CHAPTER 5

SEDIMENTARY FACIES AND CHARACTERISTICS

The sediments exposed in the lower Narmada basin reveal a full sequence from Late Pleistocene to Holocene. As described in the previous chapter the sediments exhibit a wide variety of depositional environments. In view of this, a detailed study of the various sedimentary facies was carried out to dwell upon the depositional processes and microenvironments. The vertical stacking of the sedimentary facies indicate that the sedimentation was significantly influenced both by allogenic as well as autocyclic features. In this chapter, an indepth analysis of the major sedimentary characteristics of the Late Pleistocene fluvial sediments of the lower Narmada basin is presented.

LATE PLEISTOCENE SEDIMENTS

The exposed sediments show great variability in the lithologic and textural characteristics suggesting their deposition in varied fluvial microenvironments. Lithologically, the sediment succession comprise, fluvial silts, sands and gravels with intermittent palaeosols. Lithostratigraphic studies on the exposed Late Pleistocene sediments (Chamyal et al. 2002) have revealed a basal marine pedogenised clay of 1-2 m thickness apparently deposited during the last interglacial high sea (~125 ka). Two major lithofacies have been identified in the overlying sediments by (Chamyal et al. 2002) – the alluvial fan facies and the alluvial plain facies. The alluvial fan facies comprises two large alluvial fans, termed as alluvial fan-1 and alluvial fan-2 (Fig. 4.1) by Chamyal et al. (2002). Sedimentological details of fan-1 were already known (Chamyal et al. 1997). However, the alluvial fan-2 and sediments comprising the alluvial plain facies, which stratigraphically overlie the alluvial fan sediments (Fig. 5.1), had remained unclassified prior to this study.

Fig. 5.1. Thick fluvial deposits overlying the basal marine clays at Nanderiya

The alluvial fan facies

The alluvial fan sediments overlie the basal clays with an erosional contact. Two alluvial fans designated as Fan 1 and Fan 2 (Fig. 4.1), have been mapped in the lower Narmada basin. The Narmada-Son Fault, with a known history of tectonic activity during Tertiary and Quaternary, provided the essential geomorphic and tectonic setting for the deposition of sediments in an alluvial fan environment. Facies architecture and the dominant processes responsible for the formation of Fan 1 have been described by Chamyal et al. (1997). However, during the course of this study another contemporary alluvial fan was identified and is termed as Fan 2 (Fig. 4.1). The outcrops of this fan are less in number than the Fan 1. This is due to the fact that the present day Narmada River incises the Fan 2 across its width and not along the fan axis as is the case with Fan 1 (Fig. 4.1). However, the available sediment record of Fan 2 is as spectacular as that of the Fan 1 and allows fairly detailed determination of the fan shape, nature of the deposit and its architecture. The following lithofacies have been identified that built the Fan 2 (Fig. 4.1).

Clast supported gravel (Gc) – This facies consists of a tightly packed, unsorted, clast supported gravels (Fig. 5.2). Stratification and imbrication is found lacking. The matrix consists of finer clasts, with some coarse sand and post depositional infiltrated clay. Such post-depositional infiltration of clays in gravels is a potentially important modifier of alluvial fan deposits (Walker et al. 1978). The infiltration is readily recognisable due to the presence of appreciable amounts of interclast clays locally, otherwise is clast supported gravels. The facies shows a general coarse grain size, abruptness in internal grain size, and a poor sorting, which are indicative of deposition primarily during floods (DeCelles et al. 1991). The facies forms a small part of the exposed sections of the Fan 2, since the proximal part of this fan is unexposed. Similar facies of alluvial

Fig. 5.2. Photograph showing clast supported gravels (Gc) of Alluvial Fan 2 at Maletha (length of hammer is 30cm)

fan sediments in pre-Quaternary (DeCelles et al. 1991) and Quaternary deposits (Brierley et al. 1993) is inferred to have been deposited by hyper-concentrated flood flows.

Matrix supported gravel (Gms) – This facies comprises large sediment bodies of matrix supported poorly to moderately sorted gravels and forms the most extensively exposed deposit of Fan 2 (Figs. 5.3, 5.4, 5.5). Individual beds are traceable for tens to few hundreds of metres and usually have flat non-erosional basal contacts. Clast size range from 10-40 cm. The matrix varies from coarse to fine sand and clay. Matrix supported conglomerate facies are known to form a substantial part of alluvial fan deposits and are attributed to deposition by viscous debris flows (Schultz, 1984; Hubert and Filipov, 1989). Studies of active debris

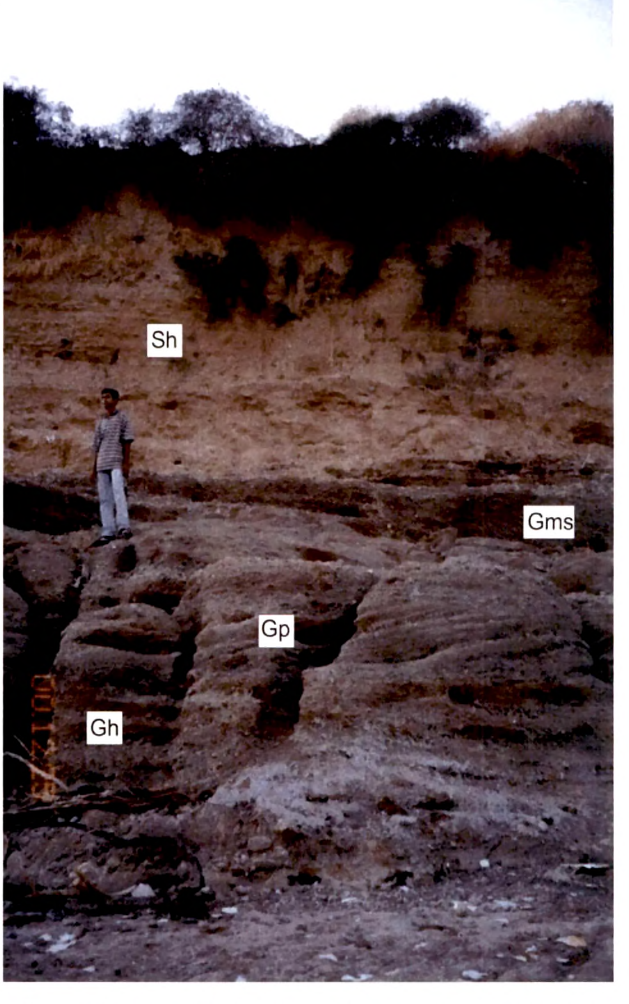

Fig. 5.3. Alluvial Fan 2 sediments (Gms, Gp, Gh) overlain by alluvial plain facies (Sh) at Nanderiya (height of the person is 1.65m)

flows in modern alluvial fan settings have shown that matrix supported and poorly sorted gravels are the characteristic deposits of viscous debris flows (Johnson, 1970; Pierson, 1980).

Horizontally stratified gravel (Gh) – This is the most dominant facies type after Gms in Fan 2. This facies comprises horizontally bedded gravel sheets (Figs. 5.3, 5.4, 5.5). These typically have flat, conformable basal contacts, which are locally scoured. Sorting is found to be highly variable from exposure to exposure. Gravel size is fairly consistent averaging between 20-30 cm. This facies is interpreted to have been deposited by sheet flood events (Miall, 1978) in which overbank style deposits spread over a fan surface with poorly defined channels (Brierley et al. 1993).

Planar and trough cross-stratified gravel (Gp and Gt) – This facies shows planar to trough cross-stratification and is moderate to poorly sorted (Figs. 5.4, 5.5). Clast imbrication is common. The foresets occasionally show steep dips upto 40°. These units are 0.5-3 m thick and show erosional bases. Grain size changes are abrupt and show no particular trends. Presence of such facies in alluvial fan sequences indicate deposition in the form of channel fills, longitudinal gravel bars and intervening channels (Nemec and Postma, 1993).

