CHAPTER 3
SEDIMENTOLOGY OF THE JABALPUR FORMATION

INTRODUCTION

In this chapter, the sedimentological aspects of the Jabalpur rocks are discussed and an interpretation of their environments of deposition is attempted, mainly based on field observations and hand specimen studies, supplemented by petrographic and other studies. To start with, it seems necessary to give a short description of the previous views.

PREVIOUS VIEWS

All the past workers have inferred the Jabalpur rocks (excluding the 'Green Sandstone') as continental sedimentary deposits (see 'Sedimentation', p.11-16, Chapter 1). The present author corroborates this and even includes the previous Lameta 'Green Sandstone' for which a marine origin was enunciated from the identification of 'glaucnite' in it by Chanda (1968) and Chanda and Bhattacharya (1966). In 1987, Brookfield and Sahni re identified the 'glaucnite' as 'ferric-illite', and interpreted the 'Green Sandstone' as a fluvialite deposit, but included it in the Lameta Sequence of rocks.

Chanda (1968) remarked that the sediments of the Jabalpur 'Group' (sans the Green Sandstone) are the typical floodplain deposits in an interior basin. In 1966, along with Bhattacharya, he mentioned that the immature character of the sediments along with the abundance of cross-bedding and
occasional presence of erosional channels, suggested these to be the product of rapid sedimentation. On the basis of field relationship, integrated with the sandstone body geometry and textural characters, he opined that the Jabalpur sandstones represents bed load deposition, while the clays are products of suspension load. The sand body construction began in the distributive net of a river system wandering through the Precambrian basement and the top stratum deposits of an earlier floodplain. The river bed was a complex of dunes migrating downstream with a current of low intensity in the lower flow regime. According to Chanda (1968), the Jabalpur 'Group' itself apparently formed on a series of migrating sluggish river channels occupying the floodplain. Migration is evidenced, he mentioned, in the overlapping of 'silty clay' (Table IB) by the sandstone and occurrences of channels in a belt in some parts of the area. Abundant cross-beddings without flat-lying beds suggest contemporaneous erosion and deposition, generally effected in rapidly migrating braided stream channels. Chanda and Bhattacharya (1966) found the principal palaeoflow direction for Jabalpurs towards WSW.

Chanda (1968) remarked that the massiveness of the glauconite-bearing "Green Sandstone" along with its perfectly winnowed out clay matrix, indicate that the sands were deposited in an agitated shallow marine environment, apparently under normal marine waters well within the zone of wave and current agitation which operated on the detritus and modified it through a prolonged period of time. The entire set up was the marginal part of a shallow epicontinental sea that transgressed over the underlying Jabalpur sediments.

Accepting the rest of the present Jabalpur Formation to be non-marine deposits, Singh (1981) inferred the 'Green Sandstone' to have been deposited in an estuarine channel under the influence of tidal currents, developing some small migrating bar-like features. Identifying Thalassinoide - type burrows in the sandstone, he opined that the channel sand was inhabited by benthonic organisms, mostly crabs. The extensive estuarine tidal flats, adjacent to the main channel had a gentle relief and small rivers from the adjacent plains drained into the flats, bringing in terrigenous material which were reworked by currents and minor wave activity. De (1993) believed it to have been deposited by high currents in an estuarine palaeo-channel.

Kumar and Tandon (1978) reverted to the fluvial interpretation of the 'Green Sandstone' and called it as a river point bar sequence. Brookfield and Sahni (1987) supported it and added that the variable current directions in it were due to point bar migration in a large river. Incidentally, they found that
the so-called "crab-burrows" in the Green Sandstone to be, "pedogenic calcrete" related features. Tandon et al. (1990) described the sandstone to represent a southwestward flowing fluvial system with multiple channelization events.

**GENERAL LITHOLOGY**

In chapter 2 (p.25) it has already been mentioned that the present investigation finds the 'Green Sandstone' to be an integral part of the Jabalpur Formation of Jabalpur and its adjoining areas. The ≈40m (maximum) thick sedimentary sequence consists chiefly of an association of fine to very coarse grained, whitish to brownish, sandstones, siltstones, white mudstones and conglomerates (minor). Carbonates are in general absent. The coarser clastics (60%) dominate over the finer ones.

The coarser clastics mostly occur as 2.5 to >25m thick vertically stacked sandstone units, interspaced with the thinner 0.5 to 3m thick units of the finer clastics. In some of the exposures, for example at Nayagaon (Fig. 2.5, 3.1), the sandbodies show a rectangular geometry (sensu Bridge 1993). When the Nayagaon section is compared with an adjacent section (Fig. 3.1), exposed at the Perfect Pottery quarry, it shows that the three sandbodies of the former are replaced by a single, very thick sandbody in the latter without any major fault in between. Further eastward, in the Railroad cut section (Fig. 2.23, see Chapter 2) the sandbodies show development of a lenticular geometry. Hence, it is clear that, though many of the Jabalpur sandbodies are tabular at the exposure scale, they do not remain so laterally at the basinal scale.

The basal bounding surface of the Jabalpur sandbodies is erosive (Fig. 3.2), at places channel-form (Fig. 2.23), and is often lined with a veneer of pebble conglomerate. Whereas, the sandstone is generally moderately sorted, the conglomerate is poorly to moderately sorted. The grain size within each of the sandbodies decreases towards top, resulting in upward gradation from the sandstone into mudstone. The sandstones are cross-stratified and the cross-strata dip fairly consistently towards SW (Fig. 2.17,2.18). No wave-generated structures have been recorded in the sandstones.

The finer clastics are generally massive siltstones and mudstones, at places crudely laminated, and showing rare ripple-drift laminations. Rare stringers of coal and disseminated plant fossils are present.
Earlier workers (for example Matley 1921a, Pascoe 1959, Chanda 1968, Robinson 1967, etc.) have variously interpreted the Jabalpur Formation as continental fluvio-lacustrine deposits. Presence of channel-form erosional surfaces and broadly unidirectional palaeocurrent pattern (Fig. 2.25) of the Jabalpur sandstones indicate that they were deposited from the unidirectional channelised flows. Stringers of coal and disseminated terrestrial plant fossils, gradational contact with subaerially exposed and pedogenically modified rocks of the Lameta Formation, moderate sorting, red colour and presence of fining upward sequence are thought to collectively indicate a fluvial origin for the Jabalpur Formation.

**FACIES DESCRIPTION**

On the basis of mineralogy, texture, sedimentary structure and sandbody geometry, the Jabalpur rocks are presently being classified into eight facies (F₁, F₂ etc.), some of which being further classified into subfacies (Table 3.1).

**F₁: CLAST-SUPPORTED CONGLOMERATE FACIES**

The F₁ is exposed at Rampur as a 1.3m thick unit that represents the basal part of the Jabalpur sequence, the only exposure to show such in the entire area. The conglomerate is reddish brown (10 R 4/8) coloured and contains mostly subspherical, well-rounded, moderately well sorted pebble and cobble-sized clasts (av. clast size is 9.02cm). The framework is to matrix ratio is 7:3. Extrabasinal fragments of quartzites and/or vein quartz make up 80% of the total framework volume, followed by chert, jasper and granite fragments. A moderately sorted, very coarse grained sandstone containing occasional granules, comprises the matrix. The conglomerate occurs as a lenticular body, traceable laterally for ≈3.5 m, on the major basal erosional surface of a >10m thick sandbody. It grades, both laterally and vertically, to either a cross-bedded sandstone or a pebbly sandstone (Fig. 2.21). Towards north (in the N-S trending exposure) a number of 3cm to 7cm thick conglomerate layers alternate with 5cm to 16cm thick layers of cross-bedded sandstones (Fig. 3.3). Laterally towards south, it is replaced by a 50cm thick massive conglomerate having a sharp base. Further south, an overlying cross-bedded sandstone unit
Table 3.1: Characteristics of the facies of the Jabalpur Formation

