwana successions are preserved in a number of discrete, intracratonic basins in peninsular India (Fig. 1). These successions share the faunal and floral characteristics of the Gondwana strata of South America, South Africa, Australia and Antarctica, which comprise the other constituents of the southern hemispheric part (Gondwanaland) of the Paleozoic supercontinent Pangea. Apart from the paleontological similarities, the successions preserved in the Gondwanan continents resemble one another in that they generally start with basal diamictite and glacial outwash deposits, followed by coal-bearing siliciclastics with *Glossopteris* and Triassic red beds with calcretes (Hobday, 1987).

The glacio-marine Talchir and the overlying coal-bearing Barakar Formations represent the lower part of the Indian Gondwana successions, showing more or less uniform lithological association in all the basins. The Barakar Formation is the primary resource of coal in India (Veevers and Tewari, 1995), and comprises of several meters thick sandstone bodies alternating with sediment bodies of equivalent dimensions, characterised by heterolithic (sandstone-mudstone) bedding, carbonaceous shale and coal that to date, are interpreted as representing deposition in freshwater alluvial settings (Casshyap, 1973;

Casshyap and Qidwai, 1971; Casshyap and Tewari, 1991; Veevers and Tewari, 1995).

In recent years, tide- and wave-influenced deposits have been recognized in association with several coal-bearing, fluvial successions demonstrating marine influence during their deposition in inland settings (Kvale and Archer, 1990; Archer et al., 1994; Archer et al., 1995; Greb and Archer, 1995; Kvale and Mastalerz, 1998; Michaelsen and Henderson, 2000; Brettle et al., 2002). In the absence of marine fossils, a possible marine influence during Barakar sedimentation has also been surmised by several workers based on the occurrences of wave-generated structures, trace fossils and high boron/sulfur contents of the coal (see Veevers and Tewari, 1995; Gupta, 1999, 2000; Biswas, 1999; Dutt and Mukhopadhyay, 2001), but sedimentary features indicating unambiguous marine influence still remain to be documented. The coal-bearing strata of the Barakar Formation, Satpura Gondwana basin, Central India (Fig. 1) have been ascribed a non-marine origin based on the absence of marine fossils and general similarities to fluvial deposits (Ray and Chakraborty, 2002). In the Mohpani coalfield of this basin, Barakar strata are excellently preserved and fortuitously exposed along the Sitarewa river (Figs. 1, 2) allowing re-evaluation of the Barakar depositional regime which has been traditionally considered to be continental. This paper presents a detailed documentation of an 18 m-thick sedimentary package of the Barakar succession that is replete with sedimentary structures indicative of tidal-flat depositional regime. The objective is to exemplify the geological record of tidal-flat deposits and their significance for marine influence during sedimentation of coal-bearing strata which, to date, remains to be recognized from the Barakar Formation.

## Geological Background

The Gondwana basins of peninsular India are intracratonic in nature surrounded by Precambrian terranes (Fig. 1). They are disposed along the ENE-WSW trending Namada-Son-Damodar valley, NNW-SSE trending Pranhita-Godavari valley and NW-SE trending Mahanadi valley (Fig. 1). There is a general consensus that these basins originated under a bulk extensional regime, due to failure of the attenuated crust along pre-existing zones of weakness imparted by Precambrian structural grains (Chaterji and Ghosh, 1970; Naqvi et al., 1974; Mitra, 1994; Biswas, 1999; Acharyya, 2000).

The Satpura basin of Central India is the westernmost Indian Gondwana basin and outcrops along the ENE-WSW trending Narmada valley (Fig. 1). The Satpura basin contains rocks of Permian to Cretaceous age, and therefore comprises the longest stratigraphic range of the Indian Gondwana basins. Interestingly, the term 'Gondwana' was