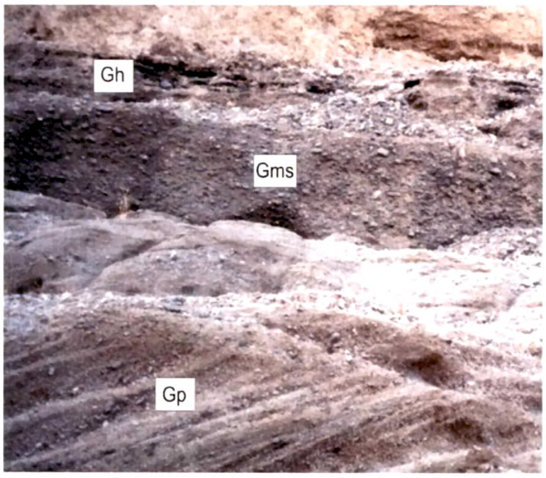

Fig. 5.4. Gp facies at Nanderiya overlain by Gms and Gh facies

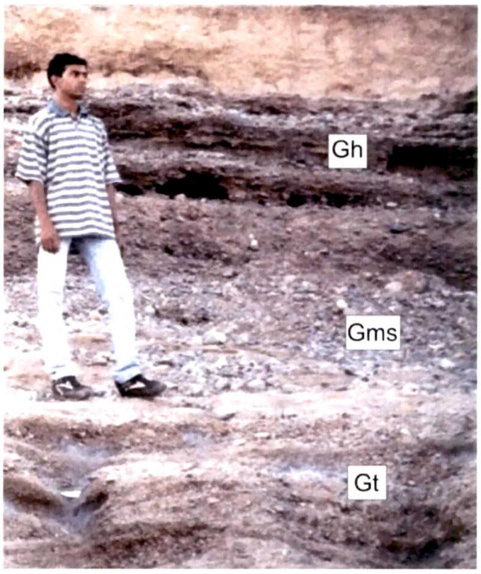

Fig. 5.5. Gt facies at Nanderiya of Alluvial fan 2 sediments

Massive sand (Sm) – This facies occurs as tabular sand sheets of 20 to 50 cm thickness. Individual beds have sharp basal contacts and can be traced laterally for tens of meters. It occurs within the Gms and Gc facies as thin structureless medium to coarse sand sheets but becomes more fine and massive towards the fan margins. This facies represent overbank deposits as in crevasse splays (DeCelles et al. 1987).

Horizontally stratified sand (Sh) – This comprises horizontally bedded (Fig. 5.3) fine to coarse sands about 20-30 m thick. These sands were deposited in upper flow regime plane bed conditions.

Planar and trough cross-stratified sand (Sp and St) – These comprise planar and trough cross-stratified medium to coarse sand units (Fig. 5.6). They are occasionally pebbly and internally graded. These facies have resulted from dune migration of lower flow regime and foresets from avalanche faces of advancing sand sheets (Miall, 1977).

Fig. 5.6. Planar cross stratified sand (Sp) at Ambali overlain by Sh facies (length of the hammer is 30cm)

The alluvial fan has been recognised by the fan shape of the deposits occurring adjacent to a tectonically active mountain front (NSF) and is characterised by coarse-grained sediments. Inspite of limitations of exposure availability in proximal reach of Fan 2, the various facies associations described above show distinct intergradation commonly observed in fan deposits. Proximal parts of fans are dominated by coarse gravel. Massive to crudely stratified, clast supported and matrix supported gravels are dominant in the middle sections, Gh and Gms however, occurs throughout the fan but show increased complexity of facies and decreasing abundance down the fan. Planar and trough cross-stratified gravels are intercalated with Gms, Gh and Gc as thin beds. Individual beds of Gc, Gms and Gh are >5 m thick. Gp and Gt vary from 2-5 m in thickness. Irregular erosional bases and channel fills are common. Fine to coarse pebbly sands make up about 50% in the distal fan sections. The most abundant lithofacies types of Fan 2 point to debris flow, sheet flow and stream channel as the dominant aggrading processes which are considered intergradational in most alluvial fan sequences (Rust and Koster, 1984). The clasts are unbedded (massive) and clast to matrix supported gravels (Gc and Gms) and horizontally stratified gravels are commonly imbricated (Gh). Thin waning flows of interbeds of sand and clay are also common alluvial fan lithofacies. Other diagnostic features of this alluvial fan are that they display considerable vertical and lateral variability of lithofacies. This is attributed to transport distance from source area to basin, the highly irregular, flashy and often catastrophic nature of the discharge which is typical of all alluvial fans and the consequent highly variable stream flow power and sediment discharge that occurs during active fan sedimentation (McPherson et al. 1987).

The alluvial plain facies

The alluvial plain sequence of the lower Narmada valley is easily distinguished from the stratigraphically older fan sediments by its finer grain size, and large scale sandy bedforms that indicate deposition by a freely meandering river in an alluvial plain. The exposed sediments were studied by preparing vertical lithologs at several places (Fig. 4.1). A large percentage (~ 70%) of these sediments is composed of stratified and unstratified overbank fines. In general, the E-W trending outcrops are largely homogenous, comprising almost entirely overbank sediments. The NNW-SSE and NNE-SSW trending cliff faces display more heterogeneous fluvial sedimentary environments.

Lithologically, the alluvial plain sediments in the Lower Narmada valley comprise fluvial sands, silts and a small proportion of clays deposited in a variety of fluvial microenvironments. A striking feature of the entire alluvial plain sequence is the large dimension of the associated sedimentary structures including channel scours and fills. The major sedimentary facies encountered include overbank fines that occur as massive and horizontal and undulatory stratified forms and associated crevasse splay and backswamp deposits, large channel fills and giant epsilon cross strata. A reddish brown palaeosol tops the overbank succession and is overlain by stratified sands and silts.

The sediments are exposed in long continuous cliff exposures along the river, which allows for accurate determination of lateral and vertical relationships of the various strata. One such outcrop, trending roughly in a N-S direction, normal to the general west oriented course of the Narmada is located at the confluence of Narmada and Orsang rivers (Fig. 5.7) deserves mention. The outcrop, about 400 m long and 35-40 m in height, exposes the full alluvial plain sequence with the distal alluvial fan facies at the base overlain by all the fluvial sediment facies mentioned above (Fig. 5.7 B). This outcrop has been particularly useful for stratigraphically constraining the various sedimentary facies exposed at other sites. Some other sections are also almost equally spectacular in dimensions but they appear to lack the completeness of the stratigraphic record of the alluvial plain facies. In the following pages the various sedimentary facies identified are described as they occur in their stratigraphic order.

Channel Fills

The channel fills observed in the lower Narmada basin are large and are well exposed in the reach between Chandod and Kanjetha. Most of the large channel fills have lost some part of their structure to the present day erosional processes of the river. However, the preservation is sufficient to allow estimation of the channel size. In lower Narmada basin, channel fills are observed at two stratigraphic levels, which are separated by the epsilon cross stratified facies (eg. Chandod, Fig. 5.7). However, all large channel fills show similar morphologic and sedimentary characteristics. In general, the channel fills of lower Narmada basin show broad and concave upward profiles, have abrupt contacts with the laterally adjacent sediments and are dominated by vertical accretion.

