CHAPTER IV

FACIES ANALYSIS AND DEPOSITIONAL MODEL

INTRODUCTION

The concept of facies has long been used in correlation and predicting particular rock units. The term 'facies' was first introduced by Gressley (1838) and is much debated and described by Teichert (1958), Krumbein and Sloss (1963), Middleton (1973), Reading (1978) and Miall (1984). A facies is defined on the basis of colour, bedding, composition, texture, structure and fossil content. In biofacies, prime consideration is given to biological contents. In the absence of fossils, emphasis is given to the physical and chemical characteristics of the rocks and the term lithofacies is appropriate (Reading, 1978). Initially the term lithofacies was used in a wide sense, but at present it is considered that each lithofacies represents an individual depositional unit (Miall, 1984). Lithofacies associations or assemblages characterise particular depositional environments.
Facies models characteristic of fluvial, deltaic, laccustrine, eolian, clastic shorelines, clastic and carbonate shelves, continental slope and deep oceanic environments have been proposed by several workers and are reviewed in Reading (1978) and Miall (1984, p. 186-201). Following these proposed models, study of Bailadila metasediments is carried out.

For identification of different facies, lithology, colour, rock unit and coset thickness, bed or set thickness, texture (grain size and sorting), rock unit and bed contacts, bed geometry and sedimentary structures have been considered. Sedimentary environments were inferred on the basis of geometry, facies sequences and facies associations.

FACIES ANALYSIS:

The Bailadila Group comprises both clastic and chemogenic sediments, developed in different environmental settings. These lithological units are described in terms of their inferred protoliths. Based on the facies analysis, four apparently recognised facies associations are, viz. 1. Shelf facies association, 2. Fan delta facies association, 3. Basin plain facies association, 4. Alluvial fan facies association.

1. Shelf facies association

The shelf facies association comprises (a) laminated mudstone facies (F1m), (b) laminated ferruginous
mudstone facies (Flfm), (c) chert-iron rhythmite facies (Fcr) and (d) oxide-rich banded iron facies (Fbif). This facies association (except Flm) is well developed towards the top of Loa Formation and in Kailash Nagar Banded Iron Formation.

The laminated mudstone facies (Flm) is characterised by thinly laminated mudstone layers (now metapelite). This facies is well developed in Bhanshi Formation, and conformably overlies the metabasalts. The laminations in these mudstones vary in thickness from 0.2-0.6 cm, and are parallel continuous. This mudstone lacks in wave generated structures or synsedimentary deformational structures. Mineralogically these are composed of muscovite-sericite and minute amphiboles altered to chlorite. Occasional presence of altered volcanic glass fragments suggests minor pyroclastic input.

The remaining three facies (Fig. 34), i.e. laminated ferruginous mudstone (Flfm), chert-iron rhythmite (Fcr) and oxide-rich banded iron facies (Fbif) occur in close association in the upper part of Loa Formation and Kailash Nagar Banded Iron Formation. Laminated ferruginous mudstone facies (Flfm) conformably overlies Gm facies (conglomerates). Its profuse lateritization and lack of primary sedimentary structures make environmental interpretation difficult. Chert-iron rhythmite facies (Fcr) is characterised by well developed rhythmically precipitated chert (now quartzite) and iron oxide (haematite) laminae,
Fig. 34: Lithostratigraphic succession of Bailadila Group.

F.U. = Fining upward.
which vary in thickness from 0.2 to 3.5 cms and 0.1 to 2.5 cms respectively (Fig. 35). The planar parallel continuous laminations lack in current generated structures. At places this facies contain flaky haematite ores, which is developed due to supergene enrichment. The oxide-rich banded iron facies (Fbif) comprises mesobanded white to dirty white chert (now quartzite) alternating with the dark grey haematitic bands. Thickness of chert and haematite mesobands varies from 0.5 to 6.5 cms. Amalgamation of iron rich mesobands give rise to the development of massive iron ore deposits, the latter occur in lenticular masses within the oxide rich banded iron facies (Fbif). The iron-rich microbands are made up of euhedral to subhedral haematite grains showing interlocking texture. Apart from planar horizontal stratification, at places these mesobands bifurcate and coalesce (Fig. 36). Current generated structure such as oscillation ripple marks is commonly observed. Synsedimentary deformational structures (Fig. 37) and rill marks (Fig. 38) in the Fbif facies are also frequently developed.