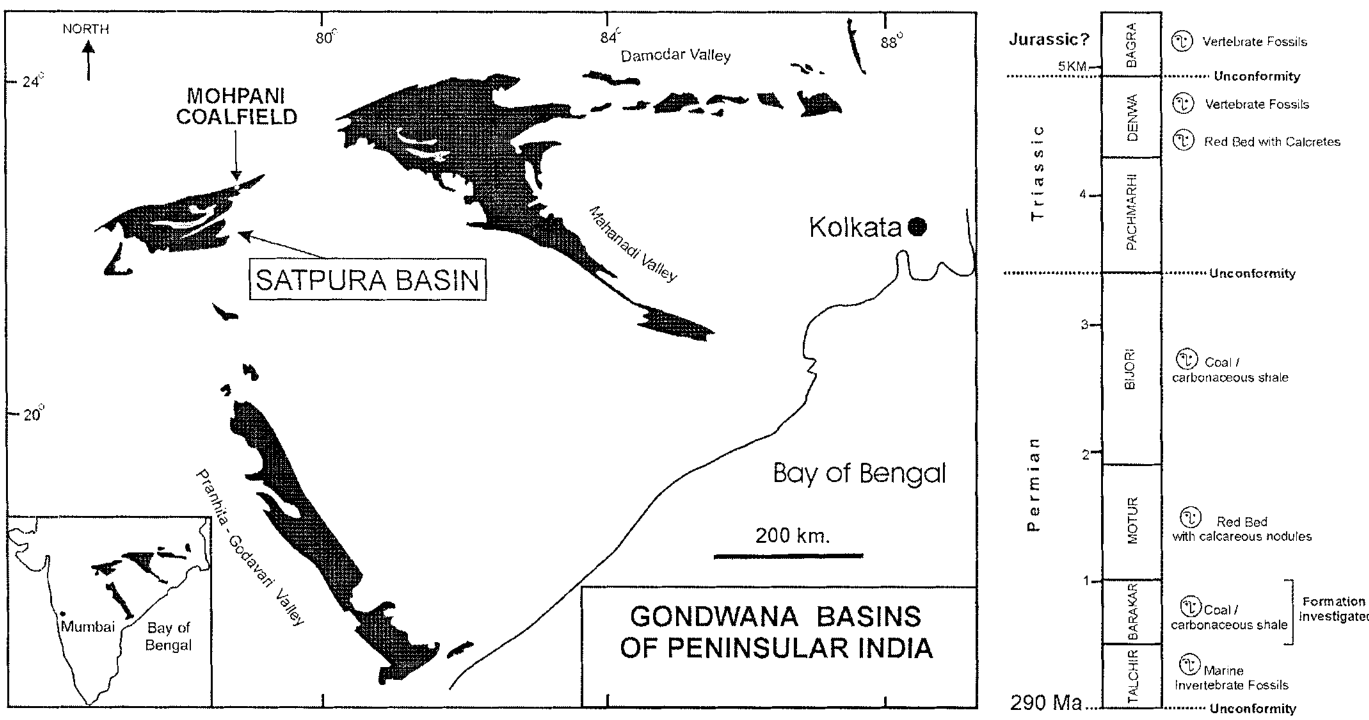


Fig. 1. Disposition of the Gondwana basins of peninsular India along the present day valleys of Narmada-Son-Damodar, Pranhita-Godavari and Mahanadi rivers. Generalized stratigraphy of the Satpura basin fill is also shown along with key features of individual stratigraphic units. The present study is confined to the Barakar Formation of the Mohpani coalfield, Satpura basin.

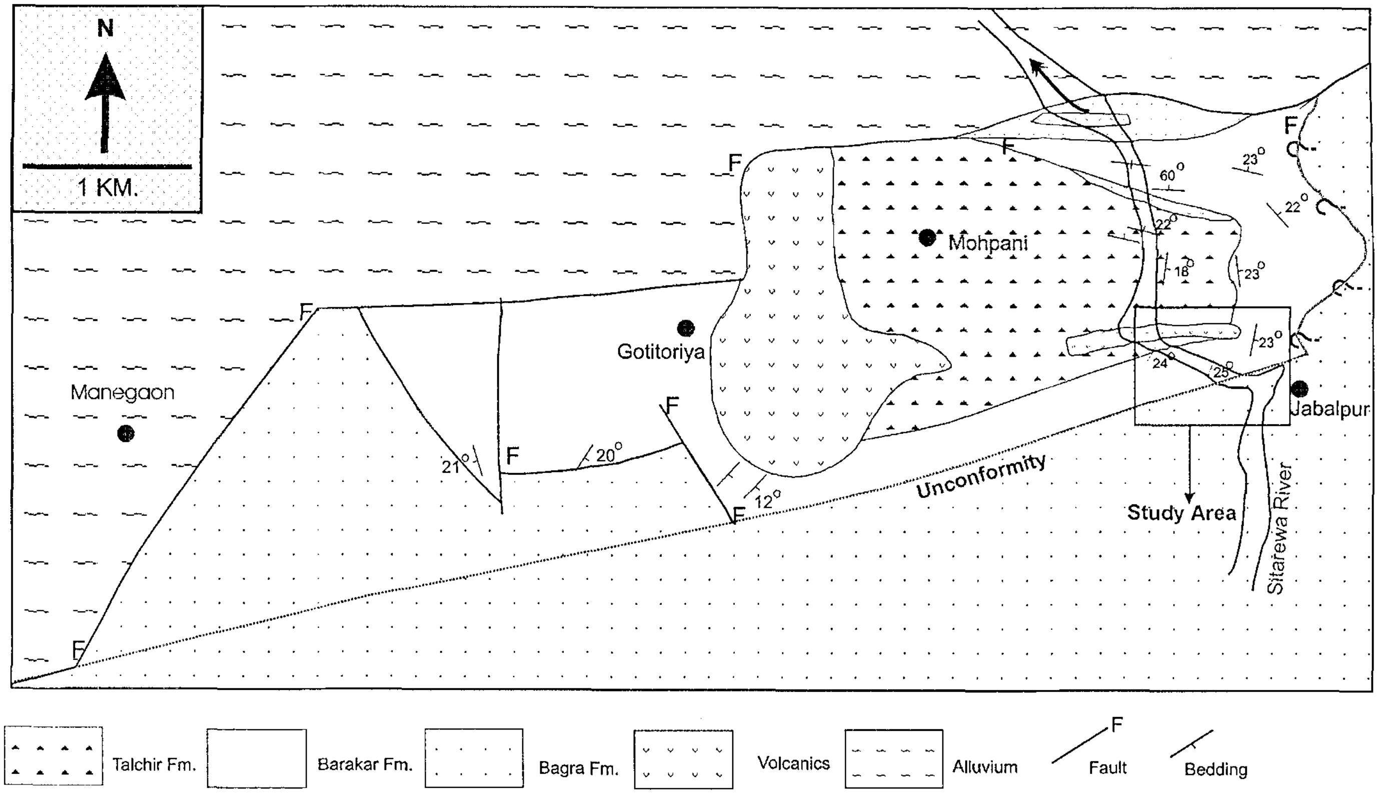


Fig. 2. Geological map of the Mohpani coalfield. Barakar Formation was investigated along the transect of the Sitarewa river shown within the box.

introduced in geology by Medlicott (1872) while he was working in the Satpura basin, after the ancient Kingdom of Dravidian Gonds, one of the principal aboriginal tribes who inhabited the Satpura area. The Satpura basin is now considered to be of pull-apart type and is filled with ~ 5 km thick pile of siliciclastic sediments as a result of fault-controlled, synsedimentary subsidence (Fig. 1; Biswas, 2003). Three major unconformity-bounded units can be recognized in the succession (Fig. 1). The hallmark of the lowermost unit is the presence of coal/carbonaceous shale, which contain alluvial strata along with those deposited under sub-aquatic condition (Peters and Singh, 2000). The upper two units represent deposition entirely in alluvial setting and are rich in 'red beds' with calcretes and vertebrate fossils (Bandyopadhyay, 1999; Casshyap and Khan, 2000; Maulik et al., 2000). The lowermost unit begins with the glacio-marine Talchir Formation (Casshyap and Qidwai, 1971) and is overlain by the coal-bearing Barakar Formation, which is the subject of the present paper (Fig. 1).