<table>
<thead>
<tr>
<th>Facies</th>
<th>Lithology</th>
<th>Thickness</th>
<th>Sandbody Geometry</th>
<th>Sedimentary Structures</th>
<th>Palaeocurrent</th>
<th>Schematic Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>F₁</td>
<td>Clast-supported Polymictic Conglomerate</td>
<td>1.3m</td>
<td>Lensoid</td>
<td>Bimodal Clast orientation</td>
<td>WSW</td>
<td></td>
</tr>
<tr>
<td>F₂</td>
<td>Clast-supported Pebby Granule Conglomerate</td>
<td>1m-2.5m</td>
<td>Lensoid</td>
<td>Trough Cross-strata</td>
<td>SSW</td>
<td></td>
</tr>
<tr>
<td>F₃</td>
<td>Matrix supported Conglomerate and Pebby Sandstone</td>
<td>4cm-10cm</td>
<td>Sheets</td>
<td>Massive; weakly defined Clast Orientation</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td>F₄a</td>
<td>Moderately Sorted Coarse to Very Coarse grained Quartzarenite</td>
<td>0.5m-1.5m</td>
<td>Sheets and Lenses</td>
<td>5cm to 30 thick trough cross-beb sets</td>
<td>S E to SW</td>
<td></td>
</tr>
<tr>
<td>F₄h</td>
<td>- do -</td>
<td>3m-7m</td>
<td>Lensoid</td>
<td>Large scale cross-stratal sets of thickness between 50cm and &gt;1m</td>
<td>WSW</td>
<td></td>
</tr>
<tr>
<td>$F_{4a}$</td>
<td>- do -</td>
<td>3m-4m</td>
<td>Tabular; rarely lensoid</td>
<td>10cm to &gt;1.5m thick planar cross-bed sets. Recrystallization surfaces present.</td>
<td>S and NW; at high angle to the associated troughs</td>
<td></td>
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<tr>
<td>$F_{5b}$</td>
<td>- do -</td>
<td>&gt;4m</td>
<td>Wedge shaped or tabular</td>
<td>Compound planar cross-bed sets, 30cm to 60cm thick.</td>
<td>SE; oblique to the associated troughs oriented S to SW</td>
<td></td>
</tr>
<tr>
<td>$F_6$</td>
<td>Medium to coarse grained moderately sorted quartzarenite</td>
<td>5cm to 30cm</td>
<td>Sheet</td>
<td>Parallel laminae, planar and trough cross-beds</td>
<td>W; oblique to the overall palaeocurrent of the tabular sandbodies</td>
<td></td>
</tr>
<tr>
<td>$F_7$</td>
<td>Very well sorted medium grained quartzarenite</td>
<td>≈7m</td>
<td>Lensoid</td>
<td>Irregularly organized gently curved, low-angle reverse graded transport strata</td>
<td>N-NE</td>
<td></td>
</tr>
<tr>
<td>$F_8$</td>
<td>Siltstones and mudstones</td>
<td>1m to &gt;5m</td>
<td>Tabular</td>
<td>Crudely laminae, ripples, climbing ripples cross-laminae</td>
<td>W</td>
<td></td>
</tr>
</tbody>
</table>
truncates it (Fig. 2.21). The cross-bedded sandstone intercalated with the conglomerate shows a palaeocurrent direction towards SSW (Fig. 2.21).

Whereas, in the conglomerate some of the pebbles are bedding plane parallel, the ab planes of most of them do not show any imbrication. The maximum angle which the ab plane makes with the bedding is 7°. The distribution of the clast long axis orientation is bimodal, the two modes lying at a high angle to each other. The stronger mode is at a high angle with the sandbody palaeocurrent direction while the weaker one lies subparallel to it (Fig. 2.21). The axis of the clasts which are longer than 7cm consistently trend along WNW-ESE (Fig. 2.21). The long axis trend of the smaller clasts is scattered (Fig. 2.21), having a mean direction around NE-SW.

**Interpretation**

The flow transverse long axis fabric of the conglomerate clasts, together with their clast-supported nature, suggests that the clasts were deposited "grain-by-grain" from a traction bedload (cf. Todd 1989). The very coarse grain size (≈2mm) of the matrix falls within the range which stays in suspension when the bed load clasts (av. 9.02cm in size) are rolled by the flow (cf. Walker 1975a, b). However, the sandy population of F1 is somewhat finer than what it should have been if it were deposited along with the bedload clasts of 9cm size (as shown in the diagram of Walker 1975a). It may, therefore, infer a minor flow fluctuation in course of deposition; in other words, the sands were deposited when the fluvial flow had diminished further since the movement of the bedload population ceased. Nemec and Steel (1984) had studied similar conglomerates interstratified with cross-bedded sandstones, as presently observed in the eastern part of the Rampur exposure, and considered them to record varying discharges and a discontinuous accretion.

The features of F1 may be correlated with those of the "diffuse gravel sheets" of Hein and Walker(1977). Such sheets generally comprise of the coarsest bed loads that move only at a high discharge, coming to a stop as the flow strength decreases, to form a coarse lag pavement (of a few clast diameter thick). The pavement then acts as the nucleus of bars (Hein and Walker 1977). Stratified conglomerate has been reported from the nucleus of low pebbly longitudinal bars (Kraus 1984, Rust 1972, Hein and Walker 1977) forming in braided streams (Eynon and Walker 1974, Smith 1974, Boothroyd and Ashley 1975, Steel and Thompson 1983, Nemec and Steel 1984).
Lack of good exposures showing the details of facies architecture and any angle of repose foresets in the conglomerate precluded in the present work the possibility of demarcating any bar-like form with certainty. However, many pebbly or gravelly bars, formed under high fluid and sediment discharge, are devoid of the angle of repose foreset stratifications (Walker 1975b). Hence, it is possible that the cross-bedded sandstones overlying the conglomerate at Rampur represent incipient sandy bar development over a conglomeratic nucleus.

Nonviscous fluids, flowing around large clasts, correspond to large Reynold's numbers, and produce the turbulent wake. In such a situation, the inertial pressure forces become more important than the viscous forces acting on the surface in order to orient the clasts with respect to the flow direction. Similar pressure forces might have rotated the larger clasts of $F_1$ about their centre of masses so that their maximum projected areas became perpendicular to the flow, to produce an a(t) fabric (cf. Blatt et al. 1980, p. 122). Similar occurrence of the flow parallel orientation of the smaller clasts of this facies, that has produced the overall bimodality in conjunction with the orientation of the larger clasts has been reported from fluvial conglomerates by Kalterherberg (1956), Byrne (1963), Blatt et al. (1980), Todd and Went (1991) and from the flume studies by Johannsson (1976). Johannsson (op. cit.) has shown that for a near bed flow of 7-8cm/s, the orientation of the clast long axis for the pebbles occurring in association with coarse to very coarse sands (a situation similar to that of $F_1$) is distinctly bimodal. He interpretated the phenomenon to be the outcome of a intense sheet transport depositional and erosional processes. However, Reineck and Singh (1980) suggest that the failure of the clast long axis to attain a flow transverse orientation may be due to the restriction of their free movement. The high load of matrix materials present in the flow can create such hindrance. In such a situation, the larger clasts would roll more freely (probably due to their larger moment of inertia) than the smaller ones. On the other hand, with increasing flow intensities the clasts tend to get deposited with their long axis oriented parallel to the flow (Johannson 1976, Blatt et al. 1980). As a corollary, a constant flow velocity would tend to orient the larger clasts transverse to the flow and orient the smaller ones (like those smaller than 7cm of $F_1$) parallel under suitable conditions (cf. Table 24 of Johannson 1976).
**F2: Clast-Supported Trough Cross-Stratified Pebby Granule Conglomerate Facies**

The F2 is well exposed in the quarry of the Perfect Potteries near Polipathar (see Fig. 1.7). The clasts are composed of mostly subangular granule and small pebbles of quartz (constituting 90% of the framework clasts), chert and jasper.

The conglomerates occur as lenses at the base of the thick Jabalpur sandbodies. They tend to occur on the depression of the major erosional surfaces (Fig. 3.4, 3.5). The thickness of F2 units vary, from 1m to 2.5m, and they are 4m to 15m wide. F2 either grades upward to a trough cross-bedded sandstone (Fig. 3.4) or is sharply overlain by a planar cross-bedded sandstone with a sloping convex-up contact (Fig. 3.4a). Locally, the F2 also erosively overlies large trough cross-stratified sandstones of F4b (discussed later). The conglomerates fine upwards (small pebble/coarse granule at the bottom to dominantly granules and very coarse sand at the top). Internally, they show cosets of trough-shaped cross-stratification (set thickness varying between 10cm and 30cm) and the sets become smaller towards the top of the individual bodies. The individual foreset laminae are 2cm to 6cm thick. In the granule-rich parts, the foreset strata show very poorly developed internal cross-laminations at places (Fig. 3.6). The trough cross-stratifications show a palaeocurrent direction towards SSW, slightly oblique to the overall palaeocurrent direction shown by the associated planar cross-beds (Fig. 3.4).