Interpretation:

Lack of wave generated structures in Flm, Fcr, and Flfm facies is suggestive of their deposition below wave base. The conformable association of Flm facies with metabasalts and its huge thickness (600 to 1000 m) points to its deposition in a rifted quickly subsiding basin (Mitchell
Fig. 35: Well developed planar continuous laminations in chert-iron rhythmite (Fcr) facies. Locality: Bend no. 4, Bacheli-Hill top road section.
Fig. 36: Hand specimen photograph of BHQ showing alternate mesobands of haematite and quartzite. Note bifurcation in haematite bands.

Fig. 37: Well developed penecontemporaneous deformational structures in Fbif. Locality: Central block, Iron Ore Deposit 5.
Fig. 38: Rill marks are observed on BHQ surface.

Fig. 39: Cross-stratified sand bed (facies B 2.2) overlain and underlain by horizontally stratified sands (facies B 2.1).
and Reading, 1978). Sedimentation of fine terrigenous clastics would have resulted from suspension settling and subaqueous accumulation of air-fall pyroclastic debris. Laminated ferruginous mudstone facies (Flfm) conformably overlying the conglomerates (Gms) of Loa Formation is interpreted to be developed as a result of rising sea level to cut off coarse sediment supply. These shales would have been deposited below wave base by suspension settling of mud in shelf condition. The chert-iron rhythmite facies (Fcr) conformably overlying Flfm facies suggests starved basin conditions as a result of peneplanation. Rhythmic chemical precipitation of chert and iron oxides suggests an episodicity in the supply of the material and/or precipitation. Rate of episodic supply of iron and silica and its simultaneous precipitation increased upwards to give rise to the development of mesobanded oxide rich banded iron facies. The presence of synsedimentary deformational structures, ripple and rill marks in the banded iron facies an unstable shelf condition is interpreted.

2. Fan delta Facies association

This facies association is well developed in Bacheli Metasiliciclastic Formation and is characterized by the presence of graded bedding (normal and inverse), trough type cross bedding and ripple marks. The grain size in normally graded sand beds varies from coarse sand to fine
silt (2–0.008 mm) while in inversely graded sandy layers it varies from fine to coarse sand (0.125–2 mm). The cosets of cross-stratified beds are medium to thick (20–50 cm) and each cross strata having a thickness of 10–30 cm (Fig. 39). The presence of silt-mud couplets with Bouma Tae, Tbcde and Tbde beds in the psammite-pelite association (Fig. 40) along with occasional sole marks, such as ball and pillow structures (Fig. 41) are suggestive of their deposition from high to low density turbidity currents. Vertical profile sections (Fig. 42) at three stations apparently display characteristics of a turbidite sequence.

Following the turbidite facies model of Pickering et al. (1986), this psammite-pelite association has been divided into five facies classes, viz. Facies class A, B, C, D and E.

**Facies class A** : The pebbly mudstone beds belonging to facies A 1.3 correspond to the classical mudstone facies of Walker (1976), occurs at the basal part of the Bachel Metasiliciclastic Formation. These beds attain a maximum thickness of 5 m and are represented by stratified, poorly sorted, ungraded pebble/cobble of quartzite embedded in fine grained silty clayey matrix (now pebbly phyllitic conglomerates) (Fig. 3). Thin to very thick bedded (8–120 cm) massive sandstones (facies B 1.1) and thinly laminated (4–10 mm) shale (facies E 1.1) beds conformably overlie the pebbly mudstone facies.
Fig. 40: Field photograph showing psammite-pelite association (facies D 2.2) in Bachel Metasiliciclastic Formation.

Fig. 41: Field photograph showing bulbous proturbations resembling ball structures at the base of psammite beds (distance between two white dots = 4 cm).
Facies class B: This facies class contains more than 80% sand grade material and corresponds to "arenaceous facies" of Mutti and Ricci Lucchi (1972). Beds belonging to this facies class are developed throughout the column of Bacheli main and Bacheli II sections (Fig. 42), however at Kirandul it is observed only at lower part of the column. Very thick to thick bedded (85 - 22 cm) disorganised sand beds (Facies B 1.1) with flat bounding surfaces (Fig. 43) and thin (3-10 cm) disorganised sand beds (facies B 1.2) with wavy base and flat top are generally followed upwards by organised sand beds (facies B 2.1 and B 2.2). B 2.1 beds are composed of thick bedded (14-35 cm) medium to coarse sand with horizontal to near horizontal stratification, and B 2.2 beds are represented by thin bedded (2 - 9 cm) tabular to trough cross stratified sand beds (Fig. 39). Normal grading and less frequently inverse grading is commonly observed in facies B 1.1.

Amalgamation of B 1.1, B 2.1 and B 2.2 is commonly observed giving rise to Bouma Tab, Tac, Tabc divisions at all the three stations.