## Barakar Succession of the Mohpani Coalfield

The Mohpani coalfield is located at the northeastern corner of the Satpura basin (Fig. 1). About 120 m thickness of Barakar strata are exposed along the Sitarewa river and the succession is unconformably overlain by the Bagra Formation (Fig. 2). The Barakar succession is composed of three broad lithologies (Fig. 3) that occur repetitively and are iterdigitated: (1) several metres thick coarse- to medium-grained sandstone bodies with scoured bases, (2) 5–20 m thick medium- to fine-grained sandstone bodies and (3) 5-20 m thick mudstone-dominated packages with variable proportions of centimetre- to decimetre-scale, fine- to medium-grained sandstone, carbonaceous shale and coal. The mudstone-dominated sediment bodies are the focus of this paper and comprise of three lithofacies that bear imprints of tidal processes during Barakar sedimentation: (1) heterolith, (2) sandstone, and (3) coal-carbonaceous shale, which alternate with one another within individual bodies. These facies are described and interpreted in the following section based on a detailed study of an 18 m thick interval in which heterolith, coal-carbonaceous shale and sandstone facies constitute approximately 50%, 30% and 20% of the succession respectively (Figs. 3, 4).

## Lithofacies 1: Heterolith

*Description*

The heterolith facies is represented by millimetre- to

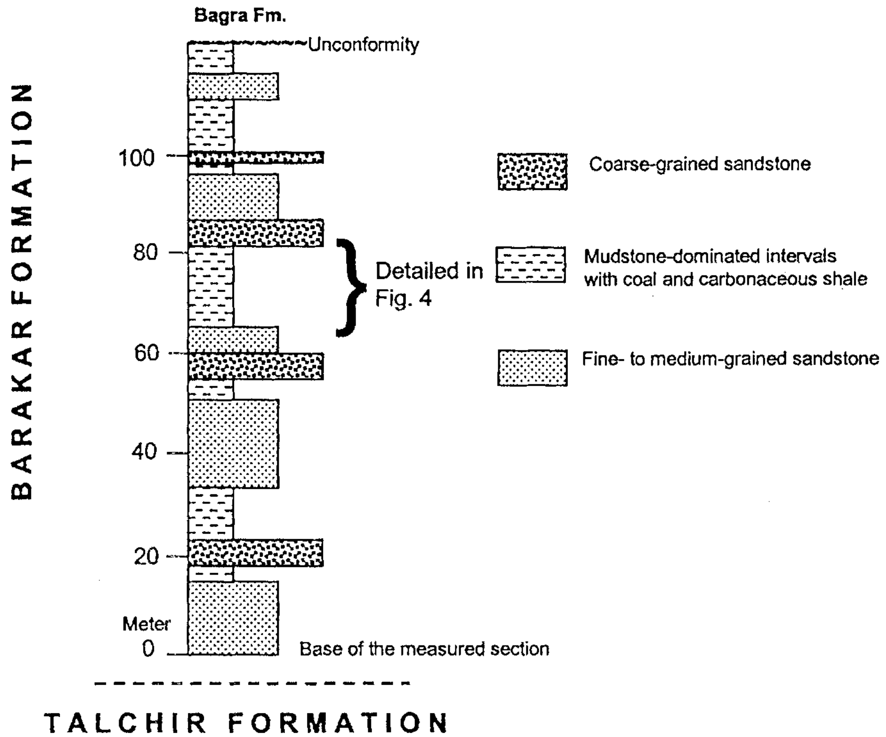


Fig. 3. Measured log of the Barakar Formation of the Mohpani coalfield exposed along the Sitarewa river shown in figure 2. Note interdigitation of three broad lithologies in the succession. The mudstone dominated intervals are the focus of this paper one of which is investigated in detail.

centimetre-scale alternation of fine-sandstone and mudstone (Fig. 5). Desiccation cracks are abundant (Fig. 6), whereas plant litters, burrows and rootlets are common in this facies. The thickness of this facies varies from 10 cm to more than 1.5 m. The heterolithic sediment bodies reveal a variety of bedding styles due to variation in the proportion of sandstone and mudstone and their internal structure (Fig. 5). Accordingly, several subfacies can be delineated as described below:

(1) Ripple-laminated sandstone with thin, discontinuous mudstone layers between lamina cosets (Fig. 7). The sandstone layers show wave-ripple cross-laminae with bi-directional orientations and chevron pattern of arrangement, along with undulatory and draping laminae.

(2) Ripple cross-laminated sandstone with thin but continuous mudstone layers between lamina cosets (Fig. 8).

(3) Ripple cross-laminated sandstone with fairly thick mudstone layers between lamina cosets (Fig. 9).

(4) Centimeter-thick flat, massive/parallel-laminated sandstone layers with intervening mudstone partings.

(5) Mudstone-rich packages with continuous ripple trains or isolated ripples occurring as form sets (Fig. 10). Ripples may be symmetrical or asymmetrical with wavelength and amplitude of 5–10 cm and 1–3 cm.

