CHAPTER VI

FACIES ANALYSIS

INTRODUCTION

A detailed and meaningful interpretation of the stratigraphic sequence under study required its subdivision into units of similar aspects - the basic "building blocks" which are generally termed 'facies'. The facies can be considered as a distinctive rock body that differs from vertically and laterally adjacent body by its physical, biological or chemical characteristics (Harms et al. 1975). A facies should ideally be a body of a rock that forms under certain conditions of sedimentation, reflecting a particular process or environment (Reading, 1986).

In the present study various facies have been recognised and defined on the basis of their colour, texture, bedding types, sedimentary structures, biogenic structures and fossils, and sediment dispersal pattern. In defining and designating the facies, emphasis have been placed on sedimentary structures and bedding sequences which are considered the most important tools for interpretation of depositional environment of clastic rocks (Harms et al., 1975). Thus, five types of clastic facies have been recognised which include planar and tabular cross-bedded sandstone facies, trough cross-bedded sandstone facies, horizontal bedded sandstone facies, ripple bedded/flaser bedded sandstone facies, and silty shale facies. In addition,
two essentially carbonate facies were identified and consist of fossiliferous wackestone-packstone and terrigenous carbonate mudstone (micrite).

The second step in facies analysis consisted of establishing the facies sequence and association. The sequence in which the facies occur provides as much information as the facies themselves (Walker, 1984). Facies associations are groups of facies that occur together and are considered to be genetically or environmentally related (Reading, 1986).

The type of contacts between facies were studied with a view to determining whether the facies immediately followed each other in time by the migration of depositional environments or originated in widely separated environments. The study of facies sequence also helped in evaluating cyclicity of sedimentation.

FACIES : DESCRIPTION AND INTERPRETATION

Planar and Tabular Cross-bedded Sandstone Facies

Description:

This facies is dominant in the eastern sector of the study area at different localities including Surpan, Mohan, Galesar, Sadiwasan and Rajawat Chicklee. In the eastern sector, the facies is rare and occurs at Khurwat. It generally forms the basal part of the different sections. The facies has a maximum thickness of 12.5 m at Surpan and minimum of 1 m at Sadiwasan.
The facies comprises white to rusty brown, coarse to fine grained, moderately sorted to well sorted, fine to coarse-skewed sandstones. The sandstone are texturally immature to submature. Multiple sets of planar cross-bedding are dominant in the facies. The sets of cross-bedding are 5 to 43 cm thick and occasionally much thicker up to 80 cm. They show regular set boundaries and straight foresets. The inclination angle of foresets is variable; it is steeper (24° to 29°) in some sets, and gentler (8°-15°) in others. The average angle of inclination of foresets is 20°. At Mohan, foresets of cross-bedding show recumbent folding as a result of penecontemporaneous deformation. The cross-bedding sets show many characteristic features such as sigmoidal foresets and convex upward foresets. The sets of cross-bedding are inter-bedded with thin layers of green and purple shales and ripple bedded sandstones. Large scale cut-and-fill structures filled with laminations paralleling the lower surface and troughs occur interbedded with the planar cross-bedded sandstones.

The facies is on average medium grained, moderately well sorted, near symmetrical and mesokurtic. With decreasing mean size, sorting improves, skewness changes from negative to positive and kurtosis becomes more variable. On improvement in sorting the sediments become negatively skewed and platykurtic.

The facies generally shows upward fining grain size and improvement in sorting, well exhibited in the Mohan and Surpan sections (Fig. 31, 33). However, coarsening upward sequences in
the facies also occur, for example at Galesar.

The palaeocurrent pattern of the facies reconstructed on the basis of large-scale planar cross-bedding is generally bimodal and bipolar. However, the pattern is bimodal with the two modes at 90° at Khurwat and unimodal at Surpan.