Facies class C: Facies C turbidites comprise sand-mud couplets showing base cut out and partial Bouma sequence development. This facies corresponds to facies C and C of Mutti and Ricci Lucchi (1972) and Walker and Mutti (1973). This is the classic turbidite facies of Walker (1976, 1978).
Fig. 43: Thick to very thick bedded disorganised sand beds (facies B 1.1) with flat bounding surface. Locality: Bacheli-Hill top road section, 0.5 km from base.

Fig. 44: Classic turbidite (Tae) observed in field at the upper part of Bacheli psammites.
and is commonly observed towards the top of the profile (Fig. 44). Thick bedded, graded (sand to mud) beds of C 1.1 and thick to medium bedded sand-mud couplets (sand 4-30 cms, mud 10-80 cm) (facies C 1.1, C 2.1 and C 2.2) with base cut out sequence (Walker and Mutti, 1973) representing Tbcde and Tbde Bouma sequences, with average sand / mud ratio of 1:1 are most abundant facies of this class. Mud dominated couplets (C 2.4) in which sand/mud ratio varies up to 1:10 are rarely observed in this turbidite.

Facies class D: Thick irregular and lenticular silt-mud couplets with more than 80% mud grade sediments are classed under D 2.2 (Fig. 40). Individual beds vary in thickness from 5-20 cm with subparallel bounding surfaces.

Facies class E: Thin to thick muddy beds characterise the facies E 1.1 occur associated with facies A 1.3. This facies is interpreted as channel levee deposit, which might have been emplaced during wanning stages of the debris flows.

Interpretation:

Facies class A 1.3 characterised by poor sorting, normal grading and angular to subrounded clasts embedded in silty-clayey matrix is suggestive of its emplacement as subaqueous debris flow in the inner fan environment. This facies pinches out southward at Kirandul, however, thin beds are observed at Bhansi, about 10 kms north of Bacheli. Facies A 1.3 represents inner fan channel
fill deposits and is overlain by thick to moderately bedded stratified muds representing channel levee deposits developed at the waning stages of debris flow.

Thick bedded disorganised sand beds (facies B 1.1) and horizontally bedded sand beds (facies B 2.1) are interpreted as to be deposited from high concentration turbidity currents by freezing of a cohesionless suspension (Hiscott and Middleton, 1979; Lowe, 1982). The graded bedded sand beds of facies B 1.2 and cross stratified beds of facies B 2.2 are suggestive of sedimentation by freezing of traction carpets at the base of high density turbidity currents, possibly lag deposits resulting from winnowing by strong bottom current and reworking of sands by tractional processes beneath dilute turbidity currents and confined channels on mid-fan lobes (Mutti and Ricci Lucchi, 1972; Mutti, 1977; Pickering et al., 1986). Facies B 1.1, 1.2, 2.1 and 2.2 resemble the mid fan association of Walker (1978). Amalgamation of these facies in the lower part of the profile (Figs. A45) is suggestive of vertical aggradation accompanied with lateral migration and gradual abandonment of channel on mid-fan delta (Moore et al., 1980).

Poorly sorted, thick bedded, graded (sand to mud) beds (facies C 1.1) are interpreted as a result of rapid deposition from muddy high concentration turbidity currents or from fluid sand-mud debris flow (Enos, 1969; Mutti et al.,
Fig. 45: Photograph showing a part of the amalgamation of facies class B, here represented facies B 2.1 and B 2.2 in Bacheli psammites.

Fig. 46: Field photograph showing chevron marks at the bottom of fine silt beds in facies E 1.2.
1978). While the beds of the facies C 2.1, 2.2 and 2.4 might have been deposited from high concentration turbidity currents with rapid settling due to deceleration of current (Pickering and Hiscott, 1985).

Thick irregular and lenticular silt-mud couplets of facies D 2.2 are considered as a result of rapid deposition under low concentration turbidity flows (Stow and Shanmugam, 1980; Stow and Piper, 1984). The laterally persistent coarse to fine-grained sand-mud couplets of facies C 2.1, 2.2, 2.4 and D 2.2 resemble to suprafan lobe facies association of Walker (1978). These facies are also characterised by base cut out sequences and Bouma Tbdde, Tbde associations. Development of suprafan lobes in outer fan overlying the mid-fan channelised sediments is suggestive of abandonment of channel or decrease in the sediment supply due to peneplanation in the provenance. Amalgamation of the general vertical aggradation facies - Inner fan → Mid fan → outer fan is suggestive of retrograding fan delta (Khan and Bhattacharyya, 1992; Bhattacharyya and Khan, 1993).

