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Research paper

Record of Permian Tethyan transgression in eastern India: A reappraisal of the Barren Measures Formation, West Bokaro Coalfield

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A B S T R A C T

The Barren Measures Formation (middle Permian, ~271–260 Ma), the non-coaliferous lithounit sandwitched between two major coal-bearing formations in the Indian Lower Gondwana succession, was earlier interpreted as continental fluvio-lacustrine deposits. The present contribution documents sedimentary attributes of marginal marine tide–wave interference from the Barren Measures Formation of eastern peninsular India, exposed along the Bokaro River section, West Bokaro Coalfield, Jharkhand. Tidalites, including various tidal bundle sequences with frequent reactivation surfaces (velocity asymmetry) and single/double mud drapes (pause planes), systematic arrangement of tidal beddings (flaser, wavy, lenticular) and tidal rhythmites with alternate sand-dominated and mud-dominated plane-laminated units, manifest sedimentation by open marine spring–neap–spring tidal cycles under diurnal inequalities in a semi-diurnal tidal system. The architecture of tidalites attests to sedimentation in shallow subtidal to intertidal flat facies, affected by intermittent strong to week reworking by open marine waves/storms. Wave reworking is manifested by wave ripples, combined-flow ripples and wave-generated tidal bundles. Their coexistence and gradation with tidalites indicate low-energy wave/storm interference with tidal currents in a sheltered, tide-dominated estuary, especially on tidal flats along estuary channel banks. Overall fining-up facies sequence, upward increase of prodeltaic mud over tide–wave led sediments, signify a sustained transgressive phase onlaping the estuary system in eastern peninsular India during middle Permian (Guadalupian).

1. Introduction

The Gondwana Supergroup (late Carboniferous – early Cretaceous) in India is well known for thick continental fluviatile sedimentary succession with economically exploitable coal-seams and rich fossil flora and fauna (Vaidyanadhan and Ramakrishnan, 2010). In peninsular India, the dominant coal-bearing lithounits are the Barakar Formation (early Permian) and the Raniganj Formation (late Permian) within the Lower Gondwana succession, commonly forming very thick sedimentary successions in the eastern Indian Gondwana basins. The West Bokaro Coalfield manifests similar characteristics. Many researchers evaluated the sedimentation pattern of these coal-bearing deposits and their tectono-climatic conditions (Fox, 1931, 1934; Sen, 1967; Casshyap, 1970, 1973, 1979; Raja Rao, 1987; Casshyap and Tewari, 1988; Chandra, 1992; Bandhyopadhyay, 1996; Mukhopadhyay, 1996; Tewari, 1998; Dutt and Mukhopadhyay, 2001; Mukhopadhyay et al., 2010; Bhattacharya et al., 2012, and many others). In comparison, the Barren Measures Formation (middle Permian), a distinct lithounit sandwitched between the Barakar and Raniganj Formations, remained neglected, possibly due to the simple fact that this lithounit is completely devoid of coal reserves. The paleoenvironmental–paleoclimatic attributes of the Barren Measures Formation remained unexplored and unassigned for long, apart from few isolated, sketchy documentations (Sengupta et al., 1979; Mukhopadhyay, 1984; Srivastava and Tewari, 2001; Dasgupta, 2005; Hota and Das, 2010; Mukhopadhyay et al., 2010). The researchers found drastic change from coal-depositing to non-coal depositing setup, commonly attributed to climatic conditions within a predominant fluviatile/lacustrine depositional realm. Marine influence was recognised from the occurrence of bryozoa and foraminifera, high content of P_2O_5 and Chamosite, and occurrence of isolated wave generated sedimentary structures, like hummocky cross strata, and extensive burrowing of *Skolithos* and *Cruziana*

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ichnofacies (Bose and Sengupta, 1993; Sengupta et al., 1996; Dutt and Mukhopadhyay, 2001; Mukhopadhyay et al., 2010). Untill today these interpretations are ambiguous and debatable due to lack of appropriate supporting evidences including detailed sedimentary facies architectures and ichnofabrics (Bose and Sengupta, 1993; Mukhopadhyay et al., 2010). So, the Barren Measures Formation should be treated more holistically in terms of sedimentological–paleontological–paleogeographic attributes as this lithounit can potentially provide some intermittent missing links between the coal–noncoal–coal transitions during Lower Gondwana sedimentation in peninsular India. Such attempts will definitely add new insights in the understanding of the tectono-sedimentary evolution of the Gondwana Basins during the middle Permian time. Well exposed, undeformed and unmetamorphosed, siliciclastic sedimentary rocks of the Barren Measures Formation along the Bokaro River section in West Bokaro Basin, Jharkhand, eastern peninsular India, provide a good scope for such study.

Apart from fossil records, tidal- and wave-generated sedimentary attributes are considered most conclusive signatures of marine sedimentation in modern and ancient records (Reading, 1996; Mazumder and Arima, 2005; Dalrymple, 2010; Davis and Dalrymple, 2011; Fan, 2013; Bhattacharya and Jha, 2014; Bhattacharya et al., 2015, and many others). The present contribution is the first documentation of definite signatures of marine tide–wave influences within the Barren Measures Formation in peninsular India, establishing a significant landward incursion of the Tethyan strandline onto the Indian plate during the middle Permian.