At Chandod, the stratigraphically oldest channel fill overlies the gravel deposits which

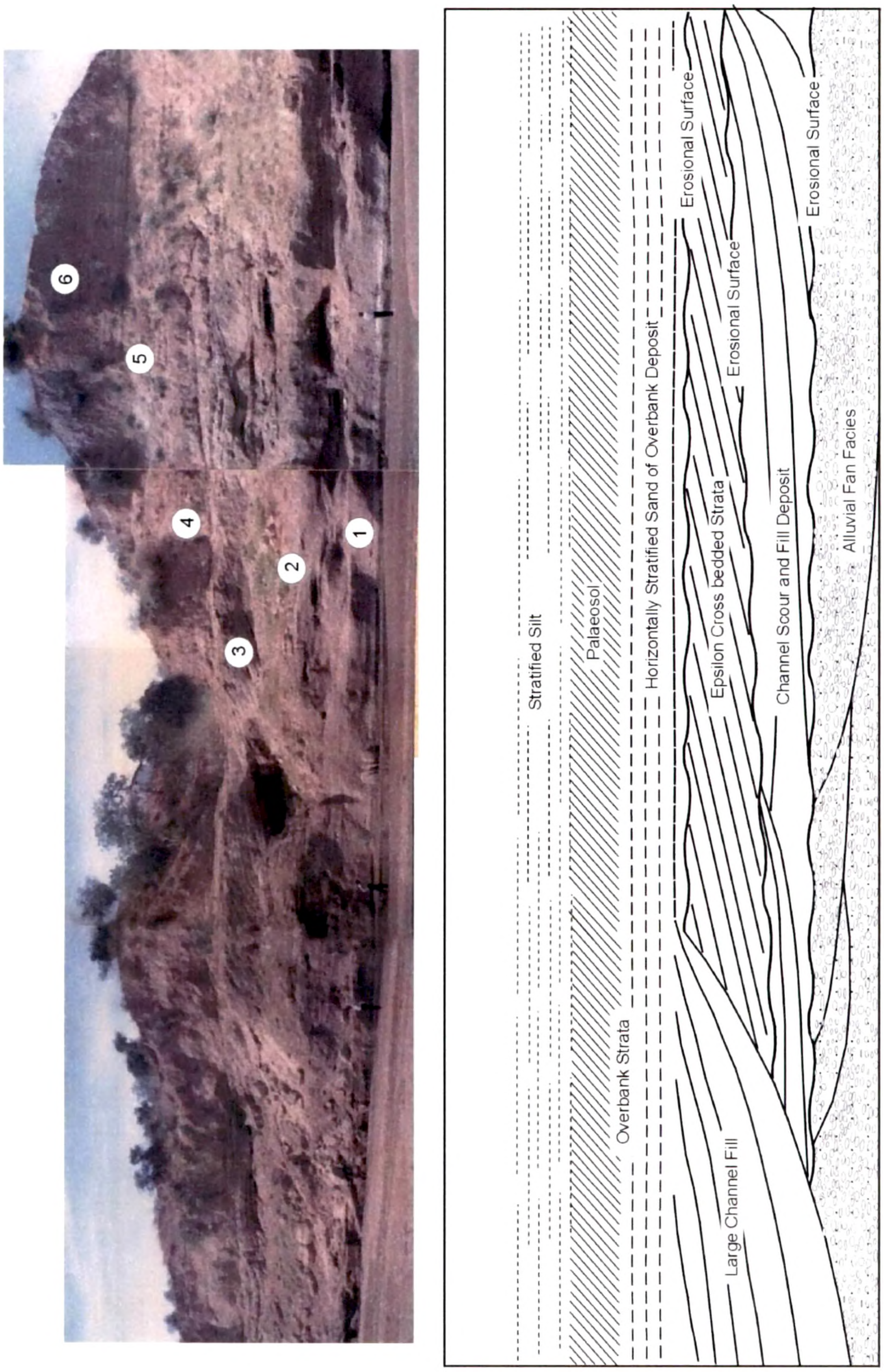

Fig. 5.7. Photomasaic of laterrallly extensive cliff exposure at Chandod. All units show erosional bases. Height of the person is 1.78m. 1. distal alluvial fan facies, 2. large channel fill sands, 3. gaint epsilon cross bed strata, 4. horizontally stratified overbank strata, 5. palaeosol, 6. thinly stratified sands and silts. The sketch figure(not to scale) shows the vertical relation of the sediments at Chandod. Note the vertical stacking of the sediments and the two generations of channel fills

belongs to the distal alluvial fan facies (Chamyal et al. 2002) with a deeply scoured base. The

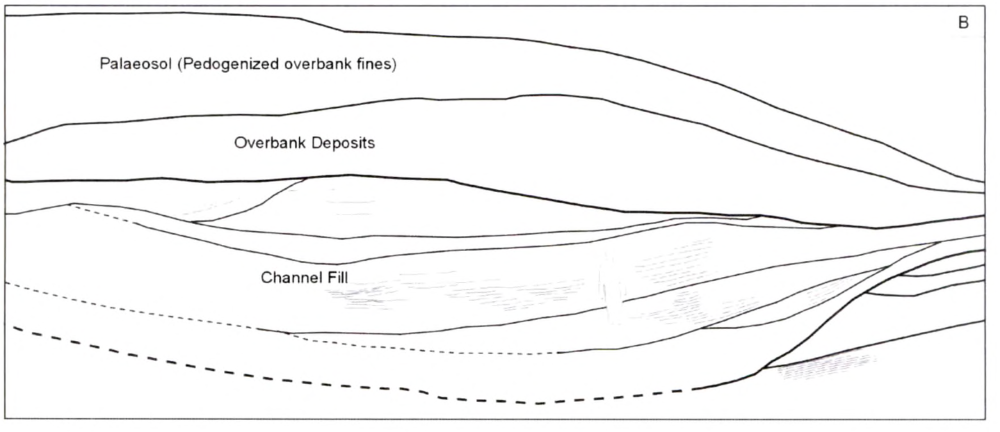

Fig. 5.8. Large channel fill structure exposed 1km downstream of Kanjetha. Note the prominent concave up geometry of the fill and the internal laminations. Tracing overlay brings out the major features of the channel fill

channel fill is overlain by epsilon cross bedded horizon midway in the succession exposed at Chandod (Figs. 5.7). The channel fill shows a gentler concave-upward geometry and is filled by vertically accreted fine to medium sands. Overall, the structure indicates a westward oriented channel that was ~70 m wide and about 4 m deep. A stratigraphically comparable large channel fill of about 70 m width and 5 m depth is located at Kanjetha (Fig. 5.8). Here, the channel fill sediments comprise concave shaped sand sheets separated by erosive surfaces that progressively become horizontal towards the top (Fig. 5.8). Each channel filling sheet is about 1 m thick along the channel axis, decreasing to 0.3 m at the margins. Internally, the sands show fine horizontal laminations and a complete absence of lateral accretion features. This suggests filling up of the channel primarily through vertical accretion in an almost standing body of water. This happens normally in chute cutoffs where deposition takes place in the remaining body of standing water after the channel is abandoned. The channel margins show low dips of 15°-20°. This suggests that the channel was not produced by incision, which is consistent with the deposition in a subsiding environment (Chamyal et al. 2002). The large channel fills can be attributed to frequent shifting of a large river in an alluvial plain. Occurrence of two large channel fills several kilometers apart in the same stratigraphic horizon indicates a river that frequently changed its course in a very short period.

The stratigraphically younger channel fill at Chandod (Fig. 5.7) indicates a much deeper and larger channel although only about 30% of the total structure is observed, the rest having been eroded away by the present river (Fig. 5.9). The channel fill is exposed at the southern

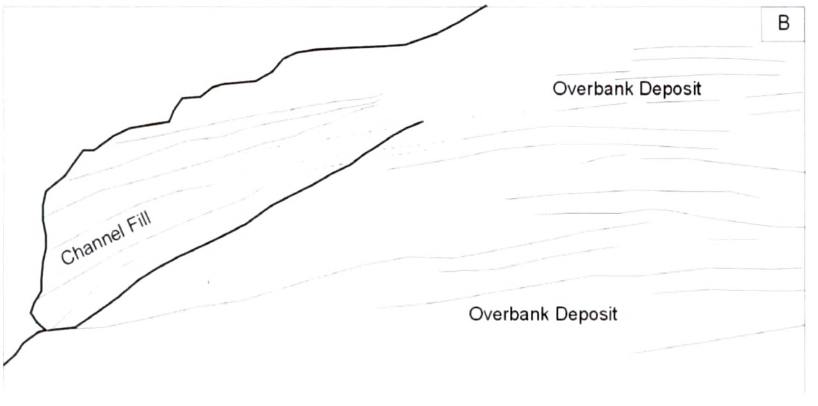

Fig.5.9. Partially eroded channel fill structure at the southern tip of the laterally extensive cliff exposure at Chandod. Tracing overlay of the photograph shows the major characteristics of the channel fill as seen in the outcrop

extremity of the ~400 m long outcrop. This channel fill occurs above the epsilon cross bedded strata (Fig. 5.7). The margin has a steep dip of about 30°. Extrapolation of the channel margin suggest a ~80-90 m wide and ~10 m deep channel. The channel trough is filled by sand sheets with concave up geometry which show internal stratification. Laterally sediments of this channel fill are found to grade into stratified overbank sands (Fig. 5.9).

