Facies characteristics of the basal part of the Talchir Formation, Talchir Basin, India – depositional history revisited

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The lowest unit of the Talchir Formation of Talchir Basin, Orissa, was described by pioneer workers as the 'basal boulder bed'. In an attempt to explain the co-existence of gravel and clay, materials of contrasting hydraulic properties, a probable situation resembling the effects of the action of ground-ice enabled boulders to be carried down by sluggish currents resulting in an intermixture of large boulders and fine mud was conceived. Misinterpretation of this conclusion led to a general tendency to describe the 'basal boulder bed' as 'glacial tillite'. However, the unit described as 'basal boulder bed' is actually represented by a matrix rich conglomerate with pockets of normally graded silty clay. The present study reveals that the depositional imprints preserved in this part of the sedimentary succession indicate emplacement of successive debris flows generated through remobilization of pre-existing unconsolidated sediments. Small pockets of fine-grained turbidites presumably deposited from the entrained turbidity currents associated with the debris flows suggest the composite character of the debris flow deposit.

1. Introduction

The onset of Gondwana sedimentation marked the end of a long period of non-deposition that prevailed in peninsular India from late Proterozoic to upper Paleozoic, and hence is considered as one of the significant geological events of this part of the globe. The Talchir Formation, being the lowest unit of this upper Paleozoic sedimentary succession, thus deserves special attention for a proper understanding of the Paleozoic geological history of the Indian subcontinent.

Blanford *et al* (1856) were first to describe the Gondwana succession of the Talchir Basin, Orissa and designated its lower part as the Talchir Group of rocks. Since then its lithological equivalents encountered at the lowest levels of all Gondwana basin-fills in India have been identified as Talchir deposits with the status of 'formation' in present day lithostratigraphic classification (Sastry *et al*

1977). The Talchir Formation of different Gondwana basins has been widely studied by generations of workers and a wide spectrum of views regarding the depositional setting have been expressed in the literature. A literature survey reveals that the pioneering contribution of Blanford *et al* (1856) is often cited in favour of the glacial origin of the lower part of Talchir succession (Sastry *et al* 1977). The Talchir Formation of the Talchir Basin was subsequently classified into three informal units (Pandya 1990; Maejima *et al* 1999). A critical review of the classification described by Maejima *et al* (1999, p. 105) reveals that in the original proposal Pandya (1990) either classified the Talchir succession excluding the basal *glacial tillite* or the same unit (Facies A, Pandya 1990) was interpreted as of fluvial origin. However, according to Maejima *et al* (1999), the lowest unit of that proposed classification starts with glacial tillite, which gradually passes upward into fluvial sediments.

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The other two units were attributed to lacustrine regime. Maejima *et al* (1999) did not furnish any descriptive parameter for the 'glacial tillite' and cited the work of Blanford *et al* (1856) in support of their interpretation. Maejima *et al* (2004) described the lowermost part of the Talchir succession as of glacial origin. Surprisingly, no unequivocal evidence in favour of such an interpretation was furnished. Marked mismatch in thickness between the lithologs (Maejima *et al* 2004, figures 3, 4 and 5) and the radical difference between the general successions illustrated by figure 4 in Maejima *et al* (1999) and figure 3 in Maejima *et al* (2004) made the whole thing more confusing. In support of the interpretation it was reiterated (Maejima *et al* 2004, p. 341) that the idea of glacial origin for these sediments was introduced by Blanford *et al* (1856). But a careful analysis of the inferences drawn by Blanford *et al* (1856) reveals a different picture.

Blanford *et al* (1856) made an attempt to explain the co-existence of boulder and fine mud within the 'basal boulder bed' and analyzed different possibilities (Blanford *et al* 1856, p. 49–56) for the simultaneous deposition of the materials of contrasting hydraulic properties. Finally, a probable situation very similar to the effects of the action of ground-ice that enabled boulders to be carried down by sluggish currents and produced an intermixture of large boulders and fine mud was postulated (Blanford *et al* 1856, p. 49). Simultaneously the possibility of transport by true glaciers was strongly ruled out (Blanford *et al* 1856, p. 50). Hence, the idea of a pure glacial origin of the lower part of Talchir succession of Talchir Basin and identification of the 'basal boulder bed' described by Blanford *et al* (1856) as tillite do not have any strong foundation, and the sediments deserve re-examination for the decipherment of the actual depositional mechanisms involved. This is of great significance to work out the actual time relation between Permo-Carboniferous glaciation and origin of intracratonic Gondwana basins, two important events in Palaeozoic history of peninsular India. The present work aims at the detailed study of the so-called 'basal boulder bed' with a view to expound the depositional history. This understanding has an important bearing on the reconstruction of the tectonosedimentary history of the initial phase of Gondwana sedimentation in peninsular India.