(6) Mudstone-rich packages with millimetre-scale streaks of sandstone defining pinstripe stratification (Fig. 5)

*Interpretation*

The characteristics of lithofacies 1 clearly indicate alternate traction and suspension sedimentation. The ripples and their internal laminae formed due to traction, whereas the intervening mud layers represent suspension settlement implying periodic waxing and waning of flow. Within individual heterolithic packages, the sandstone:claystone ratio along with the bedding style, varies cyclically upwards giving rise to alternate sandstone-dominated and claystone-dominated intervals (Fig. 11). The succession of different subfacies and their bedding styles resulted due to temporal variation in the ratio of the rates of traction sedimentation and suspension settlement in response to a longer-period flow fluctuation than that associated with deposition of a single sandstone-mudstone couplet. Thickness plots of successive layers within heterolithic bodies also reveal cyclic variation for both sand and mud layers (Fig. 12). Presence of desiccation cracks indicates a depositional environment that suffered periodic submergence and emergence and points towards a tidal-flat system.

Although not uncommon in other sedimentary environments, sandstone-mudstone heterolithic units displaying flaser, wavy, lenticular and pinstripe beddings are the most common characteristic features of the tidal-flat system signifying periodic flow fluctuations (Reineck and Wunderlich, 1968; Reineck, 1972). Similar features may also develop within continental fluvial systems that are affected by periodic rise and fall of water level due to propagation of tidal waves far inland through the fluvial channels. However, we preferred the coastal, tidal-flat interpretation as this facies is associated with facies deposited under the influence of wave and tide in open marine condition (see following sections).

The alternation of sandstone and mudstone layers is interpreted to reflect tidal rise and fall (Rahmani, 1988; Tessier et al., 1988; Williams, 1989; Dalrymple et al., 1991; Nio and Yang, 1991). Each sand-mud couplet, representing sand deposition from traction and/or suspension (high velocity stage of the flow) followed by suspension fallout of mud (stillstand or slack water stage of the flow) records a single tidal fluctuation in a diurnal or semidiurnal system (Archer et al., 1995). The tidal influence on the origin of these rhythmites is also indicated by the cyclic occurrence of sandstone-dominated and mudstone-dominated

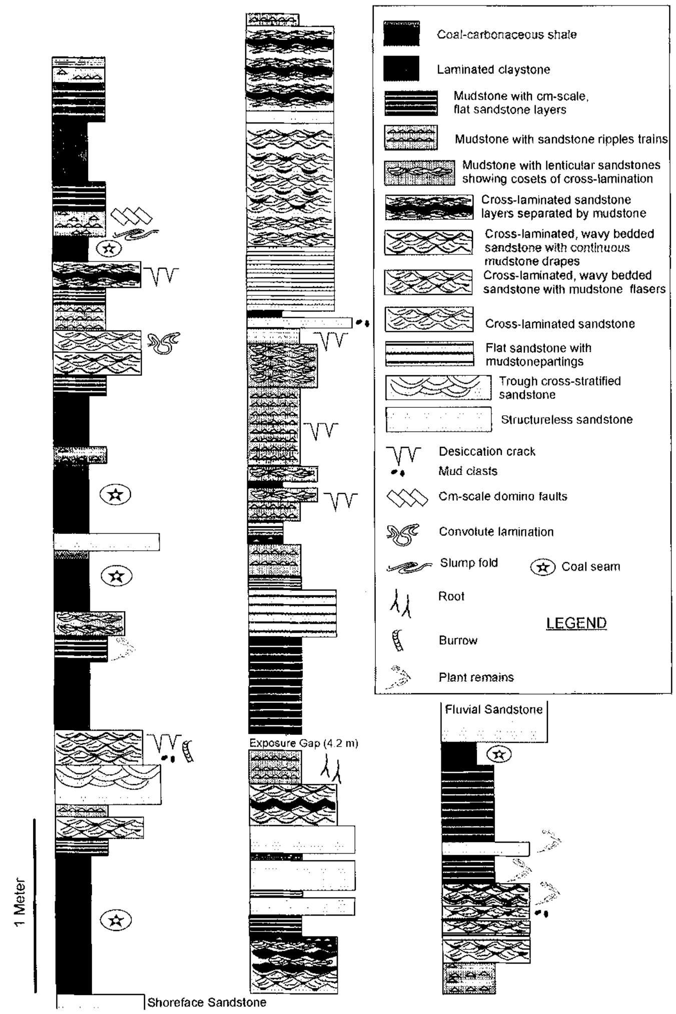


Fig. 4. Detailed litholog of a mudstone-dominated interval (shown in Fig. 3) of the Barakar succession of the Mohpani coalfield. Note interdigitation of the three major constituent lithofacies: (1) heterolith, (2) sandstone, and (3) coal-carbonaceous shale.

