Prof. Supriyo M. Sengupt
with regards,
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Fluvial–aeolian interactions in a Proterozoic alluvial plain: example from the Mancheral Quartzite, Sullavai Group, Pranhita-Godavari Valley, India

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Abstract: The coarse-grained alluvial succession of the Proterozoic Mancheral Quartzite encloses within it a few 2–6 m-thick, typically salmon red, fine-grained, very well-sorted sandstone units. Some 25–40% of the fine-grained sandstone units is aeolian — mostly adhesion laminae with subordinate adhesion cross-laminae and wind-ripple strata. The remainder of the sequence is aqueous; either massive or with faintly-developed trough cross-bedding. Based on their grain size, sorting and roundness, the bulk of the aqueous deposits appear to be reworked aeolian deposits. Thick adhesion laminated units within them show a number of superimposed drying-upwards sequences, represented by an upward decrease in laminae spacing within each of the sequences. Individual drying-upwards sequences, 5–15 cm thick, are in places bounded by disconformity surfaces marked by iron crusts.

Stratigraphic relationships with associated fluvial facies indicate that these aeolian sandstones formed in the distal part of the floodplain. An arid climate, vegetation-free landscape, quickly avulsing channel behaviour and rapid basin subsidence favoured development and preservation of these rather thick alluvial plain aeolian deposits. Fluvial dynamics, in contrast to the erg dynamics as interpreted from other interlayered aeolian–fluvial deposits, was the primary control on the depositional features and their internal organization within these aeolian sandstone units.

Much attention has been devoted in recent years to the study of the dynamics and products of interacting fluvial and aeolian systems (Sneh 1983; Langford 1989; Langford & Chan 1989; Clemmensen *et al.* 1989). However, all of these studies focus on the erg-margin situation, where an aeolian sand sea provides the background sediment and erg dynamics exert an overall control on the depositional facies and their organization. Exposed parts of the bar, sandflat or floodplain in the sand-dominant fluvial system are also commonly subjected to wind reworking during the periods of low flow (Rust 1972; Cant & Walker 1978; Bluck 1979; Tunbridge 1984; Shepherd 1987). Preservation of these aeolian deposits interlayered with the channel deposits is, however, rare and when preserved they tend to be very thin. In an arid climatic setting or in a pre-Silurian vegetation-free landscape, wind reworking of the exposed parts of the sandy, braided alluvial tracts may become significant and their products, if preserved, become a useful tool for environmental analysis.

This paper reports several well-sorted, fine-grained aeolian sandstones, 2 to more than 6 m thick, and interlayered with conglomeratic to pebbly, coarse-grained sandstones of fluvial origin, in the Proterozoic Mancheral Quartzite of the Pranhita-Godavari Valley, India. It also discusses the origin of the aeolian sandstones and attempts to focus on the dynamics of fluvial–aeolian interactions in an alluvial plain setting.

Geological setting

The Pranhita-Godavari Valley is one of the major Proterozoic basins of India which exposes two linear belts of Proterozoic rocks flanking an axial belt of Permo-Jurassic Gondwana rocks (Fig. 1). The Sullavai Group is the youngest group of the Proterozoic sequence exposed in this basin (Table 1). The Mancheral Quartzite, a constituent of the Sullavai Group, is very well exposed around Mancheral and Ramgundam in the southwestern Proterozoic belt (Fig. 1). The Quartzite unconformably overlies the rocks of the Middle Proterozoic Pakhal Group and is overlain by the Venkatpur Sandstone (Table 1). In and around Mancheral, the fluvial sequence of the Mancheral Quartzite gradationally passes upward through a transition zone of flat-bedded sabkha-playa sediments into the erg sequence of the Venkatpur Sandstone (Chakraborty 1991*a*).

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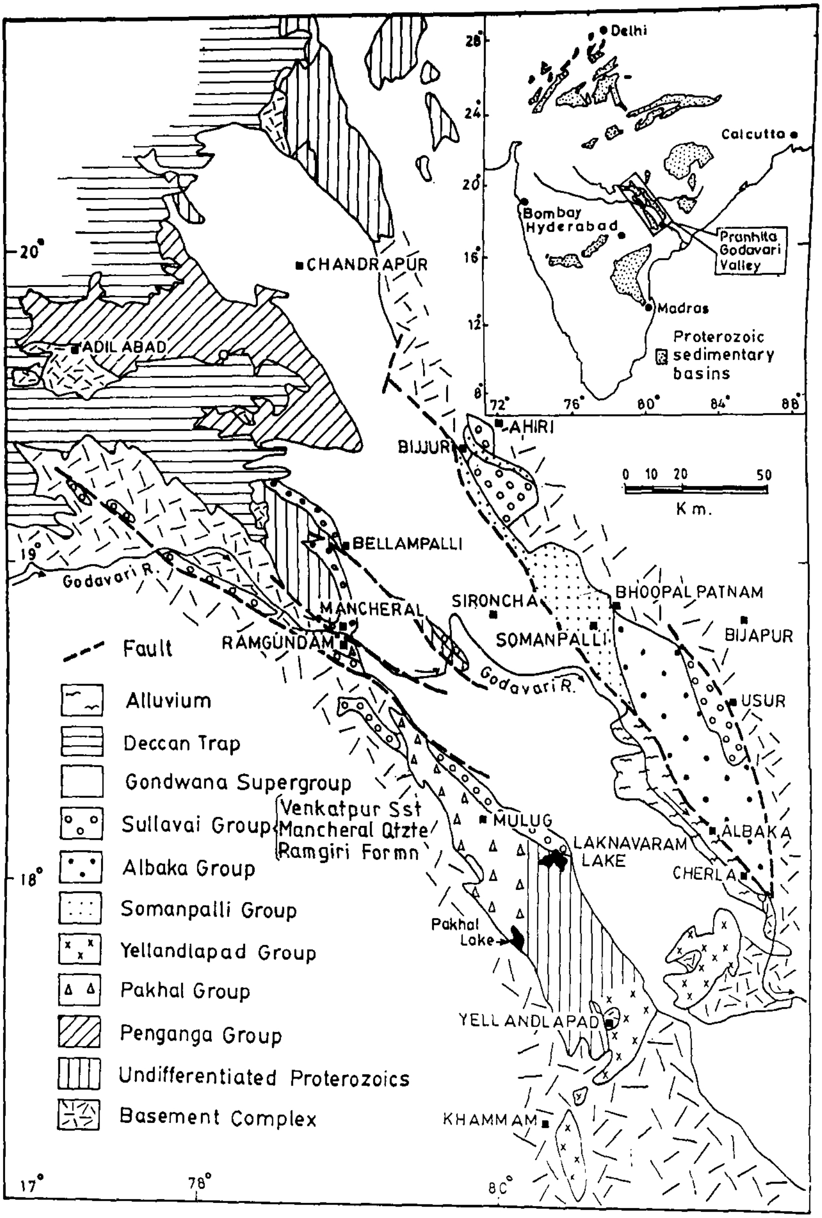