Overall, the dimensions of the channel fills in the lower Narmada basin are greater than those of the present day channel. Almost all the channel troughs trend roughly west and indicate that the channel filling took place from the bottom up and to a lesser extent from the margins. The channel fill deposits are bounded by surfaces of non-deposition making them discrete geometrical sets topped by a horizontally stratified overbank deposits. More than one channel fill has been observed in the stratigraphically comparable strata though these are seen to occur tens of kilometers apart. These channels may therefore be roughly contemporaneous. They also indicate relocation of channels due to avulsion over a very short period of time. However, laterally adjacent channel fills are not seen which suggests the existence of a large single channel river.

Epsilon cross strata

The term epsilon cross strata was coined by Allen (1963) to describe large scale, gently dipping bounding surfaces that correspond to the successive increments of lateral growth of a point bar. In simple words, the epsilon cross strata are large scale, low angle point bar accretion slopes (Miall, 1996). The cross strata are lithologically heterogenous, usually consisting of alternate layers of clayey silt and sand and may vary from straight to convex upward or curved in plan (Allen, 1963). The process of formation involves erosion of the outer bank of the meandering channel from the channel floor upward and concomitant deposition on the gently sloping inner bank or point bar (Allen, 1963). Epsilon cross strata are deposited on the point bar of the channels while contemporaneous trough cross bedded sands are deposited in the channel bottoms (Mossop and Flach, 1983). The height or thickness of the epsilon cross strata approximates the depth of the channel (Miall, 1996) and can be used to estimate the channel scale (eg. Mossop and Flach, 1983).

In lower Narmada basin, individual outcrops are found to show one set of epsilon cross strata that ranges in thickness from 10-15 m (Fig. 5.7, 5.10). The epsilon cross sets normally terminate against the overlying thick bedded overbank facies. Laterally, the epsilon beds pass into horizontal strata and further away merge with the overbank deposits in the updip direction. The contact is therefore both of truncation and transitional. Fig. 5.10 shows a well defined set of epsilon cross beds. The surfaces dip 10°-15°. The epsilon cross strata consist of 25-50 cm thick beds of very fine sands with the top marked by clayey silt. The base of each stratum is sharp with evidence of small scale scouring. Each stratum is dominated by current ripple cross lamination with 5-15 mm thick ripple sets. Local occurrences of epsilon cross sets have less than average depositional dips (~5°). Such local variations are believed to represent gradation between epsilon cross stratified facies and the thick bedded sand facies (Mossop and Flach, 1983). Palaeocurrent data recorded from the epsilon cross sets and other channel troughs indicate a unidirectional pattern of transport towards the W-WSW. The palaeocurrent directions are found to be approximately parallel to the depositional strike of the epsilon cross sets.

The large scale stratification and thicker bedding of the epsilon cross strata in the lower Narmada valley indicate deposition under higher flow regime compared to the present. The deposition of this facies is attributed to lateral migration of very deep (15-20 m) sand bed river channels. Similar large scale epsilon cross bedded strata have been attributed to deposition in deep water (Jackson, 1978).

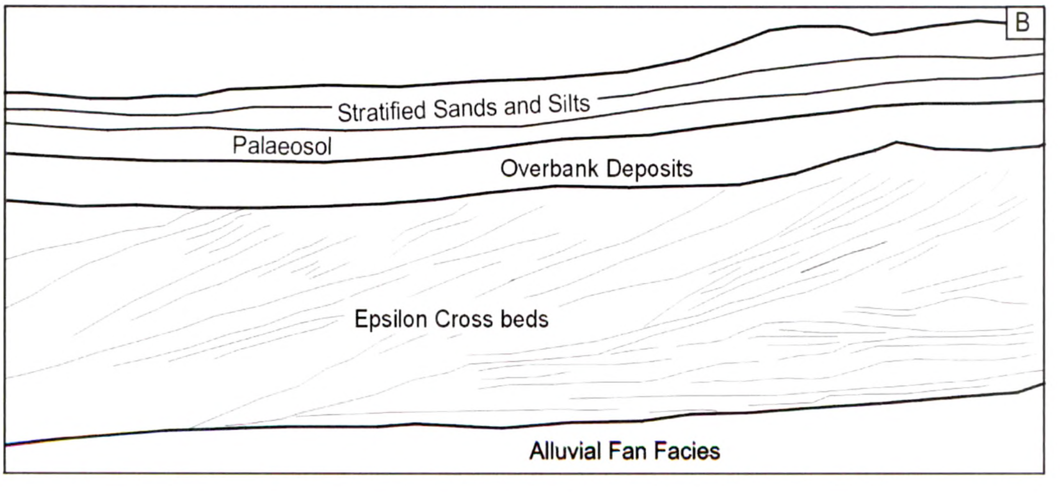

Fig.5.10. Field photograph of the Epsilon cross bedded strata 2 km downstream of Kanjetha which overlies channel fill structure. Tracing overlay brings out the Epsilon cross bedding

Overbank Deposits

Overbank deposits are defined as deposits left on the floodplain by flood waters flowing outside the normal channel. Floodplains border the channel belts of all alluvial rivers that experience overbank floods, regardless of the channel pattern. These areas receive sediment as bedload and suspended load via crevasse channel flows or sheetflows (Bridge, 1984). Apart from the flood plain, the continuum of overbank environment includes crevasse splay and backswamp deposits. In lower Narmada basin, overbank deposits overlie the epsilon cross strata and comprise following sediment types.

Horizontally Stratified Sands

This facies forms the bulk of the exposed sediment column in the lower Narmada basin. Exceptional thicknesses in the range of 20-25 m are seen in some of the cliff sections, particularly towards the mouth where the entire exposed sections consist of these sediments. In other sections, they occur with other sediment facies and range from 5- 10 m in thickness. These deposits are well exposed at Chandod, Nanderiya, Moletha, Ambali, Patan, Kanjetha and Sinor, where they comprise laterally extensive and horizontally stratified fine to medium sand sheets (Fig. 5.11). Internally each sand sheet is characterized by flat parallel laminations and they typically lack lateral accretion features. Internal stratification is generally well preserved mainly due to very weak pedogenesis. Each sand sheet shows fining upward trend and may have been deposited in a

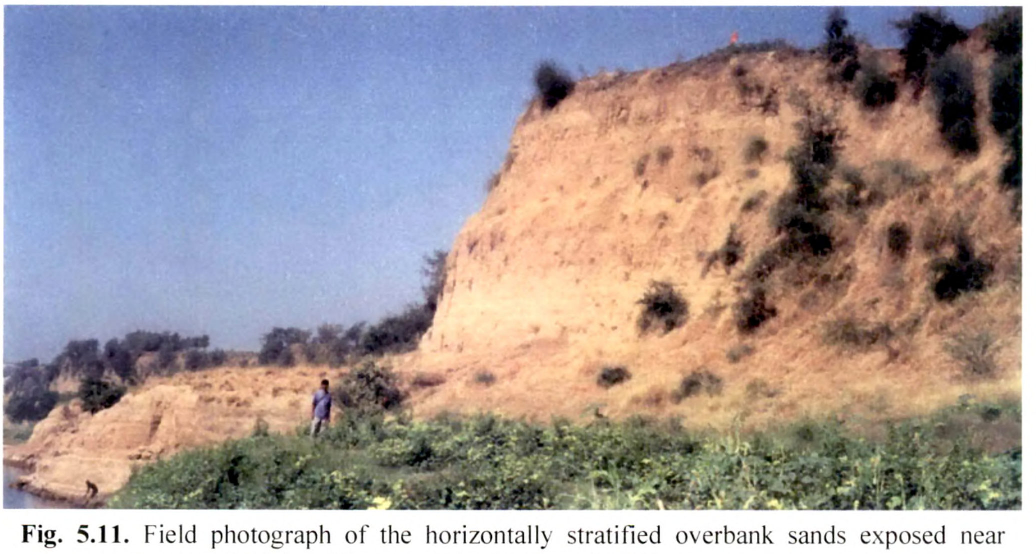

Fig. 5.11. Field photograph of the horizontally stratified overbank sands exposed near Ranapur. Height of the person in the photo is 1.65 m

single dynamic event, when flow conditions remain in a critical stage for many hours such as in the case of large floods (Kale et al. 1997). The facies may be attributed to overbank deposition resulting because of successive episodic floods (Miall, 1985).