**Interpretation**

The clast-supported fabric and the trough cross-stratified nature of the F2 indicate that the conglomerates were deposited under tractive flow (cf. Todd 1989, Nemec and Steel 1984). The tendency of the conglomeratic units to occupy the depressions of the erosional surfaces suggests a scour-fill origin, produced by the trapping of the clasts during their transportation along the channel bottom (cf. Mader 1985). However, the cross-stratal cosets showing an upward decrease in set thickness, accompanied by the FU nature of the sediments, may also suggest that the conglomerates were deposited by a train of 3D ripple or dune bedforms that migrated along the deeper parts of the channels (cf. Bluck 1971).
Fig 3.4: A) Field sketch showing the details of a lenticular body of trough cross-bedded conglomerate (F2), overlain by trough cross-beds of F4a and planar cross-bedded sandstones of facies F5a. Arrows indicate paleocurrent direction w.r.t. the section orientation. B) Sketch showing the details of F2 and F4a in the same section shown in (A). Note the erosive concave up basal contact of the conglomerates and their upward gradation to the trough cross-bedded sandstones of facies F4a.
Fig 3.5: Field sketch showing the details of a lenticular body of trough cross-bedded conglomerate of facies F2 erosively overlying mudstone unit of Fg and overlain by trough and planar cross-bedded sandstone facies (F4a and F5a respectively).
The conglomeratic dune bedforms and/or bars are known from many recent gravelly braided rivers (Fahnestock 1963, Eynon and Walker 1974, Smith 1974, Bluck 1976, Collinson 1986, Hein and Walker 1977), and rarely from the meandering streams (Bluck 1971). Johannsson (1976) has experimentally developed dune bedforms in conglomerates to show that the migration of such bedforms, having curved crest lines, can produce similar cross-stratified conglomerates.

**F₃: Massive Matrix Supported Conglomerate** to **Pebbly Sandstone Facies**

The F₃ is well developed within many of the tabular sandstone bodies, say, for example, the exposure in the Perfect Potteries quarry (Fig. 1.7). It comprises of intraformational clasts of white clay and extraformational clasts of quartz, floating in a matrix of very coarse grained light brown (5 YR 5/6) sandstone (Fig. 2.16, 3..7). The clay clasts are platy and are angular to subrounded, ranging in size from small pebble to small cobble. The quartz clasts are subspherical, rounded to subrounded and granule to small pebble sized, being distinctly smaller than the clay clasts. In the conglomerates and pebbly sandstones the ratio of the clast and the matrix varies between 3:1 and 3:7.

F₃ units are internally massive (Fig. 3.7) and occurs as 4cm to >10cm thick sheet-like bodies which drape the minor, gently undulating erosional surface occurring within the thick and tabular sandbodies. The F₃ grades upward to a cross-bedded sandstone. In general, a number of such sheet-like conglomerates and/or pebbly sandstones are encountered in a single vertical section through a single tabular sandbody (Fig. 3.1).

It has been noted that the clay clasts are more abundant in the deepest part of the basal erosive surface, whereas the quartz grains chiefly occupy the elevated parts. The a-b planes of the clay clasts are not imbricated. However, at places, where the conglomerates are matrix poor, the clast long axes, disposed horizontally, are oriented subparallel (E-W) to the westerly local flow direction, as indicated from the associated cross-beds. The quartz clasts are not imbricated, and their long axes are oriented oblique to the local flow direction (NW-SE).
**Interpretation**

The F3 conglomerates and pebbly sandstones are distinct from the conglomeratic channel lag materials by their matrix-supported floating grain fabric, which in conjunction with the lack of any a-b plane imbrication of the constituting clasts, indicate that the sediments were deposited *en masse* rather than from the tractive currents. This also accounts for the poor sorting and the lack of any internal primary structures. The bed-parallel clast fabric suggests that the sediments experienced a full laminar shear prior to freezing (cf. Todd 1989). The upward gradation of the conglomerates and pebbly sandstones to cross-bedded sandstones may indicate that the flow which emplaced the conglomeratic sediments probably waned out with time to form the overlying tractive flow deposits, thereby, implying that the F3 was not a product of any independent self-sustained mass flows, but was a part of the stream bedload. It may be suggested that the sediments were moved by high density dispersions due to strong flows, producing thereby high density traction carpets, similar to those described by Todd (1989). The traction carpets moved by the processes similar to that of the grain flow (cf. Middleton and Hampton 1976). It is also possible that the depositional processes of the conglomerates and their overlying cross-bedded sandstones are not related to each other. Reworking of the upper surfaces of the *en masse* deposit by tractive currents might result in the observed gradation.

**F4: Very Coarse to Coarse Grained Trough Cross-stratified Sandstone Facies**

The F4 is moderately sorted quartzarenite, locally gritty or pebbly. The pebbles are dominantly subangular clay chips, (maximum 10cm in diameter) and (minor) rounded quartz. The sandstone is trough cross-stratified; the cross-strata occur in cosets. On the basis of two distinct populations of trough size and coset thickness, two subfacies have been recognized, viz. 4a and 4b.

**F4a: Small Trough Cross-bedded Sandstone Subfacies**

The subfacies is a brown (10 R 3.5/8) sandstone with 5cm to 30cm thick (on average 10cm) sets of trough cross-beds that occur in 0.5m to 1.5m thick cosets. The sets become smaller upwards within individual cosets, accompanied by a weak fining up grainsize trend. At the coset base, there is a concentration of granules (Fig. 3.8). The cosets occur as lenticular units at the
Fig. 2.25: A number of vertically stacked palaeosol profiles in Lameta Formation near Sivni. Note two well developed platy caliche horizons (projecting outwards) and a rhizocretion rich zone (R) in between them. Stick length 1.5m.

Fig. 5.26: Part of coarse calcareous sandstone body of the Lameta Formation internally showing two minor erosion surfaces mantled with conglomerate. Stick length 1.5m.

Fig. 2.27: A caliche horizon in the Lameta Formation erosively overlain by a conglomeratic sandstone body. Note the concentration of granule to small pebble sized material near the base of the sandstone body.
Fig. 2.28: A pedogenically modified pebbly sandstone with poorly preserved traces of cross-strata (arrow). Stick length 1.5 m.

Fig. 2.29a: Photomicrograph showing a pedogenically altered sandstone. Note floating quartz grains in micritic-microspar matrix, complete replacement of a few quartz grains by calcite (arrows), probable transverse section of a root mold showing concentric zonation (in the lower right part of photograph) and fragmentation of grains due to calcitization (top middle of photograph). Crossed polars, 52x.

Fig. 2.29b: Photomicrograph showing a root channel in a pedogenically altered host. Note the downward tapering nature of the root channel and its branching in the lower part. Oblique polars, 41x.
Fig. 2.30: Coalesced chert nodules forming discontinuous bands in pedogenically modified Lameta sandstone. Scale length 1.5 cm. Lameta Section.

Fig. 2.31: A thin clay band (c) in noncalcareous sandstone of the Lameta Formation at Polopathar. Stick length 1.5 m.

Fig. 2.32: Lenticular bodies of calcareous coarse sandstone (projecting outward) interleaved with calcareous fine sandstone. Stick length 1.5 m.
Fig. 2.33: Calcic soil developed in the fine sandstones of the Lameta Formation. Note profuse development of the pedogenic glaebules towards the top and a well developed rhizocretion in the center. Measuring tape case is 5cm across.

Fig. 2.34: A palaeosol profile in the Lameta Formation near Sivni. Note a well developed hardpan or platy caliche horizon in the upper part underlain by a glaebule rich zone. Also note gleying in further lower part. Stick lying on the hardpan is 1.5m long.

Fig. 2.35: A thin lens of calcareous coarse sandstone (arrows) enclosed in pedogenically altered fine sandstone. Stick length 1.5m.
Fig. 2.36: A poorly exposed lenticular body of pedogenically altered coarse sandstone erosively overlying a well developed palaeosol profile in clayey fine sandstone of the Lameta Formation. Barasimla section. Stick length 1.5m.

Fig. 2.37: Uppermost noncalcareous sandstone of the Lameta Formation (white) overlain by Deccan basalt (dark). Contact is blurred due to weathering.
Fig. 3.2: Erosional lower boundary of a sandbody. Note the undulating nature of the surface cutting into white mudstone facies. Nayagaon section. Stick graduated at 50 cm.

Fig. 3.3: Clast-supported conglomerate facies F1 at the base of the Jabalpur Formation. Note interbedded sandstone lenses (arrow).
Fig. 3.6: Granule conglomerate of facies $F_2$ showing faintly defined foreset laminae (arrow) within it.