Interpretation:

The erosive base, upward fining size and association with shales suggest that the facies was deposited in channels. The cosets of planar cross-bedding in the facies were deposited by a train of migrating sandwaves or bars. In general the bedforms had a straight depositional foreset plane. The process that caused accretion of the lee face did not erode the surface over which the later migrated. However, deposition of planar cross-beds was often interrupted by either lower or higher velocity current as is evidenced by interbeds of ripple bedded sandstone and large-scale cut-and-fill structures. The small ripple bedding suggest a decline in current velocity and deposition by small ripples under conditions, where relatively less sediment was available and reworking was stronger. The small ripple-bedded sandstone and shales abruptly overlie the large-scale planar cross-bedded sandstone with a sharp contact thereby indicating sharp fluctuations of currents. The cut-and-fill structures also suggest a sharp increase in current velocity which eroded the depositional surface, followed
by a sharp decline in the currents when sand was deposited from suspension with in the eroded through.

Ripple cross lamination (Plate VA) resemble tidal bundles (Visser, 1980; Terwindt, 1981, Reineck and Singh, 1980). Deformed cross-bedding of the facies resembles that reported mainly from fluvial environment (See Allen, 1982). The lateral persistance, similar form and recumbent nature of the folds suggest that deformation has resulted from current drag on the upper surface of the cross-bedded sands which was liquidized at the time of deformation (Allen & Banks, 1972). Penecontemporaneously deformed cross-bedding though mainly reported from fluvial deposits, can also occur in other environments. Allen & Banks (1972) demonstrated that it could result from the drag of ordinary river or tidal currents, provided the sand was liquidized.

Some features of the facies suggest a tidal environment. For example, the sediment dispersal of the facies is generally NNW and SSE directions. The average angle of dip of planar cross starta is commonly 30° or more, i.e. close to the static angle of repose (Harms et al., 1975). The gently dipping cross-beds (8 to 10°) in the facies may be a product of tidal reworking (see Dalrymple, et al., 1975). Mud drapes over sets of cross-bedding also suggest tidal processes.

To summarise, the facies was deposited in channels in which sand was transported mainly as bed load in the form of straight-
crested becforms. The channels were frequently subjected to current fluctuations and were in all probability tidally influenced.

**Trough Cross-bedded Sandstone Facies**

**Description:**

This facies occurs mostly in the eastern part of the study area at the localities Umrali, Walpur, Hatwee and Tamria. The facies is generally 2 to 4.5 m thick; at Walpur and Tamria it shows greater thicknesses of 11 m and 16 m respectively. The facies comprises light coloured sandstones showing purple grey and brown shades. A variant of the facies is trough cross-bedded pebble sandstone facies which is 3 m thick and occurs at Umrali, overlying the horizontal bedded pebbly sandstones. The sandstones are coarse grained, granular and trough cross bedded.

The facies and its pebbly variant are characterized by multiple sets of large-scale trough cross-bedding. The sets of cross-bedding are 8 to 40 cm thick. The foresets show graded bedding. The inclination angles of foresets range from 10° to 20°. At Tamria the facies is closely interbedded with planar cross-bedding.

The sandstones are fine to medium grained and contain granule-size quartz grains in the basal part of the section at Tamria. They are moderately sorted to well sorted and fine to coarse skewed. The textural maturity of the sandstones is highly variable and ranges from supermature to immature. On average, the sandstones are fine.
grained moderately well sorted, near symmetrical and mesokurtic. Decrease in mean size is accompanied by improvement in sorting, change from positive to negative skewness, and decrease in kurtosis. Improvement in sorting is related to change from negative to positive skewness. Kurtosis decreases with a change from positive to negative skewness.

The facies shows upward fining mean grain size at Tamria and Walpur, where it is considerably thick. However, sorting both decreases and increases upward.

The palaeocurrent pattern of the facies is bimodal at Walpur and indicates sediment transport in SW and SE directions. The bimodal pattern at Hutwee suggests reversing currents oriented WNW and SE; the WNW currents being stronger. At Tamria the palaeocurrents pattern is unimodal and directed WSW. In the pebbly variant at Umrali, Palaeocurrents are directed ENE to N.