2. Geological setting

The Talchir Basin is the eastern-most member of the Gondwana basins of Mahanadi Valley (figure 1). It is a NW–SE trending elongated basin

amidst Archean rocks and lies between latitudes 20°45'N and 21°20'N and longitudes 84°32'E and 85°32'E. In this basin, the lower Gondwana succession, overlying the Archean basement, starts with the Talchir Formation (lower Permian). This is followed successively upward by the Karharbari, Barakar and Kamthi formations (Blanford *et al* 1856; Raja Rao 1982; Pandya 1990; Maejima *et al* 1999) (figure 1). The 'basal boulder bed' (as described by Blanford *et al* 1856) under study constitutes the lowest part of the Talchir Formation and is exposed along the Nandir Jhor and its tributary streams in the south-southeastern part and partly in the Tikra river in the northern part of the basin (figure 1).

3. The 'basal boulder bed'

3.1 Description

The lower part of the Talchir Formation is mainly represented by a matrix-rich conglomerate-shale succession with relatively minor amount of sandstone. As mentioned earlier, Blanford *et al* (1856) described the lowest unit of this succession as the 'basal boulder bed', which is best exposed along the Poipani (a tributary of Nandir Jhor) section (figure 1). The 'basal boulder bed', resting on the Archean basement gneiss, attains a thickness of about 9 meters and is conformably overlain by 16 meters of thick gray shale with a sharp contact. The 'basal boulder bed' is represented by matrix-rich conglomerate (matrix content is about 60–70% by volume of the whole rock) with very poorly sorted gravel fraction randomly distributed within clay-rich matrix material (figure 2A). Gravel fraction ranges in size from large boulder to granule, with modal value around coarse pebble to fine cobble. The largest boulder measures 67 cm in diameter. Boulders are sub-angular (in the lower part) to well rounded (in the middle and the upper part) and the other members of the gravel fraction are sub-rounded to rounded. Fragments of amphibole gneiss and quartzite constitute the main bulk of the gravel population. The presence of upright cobbles and boulders characterizes this conglomerate. In the lower part, occasionally, the elongate boulders show an alignment apparently subparallel to the depositional surface (figure 2A). The most significant feature is the presence of a lenticular pocket (about 1 meter thick and 15 meters wide) of graded silty clay within this matrix-rich conglomerate (figure 2A, B). The basal contact of this pocket is gradational with the conglomerate while it shows truncation relation with the same conglomerate at the top. The silty clay layers gradually pinches out towards north while towards south the bedding

Figure 1. Geological map of the Talchir Basin, India (after Raja Rao 1982).

Figure 2. (A) Matrix-rich conglomerate with pockets of graded silty clay. Variation in the orientation of the long axes of the gravels with reference to the depositional surface is noteworthy. Some members of the gravel fraction are in upright position (marked ‘U’) while some others are parallel to the depositional surface (marked ‘P’), bending of the graded silty clay due to the shearing effect of the over-riding conglomerate is apparent (the hammer is 32 cm long). (B) Close-up view of the graded silty clay. The arrow shows load structure at the clay-silt interface (the scale is 8 cm long). (C) Bitmap images of graded silty clay. The rectangular area is enlarged to show the graded character. The two specimens show variation in the degree of penecontemporaneous deformation at the silt-clay interface.

planes suffered an upward bending and finally truncated against the host conglomerate (figure 2A). In the lower part of the unit, the graded layers are about 10 to 15 mm thick and are characteristically silt-rich. The thickness of these graded-layers gradually increases upward and attains a maximum

value of about 4 cm with simultaneous increase in the proportion of clay. In the lower part, the interface between the silt-rich and the clay-rich parts of successive layers suffered penecontemporaneous deformation, as is evident from the well-developed load structures and layer contortions (figure 2C).

3.2 Interpretation

Absence of any unequivocal signature of glacial origin and dominance of rounded gravel within this matrix-rich conglomerate go against the interpretation of glacial tillite. Remobilization of the pre-existing sediments in bringing about the present conglomerate appears more plausible. The overall massive character and chaotic distribution of gravel fraction floating within clay-rich matrix indicate deposition of this conglomerate possibly from cohesive debris flow. Presence of upright cobbles and boulders are suggestive of the thixotropic nature of the flow.

Abrupt freezing of a single debris flow is difficult to be conceived as the mechanism to bring a thick deposit into existence. The thick debris flow deposits are generally considered as the product of deposition from incremental aggradation of a number of surges (Davies 1986, 1990; Major 1997; Sohn *et al* 1999). Deposit of the earlier surge does not normally consolidate before emplacement of the later one and the single massive layer results through amalgamation of successive surges. Apparent alignment of a few elongate clasts parallel to the depositional surface can be attributed to the high rate of laminar shear straining of individual surges (Fisher 1971; Enos 1977) associated with spreading or extensional deformation during emplacement and subsequent smearing by later surges before the deposit of earlier surges consolidated. The cumulative deposit thickness thus greatly exceeded the average flow thickness.