Fig. 3.7: White claystone clasts floating in a matrix of very coarse sandstone. Note the transitional contact with the overlying foreset, and erosive nature of the lower bounding surface. Graduated part of the scale is 10cm.

Fig. 3.8: Trough cross-bed sets of Facies $F_{4a}$ with concentration of granules at their base. The graduated part of the scale is 10cm.
lower parts of the thick tabular sandstone bodies. F4a overlies either 
gradationally the stratified conglomerates of F2 or erosively the planar cross-
bedded sandstones of F5 (described later). It grades upwards to a fine to 
medium grained ripple laminated or planar cross-bedded sandstone (F5b, 
described later). Locally, the planar cross-beds of F5a (described later) 
truncate F4a.

The mean palaeocurrent direction of the F4a varies widely, not only 
from exposure to exposure, but also from coset to coset. Whereas most of 
them show a direction between SE and SW, the mean palaeocurrent direction 
of the entire facies lies at a high angle to that of the associated planar cross-
bedded sandstones of the F5.

**Interpretation**

F4a records the migration of lunate megaripples or dunes which usually 
occupy the deeper parts of the fluvial channels (i.e., thalwegs; c.f. Bluck 1971, 
Cant and Walker 1976, Taylor and Ethridge 1983). However, Hazeldine 
(1983a, b) has reported curve crested dune bedforms from the top of large-
scale bedforms and bars. In the present case, the close association of trough 
cross-bedded sediments with conglomeratic lags and major erosional surfaces 
at the base of the sandbodies suggests that most of the troughs migrated close 
to the channel floor.

Similar oblique palaeocurrent direction as shown by the trough sets with 
respect to that shown by the associated planar cross-bed sets has been reported 
from the braided channel-fill sequences (Cant and Walker 1978).

**F4b: Large Trough Cross-bedded Sandstone Subfacies**

The F4b is grayish yellow (5 Y 9/2) and moderate olive brown (5 Y 
4/4), moderately sorted, coarse grained quartzarenite, internally stratified in 
the form of large to very large troughs which are organized in cosets (Fig. 
3.9). The thickness of the sets varies between 50cm to more than 1m and the 
mean thickness is around 60cm. The thickness of the cosets ranges from 3m to 
7m. The individual foreset laminae are 1.5cm to 9cm (av. 3cm) thick, and are, 
at places, internally normal graded. Large pebble sized mudstone chips are 
concentrated at the base of some of the trough sets. Locally, the foreset toe 
regions pass down to very small troughs and/or ripple laminae. Within individ-
ual cosets, the set thickness decreases upwards (Fig. 2.22) side by side with a
decrease in grain size. The overall geometry of the sandbody consisting of such coset(s) is not always apparent in the field due to exposure limitations. However, at places, the cosets fill up the channel-form erosional hollows, up to 6 m deep and tens of meters wide, and having a scalloped lower bounding surface (Fig. 2.22). This subfacies is usually overlain by the cosets of planar cross-beds of the F5a.

The F4b in general exhibits a WSW palaeoflow direction, which is at a high angle to the mean palaeo-current direction of the associated planar sets of the F5a (Fig. 2.23).

Interpretation

Large trough cross-strata in sandy sediments are considered to record the migration of 3D dune bedforms (Harms et. al. 1982) or lunate bedforms (Allen 1982, Taylor and Ethridge 1983). The scale of the bedform that can produce cross-strata of the scale that are observed in F4b is quite large, and it is considered to be stable only in the deeper waters (Taylor and Ethridge 1983, Singh and Kumar 1974). The curve-crested dune bedforms of comparable scale have been reported from the major channels (during flood stage) of the rivers like, the Brahmaputra (Coleman 1969), the Yamuna (Singh and Kumar 1974), etc.. It is suggested that the migration of such large curve crested dunes, related to the F4b, took place in the lower flow regime (cf. Simons et. al. 1965).

F5: PLANAR CROSS-BEDDED SANDSTONE FACIES

The F5 is a yellowish gray (5 Y 8/2) to light olive brown (5 Y 5/6) coloured, coarse to very coarse grained, moderately sorted quartzarenite, characterized by profusely developed planar cross-beds (Fig. 3.10). Granules and pebbles of quartz and clay chips are abundant. At places the foreset laminations show soft sediment deformations (Fig.3.11). The thickness of the cross-bed sets varies from 10 cm to more than 1.5 m, mean being 50 cm. The cross-beds occur in 3 m to 4 m thick cosets, which internally show a marked thinning (set thickness) upward and a weak FU (overall grain size) trends. The coset base is erosional and flat to gently convex up (Fig. 3.4). The lower bounding surface of the cosets is usually marked by conglomerate of the F3. In some of the sandbodies, e.g., in the Perfect Potteries quarry, a number of cosets are stacked vertically, each being separated by minor erosional surfaces.
F5, at places, sharply overlies the conglomerates of F2 or the trough cross-bedded sandstones of F4. In the exposure at Rampur (Fig. 1.7), it gradationally overlies Fj conglomerates (Fig. 2.20). In some of the exposures, the planar cross-bedded sandstones often grades upward to a ripple-laminated medium grained sandstone or mudstone of the Fg (discussed below).

Two types of distinct planar cross-beds are present - simple and compound, and these help in identifying two subfacies, F5a and F5b.

**F5a: Simple Planar Cross-bedded Sandstone**

The F5a is characterized by a profuse development of simple planar cross-beds. Generally tabular, the sets are persistent in flow parallel sections and, individually, these may be traced for more than 5m (Fig. 3.12). However, at places, the sets of lenticular profile geometry, having concave up lower bounding surface and flat to convex up upper bounding surface, are also present (Fig. 3.13a,b). The lenticular sets generally persist for 3m to 8m in flow parallel sections.

The tabular sets occur in cosets which are stacked one upon the other. The cosets have a sharp lower and a gradational upper bounding surfaces. Locally, small trough cross-strata and ripple laminations occur in between two adjacent cosets. In some of the cosets the lower bounding surface descends downcurrent, and the cosets along with the sets become thicker in downcurrent direction (Fig. 3.13b). The nature of such bounding surfaces in some exposures show a nonerosive to an erosive transition in the downcurrent direction.

The foresets are usually 1cm to 4cm thick (av. 2cm); foresets as thick as 9cm are also recorded. Internally, the foresets are usually normally graded and may show concentration of granules and small pebbles at their toe regions (Fig. 3.12). In flow parallel section, the foresets are either tabular or wedge-shaped, the former being common in tabular sets, and the latter in the lenticular ones. The wedge-shaped foresets are generally concave, may also be convex in the down-flow direction. Counter current ripples occur at the base of many of the foresets and, at places, the toes are tangential and pass into ripple laminations in the down current direction (Fig. 3.14). The foresets are inclined at an angle of 15° to 35° (av. 25°) with respect to the set boundary. In plan, the foresets are straight to gently curved; the individual foresets may be laterally traced for several meters. The individual foresets in the plan show thickening and thinning.
The individual $F_{5a}$ sets show a number of internal bounding surfaces separating different subsets within a single set. The surfaces show characters of reactivation, similar to that described by McCabe and Jones (1977). In flow parallel profiles, the following types of reactivation surfaces have been recognised (Fig. 3.13a):

1. Hanging convex up surface,
2. Steeply dipping convex up,
3. Gently dipping convex up,
4. Steeply dipping concave up,
5. Gently dipping concave up, and

Some of the sets record a downflow transition (usually imperfect) from a hanging convex up reactivation surface (1) to a sigmoidal one (6), through one or two of the other forms (2,3,4 and 5; Fig. 3.13a). The palaeocurrent direction of the successive subsets within a single set normally shows an orientational difference of 3° to 10° (Fig. 3.13a,b) between them, though, locally it can be as high as 30°. Within the individual subsets, the foreset azimuth gradually changes downcurrent. In some of the subsets, the planar cross-beds in the upcurrent end get transformed gradually to trough cross-beds (having a flow direction oblique to the planar foresets) of similar scale in the downcurrent end (Fig. 3.13b).