Fig. 1. Generalized geological map of the Pranhita-Godavari Valley. Inset map shows the major Proterozoic basins of India.

The Mancheral Quartzite comprises poorly-sorted, coarse-grained pebbly sandstones and minor conglomerates. Typically salmon red, fine- to very fine-grained sandstones occur at different stratigraphic levels and comprise a subordinate part of the Quartzite sequence. Several large-scale, concave-upward erosional surfaces have been recognized within the Mancheral Quartzite (Figs 2 & 3) which are overlain by fining-upwards sequences (Fig. 4). Some of these fining-upwards sequences are capped by 2–6 m thick salmon red, fine-grained sandstone units with abundant adhesion laminae. The sandstones and conglomerates of the Mancheral

Table 1. *Generalized stratigraphic sequence of the Proterozoic rocks (Sullavai Group) in the study area*

		Gondwana Supergroup (Permo-Jurassic)	*Lithology*	*Depositional environment*
		Unconformity		
P R O T E R O Z O I C	Sullavai Group (871 ± 14 Ma)	Venkatapur Sandstone (70 m)	Red, fine- to medium-grained, well-sorted sandstone with large planar cross-beds and flat beds; abundant aeolian strata.	Erg and erg-margin deposit
		Mancheral Quartzite (50 m)	Mauve to deep red, coarse-grained to pebbly sandstone and conglomerate; F–U sequences; thin fine-grained sandstone units	Braided fluvial with inter-layered aeolian units
		Ramgiri Formation (456 m)	Red, conglomerate and pebbly arkose; conglomerates reverse graded; thin sheet-like sedimentation units.	Distal alluvial fan-braided river.
		Unconformity		
	Pakhal Group/Penganga Group (1330 ± 53 Ma)			
		Unconformity		
	Archaean (?) Granite			

Fig. 2. Part of a large-scale concave-upward erosional surface in the Mancheral Quartzite. The surface sharply cuts into the thinly bedded fine-grained aeolian sandstone unit.

Quartzite are interpreted to have been deposited from high-gradient braided streams (Chakraborty 1988, 1991*b*). The broad facies recognized within the formation and their interpretation is shown in Table 2. The genesis of the salmon red, fine-grained sandstone units is discussed below.

Salmon red, fine-grained sandstones of the Mancheral Quartzite

The sandstone units consist of well-sorted and well-rounded, fine- to very fine-grained quartz sands (Fig. 5). The sandstones are generally 2–6 m thick but may attain a thickness of 12 m. The individual sandstone units are traceable along-strike for a distance of a few tens of metres to several hundreds of metres (Fig. 3). They are invariably overlain erosively by coarse-grained channel-lag conglomerates. The sandstone units either gradationally overlie or laterally intertongue with small-scale, trough cross-bedded coarse- to medium-grained sandstones (Facies IV in Table 2; Fig. 4) that are interpreted to have been deposited in the higher topographic levels of the channel complex or in the proximal part of the floodplain.

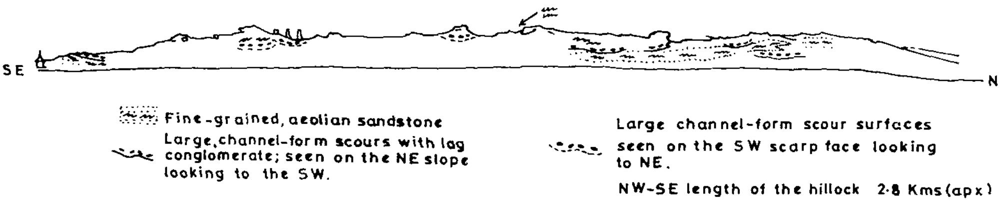

Fig. 3. Line drawing prepared from a photomosaic of the panoramic view of the Ramgundam Gutta (Hill), showing the position of several large-scale channel surfaces and the aeolian sandstone units.