**Interpretation:**

The erosive base, upward-finig grain size and upward passage into ripple-and flaser-bedded sandstones suggest that the facies was deposited in a channel by trains of migrating dunes.

The marine influence on the channels is demonstrated by close association of the facies with fossiliferous wackestones which occur as thin interbeds within the facies and contain open marine fossils. The tidal influence is shown by bimodal-bipolar cross-bedding, such
as at Hutwee. With in the channels, the bedforms migrated mainly in the WSW to WNW direction. However, sediment was also dispersed SE to some extent. The facies is interpreted to represent within channel sediments deposited in deeper subtidal part of an estuary where marine influence was more pronounced.

**Horizontal bedded Sandstone Facies**

**Description:**

This facies was mainly observed at four localities: Hutwee, Kakanpur, Galesar, and Khurwat. It occurs associated with planar cross bedded sandstone facies.

At Hutwee the facies (1.5 m thick) occurs in a channel-fill and forms a transition from large scale trough cross-bedded sandstone facies to flaser-bedded sandstone facies. The facies comprises very fine to medium grained, moderately well sorted, near symmetrical and texturally immature sandstones.

At Galesar, Kakanpur and Khurwat the facies occurs interbedded with planar cross-bedded sandstones and forms a few tens of centimeters to 2 m thick deposits of moderately sorted to well sorted, fine to medium grained, texturally immature sandstones. At Kakanpur, where thicker channel-fills occur some beds appear massive without any well-defined structure.

A variant of this facies, horizontal bedded pebbly sandstone facies occurs in the eastern part of the study area at Umrali. It is 3 to 4 m thick and consists of white coarse grained, very well
sorted, granular sandstones with abundant pebbles. The pebbles range in size from 1.5 to 3 cm, and are subrounded to rounded. The pebbles are generally composed of quartzite and jasper. The sandstones are horizontal bedded and pebble layers parallel the bedding. On average, the horizontal bedded sandstones are medium grained, moderately well sorted, fine skewed and leptokurtic. With decreasing grain size variability of both sorting and skewness increases, but that of kurtosis decrease. Both sorting and kurtosis decrease along with a change from positive to negative skewness.

**Interpretation:**

The horizontal bedded sandstones can be deposited by different processes in different environments (Rejnold and Singh, 1980). The facies of the study area which forms part of a channel fill, for example, at Hutwee, in all probability represents deposition under plane bed phase of a high flow regime. The horizontal bedding can be formed by both the migration of low relief bed forms and the turbulent brusting processes (Paola et al. 1989).

The horizontal bedded pebbly sandstone facies also appears to be a product of sand deposition under upper flow regime plane bed conditions. The alternation of pebbly layers with sandy layers does not indicate a great amount of current fluctuations (Harms et al., 1975). Relatively small fluctuations of flow strength can cause either rolling of gravel on the bed with suspension of sand or cessation of gravel rolling and simultaneous deposition of sand.
The origin of massive sandstone beds occurring in association with horizontal bedded sandstones within large channel-fills at Kakanpur cannot be attributed to bioturbation as there is hardly any evidence of organic activity in the beds. Their occurrence in large channels rather suggests rapid sedimentation and dumping of the sediment as a homogenous mass.

Ripple-bedded and Flaser-bedded Sandstone Facies

Description:

This facies is well developed in the eastern part of the study area occurring at Walpur, Hutwee, Khurwat and Tamria. It is far less developed in the western part of the area and forms thinner units at Surpan, Mohan and Kakanpur. The facies is generally 1 to 4.5 m thick, but at Walpur and Tamria it is 12 m and 12.5 m thick respectively. At Kakanpur, sandy content is higher in the facies which comprises 10-30 cm thick essentially sandstone units alternating with 20 to 120 cm thick units of interbedded sandstone and shales.