In a sequence of the cosets having internal reactivation surfaces, three orders of bounding surfaces (cf. Hazeldine 1983a,b) are present:

1. Surfaces bounding subsets (= order 4 of Hazeldine)
2. Surfaces bounding sets (= order 3 of Hazeldine)
3. Bounding surfaces enclosing cosets (= order 2 of Hazeldine)

Mean flow direction measured from all the sets within a coset differ from the mean direction calculated from the adjacent coset. In some of the cosets, the foreset dip azimuth changes gradually, usually clockwise, with increasing stratigraphic height (Fig. 3.1). On the other hand, the difference between the foreset azimuthal orientations of two superjacent sets widens towards the top of a coset. Usually the dispersion among the foreset azimuth is more within the smaller sets occurring towards the top of the cosets.
Locality wise as well as sandbody wise, the mean palaeoflow for the planar sets vary widely but most of them lies within S and NW with the principal mode towards west. In a sandbody, the foreset dip azimuth orientation shows a bimodal distribution (Fig. 3.1, 3.15), the modes being usually symmetrically disposed around the vector mean direction calculated for a given sandbody (as observed from all the primary structures present in the body). At places, the planar cross-beds are oriented at high angles to the direction given by other primary structures in the same stratigraphic level.

Interpretation

The planar cross-bed sets are considered to be the record of the migration of straight crested dunes - "2D ripples" of Harms et. al. (1982), or the linguoid megaripples of Allen (1982). The wedge-shaped geometry of the angle of repose foresets, together with their internal normal graded nature, suggests that the migration of the dune scale bedform in sandy sediments took place by successive grainflows down the bedform lee slope. The flow separation at the crest of the bedforms might have produced the counter current ripples at the base of the lee slopes. The thick cross-bed sets proclaim large precursor bedforms which are generally stable in the deeper waters. Though planar cross-beds are common in many recent and ancient fluvial deposits (Collinson 1970, Smith 1971, Banks 1973, Bluck 1976, 1979 1981, Cant and Walker 1976, Miall 1977, Cant 1978, Crowley 1983, Hazeldine 1983a, b, Roe 1987 and many others), large planar cross-strata are poorly recorded from the fluvial sediments (Rust and Jones 1987). In the large present day rivers like the Brahmaputra, such large scale bedforms have, however, been recorded (the "subsidiary dunes" of Coleman 1969) that can produce planar sets comparable to those of $F_{5a}$, having angle-of-rest foresets and internal reactivation surfaces. Reports of such large cross strata from ancient sediments are available from different rock formations in different parts of the world (e.g. Hawkesbury Sandstone, Australia; Conolly 1965, Conaghan 1980). Conaghan and Jones (1975) and Conaghan (1980) described them as the products of migration of straight-crested sandwaves. Rust and Jones (1987) described them as the product of sinuous-crested dune bedforms, whose avalanche foresets were intermittently active during the flood stage. Rust and Jones (op. cit.) however, have pointed out that these can also be the record of aggradation of straight and sinuous-crested bars.
Jabalpur Formation near Lalpur. Note the development of compound planar cross strata of facies F55 at the middle part. Arrows in the log represent palaeocurrent direction. Rose diagrams represent palaeocurrent data from planar cross strata (hatched; consistency 28.1, n 71) and trough cross-beds (stippled; consistency 77.9, n 24).

Fig 3.15: Litholog through a sandbody of the Jabalpur Formation near Lalpur. Note the development of compound planar cross strata of facies F55 at the middle part. Arrows in the log represent palaeocurrent direction. Rose diagrams represent palaeocurrent data from planar cross strata (hatched; consistency 28.1, n 71) and trough cross-beds (stippled; consistency 77.9, n 24).
Bedforms generated at the flood stage in a river before being preserved are modified during the falling stage. This is particularly true for the larger rivers like the Brahmaputra, where the falling stage is usually a prolonged one (Coleman 1969), allowing ample time for readjustment to the lower-stage conditions (Allen 1974). It is thus difficult to extrapolate the maximum thickness of the cross-stratal sets in an ancient succession to the flood stage height of bedforms in their modern analogues. The thickness of the planar cross-stratal sets of F$_{5a}$ implies deposition in a large river with deep channel(s) comparable to that of the Brahmaputra (Coleman 1969).

The term "reactivation surface" was introduced by Collinson (1970) to describe erosion surfaces developed during the low-stage modifications of the bedforms. McCabe and Jones (1977) defined it as "an inclined surface within a cross-bed set which separates adjacent foresets, with similar orientations, and truncates the lower, foreset laminae". Several processes have been invoked by different workers to explain its origin, such as:

1. change in flow stage (Collinson 1970)
2. change in flow direction (Klein 1970, McKee 1966) including the action of wave (Jopling 1965) and without any significant change in the stage;
3. random interaction of bedforms (Allen 1970) with smaller bedforms on the larger bedforms; and
4. erosion caused by smaller bedforms which migrate downward and contribute to the lee slope of larger forms (McCabe and Jones 1977, Hazeldine 1983a,b).

The closely spaced, multiple, curved reactivation surfaces, showing systematic changes of their profile geometry within a single set, as observed in F$_{5b}$, is difficult to explain by the changes in flow stage. The sharply defined smooth plan trace of the surfaces suggests a constancy of stage; since the processes that are related to the flow stage lowering have not modified them (cf. McCabe and Jones 1977). The oblique orientation of the reactivation surfaces with respect to the foresets that they truncate, on the other hand, may suggest some changes in the flow directions. It seems that the nature of the reactivation surfaces of F$_{5a}$ conforms to the mechanism suggested by McCabe and Jones (1977).

A systematic change in the profile geometry of the reactivation surfaces in the downcurrent direction has been suggested by Hazeldine (1983a) to
record the curved shape of the crest line of a bedform due to which different parts of the crest line lies at different angles with the current direction.

The downcurrent descending and thickening cross-bed sets and cosets indicate that within the channels there existed some topographic highs, possibly bars. On the sloping margins of the bars(?), these sets developed (cf. Hazeldine 1983a,b).

It may be visualised, from the symmetrical dispersion of the dip azimuths of the downcurrent descending planar cross-beds about the local palaeoflow direction, that the straight crested dunes or 2D ripples accreted down the three sides of an inchannel high (cf. Allen 1983, Collinson 1986). However, in case of absence of such symmetry and the high angular deviation of the planar cross-beds to the generalised palaeoflow direction, the origin of these cross-beds might still be related to the cross channel or the lateral bars of a braided river (cf. Cant and Walker 1976, Bluck 1980, Hazeldine 1983b) but such asymmetry may be related to a number of autocyclic and allocyclic controls (Bluck 1976, Todd and Went 1993).

**F₅b: Compound Planar Cross-Stratified Sandstone Subfacies**

The F₅b is locally developed within the thick tabular sandbodies of the Jabalpur Formation. The cross-strata dip at an angle of 10-35°. The cross-strata which taper downward (Fig. 3.16), are 10 to 25cm thick. Internally they contain cosets of 2cm to 5cm thick troughs which have their axis oriented subparallel to the strike of the cross-stratum within which they occur (Fig. 3.17, 3.18). Well-marked change in vertical trend of the grain size or set size is absent.

While the cross-strata have a straight to very gently curved plan expression, in profile their toe region is generally tangential. Very few sigmoidal profile forms, having convex up tops and concave up toes, have been observed (Fig. 3.17)The inclined wedge-shaped strata internally show bounding surfaces, with characters similar to the reactivation surfaces of McCabe and Jones (1977) (Fig. 3.16).

Usually 30cm to 60cm thick cross-stratal sets of F₅b gradationally overlie 20cm to 50cm thick trough cross-beds of F₄a to form a 50cm to 80cm thick tabular unit having an erosive base. At places, the units of F₄a and F₅b show downcurrent thickening (Fig. 3.15, 3.17), and the basal surface of the duplexes usually have a concentration of coarser materials. A more than 4m
thick sequence of such units, stacked vertically one upon another, is found in the northern bank of the Narmada River, south of Lalpur (Fig. 3.15).

The dip azimuths of the inclined cross-strata are oriented towards SE, and lie at a high angle to the associated small troughs as well as the flow direction shown by the trough cross-beds of associated $F_{4a}$ which is generally towards S to SW.

**Interpretation**

The wedge-shaped cross-strata have sigmoidal profiles in sections transverse to the local palaeoflow direction as indicated by the smaller cross-laminae and trough cross-beds within them. These are analogous to the accretionary bedding described by Allen (1963), Bluck (1971), Puigdefabregas and Van Vliet (1978), Collinson (1986). The individual cross-stratum of the $F_{5b}$ set records the successive positions of an inclined face of a large fluvial bedform (probably a bar), accreting periodically in a flow transverse direction. The internal structures of these cross-stratified sets record flow from two directions, one coming over the top of the large bedform and the other around and along its inclined face. The former current, which operated in the high flow stage, caused the periodic accretion of the larger form. On the other hand, during the lower flow stage(s), when the larger form did not accrete, the smaller dunes or 3D ripples migrated over its face under the influence of the other current (cf. Bluck 1971).