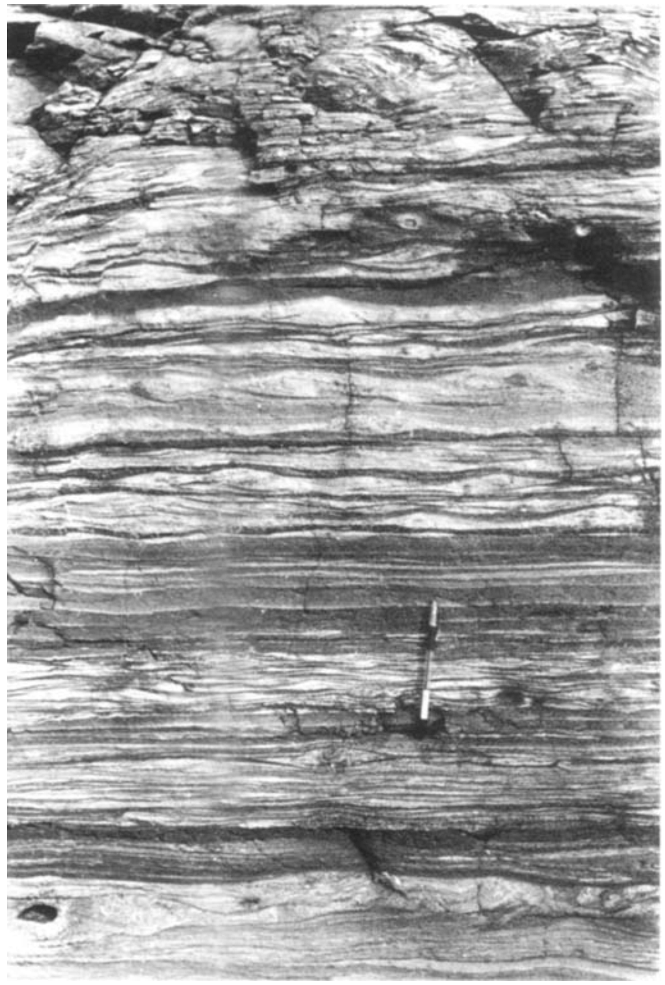

Fig. 5. Field photograph of heterolithic facies (lithofacies 1) taken from the interval shown in figure 4. Note vertical variation in the sandstone(bright bands): mudstone (dark bands) ratio and different types of stratification style. Pen is 15 cm long.

intervals reflective of the lunar orbital cycle, which causes a neap (low) and a spring (high) tide with an interval of 14.75 days (Figs. 11, 12; Kvale and Mastalerz, 1998). The average number of sand-mud couplets occurring within two successive mud-dominant and sand-dominant intervals of the Barakar heterolithic facies is approximately 12 (Fig. 12), which is close to the present-day interval of 14.75 days between halfmoon and new/fullmoon. It, therefore, follows that in the Mohpani area the tide was diurnal in nature. Tidal currents presumably interfered with wave-induced oscillatory currents to result in combined-flow ripples with their characteristic internal lamination style (Fig. 8; Arnott and Southard, 1990).

## Lithofacies 2: Sandstone

*Description*

The sandstone bodies of lithofacies 2 are dominantly

Fig. 6. Bedding plane view of desiccation cracks within lithofacies 1. Photograph was taken from the interval shown in figure 4. Coin diameter - 2 cm.

fine- to medium-grained and vary in thickness between 0.3 m to >1 m. Coarser-grained sandstone beds occur rarely, and are either trough cross-stratified (set thickness 10–30 cm) or massive. Some of these beds contain platy mud clasts. The fine- to medium-grained sandstone bodies are either parallel-laminated (Fig. 13) or wavy bedded (Fig. 14). The wavy bedding style appears to be the consequence of preservation of ripple morphologies defining set boundaries. The ripple forms vary in wavelength from 15 cm to 30 cm with amplitudes of 3.5–5 cm. The internal structures include cross-lamination and undulatory, parallel-lamination (Fig. 14). The lamina-sets show bundled and chevron upbuilding, bi-directional foreset orientations, offshooting and draping laminae, swollen lens-like geometries, scour-and-drape feature (Fig. 15; De Raaf et al., 1977). In places, platy mud clasts are present aligned parallel to the interfaces of the wavy beds. A few sandstone bodies show a systematic upward variation in stratification style from parallel-lamination to ripple bedding.

*Interpretation*

The stratification styles of the sandstone lithofacies point towards wave-influenced sedimentation. Relatively larger size of the bedforms coupled with the occurrences of undulatory/parallel-laminations and scour-and-drape feature suggest strong flows. Presence of mud clasts and vertical variation of stratification style from parallel-lamination to ripple-bedding also corroborates deposition from temporally waning shooting flows such as those associated with storms. The storm-induced oscillatory flows were probably associated with unidirectional currents as indicated by the trough cross-stratification, as well as the internal laminations of the ripples which are suggestive of combined-flow regime (cf. Arnott and Southard, 1990). The sandstone lithofacies occurs in association with the tidal-flat deposits of lithofacies 1 and forms only 20% of the succession (Fig. 4). We thus infer that lithofacies 2 was deposited in the tidal-flat regime during occasional storms.

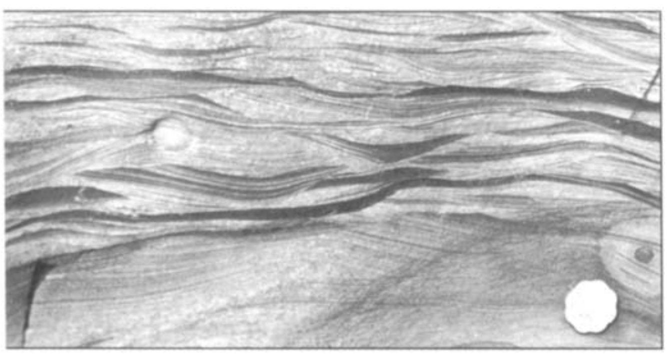

Fig. 7. Photograph of lithofacies 1 showing ripple cross-laminated sets with discontinuous mudstone drapes. Note draping and offshooting laminae and variable foreset orientations. Photograph was taken from the interval shown in figure 4. Coin diameter - 2 cm.