The facies comprises white to light brown, calcareous sandstones with very thin (mm-thick) olive and chocolate shale partings occurring as discontinuous layers, lenticles and flasers. The sandstone layers are 1 mm to 1.5 cm thick. Shale pebbles are common.

The sandstones show uneven ripple bedding, lenticular-bedding and flaser-bedding. The sandstone lenses show planar cross-bedding. Occasional single sets of large-scale planar cross-bedding and trough
cross bedding occur within the facies. Straight crested, asymmetrical ripple marks of average 5-8 cm wave length and interferences ripple marks are common on the bedding surfaces. Small-scale troughs (rib-and-furrow) are developed on the foresets of the large-scale planar cross bedding and are oriented at 90° in the Hutwee section. Bioturbation and cyclic deposits were observed in the facies. The lower part of the facies appears massive as a result of bioturbation. The cyclic deposits comprise individual cycles of average thickness of 5 cm. Commencing with very fine sandstone and gradually passing upward into purple shales.

The sandstones are fine to very fine grained, moderately sorted to moderately well sorted and fine skewed to coarse skewed. On average, the sandstones are fine grained, moderately well sorted, near symmetrical and platykurtic. With decrease in mean size, sorting and kurtosis also decrease and skewness changes from positive to negative. Improvement in sorting is accompanied by an increase in kurtosis and change from negative to positive skewness. Layers of medium sand (1.5 φ to 2.0 φ) alternate with those of very fine sand (3.5 φ to 4.0 φ). The individual layers consists of either well sorted medium sand or well sorted, very fine sand. However, such thin sections as a whole show moderate sorting. Bioturbation in certain layers has resulted in mixing of the two size populations and poor sorting.

At Surpan, Walpur and Tamria, where the facies is considerably thick (8.5-15 m thick) vertical variation in grain size parameters could be properly evaluated. In general, the facies is characterized
by an upward-fining cycle. Sorting improves upward and skewness changes from negative to positive.

At Mohan, palaeocurrents reconstructed on the basis of single sets of large-scale cross bedding occurring in the facies suggest southerly transport of straight crested sand waves and bars and westerly migration of dunes.

**Interpretation:**

The facies shows many features characteristic of tidal deposits which have been described by Van Straaten, 1954; Klein, 1970; de Raaf & Boersma, 1971; Reineck, 1972, Boersma & Terwindt; 1981; Törwindt, 1981, 1988; The features suggesting a tidal origin of the facies include very thin, flaser and lenticular bedding, a general fining upward sequence, drainage ripple cross-lamination almost perpendicular to megaforesets, interference ripple marks and micro scale cyclic deposition and shale pebbles.

An intertidal environment is indicated by small ripple bedding developed almost perpendicular to the large-scale foresets which represent drainage via the trough of the sand waves at the time of emergence. An intertidal origin is also supported by the occurrence of shale pebbles.
Laminated Siltstone-Shale Facies

Description:

This facies is generally highly weathered and hence it is difficult to observe its features. The facies was observed mainly in five sections: Surpan, Mohan, Hutwee, Tamria and Khurwat where it generally overlies the flaser bedded-ripple sandstone facies. At Tamria the facies is thickest (12.0 m thick). It comprises mainly laminated siltstones interbedded with very fine to medium grained calcareous sandstones and shales. The silt layers, when examined under the microscope, show alternation of coarse, medium and fine (Plate XV A,B) silt and abundance of mica flakes. Cross-lamination occur occasionally in silty layers. The layers are generally well sorted. The sandstones are moderately to well sorted, and fine-to strongly fine-skewed, and texturally submature.

At Mohan, the facies comprises 2 m thick parallel laminated red shales overlying the multiple planar cross-beded sandstones facies. The upper 10 cm of this shaly unit is olive coloured. The shale unit is overlain by a 70 cm thick upward-fining cycle which comprises a 50 cm thick cross-beded sandstone overlain successively by 12 cm thick ripple laminated sandstone and 7 cm thick chocolate and olive shales.