The cross-stratal sets of $F_{5b}$, having profuse accretionary strata, indicate an unsteady flow condition and highly fluctuating flow. It is also indicated by the presence of the small reactivation surfaces within the individual inclined stratum.

**$F_6$: Sheet-like Cross-bedded and Parallel Laminated Sandstone Facies.**

The facies is characterised by a dark reddish brown (10 R 3/4) to moderate reddish brown (10 R 4/7) coloured, medium to coarse grained moderately sorted quartzarenite which occurs mostly as 5cm to 30cm thick sheet-like bodies enclosed within the finer grained facies, $F_8$ (discussed later) (Fig. 3.19). These bodies at places project out as tongues from the thick tabular bodies. At places the bodies may also be lenticular (in flow transverse sections) (Fig. 3.20). The lower bounding surface of both the sheet-like and
Fig. 3.20: Cross-bedded and low-angle laminated sandstone body of F6 encased within mudstone. Note convex up bounding surface of the sandbody and the irregular, erosive lower contact.
the lenticular bodies is erosive, showing centimeter-scale undulations (Fig. 3.20, 3.21) and supporting a concentration of granules and small pebbly clay chips over them. The upper bounding surface of the bodies is sharp and non erosive (Fig. 3.22). Within the bodies the sediment grain size decreases upward.

The sheet-like units are dominantly parallel laminated, individual laminae is less than a cm thick (Fig. 3.21). Locally, cosets of centimeter scale trough cross laminations replace the parallel lamination (Fig. 3.22). Parallel laminae can also be found closely associated with the 5cm to 8cm thick sets of convex-up planar cross-laminations, which are at places laterally extensive and can be traced in the flow parallel sections for ≈1m or so (Fig. 3.23). The bounding surface of the sets often descends downcurrent in tandem with the thickening of the set concerned. The foreset laminae are less than 0.5cm to 1cm thick. Locally, they show a downcurrent transition from convex up to concave up profile forms. Within the sets, a number of convex up internal bounding surfaces, having characters comparable to the reactivation surfaces of McCabe and Jones (1977), are present. The lenticular bodies, in contrast to the sheet-like bodies, show a dominance of small cross-beds that occur in cosets (Fig. 3.20).

The palaeocurrent data, sparsely available from F6, show mean flow direction towards W which is oblique to the overall palaeoflow direction of the associated larger sandbodies (Fig. 3.24).

**Interpretation**

The parallel laminated medium to coarse grained sandstones of F6 were presumably produced by bedforms similar to the plane beds. Such bedforms are stable in either higher flow velocities of the upper flow regime or under the low flow velocities of the lower flow regime. The upper flow regime plane beds in sediments coarser than the medium sand have rarely been noted in flume studies (Harms et al. 1982). Harms *et al.* (1975) suggested that the lower flow regime plane beds are laterally discontinuous in contrast to the persistent parallel laminae of F6. However, the occurrence of the parallel laminated sandstones directly over the erosive surfaces suggests its close relationship with the high flow velocities and tend to support their deposition from upper flow regime plane beds.

The cross-laminae with convex up foreset laminae in F6 have presumably been produced due to the migration of the 'hump back dunes' (of Allen
1983b, Roe 1987), having a convex up lee slope. Such dunes are reported to be stable in the transition zone between the lower and the upper flow regime. The fluctuations in the flow velocities or any slight change in the flow direction might have resulted in the reactivation surfaces within the cross-bed sets of F6.

The coset of the small trough laminae is the record of the migration of small curve-crested aqueous dunes. The smaller thickness of the cross-stratal set indicates a shallow flow depth, which is quite consistent with the sheet-like nature of the flow inferred from the plane-bedded units of F6.

The lenticular bodies of F6 are believed to have been produced when the sheet-like flow became somewhat channelised, probably due to local factors. Reineck & Singh (1980), Taylor & Ethridge (1983), O'Brien & Wells (1986) and others have interpreted similar sheet-like coarse clastic bodies with erosional base and occasional convex up tops, having an internal FU grain size trend, occurring within the thick finer clastic deposits and showing a palaeoflow oblique to that of the inchannel deposits, as overbank flood deposits. In fact, they are common in high sinuosity river deposits.

While the F6 sheet-like bodies represent deposits of sheet floods, lenticular parts presumably formed at the locations where the flood was weakly channelised. Flood water might have eroded out the smaller channels or followed preexisting depressions in the floodplains.

F7: VERY WELL-SORTED MATRIX-FREE THINLY STRATIFIED SANDSTONE FACIES

This facies is very rarely developed, one good exposure is located near the origin of the Majdalia Nala along the southern scarp of the Patbaba Ridge (Fig. 1.7). It develops over the F4a with an intertonguing contact and is erosively overlain by the calcareous Lameta rocks.

Pinkish gray coloured (5 YR 8/1), medium grained, matrix-free quartzarenite represents this facies. The grains are very well sorted and subrounded. Internally, the sandstone is thinly stratified, the strata, on average, are 4cm thick, and laterally very persistent (>1m) (Fig. 3.25). Most of the laminae are reverse graded and show ill-defined ripple foresets (Fig. 3.26, 3.27). The thinly laminated sandstone units are organised in large-scale cross-strata and flat-bedded units (Fig. 3.28). Cross-beds are 0.7 to 1m in thickness. Mostly these are low-angle cross-sets with gently curved foresets passing
down gradually into flat stratified units (Fig. 3.25, 3.28). Foreset laminae is often wedge shaped in profile and in plan view they show pinch and swell. The cross-sets are stacked in an irregular fashion and are generally separated from each other by flat stratified units. The flat-bedded units are 20 to 70 cm thick and contain numerous low-angle erosional surfaces within them.

Large low or high angle cross-bed foresets of $F_7$ dip towards N and NE and is distinctly different from the southwesterly overall palaeocurrent direction of the other facies of the Jabalpur Formation.

**Interpretation**

Well-sorted, matrix-free sandstones with moderately well rounded grains as that of $F_7$ resemble many of the reported aeolian sandstones, though these attributes are as such not diagnostic of such origin (Kocurek and Dott 1981). However, reverse graded thin lamination with ill-developed ripple foreset laminae identify them as wind ripple strata (Hunter 1977a,b, Fryberger and Schenk 1981). Two other features of this facies namely, (i) the low-angle, asymptotic to base cross-bedding in which the toe grades into flat bedding and (ii) the palaeoflow direction at high angle to the palaeoslope as determined from the associated fluvial facies, have been considered as important clues for recognising aeolian reworking within sandy fluvial deposit (Trewin 1993a). The low-angle cross-beds in $F_7$ are thought to indicate development of low amplitude aeolian bedforms which merged laterally into sub-horizontal sand sheet type environment dominated by the wind-ripple strata (cf. Fryberger et al 1979, Clemmensen and Dam 1993, Trewin 1993b).

**Fg: Mudstone Facies**

The lithology of this facies is siltstone (dominant) and claystone (subordinate). Claystone usually occurs above the siltstone. Siltstone is white (N 9) to very light gray (N 8) coloured, may be red (5 R 5/4) at places. The claystones are bluish white (5 B 9/1) in colour with occasional gray streaks. The internal structures of the mudstone is more conspicuous where the facies is slightly sandy and micaceous. The facies shows sinuous crested current ripples, imperfect parallel laminations, rare occurrence of about a centimeter thick, trough sets, starved ripples, ripple drift laminations and load casts (Fig. 2.19). The sand-free parts of the mudstones are usually massive. The claystones break with conchoidal fractures. At places, disseminated plant debris
and thin stringers of jet coal occur in the claystones. In Jabalpur railroad cut section (Fig. 1.7), a very thick (more than 5m) deposit of this facies is exposed along with enclosed internal lenticular sandbodies (F_4 and F_5). In Nayagaon, a section shows 1m to 3m thick units of this facies alternating with thick tabular sandbodies. This facies gradationally overlies and is erosively overlain by the sandstones of F_4, F_5. At places, F_g encloses sheet-like sandbodies of F_6. The small ripple and trough cross-laminae show a general westerly paleocurrent direction (Fig. 2.23).

**Interpretation**

The silt and clay of F_g are interpreted to have been deposited in a low energy environment within a fluvial setup. The sinuous crested current ripples indicate a low flow velocity and flow depth (Allen 1968), the latter being supplemented by the small size of the associated trough cross-laminated sets. The ripple drift laminations, on the other hand, indicate the presence of unidirectional currents and high sediment loads. In a fluvial setup, a low energy environment is commonly observed in the overbank areas where unidirectional shallow flows operate. However, in abandoned channels, such environment may also exist. The thick tabular units of fine grained sediments proclaim a floodplain setup.