In the lensoid pocket, embedded within the conglomerate, distribution type normal grading observed within the silty-clay layers indicates in-flow differentiation of grains, likely to take place within turbidity currents as demonstrated by Middleton (1966a, 1966b, 1967). Appearance of load cast and contorted layers suggests rapid sedimentation before minimum compaction of the clay material of the earlier deposit. So influx of turbulent surges in quick succession can be inferred. Gradual decrease in the proportion of silt and simultaneous increase in clay content towards the top of the unit further suggests gradual decrease in the energy condition of successive turbulent surges. The turbidity currents were probably generated at the interface between the debris flow

Figure 3. Schematic diagram showing the inferred stages of development of the pockets of graded silty clay within conglomerate. (A) and (B) depict gradual progression of a debris flow with entrained turbidity current. (C) The next influx of debris flow set in after deposition from the earlier phase of debris flow and the associated turbidity current. (D) During emplacement of the debris flow over the earlier fine-grained turbidites, the latter underwent ductile deformation due to the shearing effect of the denser debris flow.

and the ambient water due to frictional drag during emplacement of the former (entrained turbidity current) (Nemec 1990; Dasgupta 2003). The experimental observations of Felix and Peakall (2006) also go in favour of such processes of generation of turbidity currents from debris flow. After the deposition from the debris flow, the entrained turbidity current proceeded further and deposition took place beyond the snout of the debris flow deposit (figure 3). The upper part of the turbidite deposit was dragged during emplacement of the next debris flow, which caused bending and finally truncation of the silty clay layers due to shearing. Hence, presence of the lensoid turbidite pocket of graded silty clay within the matrix-rich conglomerate goes in favour of the origin of host sediments through amalgamation of deposits from successive debris flow surges. Mulder and Alexander (2001) described a similar deposit from northwest Mediterranean Sea as spillover turbidite deposit. Talling *et al* (2004) described co-genetic debrite-turbidite successions from three widespread successions of variable age: Miocene Marnoso Arenacea Formation in the Italian Apennines, Silurian Aberystwyth Grits in Wales, and Quaternary deposits of the Agadir Basin, offshore Morocco. Detailed study of the anatomy of turbidites and linked debrites from the Marnoso Arenacea Formation, northern Apennines, Italy led Amy and Talling (2006) to conclude that

a single subaqueous flow event can comprise multiple flow phases and deposit a bed with complex lateral changes between mud-rich and mud-poor sandstone.

4. Discussion

The depositional imprints preserved in the lower part of the Talchir Formation of the Talchir Basin indicate that within this basin the Gondwana sedimentation was initiated through emplacement of successive debris flows. Remobilization of the pre-existing unconsolidated sediments possibly led to the deposition of the debris flow conglomerate. Small pockets of fine-grained turbidites presumably deposited from the entrained turbidity currents associated with the debris flows suggest the composite character of the debris flow deposit.

Deposition of the lower part of the Talchir Formation through resedimentation processes has also been inferred from other Gondwana basins of peninsular India. After studying the rocks of Talchir Formation in the Damodar valley basins, Fox (1930) expressed serious reservations regarding the identification of these sediments as purely glacial deposits. Fox (1930) emphasized that although the general character of the gravel fraction indicates ultimate derivation by some moving ice sheet from a distal source, the character of the deposits lacks evidence for a primary glacial origin, and instead shows indications of reworking. Ganju and Srivastava (1959) and Niyogi (1961) also advocated the deposition of the Talchir sediments through reworking of glacial moraines. Dasgupta (2006) made a detailed study of the Talchir succession of the Jharia Basin of Damodar Valley and established a time relation between the Permo-Carboniferous glaciation, formation of Gondwana basins and the onset of Gondwana sedimentation, and evidences from other basins substantiated the view. This analysis also indicates a post-glaciation resedimentation process involved in the initiation of the Gondwana sedimentation. In the present context also remobilization of some pre-existing glacial debris in generation of the debris flows cannot be ruled out.

Hence the depositional mechanisms postulated by Blanford *et al* (1856) appear to be very close to the inferred situation. Their idea of *the probable situation resembling the effects of the action of ground-ice that enabled boulders to be carried down by sluggish currents and produced an intermixture of large boulders and fine mud* (Blanford *et al* 1856, p. 49) can be regarded as one of the pioneering contributions in the concept of debris flow.

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