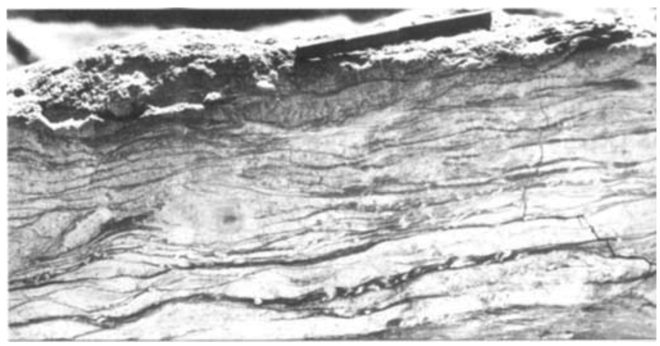

Fig. 8. Photograph of lithofacies 1 showing a ripple-bedded unit with thin but continuous mudstone partings (dark) between cross-sets. Pen length - 15 cm. Photograph was taken from the interval shown in figure 4.

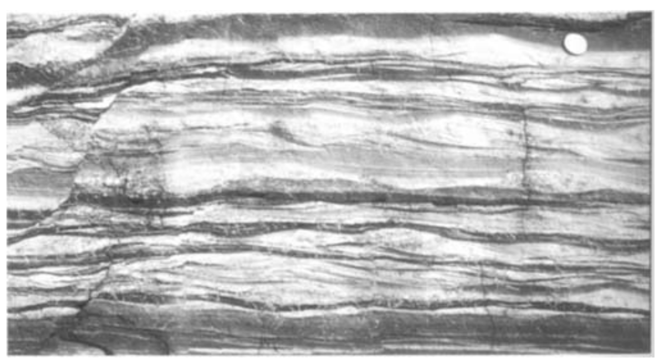

Fig. 9. Photograph of lithofacies 1 showing a ripple-bedded unit with thick and continuous mudstone layers (dark) between cross-sets. Coin diameter - 2.5 cm. Photograph was taken from the interval shown in figure 4.

## Lithofacies 3: Coal-carbonaceous Shale

*Description*

This facies comprises interlaminated to interbedded, dark grey to black carbonaceous claystone and coaly stringers that often grades vertically and laterally into economically exploitable coal seams (Figs. 4, 13). In the measured section (Fig. 4), the thickness of this facies ranges between 0.2 and 1 m. Subsurface drilling revealed occurrence of four major coal seams ranging in thickness from 1.22 m to up to 10 m (Raja Rao, 1983). The thickness, however, varies laterally. The coal stringer/claystone ratio tends to increase towards the coal seams. Some claystones show very fine lamination. Finely macerated organic debris and leaf imprints on bedding planes are very common. The coal is generally dark and partly shining with a moderate specific gravity showing interlayering of vitrain-clarain and vitrain-durain bands with very little fusain. Approximate maceral composition is: vitrain-40%, clarain-48%, durain-10%, fusain-2%. The rank of the coal ranges from medium-volatile bituminous (mvb) to high-volatile B-bituminous (hvBb) (Raja Rao, 1983).

*Interpretation*

High organic carbon content of lithofacies 3 points towards accumulation of fine-grained, terrigenous

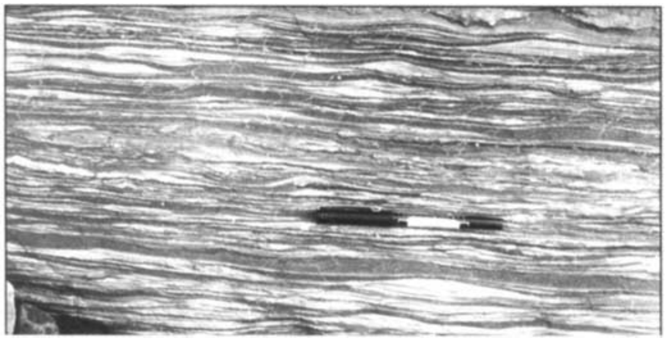

Fig. 10. Photograph of lithofacies 1 showing isolated sandstone ripple trains encased within mudstone (dark). Note profuse, thread-like desiccation cracks in the upper part. Pen length - 15 cm. Photograph was taken from the interval shown in figure 4.

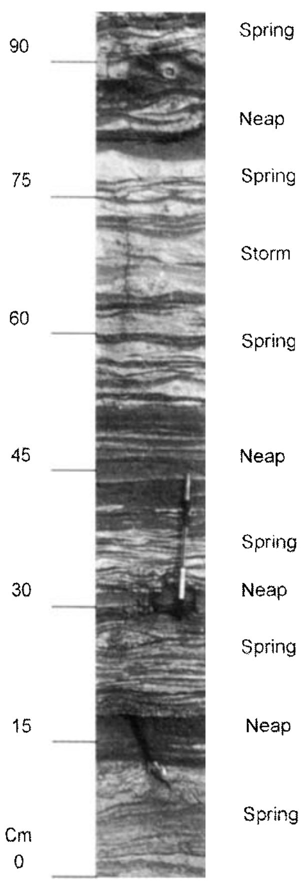


Fig. 11. Periodic vertical variation in the sandstone (bright): mudstone (dark) ratio within a continuous succession of lithofacies 1 suggesting spring-neap-spring tidal cycles.

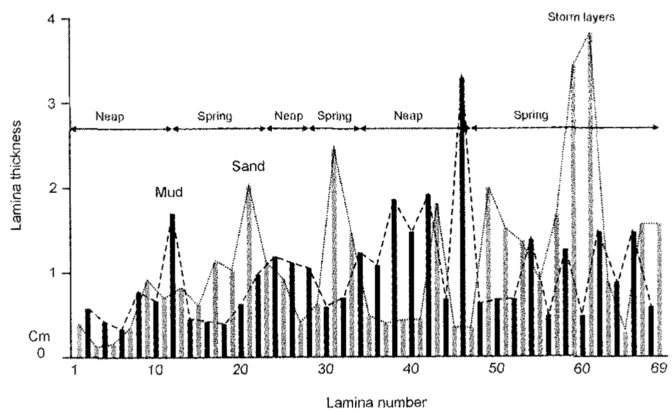


Fig. 12. Lamina-thickness plots from a continuous succession of lithofacies 1 revealing alternate sandstone- and mudstone-dominated intervals. Note also periodic thickness variation of the sandstone as well as mudstone laminae and that the crests of the sandstone curve (dotted line) coincide with the troughs of the mudstone curve (dashed line). Number of sandstone-mudstone couplets within two successive sandstone- and mudstone-dominated (or vice versa) intervals are found to be around 12 suggesting spring-neap-spring tidal cycles. Anomalously thick sandstone layers are probably storm deposits.