**FACIES ORGANIZATIONS**

The different facies of the Jabalpur Formation as discussed above are interpreted to be the products of the local hydrodynamic setups that existed at different geomorphic domain of a fluvial system. In characterising different facies organisation within Jabalpur Formation, disposition of facies units, their interrelationships and large scale architectural features have been taken into account and these features are believed to collectively reflect the characteristics of the inferred Jabalpur fluvial system. The discussion also attempts to provide information regarding the depositional basin of the Jabalpur sediments (see also Chapter 7).

Several different kinds of channel-fill sequence has been observed within the Jabalpur Formation. The typical organisation of these channel-fill sequences have been described below. Each of these facies organisation usually comprise erosively based fining upward, cross-bedded sandstone bodies, some
of which show a thinning upward trend in cross-bed set thickness and a concentration of conglomeratic materials at their base. Each of these facies organisation (abbreviated as FO1, FO2 etc.; summarised in table 3.2) are interpreted as channel-fill sequence.

**FO1: CHANNEL FILL SEQUENCE TYPE-I**

This type of facies organization is well developed in the Perfect Potteries quarry section, at Polipathar (Fig. 1.7), and also in the sections exposed near Nayagaon and Rampur. In all these sections, the organisation is found within the 3 to >25m thick tabular bodies, erosively overlying the siltstones and claystones of Fg. The basal contact of the tabular bodies at places is undulatory, showing a relief of 2m (Fig. 3.2). Conglomerate lenses of both F1 and F2 may occur at the basal part. The conglomerates are locally associated with the trough cross-bedded sandstones of F4a. The bulk of the sandbodies are dominated by a number of vertically stacked cosets of the planar cross-beds of F5a type. The cosets are in general separated by flat, laterally extensive, erosional surfaces, often draped with thin sheet-like conglomeratic units (F3), which may be associated with thin units of trough cross-bedded sandstones.

Though many of the cosets individually show a fining upward grain size trend, the sandbodies as a whole do not, generally, show any such well-defined trend. However, near the top of the bodies a significant fining upward trend may be recognized. The palaeocurrent trend within individual cosets is generally consistent, but between the adjacent cosets there may be a large deviation (both vertically and laterally).

The conglomerates at the base of the sandbodies occur as either lenses (F1) or scour-fill (F2). The scour fill conglomerates usually occur along with small trough cross-bedded sandstones of F4a. In some cases, the internal record of a sandbody consists only that of the stacked planar cross-beds. Vertically stacked cosets of the planar cross-beds, lying over the minor erosional surfaces, draped by lag conglomerates of F3, characterize this organization. The trough cross-beds (F4a) are locally present at the base of some of the planar cross-bed cosets.
Remarks
No marked FU or TU trends for the whole but many constituent facies FU and TU.
Both FU and TU trends.
No distinct FU or TU trend.

Schematic Representation

| Table 3.2: Organizations of the different facies of Jabalpur Formation. |
| --- | --- | --- | --- | --- |
| Organization | Thickness | Geometry of the body | Constituent Facies | Remarks |
| FO₁ | 3m - >25m | Tabular | F₁, F₂, F₃, F₄a, F₅a and F₅b | No marked FU or TU trends for the whole but many constituent facies FU and TU. |
| FO₂ | 3m - >5m | Lensoid | F₄b, F₅a and F₄a | Both FU and TU trends. |
| FO₃ | >4m | Tabular | F₃, F₄a and F₅b | No distinct FU or TU trend. |
Interpretation

The depositional sequence of any single channel, high sinuosity river is characterized by a point bar deposits (Allen 1963, Bluck 1971). However, in the present case, neither lateral accretion surfaces are present, nor do the sandbodies show a well-defined fining up trend. Moreover, the sand-dominant lithology, dominance of planar cross-beds in the channel-fill sequence and the presence of medial bars help to identify these channel-fills as the braid channel deposits (c.f. Collinson 1970, 1986, Smith 1971, Miall 1977, Allen 1983, Crowley 1983, Hazeldine 1983a,b). The straight-crested transverse bars (Collinson 1986) were probably the dominant macroforms in these braid channels since the fills are dominated by planar cross-beds, associated with subordinate 3D dunes. The thickness of the individual bedforms (in excess of 75 cm) within the fining and thinning upward cosets, indicate that the channels were fairly deep. The occurrence of *en masse* deposited conglomerates of $F_3$ at the base of many of the channel-fills may indicate some degree of ephemeral nature of the fluvial system. It may be suggested that the thick tabular bodies that comprise a number of such vertically stacked channel-fill sequences were the result of amalgamation of a number of channel-fill sequences and formed during the lateral combing of the braid channels, at a time when the subsidence rate was lower than the rate of accumulation of the sediments (Blakey and Gubitosa 1984, Miall 1985, Todd and Went 1991).

Within the type I channel fill sequences the planar cross-beds often show a complex arrangement - a feature that can be interpreted in terms of fluvial bars or foreset macroforms (sensu Miall 1985).

Bar sequences of the channel fill sequence type-I

The bar sequence is characterized by a complex organization of planar cross-bed sets and their cosets. The planar cross-beds of $F_{5a}$, dominate the sequence with subordinate trough cross-beds, while other primary structures occur as intrasets or topsets.

The geometry of the cross-sets, in the flow-parallel sections is lenticular. The terminal part of the sets are thinner in comparison to their middle. In the stream-wise profile, the upper boundary of the sets is slightly convex-up or flat. The lower boundary changes its shape from convex-up in the up-stream to concave-up in the down-stream ends. The successive sets, in the down-current direction, descend downward. The maximum thickness of
one set usually offset in the down current end relative to the thickest part of the underlying set(s) (Fig. 3.13a,b).

The sequence consists of several downcurrent thickening cosets. Some of these sequences show an upward decrease in the set size. The top of these large planar cross-beds are locally scoured. Smaller trough cross-beds and channel-form laminae fill up these scours (Fig. 3.4, 3.13a,b).

The whole sequence is draped by an extensive, thin (3cm) bed of fine grained clayey sandstone, showing poorly preserved ripple laminations.

Almost all the sets of the sequence contain a number of reactivation surfaces, separating the subsets. The foreset laminae within the subsets are convex-up to a concave-up in shape. The former type commonly passes downflow into the other. The foresets grade downdip into bottomsets (sensu. Reineck and Singh 1975, Roe 1987) tangential to the lower subset boundary. In the down-current direction, the foresets often give way to the low-angle laminae which pinch out further downcurrent within a couple of meters or so. However, there are a few bottomsets that are more than 6m in length. These low-angle laminated bottomsets generally comprise parallel laminated, medium grained sandstones, internally showing cross-laminations at places. At several occasions, the foreset strata pass down-current to channel-form stratification (Fig. 3.13b).

The overall palaeocurrent of the sequence is towards west. The foreset dip azimuths of the planar sets are also consistently oriented towards west, but those for the channel-form strata show a southerly direction (Fig. 3.13b). The higher order bounding surface (mainly coset bounding surface) is also inclined downpalaeoflow (towards west). The adjacent subsets of a set often show a quite high variation in the foreset azimuth orientation (often as high as 30°).

**Interpretation**

Absence of lateral accretion surfaces (sensu Allen 1963, Puigdefabregas and Van Vliet 1978) or features similar to the inner accretionary bank deposit (Bluck 1971, 1979) indicate that the bar sequence is not comparable to the point bar deposits of the high sinuosity rivers.

Dip of the bounding surfaces within the sequence at low angle to the mean flow direction, and dominance of the planar cross-beds, on the other hand indicate the resemblance of the sequence with the medial and lateral bars
of the present day low sinuosity braided streams (Smith 1971a, Bluck 1976, 1979, Cant and Walker 1978, Crowley 1983).

Planar cross-beds of the bar sequence are interpreted to have been deposited from large 2-D bedforms (Harms et al. 1982). These bedforms probably carried on their back small ripples and migration of these ripples over the lee of the larger bedforms produced the regularly spaced reactivation surfaces (McCabe and Jones 1977, Hazeldine 1983a).

The sets within each coset descend in the down-palaeoflow direction and thicken as they overtake the underlying set. By overtaking the underlying bedforms, the overlying bedforms became larger as they entered in the deeper water. As a corollary, it may be visualized that the bedforms migrated over a surface which had marked topographic changes. Hazeldine (1983a) has interpreted similar organizations as a record of migration of sand-sheet bedforms (=2-D ripples of Harms et al. 1982) down the lee face of a large, slower moving sand-wave bedform (cf. Allen 1968 p.107; Banks 1973).