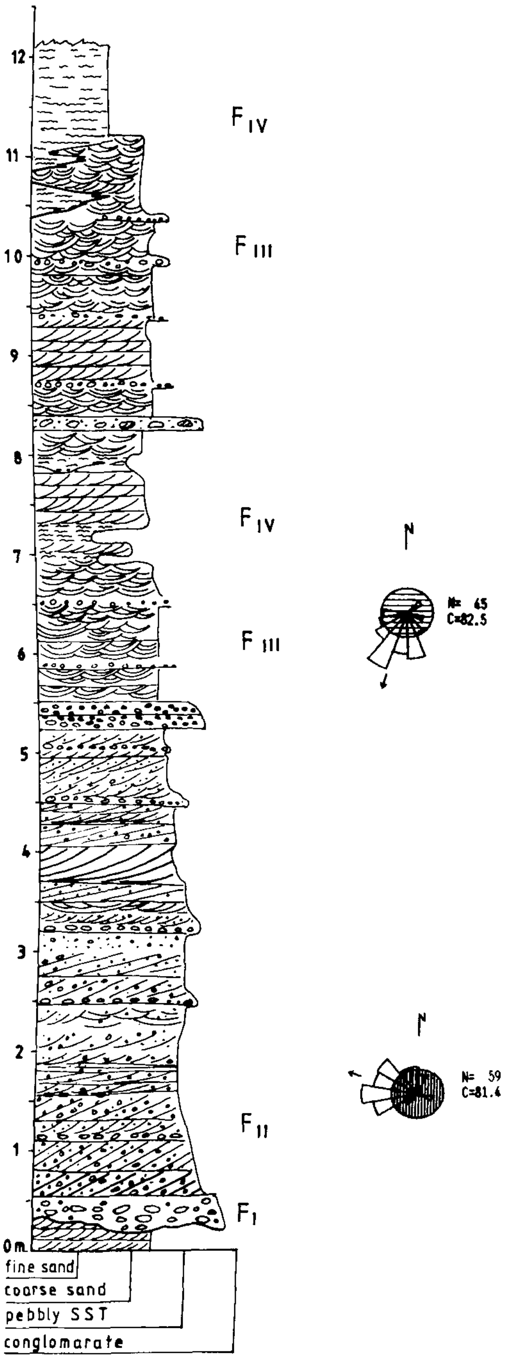

Fig. 4. Vertical log through the Mancheral Quartzite. The fining-upwards sequence is marked at the top by a fine-grained aeolian sandstone which also overlies and intertongues with a medium-scale trough cross-bedded unit (Facies IV, Table 2).

Facies

The following facies have been recognized in the salmon red, fine-grained sandstones.

Fine-grained sandstone with adhesion laminae (F1)

The well-sorted, fine-grained sandstone of this facies is characterized by well-developed adhesion plane beds (Fig. 6). The facies units are 6–8 cm thick and grade rapidly laterally or vertically into massive or faintly developed trough cross-bedded sandstone units (F4, see below). Adhesion laminae are horizontal or in places gently inclined. Individual lamina thickness varies from less than 1 mm to 3 mm.

Adhesion laminated facies show internal, low-angle, bedding-parallel discordant surfaces which bound 5–15 cm-thick packages of adhesion plane beds (Fig. 7). Adhesion plane beds within such packages show a distinct upward-thinning of the laminae (Figs 7 & 8).

The adhesion-laminated facies comprise 20–35% of the fine-grained, salmon red sandstone units of the Mancheral Quartzite and overwhelmingly dominate other types of wind-laid strata in the sequence.

Interpretation. At lower (<80%) moisture contents of the substrate, adhesion plane beds develop over adhesion ripples (Kocurek & Fielder 1982). Parallel layers of adhesion plane beds accrete vertically until the moisture content of the substrate is lowered still further to a level where adhesion structures cease to develop altogether. Low-angle discordant surfaces within the sequence of adhesion plane beds indicate minor erosion along flat surfaces. The upward reduction of the adhesion laminae thickness within packages bounded by a pair of erosion surfaces reflects upward-decreasing capillary moisture. Lesser moisture results in a lesser amount of sand trapped by the substrate and, therefore, formation of thinner adhesion plane beds. The localized deflationary surfaces which repeatedly interrupt the drying-upwards adhesion laminae sequence were probably caused by periodic sand undersaturation of the wind.

Fine-grained sandstone with adhesion cross-laminae (F2)

Climbing adhesion ripple cross-laminae generally occur in this sequence as solitary, lenticular sets (Figs 9 & 10). Set thickness varies from 2–5 cm and sets are laterally traceable for

Table 2. *Broad facies recognized within the Mancheral Quartzite*

	Facies	*Environment*
I	Poorly-sorted conglomerate and conglomeratic sandstone overlying large-scale, concave-upward erosion surfaces (Fig. 2)	In-channel coarse lag deposits
II	Complex organized co-sets of planar cross-beds and a few trough cross-beds in the coarse-grained sandstone	Medial or lateral braid bars
III	Sheet-like units of medium- to coarse-grained sandstone made up of sets or co-sets of trough cross-beds; ripples, mud cracks in places	Proximal floodplain/higher topographic levels adjacent to the main channels
IV	Very fine- to fine-grained sandstones with adhesion structures; small aqueous cross-beds, shallow channel-fills	Aeolian/reworked aeolian deposits on the highest topographic levels in the floodplain