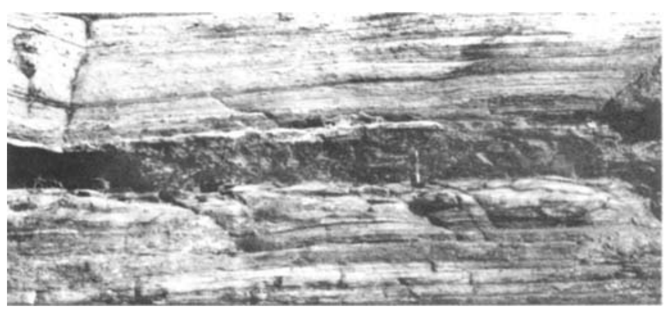

Fig. 13. Parallel-laminated sandstone bodies of lithofacies 2 with an intervening coal layer (dark). The pen is 15 cm long. Photograph was taken from the interval shown in figure 4.

sediments along with plant debris in a marsh environment. Thick coals presumably developed in low-lying, peat mires that used to remain starved of siliciclastic input for a considerable period and sustain accumulation of vegetal matter, but suffered episodic burial by siliciclastics that led to transformation of the organic debris into coal. Occurrence of this facies in association with tidal-flat deposits (facies 1 and 2; Fig. 4) suggests a supratidal marsh enviroment.

## Discussion

Recognition of tidal signatures within a continental succession has manifold significance: (1) tidal deposits are unambiguous evidence of marine influence, in contrast to wave-influenced deposits which may also form in exclusively continental domains (e.g., lakes and fluvial flood basins); (2) it enables reconstruction of the broader paleogeography of the basin revealing the transition between alluvial and marine domains (Dalrymple et al., 1992; Kvale and Barnhill, 1994), as well as estimation of the inland extent of the tidal influence in ancient settings; and (3) it facilitates chronostratigraphic correlation between marine and alluvial strata leading to a proper sequence stratigraphic interpretation of the continental succession (Shanley et al., 1992).

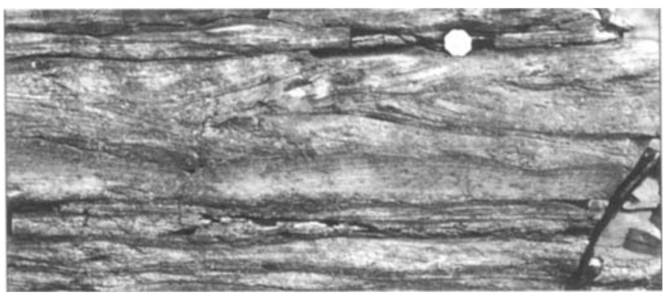

Fig. 14. A wavy-bedded sandstone body of lithofacies 2 displaying undulatory parallel-lamination (middle part) that gives way to cross-laminated sets with variable foreset orientations. Coin diameter - 2 cm. Photograph was taken from the interval shown in figure 4.

Fig. 15. A wavy-bedded, cross-laminated sandstone body of lithofacies 2 displaying: (a) swollen lens-like sets, (b) bundled and chevron upbuilding of laminae, (c) draping and offshooting laminae, (d) scour-and-drape feature and (e) opposite foreset orientations. Coin diameter - 2.5 cm. Photograph was taken from the interval shown in figure 4.

The Barakar Formation of the Satpura basin including that of the other Gondwana basins is traditionally considered to be of alluvial origin (Veevers and Tewari, 1995). There are indeed fluvial deposits within the Barakar succession of the Satpura basin represented by several meters thick, coarse-grained, multistoreyed, sheet sandstone bodies that are thoroughly cross-stratified displaying unidirectional, angle-of-repose, 0.5 to 1.5 m thick, trough and planar cross-sets (see Ray and Chakraborty, 2002; Fig. 3). However, the foregoing description of the mudstone-dominated lithological intervals occurring in association with the coarse-grained, fluvial sandstone bodies (Fig. 3) clearly reveals operation of tidal current implying marine influence. There are also meter-scale, fine- to medium-grained sandstone bodies that interdigitate with the fluvial and tidal-flat deposits (Fig. 3) displaying hummocky, swaley cross-stratifications, cross-stratified bundles with mud drapes and herringbone cross-stratification (Ghosh, 2003). Presence of herringbone cross-stratification is indicative of tidal current. Cyclic occurrences of bundles of clay-draped foresets also suggest fluctuating flows of tidal periodicity (Boersma, 1969; Terwindt, 1981; Shanley et al., 1992; Yang and Nio, 1985; Nio and Yang, 1991). On the other hand, hummocky and swaley cross-stratifications indicate storm-induced flows. This association of sedimentary structures thus points towards a tide-storm interactive subtidal, shoreface setting for the deposition of the fine- to medium-grained sandstone bodies.