Interpretation:

The fine grain size and absence of current generated
Plate XV  

(A) Laminated siltstone-shale facies (x 64, uncrossed)  
Dark irregular carbonaceous patches are marked by arrow in the upper right part of the photograph, Mica is abundant.

(B) Laminated siltstone-shale facies (x 64, crossed)  
Coarse layers alternate with finer layers near the bottom of the photograph.
sedimentary structures suggest that the facies was deposited from suspension in low energy environment. A characteristic feature of this facies is thinly interlayered bedding, which is rather common in intertidal flats and river estuaries (Reineck and Singh, 1980).

**facies and its position**

The occurrence of marine fossils within the immediately below the fossiliferous wackestone-packstone facies at Tamria and Hutwee suggest involvement of basinal processes in its deposition. Since the facies overlies an upward-fining channel fill sequence at Surpan, Tamria and Hutwee, it represents deposition at the end of a channel migration. The facies was deposited from suspension under quiet water condition, at the end of a channel migration, when supply of clastics became deficient and marine influence increased.

**Terrigenous Micrite Facies**

**Description:**

The facies occurs only in the eastern part of the study area at the localities Walpur, Hutwee, Khurwat and Tamria where the thicknesses of the facies range from 1 m to 4.5 m. The facies comprises yellow-brown, thinly laminated terrigenous micrite (Plate XVI A) often interbedded with very fine calcareous sandstones. Bioclasts are scarce and difficult to identify because of recrystallization. Laminated and brecciated crusts, intraclasts and pisolitic structures are common. The facies generally forms the topmost part of different sections and shows extensive replacement by cryptocrystalline silica. In the
Plate XVI  

(A) Terrigenous micrite facies. Note scarce, recrystallized bioclasts near the bottom left and top right of the photograph (x 64, uncrossed).

(B) Fossiliferous packstone containing poorly sorted and large bioclasts (x 64, uncrossed).
Walpur section this facies has a maximum thickness of 4.5 m and occurs at the base of the section. Here the facies shows an upward change from continuous wavy bedding to nodular bedding concomitant with an upward increase in shale content from 5 per cent to 20 per cent.

**Interpretation:**

This facies represents intertidal-supratidal deposition as is evidenced by laminated and brecciated crusts, intraclasts and pisolithic structures. The facies may have been deposited during the period of low siliciclastic influx or in isolated pools or along base with in siliciclastic tidal flats. The facies shows characteristics of the facies belt 8 of the carbonate depositional model constructed by Wilson (1975) which represents very shallow, cut off lagoons and coastal ponds with restricted circulation.

**Fossiliferous Wackestone - Packstone Facies**

**Description:**

This facies occurs in the eastern part of the study area, associated with terrigenous micrite and shales, at the localities Walpur, Hutwee, Khurwatt and Tamria. The facies is 10 cm to 2 m thick. In the Tamria section, this facies occurs at two horizons, the first one is very thin (10 cm thick) and occurs interbedded with planar and trough cross bedded sandstones. The facies comprises white to light grey fossiliferous wackestones - packstones which show persistent
wavy and sometimes lenticular and nodular bedding. The bedding thicknesses range from 4 to 12 cm. The wackestones and packstones (Plate XVI B) contain bioclasts of bryozoa, echinoderm and gastropods etc. The bioclasts are poorly sorted and include very large fragments of bryozoa. Some echinoderms grains are glauconitized. A thin band of intraclastic bryozoa grainstone lies at the top of this facies at Hutwee. The intraclasts comprising dark brown micrite show variable size and roundness. In the upper part of Khurwat Section, the fossiliferous wackestones and packstones are overlain by terrigenous micrite.