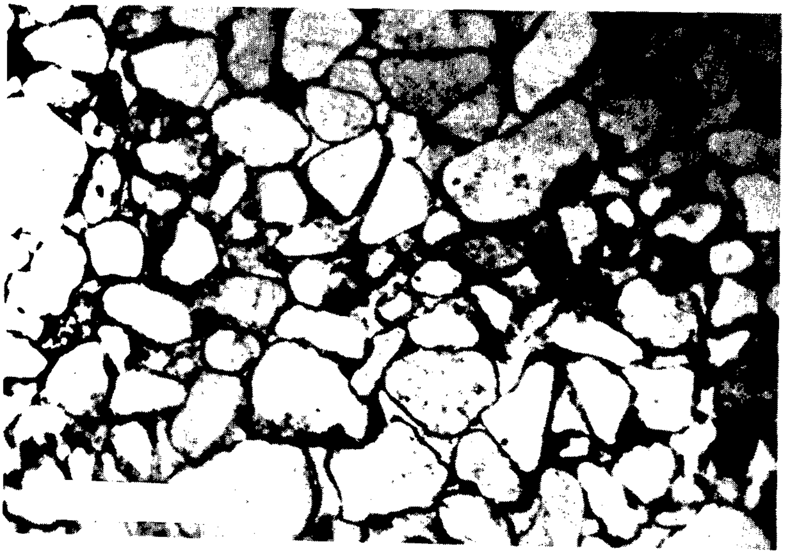

Fig. 5. Photomicrograph showing well-sorted, well-rounded sand grains of the aeolian units of the Mancheral Quartzite. Scale bar 0.25 mm.

Fig. 6. Adhesion plane beds in the fine-grained sandstone units. An aqueous cross-bed is in the central part of the photograph (A) and a water-injection feature in the lower left corner (I). Note a prominent rim of iron oxide around the water-injection feature.

Fig. 7. Sub-horizontal, parallel surfaces bounding packages of thinning-upwards adhesion plane beds. Note dark iron oxide layers mark the bounding surfaces (arrows).

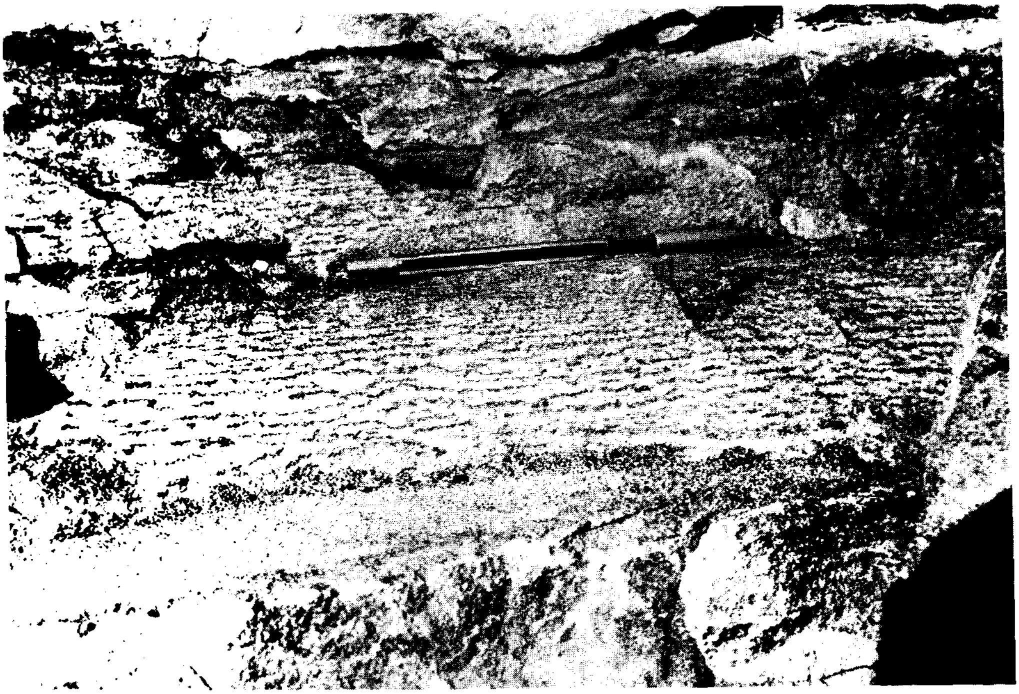

Fig. 8. Close-up view of a thinning-upwards sequence of adhesion laminae. Pen for scale.