2. Stratigraphy and sedimentology of the study area

Thick sedimentary succession of the Gondwana Supergroup (late Carboniferous to early Cretaceous) in peninsular India is known for varied litho-associations, fossil abundances and presence of coal. Exposures of these sedimentary rocks are available in some isolated coalfields, which are aligned along three major river valley basins, namely: a) E–W trending Son-Damodar Valley lineament, b) NW–SE trending Mahanadi Valley lineament and c) NW–SE trending Pranhita-Godavari Valley lineament (Vaidyanadhan and Ramakrishnan, 2010), all converging to meet in the Satpura region in the central part of India (Fig. 1A). The West Bokaro Coalfield in Damodar Valley bears ~1500 m thick, well preserved Lower Gondwana succession, represented by glacio-marine Talchir Formation (late Carboniferous-early Permian) at the base, followed successively by alluvial fan–fluvial Karharbari Formation (early Permian), coal-bearing fluvio-marine Barakar Formation (early Permian), fluvio-lacustrine Barren Measures Formation (middle Permian) and coal-bearing fluviatile Raniganj Formation (late Permian) (Vaidyanadhan and Ramakrishnan, 2010; also see, Bhattacharya et al., 2005). These sedimentary rocks directly overlie the Precambrian gneissic basement with faulted contact along the northern basin margin and unconformably overlie the basement along the southern basin margin. Detailed lithostratigraphy of the coalfield is depicted in Table 1.

The rocks of the Barren Measures Formation, exposed dominantly in major river sections of the coalfield, viz., Chotha Nala, Bokaro River, Chutua Nala, etc., are represented by thick sequence of grey micaceous shale and carbonaceous shale alternating with cross-bedded fine to medium grained, compact ferruginous and/or siliceous sandstones. The present study was carried out on the rocks of the lower-middle part of the sedimentary succession in Barren Measures Formation, excellently exposed along the northern banks of the Bokaro River (see Figs. 1 and 2). The rocks rest directly on the trough cross-stratified sandstone of the Barakar Formation (Fig. 3B). In some places, along the river section, the contact is demarcated by multiple close-spaced normal faults.

Sedimentologically, the studied Barren Measures succession (~125 m vertical thickness, Fig. 2) is represented by vertical arrangement of alternately appearing five distinct facies types. The thick-bedded trough cross-stratified sandstone facies (Figs. 3C and 4) is characterized by thick, amalgamated sandstone beds with large trough cross-strata, and is exposed at certain intervals within the succession. The thinly-bedded sandstone–mudstone heterolithic facies (Fig. 3A–C) is the predominant facies type, characterized by alternation of thick/thin beds of sandstone–mudstone with abundant tide-generated and wave-modified depositional features. The wave rippled sandstone facies is often closely associated with the sandstone–mudstone beds of the heterolithic facies, and is relatively restricted in its occurrence. A massive red sandstone facies (Fig. 3D), characterised by relatively thin bedded, massive sandstone, alternates with thick shale facies in the upper part of the studied succession. The massive to laminated nodular shale facies (Fig. 3A–D), one of the predominant facies occurring throughout the succession, is characterized by thick-bedded carbonaceous shale. The overall facies architecture with distribution of different facies types is depicted in Figure 2. It manifests increasing mud content towards the top, leading to an overall fining-upward succession. Tide- and wave-generated stratification architectures are well preserved within the lower-middle part of the studied succession and are described in the following sections.

3. Architecture of tidal sedimentation

Tidalites, the tidally-generated sedimentary units, include laterally-accreted and sigmoidal strata bundles (tidal bundles), and cm- to mm-thick, vertically-accreted, near-planar sand-/mud-dominated heteroliths (tidal rhythmites). In the study section, tidal sedimentation is portrayed in four dominant variations.

3.1. *Type-1 tidalites (Fig. 4)*

Large strata bundles (20–30 cm vertical thickness, length 55–125 cm), characterised by mud-draped sandstone foresets with variable foreset thickness, are developed in thick-bedded, trough cross-stratified sandstone facies. Within sandstone beds, multiple strata bundles are vertically amalgamated. Foresets are characterized by double mud drapes in both transverse and longitudinal sections. Bundles manifest lateral accretion with frequent down-current change in inclination and thickness of foresets against prominent reactivation surfaces. Within individual strata set, sandstone foreset type laterally changes from truncating tabular to concave up, and/or sigmoidal through mud-draped reactivation surfaces.

3.2. *Type-2 tidalites (Fig. 5)*

Smaller tidal bundles (vertical thickness 5–12 cm), represented by cm- to mm-thick sandstone/siltstone foresets with mud drapes, occur in sandstone beds of the sandstone–mudstone heterolithic facies. Climbing ripple cross-laminae are abundantly present with overall upward decrease in grain size and foreset thickness. Lateral accretion of strata bundles is common, manifested by change in thickness and/or inclination of the sandy foresets against frequent reactivation surfaces or mud drapes. Several such strata bundles are often amalgamated vertically with or without sediment veneers. Bidirectional strata bundles in adjacent sets are common. Mud drapes often cover the complete strata bundle and separate it from adjacent bundles, both vertically and laterally. Flaring of sandy foresets within mud near the toe region of the strata set is common, often leading to intermittent mud partings in between the strata bundles.