It, therefore, follows that an entirely alluvial condition cannot be invoked for the coal-bearing Barakar Formation of the Satpura basin. Available evidence favours for a transitional marine depositional setting characterized by coeval fluvial, marginal marine and shoreface environments. The trends of ripples (Fig. 16) measured from the tidal-flat facies association indicate a roughly E-W shoreline. Paleocurrent data of the fluvial deposits reveal northerly river flow (Fig. 16), with some small petals in the rose indicating southerly flow and suggesting tidal influence. The shoreface strata reveal prominent bi-polarity roughly along the N-S line (Fig. 16).

The detailed paleogeographic reconstruction of the Barakar depositional regime for the whole Satpura basin is out of the context of the present paper and will be presented in a separate publication. However, the stacking pattern of the fluvial, tidal-flat and shoreface deposits in the Barakar successions depicts a number of progradational cycles (Fig. 3) and points towards a wave and tide-influenced, fluvio-deltaic environment for the deposition of the Barakar Formation instead of an estuarine condition (cf. Shanmugam et al., 2000). The upper part of the underlying Talchir succession is represented by shallow-marine deposits and in the Satpura basin the Talchir-Barakar transition appears to be continuous (Ghosh, 2003). Beds containing marine fossils have been identified within the Talchir Formation at several localities along the Son and Damodar valley as well as from the Satpura basin (Ghosh, 2003) indicating an early Permian marine incursion in the form of a seaway following a relative sea level rise (cf. Veevers and Tewari, 1995). Presumably, the Barakar fluvio-deltaic regime was established as the rate of sediment supply exceeded the rate of relative sea level rise. Lower Gondwana deposits also occur in the eastern Himalayan region (Krishnan, 1982). It thus seems that the marine regime during the late Talchir-Barakar period represented kind of a strait along the ENE-WSW elongate Narmada-Son-Damodar valley connected with the Tethys in the east (cf. De, 1996, Ghosh, 2003).

## Conclusions

The major conclusions of the present study are as follows:

(1) The Barakar coal measures of the Mohpani coalfield, Satpura Gondwana basin contain strata bearing imprints of sedimentation under the influence of wave and tide as has recently been documented from several other coal-bearing successions of the world.

(2) The wave/tide-influenced strata described here show rhythmic interlayering of sandstone and claystone resembling flaser, wavy and lenticular bedding, as well as pinstripe stratification. The tidal influence on the origin of these rhythmites is indicated by the cyclic occurrence of sandstone-dominated and mudstone-dominated intervals reflective of the lunar orbital cycle, which causes a neap (low) and a spring (high) tide with an interval of 14.75 days. Presence of desiccation cracks implies a tidal-flat environment.

(3) The overall paleogeography appears to be transitional marine instead of alluvial as was considered previously. The paleocurrent data indicate a roughly E-W shoreline and northward fluvial transport.

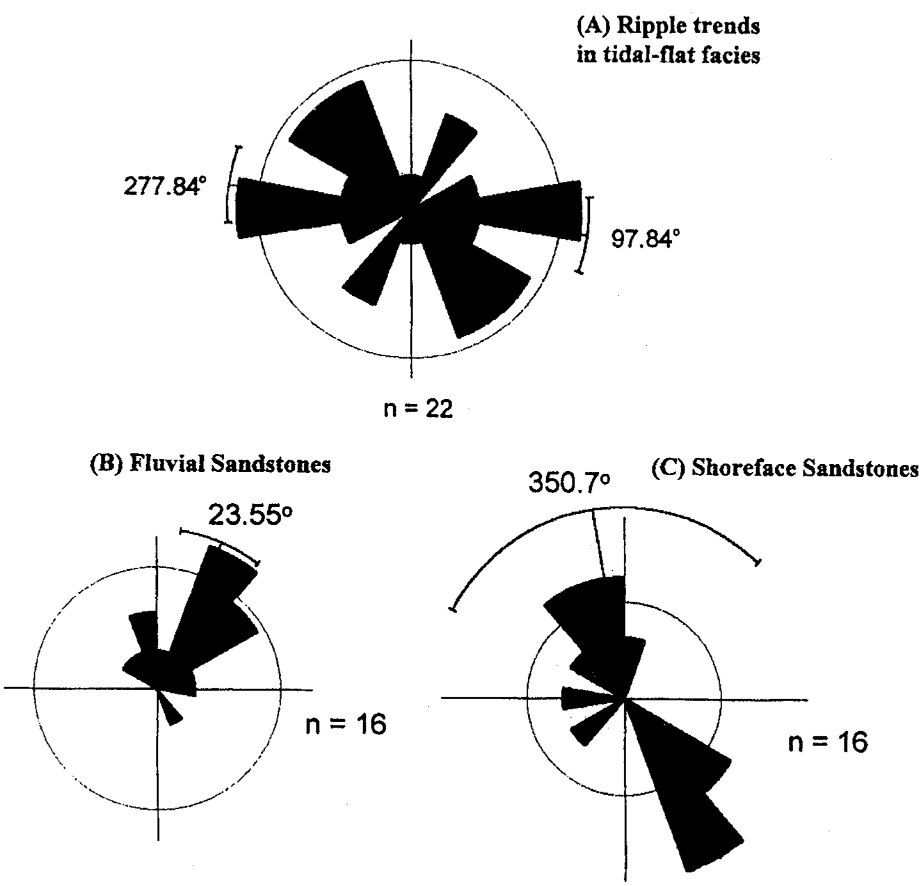


Fig. 16. Trends of ripples in the tidal-flat facies (A) Paleocurrents of the fluvial (B) and shoreface (C) sandstone bodies are also shown. Note distinct bi-polarity in the shoreface paleocurrents and orthogonal relationship of fluvial and shoreface paleocurrents with the mean ripple trend.

(4) The deposition of the Barakar Formation was presumably associated with an ENE-WNW trending embayment connected with the Tethys in the east.

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