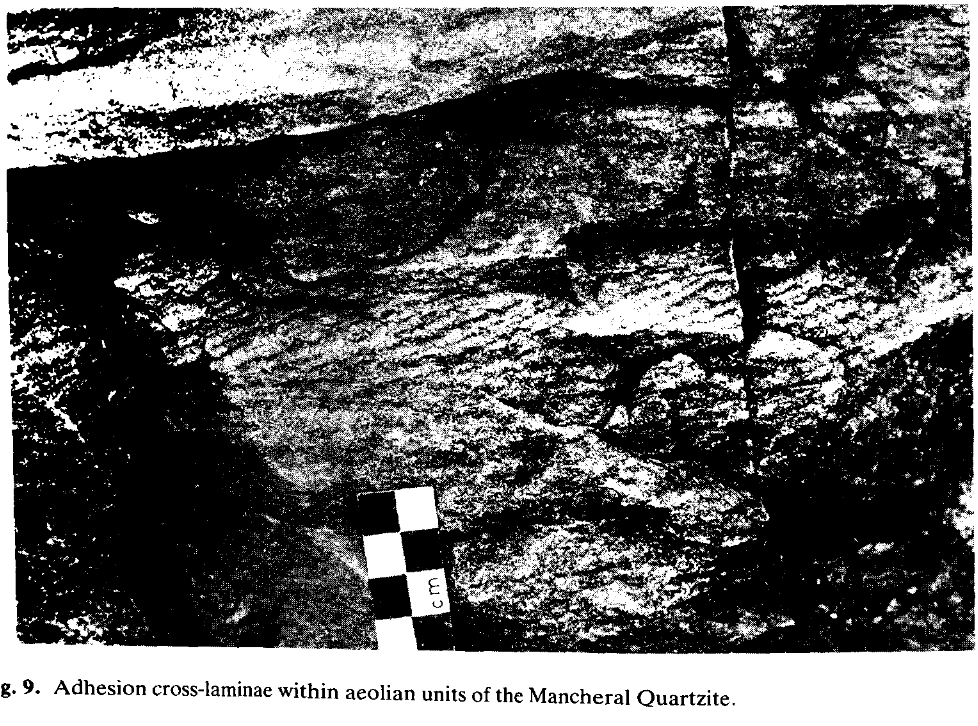

Fig. 9. Adhesion cross-laminae within aeolian units of the Mancheral Quartzite.

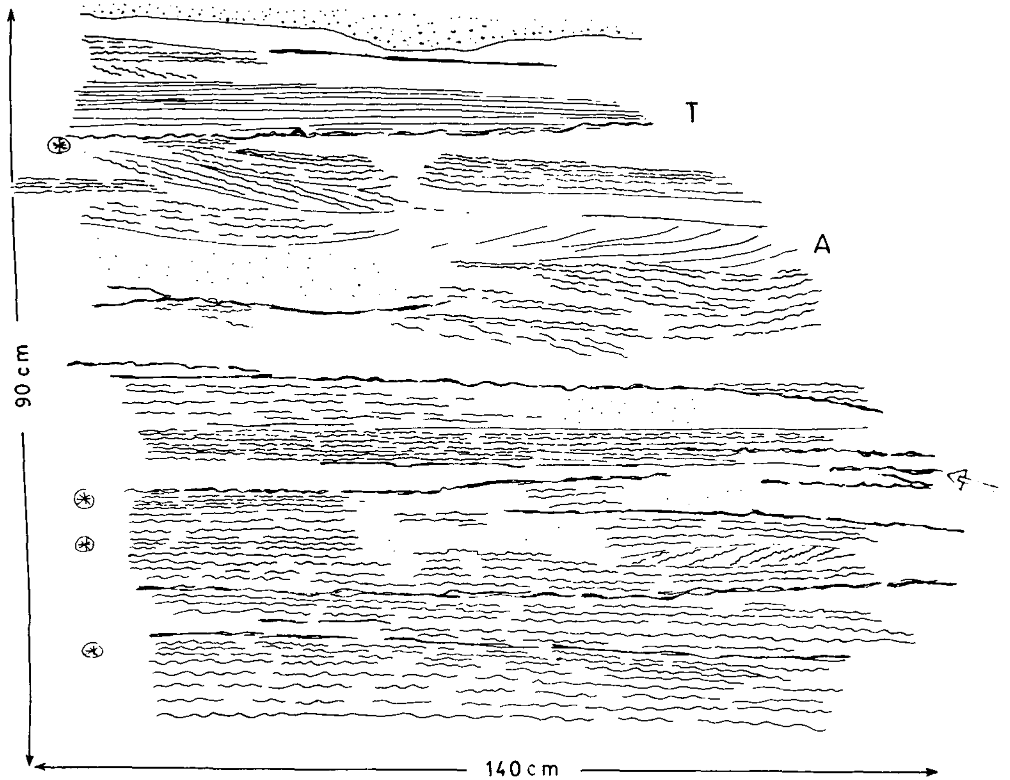

Fig. 10. Sketch showing a 90 cm-thick sequence dominated by adhesion laminae. The arrow marks the irregular iron-rich surfaces; asterisks mark thinning of adhesion laminae; T: translatent strata; A: erosively overlying aqueous beds.

15–40 cm. Sets of adhesion cross-laminae commonly grade both laterally and vertically into adhesion laminated strata. In places, however, adhesion cross-laminae overlie water-laid strata. Among adhesion structures the adhesion cross-laminae are volumetrically subordinate, although isolated sets are encountered quite often.

Interpretation. Adhesion cross-laminae form by the upwind migration and climb of the adhesion ripples on damp surfaces. Formation of adhesion cross-laminae requires both more than 80% water saturation of the substrate pore spaces, as well as adequate supply of dry wind-blown sand. Limited occurrence of the adhesion cross-laminae in this sequence and their rapid spatial and temporal gradation into adhesion plane beds may result from a paucity of any of the above two factors or a combination of the two (cf. Hummel & Kocurek 1984).

Wind-rippled fine-grained sandstone (F3)

Within these 2–6 m-thick aeolian sequences wind-ripple strata are conspicuous by their rarity. Sequences of wind-ripple strata, 10–30 cm thick, occur in places. Strata are flat-lying, laterally persistent, a few mm to 1 cm thick and show inverse grading (Fig. 10).

Interpretation. Thin units of F3 indicate the presence of localized wind-rippled dry sand cover. Thin inversely graded strata are typical of climbing wind ripples (Hunter 1977).

Massive or faintly cross-bedded fine- to medium-grained sandstone (F4)

These are fine- to medium-grained sandstone units with a lighter shade of red and the facies units vary in thickness from 5–25 cm, locally attaining thicknesses of up to 49 cm. The lower bounding surfaces of these beds are slightly irregular (Fig. 11), either concave-up or flat, giving rise to sheet-like or lensoid depositional units. The upper bounding surfaces of the beds are flat. The massive/cross-bedded units erosively cut into the underlying adhesion laminated units and grade upward into sandstones with adhesion structures. The F4 beds in places contain small clasts of fine sandstone/siltstone and in rare instances show a weakly developed fining-upwards grain size trend. The sediments have the same grain size and grain roundness but are relatively less well sorted than the adjacent adhesion laminated sandstones (Fig. 12). The facies units laterally as well as vertically grade within a short distance into the adhesion laminated or cross-laminated units (Fig. 10).