3. Basin plain facies association:

This facies association comprises varicoloured shales (Facies E 1.2), carbonaceous shales (Facies E 2.2), and bedded chert facies (Facies G-3). This facies association (Fig. 4b) overlies the fan-delta facies association and forms
the East Ridge Shale Formation. The facies class E is represented by varicoloured tuffaceous shales (Facies E 1.2) and carbonaceous shales (Facies E 2.2, Pickering et al., 1986). These shales are thinly laminated (thickness 0.2-1.5 cm), structureless and occur interbedded with bedded chert-facies (Facies G-3, Pickering et al., 1986). Facies G-3 comprises thinly laminated to thin bedded chert beds (0.7-5 cm). The shales are buff to green coloured composed of chloritic-micaceous minerals and altered volcanic glass. Individual shale beds are sharp based with few loading structures or roapy chevron marks at their base (Fig. 46).

Interpretation:

Presence of horizontal laminations continuing for 3 m in the shale facies E 1.2 and 2.2 suggests to their deposition by settling of fine clastic materials below wave base from water column and by transfer of bottom water currents. Presence of relict glass shards and nonundulatory quartz alongwith chloritic mass testimony to airfall pyroclastic debris. The occurrence of alternate chert beds (of facies G-3) suggests to chemical precipitation at the onset of silica saturation and diminished terrigenous supply. The silica in solution might have been derived due to halmyrolysis of pyroclastic material and would have got precipitated at the time of diminished terrigenous supply.
Low abundance of trace elements in chert samples compared to interbedded shales further substantiates the derivation of silica in solution as a result of halmyrolysis of pyroclastic material. The black carbonaceous shale facies (Facies E 2.2) occurring in lenticular masses associated with tuffaceous shale facies (E 1.2) is characterised by development of 0.2 - 2.5 cm thick laminae and is interpreted to have developed under anoxic conditions in the basinal lows.

4. Alluvial fan facies association

This facies association comprises massive to graded bedded conglomerate (Gms) and gritty sandstones (St). The massive to graded bedded conglomerate facies is characterised by clast and matrix supported polymictic conglomerates. The clasts include quartzite, chert, metabasalt and subordinate granitoids varying in size from boulder to pebble (24-4 cm). The size of the clast varies with the rock type showing a degree of flatness from 1.07 - 7.61 with an average of 2.39, which is comparable to the degree of flatness characteristic of fluvial conglomerates (Callieux, 1952). The sand size detritus along with chloritic mass and ferruginous material makes up the matrix in these conglomerates. Crudely cross bedded gritty sand facies (St) occurs interbedded with conglomerates in lenticular masses (Fig. 47). These sands contain mainly feldspatic rich
Fig 47: Partial measured section in a part of west ridge containing facies Gms, St and Flfm.
The thickness of the gritty sand beds varies from 0.50 - 0.70 m.

Interpretation:

The conglomerates appear to be similar to deposits attributed to hyperconcentrated flows (Nemec and Muszynski, 1982; Nemec and Steel, 1984) in which clasts are supported by turbulent suspension. Presence of stratification suggests a transition to tractive processes associated with an increase in fluid condition and high flow velocities (Nemec and Muszynski, 1982). The vertical change from conglomerate to gritty sandstones suggests a shift from debris flow to sheet high viscosity mass flow processes. 1-1.5 m thick conglomerates resemble gravel bar or sheet flood deposit developed on an alluvial braided plain (Miall, 1985). However, the lenticularity (consistent thickness vs. extensive lateral continuation, Clifton, 1973) of this conglomerate is not compatible with an alluvial interpretation. Following Swift (1968) and Harris and Eriksson (1990), it is interpreted that the lenticularity of these conglomerates is a result of transgressive reworking of alluvial conglomerates along ravinement surfaces during a gradual relative sea level rise. The development of laminated ferruginous mudstones (shales) capping these conglomerates is suggestive of sufficient sea-level rise to cut off
coarse ferruginous debris (Plint et al., 1986; Bergman and Walker, 1987).

Crudely cross bedded gritty sand facies (St) associated with conglomerates resembles both alluvial and shoreface deposits (Miall, 1985; Bourgeois and Leithhold, 1984; Harris and Eriksson, 1990). These gritty sands most probably reflect migration of megaripples in unconfined channels (Harris and Eriksson, 1990).