Massive Sands

Massive sand deposits are exposed throughout the lower Narmada basin. The facies is composed of extensive sheets of fine to medium sands. These comprise laterally extensive sheets having an individual average thickness of 1.5-2 m. At some places these reach a thickness of 5 m. These sand bodies are devoid of any internal stratification and lack lateral accretion surfaces, suggesting vertical accretion. This indicates frequent shifting of the channel belt and rapid sedimentation. The sediments show only weak pedogenesis and are well short of being categorised as typical palaeosols (Chamyal et al. 2002). The deposits resemble those of a meandering channel where large floods submerge the floodplains depositing sand sheets across the valley (Miall, 1985).

Undulatory bedded sands

Undulatory bedded overbank sands and silts occur in association with the stratified sand facies and are separated from the underlying sediments by erosional surfaces. The undulations are prominent in sections perpendicular to the regional palaeocurrent direction (Fig. 5.12). The grain

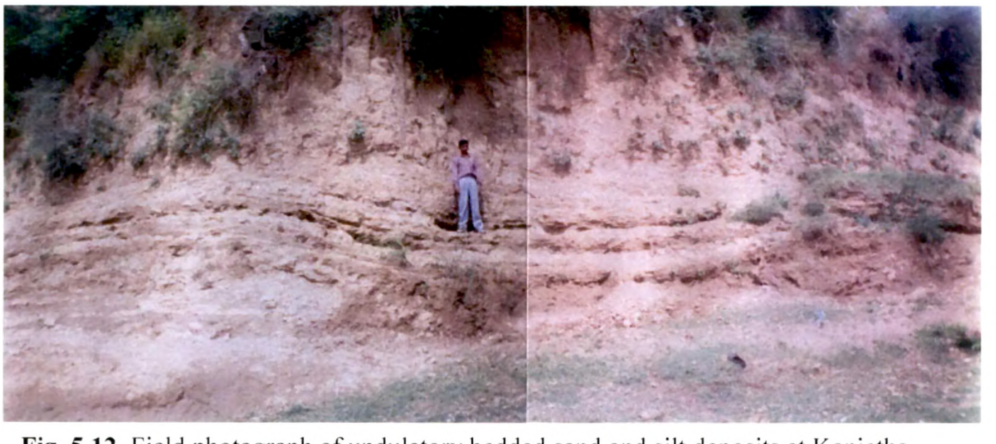

Fig. 5.12. Field photograph of undulatory bedded sand and silt deposits at Kanjetha. Height of the person in the photo is 1.65 m

size varies from fine silty sand to medium sand. The undulations have an average wavelength of about 10 m and heights up to 1 m. Individual beds are 0.25 to 1 m thick. The beds progressively change height from one crest to another. In plan view, the undulations appear as cross sections through long low ridges parallel to the flow occurring along the sides of large river as described by McCabbe (1977). Internal erosion surfaces are common within the undulatory beds. A similar facies consisting of fine sands is reported from the Brahmputra (Coleman, 1969) where the crest to crest length is 9-30.5 m and heights of 1.2 m. The generally massive nature of the beds suggest rapid deposition by strong currents under peak flood conditions (McCabbe, 1977).

Crevasse splay deposits

Crevasse splay deposits of the lower Narmada basin are found adjacent to the margins of the main channel and occur as thin sheet like bodies several tens of meters across and 1-2 m thick passing laterally into overbank fines. These are fine to medium grained sands with interbedded laminae of sand, silt and mud. These deposits are characterized by thin bedding and abundant surfaces of non-deposition reflecting their origin by sheet flooding. The grain size decreases away from the main channel towards the fringes of the splay and fines upward within the splays. Levee deposits are normally associated with crevasse splays but are difficult to distinguish since they are lithologically similar because both are deposited from decelerating sheetfloods that overtop natural levee and crevasse channels (Farrell, 1987).

Backswamp deposits

These are represented by the clayey sands and sandy silts upto about 5 m thick. These deposits are introduced into backswamps by crevasse channels and are deposited as a result of flow expansion and loss of flow power. Rhizocretions (root structures) are abundant. The backswamp deposits represent a periods of standing water deposits (Fig. 5.13), incursions of splay sediments (silty sand unit), into the standing water body and progradation of overbank deposits from the channel belt into the flood basins.

Fig. 5.13. Field photograph showing close view of the backswamp deposits at Nava Tavra. Note the abundant root structures in the form of rhizocretions

Palaeosol

Towards the top of the alluvial plain sediments, a 3-6 m thick brownish red to reddish brown soil occurs, which is easily identifiable by its distinct appearance and laterally consistent nature in the lower Narmada basin. The soil is well exposed at Chandod, Nanderiya, Moletha, Ambali, Patan, Kanjetha, Sinor, Ranapur, Nikora and Tavra. The parent material for the soil is fluvial overbank fine sands and silts, though the internal stratification is totally obliterated by pedogenesis (Fig. 4.10) particularly by the formation of calcrete throughout the soil. The paleosol marks the post-depositional phase of pedogenic transformation of the overbank sediments.

The palaeosol in lower Narmada basin has been attributed to a regionally correlatable phase of pedogenesis (Chamyal et al. 2002) which is seen in the adjacent Mahi and Sabarmati basins also (Merh and Chamyal, 1997). This buried soil has been used by earlier workers as a marker horizon for stratigraphical correlation of Late Pleistocene sediments in the various river valleys of Gujarat alluvial plains (Pant and Chamyal, 1990; Merh and Chamyal, 1997). Thermoluminescence dating of fluvial sediments in which the palaeosol is formed have yielded an age of 40 $\pm$ 10 ka in the Mahi basin (Juyal et al. 2000) and 58 $\pm$ 5.2 ka in the Sabarmati basin (Tandon et al. 1997). Pedogenic calcrete nodules of this palaeosol in lower Narmada basin have been dated to ~24,000 yr B.P. (Allchin et al. 1978) and from Mahi to 26,410 $\pm$ 690 yr B.P. (Maurya et al. 2000) which mark the pre-lgm phase of pedogenic alteration of the overbank sediments.

Thinly Stratified Sands and Silts overlying Palaeosol

Thinly stratified fine sands and silts overlie the palaeosol (Fig. 4.10). They occur consistently throughout the cliff sections marking the top of the exposed Late Pleistocene sequence. Apart from the well preserved stratification, no other sedimentary structure is observed. Morphologically, they appear similar to the stratified overbank sand facies described earlier; the only difference being the significantly thinner bedding (Fig. 4.10). The beds average 0.25 m in thickness and each bed may represent a single overbank flood. There is no evidence of pedogenesis. The thin bedded nature in comparison to the thick bedded sequence underlying the palaeosol, suggest that the sediments were deposited by a river that was significantly shallower with a lower discharge level. The chronological data available for the underlying palaeosol (Allchin et al. 1978) indicates that these sediments were deposited during the arid phase of the Last Glacial Maximum. In the Orsang basin, a tributary of the Narmada River, the aeolian sediments of this phase directly overlie the palaeosol (Juyal et al. in press). These sediments are attributed to the extreme arid climate during Late Pleistocene which peaked around 18 ka (Yan and Petit-Maire, 1994) resulting in the extension of the Thar desert into the Gujarat alluvial plains (Allchin et al. 1978). However, the absence of aeolian sediments along the cliff exposures in the lower Narmada valley and their presence in Orsang valley suggests that the geographic limit of aeolian accretion during the LGM was very close to the Narmada River, though a significant reduction in fluvial activity is suggested by the thinly stratified fluvial sediments overlying the palaeosol. Absence of root structures and dessication cracks indicate that the river may still have been perennial and that the river retained the large catchment even during the extremely arid phase of Last Glacial Maximum.