Interpretation. The channel-form shape of the sand beds, locally developed fining-upwards trends, presence of siltstone/fine-grained sandstone clasts and relatively poor sorting, collectively indicate an aqueous origin for these beds. It appears that these aqueous deposits inherited the characteristics of grain size and grain roundness from the aeolian deposits which were fluvially reworked in situ. The rapid lateral and vertical transition into aeolian facies indicates the transient nature of the aqueous activity.

Iron-rich fine- to very fine-grained sandstone (F5)

The fine-grained sandstones of this facies are dark red in colour and are crossed by numerous irregular iron-rich surfaces (Fig. 10). Thin-section study reveals the presence of abundant iron oxide concentrated along solution planes (Fig. 13). The fine-grained iron-rich units mostly occur at the top of the drying-upwards sequences of adhesion laminae (Fig. 7) but may also occur within massive sandstone units or at the contact of the massive and adhesion laminated units (Fig. 10).

Interpretation. The iron-rich irregular surfaces occurring mostly at the top of the drying-upwards sequences of adhesion laminae are interpreted to represent iron-crusts formed on the exposed surfaces. Prolonged exposure at the damp surface–air interface would favour formation of an iron crust through evaporative con-

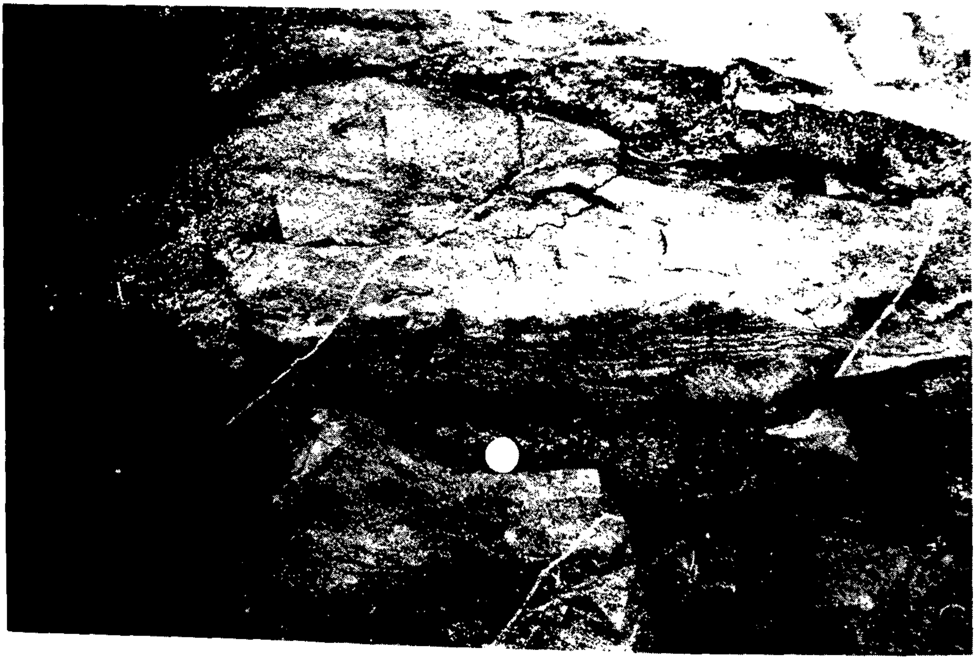

Fig. 11. Flat but very irregular erosive lower bounding surface of the massive sandstone units. Note underlying adhesion plane beds.

Fig. 12. Photomicrograph showing poor sorting of the aqueous units. Scale bar 0.25 mm.

centration and precipitation from capillary water. It is noteworthy that an iron oxide rim marks the margin of the sandstone dyke protruding through the adhesion laminated units shown in Fig. 6. The iron oxide rim presumably formed by similar processes at the interface of water saturated and damp/dry sediments.

Facies sequence

A typical sequence of salmon red, fine-grained sandstone exposed in the Ramgundam area is shown in Fig. 14 and the detail of a sequence dominated by adhesion structures is shown in Fig. 10. All of the three measured sections show the following common features.

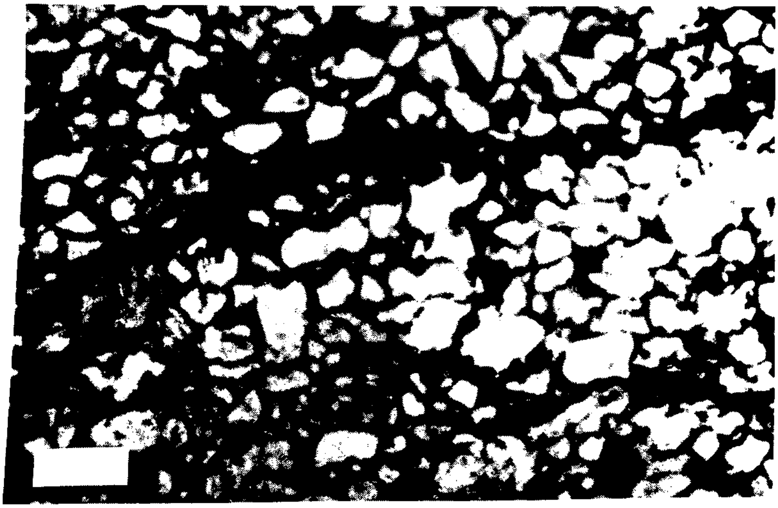

Fig. 13. Photomicrograph showing rocks with irregular iron-rich surfaces (F5); note the solution planes. Scale bar 0.25 mm.