**Interpretation:**

The facies shows characteristics of facies belt 2 (open sea shelf facies) and facies belt 7 (open marine platform facies) of the Wilson Model, both of which in many respects are similarly formed (Flugel, 1982). However, close association of the facies with the terrigenous micrite facies (Facies belt 8) favours an origin in the facies belt 7. This implies deposition in open lagoons, bays and straits with moderate water circulation, normal marine to somewhat hypersaline conditions, and shallow water depth, generally a few metres to tens of metres deep.

**FACIES ASSOCIATIONS**

The various lithostratigraphic sections measured in the study area showed much vertical facies variations. However, a broad cyclic association of facies is discernible in the various sections, especially
in the eastern sector of the study area (Fig. 46). The various facies can be arranged into two types of associations: (1) an upward-fining facies sequence consisting of three facies which are, from base upward, cross bedded sandstone facies, flaser bedded/ripple bedded sandstone facies, and horizontal bedded sandstone facies; (2) a carbonate, shale association comprising fossiliferous wackestone-packstone, terrigenous micrite and shales.

The upward fining sequence comprising the three facies is well developed in the eastern sector of the study area, especially at Tamria where it is considerably thick (45 m thick) and shows thickly developed individual facies. At other localities in the eastern sector the upward fining facies association is developed on a smaller scale and their thicknesses range from 5.5 to 12.5 m. The association is overlain by carbonate-shale association, and underlain by flaser bedded/ripple bedded sandstone facies. At Hutwee two fining upward facies associations are superimposed. The western most locality of the study area, Surpan also shows a well developed upward fining facies association which is overlain by carbonate-shale association, as in the eastern sector.

The upward fining facies association was deposited in subtidal and intertidal channels. The cross bedded facies (mostly trough cross bedded) forming the base of the association represents within channel sediment deposited in deeper subtidal part of an estuarine channel where marine influence was more pronounced. The over-lying flaser
Fig. 46 Cretaceous facies associations in the eastern sector of Rajpipla-Jobat area, Lower Narmada basin.
and ripple bedded sandstone facies was deposited mainly in the inter-
tidal environments.

The laminated siltstone-shale facies forming the top of the
upward fining sequence represents deposition on inter-channel
flats. The facies sequence in the western part of the study area
(Fig. 47) is rather different from the well-organised upward fining
sequence generally observed in the eastern sector. The channel fills
in the western sector are characterized by abundance of planar cross
bedded facies and absence of flaser and ripple bedded sandstone
facies as well as carbonate-shale association. That the channels
were braided is evidenced by several features such as lack of internal
organization, abundance of tabular sets of cross bedding, both upward
fining and upward coarsening grain size and cut-and-fill structures
(see Walker and Cant, 1984, Collinson, 1970). These channels flowed transverse to
the Narmada embayment and brought sediment from highlands at the
basin margin.

The carbonate shale association comprises three facies which
include terrigenous micrite facies, fossiliferous wackestone-packstone
facies and shales. The terrigenous micrite facies was deposited in
very shallow cut off lagoons and coastal ponds with restricted circula-
tion, during the period of low siliciclastic influx. With an increase
in the depth and circulation of water, fossiliferous wackestone-
packstone facies were deposited. The carbonate shale association thus
represents deposition in water of restricted to moderate circulation
where depth ranged from a few metres to tens of metres.
Fig. 47 Cretaceous facies changes in the Western sector of Rajpipla-Jobat area, Lower Narmada basin.
DEPOSITIONAL MODEL

The Cretaceous sediment in the Rajpipla-Jobat area of the lower Narmada Basin were deposited in channels, interchannels flats, lagoons and bays. There were large, deeper estuarine channels that flowed westward along the basin. Transverse channels brought sediment from the Satpura highlands located at the southern boundary. These channels were braided, tidally influenced and dominated the western sector of the area. The interchannel areas, especially in the estuarine part, were occupied by mud flats.

When channels migrated and supply of clastic sediment ceased, sediments of carbonate-shale association were deposited in ponds, lagoons and bays.