EARLY HOLOCENE FAN SEDIMENTS

The Early Holocene sedimentary surface is a gravelly surface comprising a series of alluvial fans deposited along the mountain front scarps of the NSF near Rajpipla. This fan surface is bounded by a NW-SE trending fault passing through the river Narmada on its eastern side and by a NNW-SSE trending fault passing through the Karjan River, a tributary of the Narmada on its western side (Fig. 4.16). These alluvial fans along the Narmada-Son Fault are found to overlie the semi-consolidated to unconsolidated Late Pleistocene sediments forming the S_1 and S_2 surface elsewhere in the study area. Field relationships further suggest that the fan deposits are older than the valley-fill terraces that date from the Middle to Late Holocene (Maurya et al. 2000). The alluvial fans are thus of Early Holocene age and related to the tectonic activity in the area during this interval.

The NSF provided the necessary physiographic setting for the formation of alluvial fans around Rajpipla (Figs. 4.16, 4.17). Bhandari et al. (2001) have identified five fans which form the S_3 surface gently sloping towards the north. The various facies identified in the sections of the proximal fan areas are Gc, Gms, Gh and Gp. In the medial parts of the fans Gms, Gp, Gh, Sh, Sm and Sp are the facies identified. The facies Gh, Gp, Sh, Sp and Sm are found in the distal parts. The facies show a very distinct proximal to distal relationship. The proximal parts of these fans are dominated by the hyperconcentrated debris-flows. The mid-fan facies are related to the consequent repeated progradation of the alluvial system (Al-Sarawi, 1988).

The sediments of the distal fan facies are fine grained, well sorted and show distinctive stratification. The sedimentary facies identified in the alluvial fan sediments suggest debris-flows and sheet-flows as the two primary aggradation processes in the formation of the alluvial fans of S_3 surface around Rajpipla area. A major tectonic uplift along the Narmada-Son Fault (NSF) probably caused a sudden change in gradient, resulting in the accumulation of particles derived from steep drainage basins in the subsiding basin with an alluvial fan environment. Uplift of adjacent areas along the NSF controlled the fan stratigraphy and increased sediment supply. The sediments were deposited in a fan shape over the pre-existing alluvial basin floor. The alluvial basin floor is exposed beyond the fan areas to the north.

The fan deposits have been studied in their proximal, medial and distal parts and various facies have been identified following Miall (1985) and Brierley et al. (1993).

Facies Description

Gc facies – This facies comprises cobbly, pebbly clast-supported gravels and is devoid of any primary stratification, and forms a major part of the proximal fan sections. The clasts range in size from 1-0.5 m, do not show any preferred orientation, and have a diagnostic angular to subangular shape (Fig. 5.14). The bedding is not easily identifiable, but at places wide concave erosional surfaces cutting each other are noticeable. On account of their indistinct basal contact, dominance of clast support, extremely poor sorting and lack of well defined imbrication, they have been interpreted as deposits resulting from hyperconcentrated flood flows (cf. Brierley et al. 1993).

Fig. 5.14. Closeup view of the Gc facies at Mota Amba

Gms facies – This facies is made up of angular to subangular, poorly sorted and inversely graded gravels that are matrix-supported (Figs. 5.15, 5.17). The clast size ranges from 0.5-0.1 m. There is a distinct clustering of coarser clasts. The clasts show down fan inclination of the longest axis pointing towards NW to NNW directed palaeocurrent. The larger clasts are found at the upper margin of each unit. The individual unit of this facies varies in thickness from 0.5 to 2.2 m. The upper and lower bounding surfaces are gently convex upward and are non-erosive. The clasts are tabular and discoidal. The facies shows a typical lobate geometry, basal or overall inverse grading, large floating or protruding clasts, subvertical clast imbrication and vertical variation in clast alignment. In some sections they show rhythmic repetition. The

Fig. 5.15. Close view of the Gms facies at Vavdi

facies is interpreted to have been deposited by viscous debris flows (cf. Shultz, 1984; Chamyal et al. 1997).

Gh facies – The facies is made up of cobbly pebbly matrix-supported gravels showing horizontal stratification (Fig. 5.16). The proportion of sand units and the degree of sorting tend to increase in down fan direction. They are found to occur as 0.3 to 1.8 m thick bands. They generally show normal grading, however, a few beds have inverse grading. The clasts are of 0.25 to 0.1 m in size, moderately to poorly sorted and decrease in size in down fan direction. Imbrication is common towards NW to NNW. The facies is interpreted as to represent overbank style deposit spread over a fan surface with poorly defined channels (cf. Brierley et al. 1993).

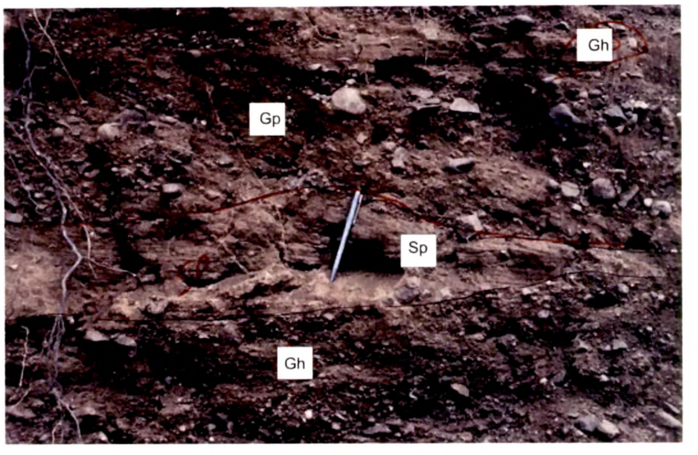

Fig. 5.16. Sp facies overlain by Gp facies and underlain by Gh facies

Gp facies – This facies is characterised by cobbly, pebbly matrix-supported gravels showing planar cross-stratification (Fig. 5.16) and occurring as laterally continuous bands and as lenses (0.5 to 2.5 m thick) within the Gms facies of the medial fan sections. Their bounding surfaces are non-erosive. The gravel clasts range in size from 0.2- 0.05 m. Each band/lens displays unique grain size and palaeocurrent direction suggesting different flow events. This facies has been interpreted to have formed during a period when the gravel loaded flows were rechannelised as small streams (cf. Chamyal et al. 1997).

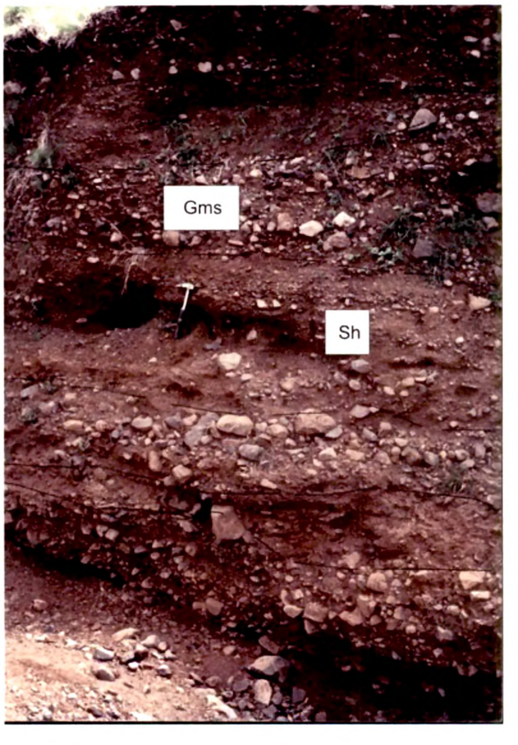

Fig. 5.17. Four aggradational phases of Gms facies with intervening Sh facies at Phulwadi

Sh facies - The facies shows horizontally bedded coarse to fine sand (Fig. 5.16) and is at places graded. They occur as 0.2 to 2 m thick lenses or as continuous bands. The facies represents an intervening quiescent period between fan aggradational events. In the distal part, they show better rounding and sorting, and are common in distal fan sections. They are interpreted as deposits of lower flow regime of sand (cf. Brierley et al. 1993).