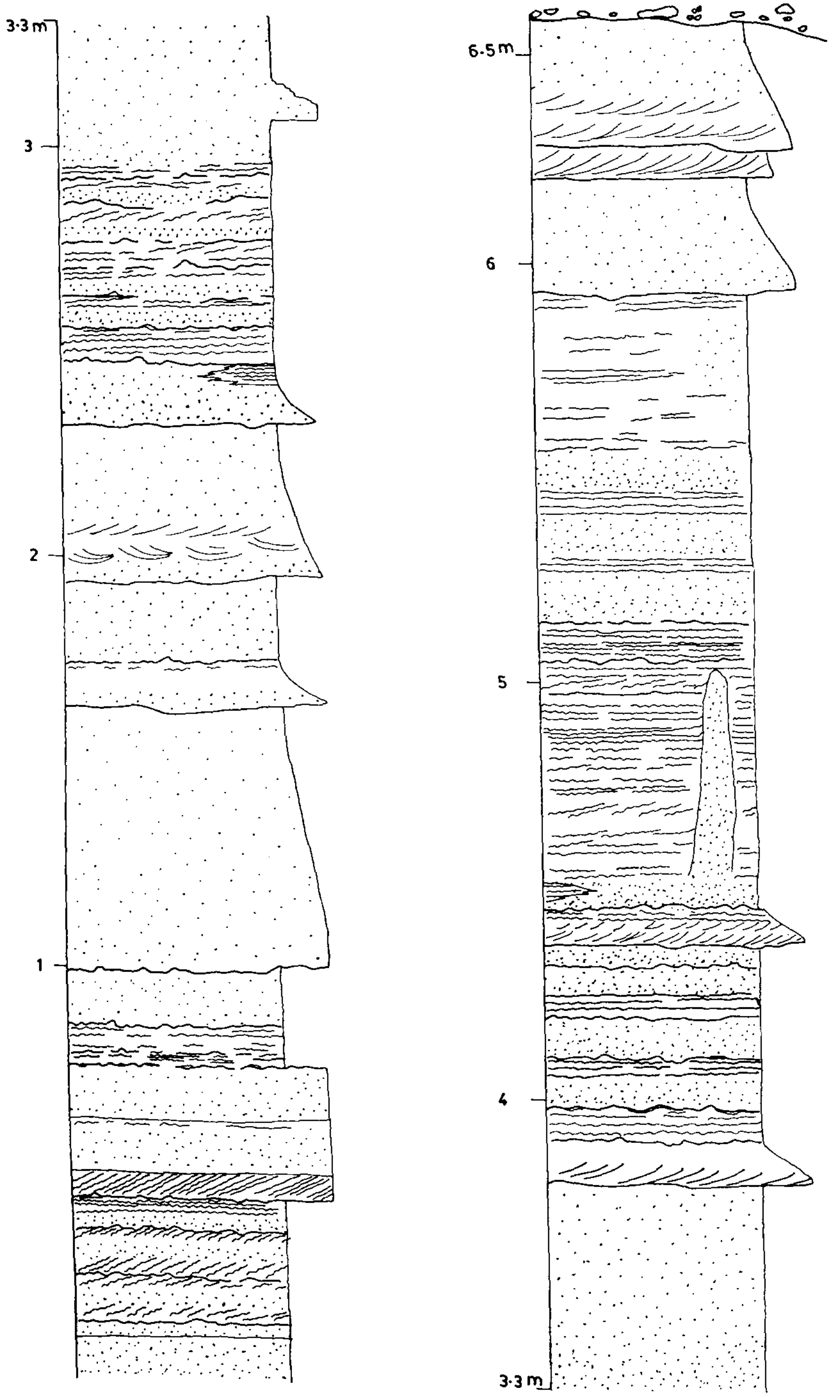

Fig. 14. A vertical log through the fine-grained sandstone unit of the Mancheral Quartzite. Note lack of grain-size differences in some of the massive units and the presence of a few floating adhesion laminae in some other massive sandstone units.

1. Some 25–40% of the total sequence is made up of aeolian strata and the rest consists of aqueous deposits. The aqueous beds have a very similar grain-size range to the aeolian strata. The aqueous beds are generally marked by sharp, erosional lower bounding surfaces and frequently show fining-upwards grain-size trends.
2. Vertical and lateral gradation from massive/cross-bedded units to adhesion laminated units is very common. Upward gradation of aqueous beds to adhesion plane beds through adhesion cross-laminae is rare. Adhesion cross-laminae are much less abundant than the adhesion laminae.
3. Drying-upwards sequences, exhibited by the upward decreasing spacing of adhesion laminae, are very common. These sequences are often bounded by horizontal deflation surfaces and/or irregular iron-rich surfaces (F5).
4. The sequences of sedimentary structures show very rapid lateral variation, and transitions between all the different facies are very common.