DEPOSITIONAL MODEL

Representative stratigraphic succession of Bailadila Group (Fig. 34) apparently displays two major fining upward sequences. These fining upward sequences represent transgressive systems tract (cf. Vail, 1987; Harris and Eriksson, 1990), resulting from tectonic movements. Above metapelites of Bhansi Formation, a subtle disconformity, fan delta - basin plain facies associations (depositional systems) together constitute a transgressive systems tract (cf. Harris and Eriksson, 1990), that records transgression of the Bailadila shelf. The second transgressive cycle is represented by alluvial fan-shelf facies associations above the East Ridge Shale Formation representing a disconformity.

The first phase of basin evolution was recorded by rifting. Presence of basalts, abundant feldspathic wackes and thick delta fan deposits, altogether provide an unequivocal evidence of rifting. The deposition of fine
terrigenous clastics (Flm) with subordinate pyroclastic component now being represented by pelites (Bhansi Formation) conformably overlying the metabasalts might have been deposited in a drowning shelf as a result of thermal cooling following rifting (McKenzie, 1978; Heller and Angevine, 1985). Continued subsidence with simultaneous upliftment in the provenance caused high erosional rate and increased supply of coarse terrigenous clastics. Absence of wave generated structures and beach facies, alongwith development of classic turbidites (Facies class C) characterises the delta front environment. Facies A 1.3 represented by pebbly mudstone beds were emplaced as subaqueous debris flow in the inner, proximal part of prograding fan delta. Facies association B 1.1, 1.2, 2.1 and 2.2 is typical of mid fan environment. Amalgamation of these facies in the lower part of the profile (Fig. 45) is suggestive of vertical aggradation accompanied with lateral channel migration and gradual abandonment on mid-fan delta (Moore et al., 1980). Facies association C 2.1, 2.3 and 2.4 represents the supra-fan lobe depositional system. The development of suprafan lobes overlying mid fan channelised sediments is suggestive of abandonment of channel or decrease in the sediment supply due to peneplaination in the provenance (Barley, 1987). Widely dispersed palaeocurrents in facies class B and C (N 173° to N 340°) are a reflection of tectonically active nature of the
basin during accumulation of mid-fan and supra-fan lobe sediments. On the basis of unusual dispersal in these deposits, the Bacheli fan delta is interpreted as an example of marginal fan in Early Proterozoic sequence. The general vertical aggradation facies inner-fan \(\rightarrow\) mid-fan \(\rightarrow\) outer fan \(\rightarrow\) basin plain is suggestive of retrograding fan delta, due to marine transgression.

The basin plain association comprising tuffaceous shale, carbonaceous shale (Facies E 1.2, 2.2) and bedded chert facies (G-3) overlying the suprafan lobe is interpreted to have developed as a result of wanning of terrigenous supply due to peneplanation of the provenance. The tuffaceous component in these shales suggests felsic volcanic activity in the provenance. The carbonaceous shales might have been developed in secondary basins experiencing restricted water circulation. The bedded chert facies developed as a result of chemical precipitation of silica. Interbedded nature of bedded cherts and tuffaceous shales points to the episodic supply of terrigenous debris.

Second cycle of basin evolution would have commenced subsequent to the uplifting of the basin, which is reflected in accumulation of polymictic conglomerates of Loa Formation which comprises clasts of underlying formations of Bailadila Group. These conglomerates appear to be alluvial deposits, although, their sheet-like geometry is not
compatible with alluvial interpretation. However, transgressive reworking of these conglomerates is evidenced by the shales, capping these conglomerates (Swift, 1968). Evenly laminated ferruginous shales (Flfm) without any wave induced structures above these conglomerates suggest outer shelf low energy environments. Due to peneplaination in the provenance terrigenous supply was constrained. The basin experienced starving conditions. However, intense chemical weathering in the provenance released ferrous iron and other constituents in solution to be delivered to the basin. An open shelf with sufficient oxygenated environment, negligible terrigenous supply, having iron saturated solution was most conducive for chemical precipitation of BIF. Rare earth element patterns with high positive Eu anomaly, evidence for a hydrothermal input into the basin, however, high positive correlation of REE with SiO along with high negative correlation with FeO, K2O, Al2O3 and TiO2 suggests different sources for the silica and iron.

Based on these studies, it could be concluded that iron in solution was derived from the chemical weathering of continental rocks, while silica was introduced into the basin from submarine fumeroles. The alternate precipitation of iron and silica in the BIF further supports to the episodic supply of iron and silica to the depositional basin, indicates episodic hydrothermal/fumerolic activity.
Occurrence of penecontemporaneous deformational structures, wave ripples and rill marks in the BIF imply development of unstable shelf conditions at the time of their deposition.