Sp facies - This facies occurs in medial and distal fan sections and shows planar cross-stratification (Fig. 5.16). In medial parts of the fans, they are associated with other coarser facies as lenses of 0.5 to 1 m thickness. They represent avalanche faces of advancing sand sheet (cf. Brierley et al. 1993).

Sm facies - This occurs as an independent unit (0.5 to 2 m thick) in distal fan sections and represent rapid deposition from heavily sand laden flows during waning floods (cf. Todd, 1989; Maizels, 1993).

Facies Associations

The fan sections exposed near Umarwa, Mota Amba, Junavad and Velchhandi were logged in detail in the proximal part of the fans (Figs. 4.17, 4.18). These sites are located close to the geomorphic divide between the Deccan Trappean highlands and the adjacent alluvial fan surface. The various facies identified in the sections of the proximal fan areas are Gc, Gms, Gh and Gp. Gc and Gms are the dominant facies present in all the sections. At Umarwa, the Gms facies is separated from the overlying Gc facies by a horizon of Gp facies, and at Mota Amba by Gh facies. Gc and Gms represent debris flows whereas the thin beds of Gp and Gh are the intervening phases of sheet flows.

In the medial parts of the fans seven sections are measured, at Bhandra, Shamariya, Phulwadi, Jhunda, Vavdi, Jitnagar and Rajpipla (Figs. 4.17, 4.18). Gms, Gp, Gh, Sh, Sm and Sp are the facies identified in these sections. Gms facies dominate these sections and show cyclic aggradation in some cases. At Phulwadi, four aggradational phases of Gms facies have been recognised (Fig. 5.17). Sp and Sh facies occur as lenses or as continuous bands. Gp, Sh, Sp and Sm facies represent the intervening quiescent periods between fan aggradational events (Fig. 5.18). Boriya, Raval Moti, Vansla, Khol and Karotha are the representative sections logged in the distal part of the fans (Figs. 4.17, 4.18). The facies identified in these sections are Gh, Gp, Sh, Sp and Sm. The facies associations of the distal part represent sheet flows. The facies show a very distinct proximal to distal relationships in all the 16 vertical profiles measured. Gc and Gms are the two dominant lithofacies that occur in proximal fan sections. Gp and Gh are found in the middle part of the proximal sections. Gms is seen in the upper part of the proximal and medial sections, and at places occurs rhythmically in the medial sections. In the distal fan sections, Sm occupies the upper parts. Sh occurs rhythmically and Gp and Gh are found in the middle parts.

The sedimentary facies identified in the alluvial fan sediments suggest debris flows and sheet flows as the two primary aggradation processes in the formation of the alluvial fans of Rajpipla area (Fig. 5.18). These have produced a variety of architectural characteristics to the fan deposits in their different parts. The variations in the facies from proximal to distal result from transformations of debris to stream flows during transport (Lawson, 1981; Pierson and Scott, 1985; Smith, 1986). The Rajpipla alluvial fans are dominated by debris flows as revealed by the volume of Gc and Gms facies and a relatively small and steep catchment (Hooke, 1968; Harvey,

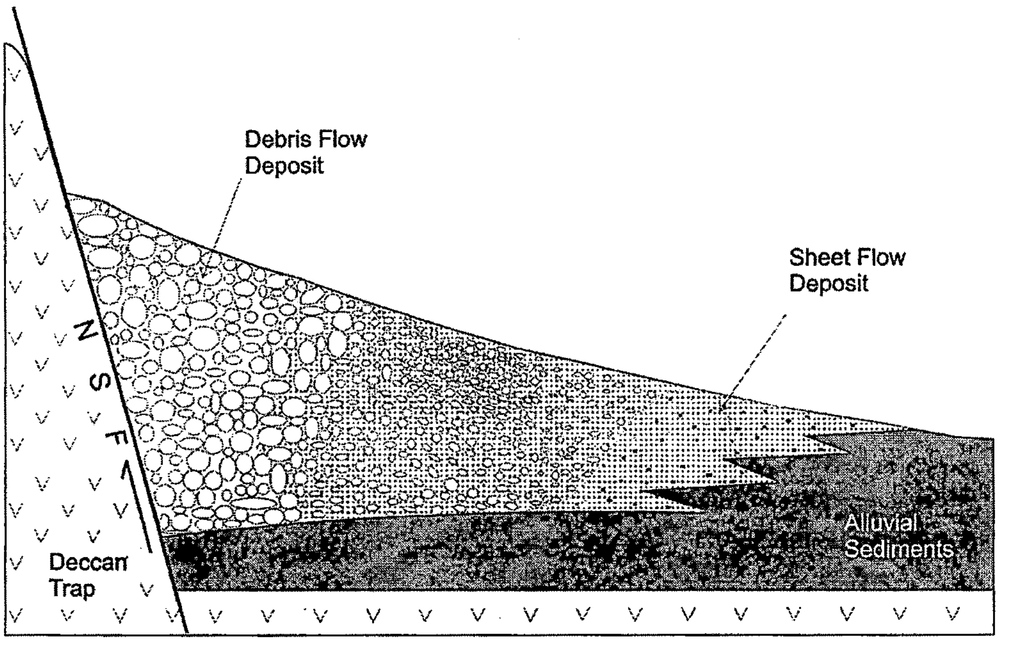

Fig.5.18. Schematic longitudinal cross-section summarising geological setting and their facies associations (as demonstrated by Blair and McPherson, 1994)

1984; Wells and Harvey, 1987). Uplift in the drainage basin area (Deccan Trappean highland) and flash floods during a high-precipitation regime initiated the debris flow process. Clast-rich debris flows occur on these fans within the channels and are also observed on the fan surface, mainly in the proximal and medial parts of the fans. These debris flows at places show erosion by subsequent water flows.

The longitudinal profiles show characteristic facies associations down the fan surface (Blair and McPherson, 1994). The variation in slope along the longitudinal profile is controlled by a number of sedimentary processes and by the sediment size (Blair and McPherson, 1994). The schematic longitudinal profiles of the Rajpipla fans show free fall accumulation such as talus or colluvial material in the precursor stage (Fig. 5.19). Stage 1 of the longitudinal profile shows debris flows, during this process Gc and Gms sedimentary facies developed. Stage 2 of the longitudinal profile comprises debris and sheet flows belonging to Gms, Gh, Gp, Sh, Sp sedimentary facies (Fig. 5.19). Sandy, pebbly, cobbly sheet flows resulted in the development of