The sheet-like geometry of these aeolian or reworked aeolian sandstones, their thickness (which locally attains as much as 12 m) and its intertonguing relationship with the deposits of the higher topographic levels of the Mancheral channel complex or proximal part of the floodplain, indicate that these units developed in the distal floodplain or inter-channel area, where reworking by high-energy, active channels was virtually absent. Overall finer grain size, better sorting and presence of abundant well-rounded grains indicate little fluvial input. Channelized aqueous beds, therefore, indicate that during the floods only weak flows reached the depositional site, carrying with them the finest fraction of the fluvial load, and/or the flows largely reworked the wind-laid sands in situ. Similar low-energy shallow channels carrying fine-grained sediments are common in the higher topographic reaches/distal floodplain of many recent coarse-grained braided rivers (Williams & Rust 1969; Brierly 1991). However, aeolian sands on this scale have not previously been reported from any of them.

The nature and extent of the floodplain processes operating on the floodplain, magnitude of the flood events and the sediment load carried in the distal overbank area appear to have controlled the accumulation of these thick aeolian units in the Mancheral alluvial plain. This is unlike the other reported erg-margin aeolian–fluvial systems where erg dynamics exert the major control on the nature and internal organization of the interlayered aeolian–fluvial deposits.

Adhesion structures reported from many erg and erg-margin environments show well-developed drying-upwards sequences in which aqueous beds grade into adhesion cross-laminae and these in turn grade into adhesion plane beds (e.g. Kocurek (1981) amongst others). Such sequences are very rare in the aeolian sandstone units of the Mancheral Quartzite. At any one point profile, adhesion plane beds are the dominant structure and in most of the places aqueous deposits directly grade into adhesion plane beds without any intervening zone of adhesion cross-laminae. Compared to the modern day braided river floodplains, water seepage was much faster through the sandy overbank areas of the Mancheral fluvial system which was virtually mud free. As a result of the high moisture content required for the formation of the adhesion cross-laminae (100–80% of the substrate pore spaces filled with water) their occurrence was spatially and temporally very restricted. Lower levels of dampness, however, prevailed over wider areas for a longer time, allowing adhesion plane beds to form and dominate over other adhesion structures. On the other hand, capping of many of these adhesion plane bed sequences by erosion surfaces rather than by the wind-ripple strata reflect undersaturation of the air flowing over the surface. Given the surrounding wet environment and the presence of active channels in the vicinity, sand supply was poor and neither wind ripples nor any larger aeolian bedforms could develop. Even if formed, wind-ripple strata, being at the top of the drying-upwards sequences had the lowest preservation potential and might have been reworked by weak but erosive flood flows.

Stacking of a number of drying-upwards adhesion plane bed sequences without intervening aqueous deposits can probably be correlated with fluctuating ground water tables due to low-magnitude flood events. During these low-magnitude events the flood water did not actually reach these distal floodplain areas but they brought about a rise in the water table and thus renewed accretion of adhesion laminae in the floodplain.

Many of the massive sandstones were obviously laid down from shallow channelized flows. Many others, particularly those lacking obvious basal scours or a discernable fining-upwards trend (Fig. 14) might have formed by other processes. Several possibilities exist. They could be grainfall deposits accumulated in shallow ponds (cf. Weiner (1981) cited by Hummel & Kocurek 1984). Surface precipitation may locally emplace massive sandstones that lack erosive lower contacts. Alternatively, rising ground water tables may destroy aeolian stratification rendering the sands massive. Isolated pockets of adhesion structures floating in some of these beds (Fig. 14) support such an interpretation.

Conclusions

Previous work has indicated that in erg-margin aeolian–fluvial systems, the nature of dune–interdune morphology, their relationship with respect to the fluvial channels, and the relation between the direction of fluvial discharge and that of wind transport appear to be the main factors controlling the nature of the deposits (Langford & Chan 1989; Clemmensen *et al.* 1989). Flood surfaces and overbank–interdune sediments appear to be the most diagnostic deposits of this environment. However, such aeolian morphologies have been found to be absent in the Mancheral alluvial plain. Here, on the other hand, a delicate balance between the capillary moisture (which was again related to the fluvial discharge regime) and supply of wind-blown sand appears to have controlled the accumulation of fairly thick units of aeolian sand.

An arid climate and probable presence of a sand sea (Venkatpur Sandstone) in the interior part of the basin (Chakraborty 1988, 1991*a*,*b*) provided the general condition for the accumulation of the aeolian sands. Discharge fluctuation in the Mancheral braided rivers exposed wide alluvial tracts. The fluvial system being virtually mud-free, loose sand on the floodplains or higher topographic reaches was subjected to wind erosion. In the absence of land vegetation during pre-Silurian times, wind action was probably more vigorous than at present. On the other hand, coarse-grained fluvial deposits and a wet surrounding environment, restricted the availability of dry sand for wind transportation. It is in this setting that a unique aeolian sequence dominated by adhesion plane beds accreted. Probably, a significant part of the sequence was later reworked by flood flows and redeposited as massive sandstone or fine-grained sandstone with faintly developed cross-beds.

Stacking of large-scale channel-form surfaces throughout the sequence indicates that the channels probably did not migrate laterally for a considerable distance but were relocated time and again through avulsion. This channel behaviour was possibly related to pulsating tectonic activity in the rapidly subsiding basin. Pockets of large-scale soft sediment deformation present in the Mancheral Quartzite (for details see Chakraborty 1991*b*) probably attest to such periodic tectonic tremors. Rapid basin subsidence allowed a thick aeolian–aqueous sequence to develop in the floodplain areas and avulsive channel behaviour favoured their preservation in the rock record.

Since many of these features are likely to be present in other pre-Silurian fluvial systems of arid to semi-arid climatic regime, it is worth re-examining the finer-grained sediments of these systems for possible records of the alluvial plain aeolian deposits.

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