The down-current descending cosets indicate that a number of superimposed sandwaves migrated down the lee face of a topographic high in the then Jabalpur river. Hazeldine (1983a,b) has interpreted similar organization of cosets as a complex of sand waves that descended down the lee of a large bar.

Ramos et al. (1986) have suggested that the planar cross-stratification passing downstream into trough or channel-shaped cross-stratification have been produced due to the obstruction in the bedform growth, as the bedform lying upcurrent runs into bedform(s) in front of it. The phenomenon is characteristic of a low water depth and commonly takes place near the head of an emergent braid bars, modified in low flow stage (Ramos et al. op. cit.).

**FO₂: CHANNEL FILL SEQUENCE TYPE-II**

FO₂ is well exposed near the top of the Jabalpur sequence and is best observed in the Jabalpur railroad cut section (Fig. 1.7). It occurs as 3m to more than 5m thick lenticular bodies of coarse to very coarse grained sandstone bodies embedded within thick deposits (5m or more) of fine grained sediments of Fg (Fig. 2.22). The basal surface of the bodies is sharp, erosive and concave upwards, whereas the upper contact with the overlying fines of Fg is flat and gradational. At places, the basal surface is undulatory in the form of scallops (Fig. 2.22). In some exposures, the lenticular sandbodies grade laterally into siltstones and claystones through a medium to fine grained sand-
stone. Internally, the lenticular bodies comprise cosets of large scale trough cross-strata of F4b which, near the top, are gradationally overlain by planar cross-beds of F5a. The trough sets within the cosets are organized as a thinning upward sequence.

Interpretation

The lenticular profile geometry of the channel-fills and their concave upward erosive bases indicate that the channels did not migrate much laterally and had stabilised banks. The presence of a number of laterally adjacent lenticular channel-fill sequences of this type may indicate the presence of multiple channel river system (Todd and Went 1991). The channels had cut into the mudstones and siltstones of the Jabalpur Formation and were later filled up to form the channel-fill sequence as described above. The large-scale curve-crested dunes or 3D ripples were the dominant bedforms that were present in those channels. The scalloped nature of the base indicates a gradual widening of the channel course by the cutting of the then existing banks.

FO3: CHANNEL FILL SEQUENCE TYPE-III

The FO3 is very locally developed. Good exposures are located only to the south of Lalpur on the northern bank of the Narmada River (Fig. 1.7). There are some poorly developed exposures in Katanga (Fig. 1.7). This type of organization forms a part of the thick tabular Jabalpur sand bodies.

The organization comprises of 40cm to 80cm thick tabular, fining upward units, each with a flat, erosive base (Fig. 3.15). The basal contact of these units, however, at places, shows a level difference of 5cm to 15cm, and is often lined by small pebbles of quartz and clay chips. Usually, 5cm to 10cm thick sheet-like body of F3 conglomerate occupies the base. A 20cm to 50cm thick coset of trough cross-beds (F4a) overlie it and in turn is gradationally overlain by a 30cm to 60cm thick accretionary cross-bed set of F5b. A number of such tabular or wedge shaped units are usually vertically stacked, forming >4 meter thick sequence (Fig. 3.15). This type of organization is found to occur closely associated with FO1 which normally overlies as well as underlies it.

The dip azimuths of the accretionary strata within F5b are oriented towards E and SE, lying at a high angle to the palaeoflow direction indicated by the underlying F4a (S to SW).
Interpretation

The overall tabular geometry of the sequences indicates that the fluvial channels responsible for the deposition of the units migrated laterally.

It is suggested that the conglomeratic lag and hyperconcentrated flow deposits were formed during the initiation of channelization from a decelerating high energy flow. With further decrease in flow velocity, the curve-crested dunes migrated on the lag-veneered channel floor, depositing the trough cross-bedded coarse sandstone. These dunes, which were probably present in the deeper parts of the channels, were covered up by laterally accreting macroform(s), occurring in the shallower parts, thus producing units with lateral accretion bedding overlying the trough cross-bedded units. The overlying macroform can either be a transverse bar or a point bar, which accreted periodically. During the intermittent low flow stages, small curve-crested dunes presumably migrated across the accretionary faces.

Assuming that the accretionary beds formed at the high flow stage and the underlying sequence of trough cross-beds at low flow stage, the thickness of the FO₃ closely approximate the bankfull depth of the channels (cf. Collinson 1986). Thickness of the FO₃ (less than 1m) indicate that the channels represented by these deposits were rather shallow.

SOME COMMENTS ON THE NATURE OF JABALPUR FLUVIAL SYSTEM

In the course of the Jabalpur sedimentation history, a periodic subsidence of the basin along with a concomitant upliftment of the source area perhaps produced the observed sequence of multistoried channel-fills, interspaced with floodplain fines. Most of the tabular sandbodies of the Jabalpur Formation are interpreted to be braid channel deposits. The then Jabalpur river was supposedly quite big and a deep one, as suggested from the large size of the hydrodynamic bedforms preserved in it. At least two types of channels existed - a deep channel (FO₁ and FO₂) and a shallow channel (FO₃).

The mudstones are floodplain deposits. In published literature the importance of floodplain deposits in the braided river sequences has been grossly underemphasised. However, recent researches in the braided rivers indicate that the floodplains are an important component of braided alluvial plain (Bridge 1985, Brierley 1991, Reinfields and Nanson 1993). In braided
rivers, however, the floodplains are discontinuous features and area wise they are less extensive when compared to the floodplains of the meandering rivers (Reinfields and Nanson 1993). Study of the Jabalpur Formation indicate that given an adequate quantity of the fine-grained sediment load and a net aggradational setup, significant amount of fines can accumulate in the floodplains of the sandy braided streams. Overall sand-dominant nature of the Jabalpur Formation with locally thick but laterally discontinuous mudstone facies closely resembles the features of the floodplains of the present day braided streams.

The overall palaeoslope of the Jabalpur basin was towards southwest. Evidences of episodic high discharge, and the presence of large bar complexes make the Jabalpur fluvial system comparable to the high gradient braidplain river systems (cf. Williams and Rust 1969, Smith 1971, Miall 1977, 1985 etc.).

Fluvial bars generally accrete at moderate to high angle to the local channel direction (Allen 1963, Bluck 1976, 1979, Cant and Walker 1978, Collinson 1986, Todd and Went 1991). Given a random preservation the bar cross-beds should display a bimodal distribution of their orientation, symmetrically disposed about the mean channel flow direction (cf. Rust 1972). In the Jabalpur Formation the trough cross-beds show a dominantly southerly flow direction, whereas the data from the large planar cross-beds are weakly bimodal with dominant mode towards west. Assuming that the trough cross-beds more reliably reflect the orientation of the channel direction (Harms et al 1963, High and Picard 1974), distribution of the planar cross-beds of the Jabalpur Formation would imply preferential preservation of west-ward migrating bars (Bluck 1980, Hazeldine 1983, Todd and Went 1991). Todd and Went (1991) have discussed in details the autocyclic and allocyclic controls that may cause such preferential preservation of the bar cross-beds. Normal autocyclic processes can result in such bias, when the examined sequence constitute the margin of an alluvial cone or margin of the drainage basin, where record is likely to be biased in favour of the channels combing in the direction away from the margin of the alluvial cone or the basin. Major allocyclic controls include the tilting of the floodplain towards the basin margin due to faulting (Alexander and Leeder 1987). Tilting and subsidence would normally effect a rise in the base level which in its turn would help aggradation of the channel deposit as the channel combs across the floodplain. A tectonic tilt model is preferred for the Jabalpur Formation because beside the explanation for the distribution pattern of the planar cross-beds, it allows for the explanation of comparatively thicker floodplain fines in the braided river
deposit of the Jabalpur Formation. Also, increased proportion of fines in an alluvial suite is interpreted to reflect rapid subsidence and/or rise of the base level (Blackey and Gubitosa 1984). A similar situation in the Jabalpur sequence (i.e., compared to many other braided river deposits greater proportion of the floodplain fines) is more likely to be explained by the model envisaging tectonically induced subsidence.

In some parts of the Jabalpur fluvial system the occurrence of confined channels within stabilised muddy banks, and the suggestion of multiple co-existent fluvial channels indicate an anastomosed pattern. The transition from the braided to anastomosed style might have resulted either due to change in the basin slope or some other climatic factors.