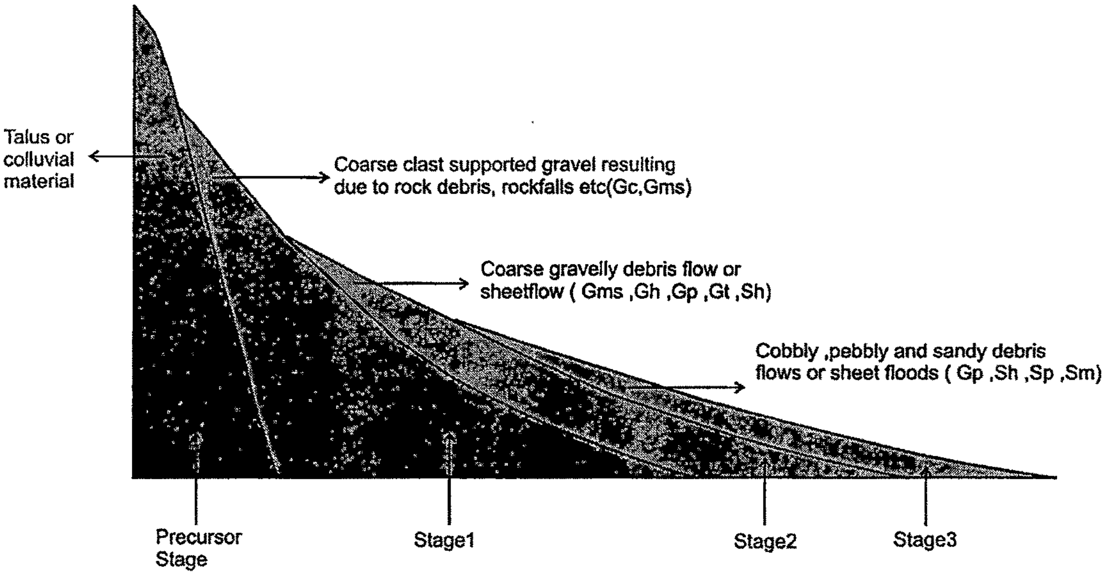

Fig. 5.19. Schematic cross-section showing evolutionary stages and their relationship to dominant sedimentary processes (as demonstrated by Blair and McPherson, 1994)

Gp, Sh, Sp and Sm sedimentary facies of the longitudinal profile in Stage 3 (Fig. 5.19).

The depositional model of the Rajpipla alluvial fans (Fig. 5.20) depicts various facies and

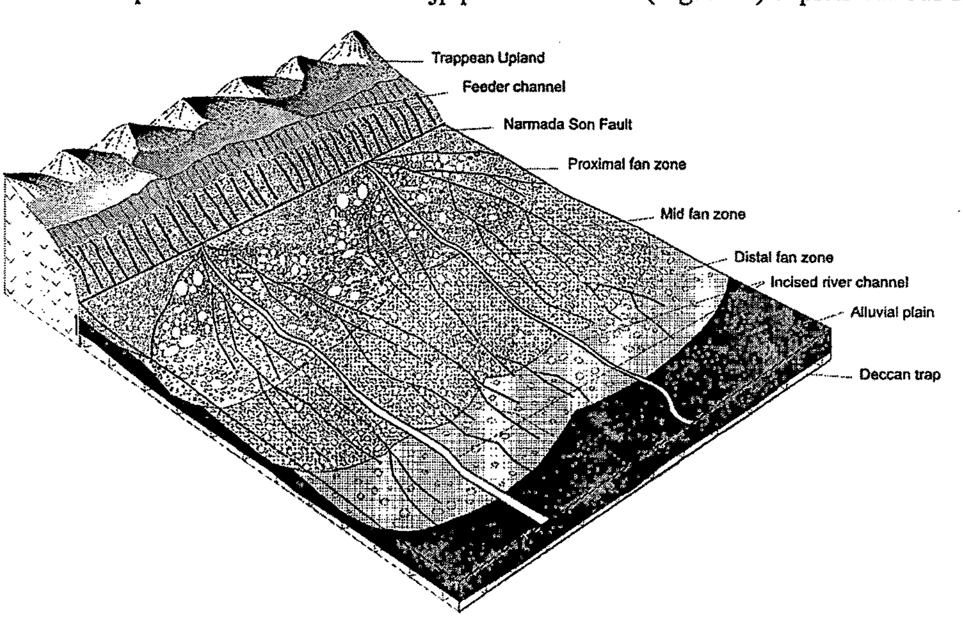

Fig. 5.20. Depositional model for the alluvial fans near Rajpipla depicting various facies and morphological features

morphological features. The topographic contrast provided by the NSF helps in the deposition of the proximal-fan facies (Gc and Gms) in the subsided basin over the alluvial basin floor (Fig. 5.18). The mid-fan facies show alternating units of Gms, Gh, Gp, Sh and Sp facies, which are related to the consequent repeated progradation of the alluvial system (cf. Al-Sarawi, 1988). The sediments of the distal fan facies are fine grained, well sorted and show distinctive stratification.

MID-LATE HOLOCENE TERRACE SEDIMENTS

The Mid – Late Holocene sediments occur in terraced surface identified as S_4 surface which occupy a deeply incised fluvial valley comprising Late Pleistocene sediments (Fig. 5.21). These terraces comprise tidal estuarine sediments in the lower reaches and fluvial sediments in the upper reaches. The terraces show no evidence of ravine erosion, and incised cliffs along the river abut against the abandoned cliffs (palaeobank) of Late Pleistocene sediments (Fig. 3.19). These palaeobanks allow for a fairly accurate determination of the morphology of the incised fluvial valley and the estuary in which the valley fill terraces were deposited. Since the base of the palaeo-valley is not exposed, the incised cliffs of the terraces reveal only a part of sediments comprising the valley fill terraces. This means that 35-40 m high precipitous cliffs of the Late Pleistocene sediments along the river actually leads to an underestimation of the total amount of incision prior to the valley fill sedimentation.

Fig. 5.21. Estuarine tidal valley fill terrace at Uchediya S_4 surface

The Holocene valley fill terrace sediments in the Lower Narmada basin comprise two lithofacies- tidal estuarine facies in the lower reaches (Fig. 3.22) and the fluvial sandy facies in the upper reaches (Maurya et al. 2000)(Fig. 3.23). The tidal estuarine facies is dominated by tidal carbonaceous muds with intervening fine to medium estuarine sands showing parallel lamination. The sands show ripple and cross - stratification with abundant mud laminae, flasers and drapes (Maurya et al. 2000). The sands also show parallel bedding and bi-directional cross - stratification. In tide dominated estuaries, the muddy sediments accumulate primarily in the tidal flats and sand marshes while sands are deposited in the tidal channels that run along the length of the estuary (Woodroffe et al. 1989; Darymple et al. 1990). The geomorphic setting suggests that these sediments were deposited as aggrading transgressive tidal estuarine facies transforming the fluvial incised valley into an estuary during the Middle Holocene high sea.

The present estuarine reach contains several islands, which are coeval with the terrace surface and are well above the present tidal range. Hence, they are the products of estuarine processes of the Mid-Late Holocene and not those of the present day. Funnel shaped morphology and increasing tidal energy landward are characteristics of tide dominated estuaries (Wright et al. 1973). An elongate tidal sand bar zone is commonly found at the mouths of tide dominated estuaries (Harris, 1988; Darymple et al. 1990). Convergence of such bars gave rise to the present Aliabet Island (Figs. 3.2, 3.3). Maurya et al. (2000) indicated that the Aliabet was earlier a group of four smaller islands. Landward of the sand bar zone is the zone of tidal energy maximum due to the confinement of the channel because of the funnel shape of the estuary (Wright et al. 1973) where mainly parallel laminated sands of upper flow regime are deposited (Darymple et al. 1992). Further, landward is the low energy zone in which the channel may become sinous (Ashley and Renwick, 1983, Woodroffe et al. 1989) termed as straight-meandering-straight and contain several mid-channel bars and bank attached bars (Darymple et al. 1992). The several islands in the present estuarine reach are interpreted to have been deposited as mid-channel bars in this zone. The causes of such channel patterns in tide dominated estuaries are not known (Darymple et al. 1992).

Upstream of the tidal estuarine terraces, comparable fluvial terraces occur right upto the upland zone with identical geomorphic setting. These terraces mainly consist of horizontally stratified fluvial silty sands (Sh). The lateral accretion surfaces are completely absent indicating aggradation of the incised valley through vertical accretion when the lower reaches of river was undergoing tidal estuarine sedimentation. However, the change from fluvial to tidal facies is not sharply defined and appears to be transitional.