Chapter 4

SEDIMENTARY FACIES: CLASTICS

4. SEDIMENTARY FACIES: CLASTICS

The succession of the continental Quaternaries exhibits a diverse assortage of sediment characters. These characters herein are classified to facilitate description and classification. The approach used is similar to that outlined by Miall (1996). In recent years the spatial variations in facies distribution at a given stratigraphic level have been increasingly recognized. There have been criticisms by Bridge (1993) of this approach, who objects that while taking refuge to lithofacies codes, objective descriptions and assessments are often ignored by many workers. Fluvial sediments are split into 'building blocks' at two hierarchical levels. Individual facies make up the 'bricks' that build 'walls' representing identical flow conditions or depositional sub-environments. The latter are termed as 'architectural elements' a term introduced by Allen (1983) or 'lithosomes'. A distinctive suite of architectural elements characterize a given type of river deposit. For example the architectural elements of perennial gravel-bed rivers would differ from those of ephemeral mixed-load rivers to that of meandering or anabranching rivers. This approach assists in identifying with ease the depositional sub-environments and contrasts in depositional styles through time and space in a fluvial stratigraphic record.

The methodology adopted involves the recognition of various lithofacies that are distinguished solely on the basis of sedimentary structures and grain size class (i.e. gravel, sand, silt, clay). A binomial coding scheme uses upper case letters to describe the size class as the first part while the second alphabet or sets of alphabets denote the sedimentary structures and are given in lower case. Further complications arise when a given structure forms through different mechanisms that may be understood by observing subtle differences in attitudes of major bounding surfaces. These differences at times may be fundamental enough to necessitate a trinomial classification code. When such a situation arises a third components is introduced and is given in lower-case subscript alphabet in the present study.

The description of facies is compartmented in two chapters: clastic facies and non-clastic facies. In this chapter structures formed by physical processes (entrainment-transport-deposition) are described while in the following chapter features related to soil and groundwater activity are documented.

4.1 Trough cross-stratified conglomerate (Gt)

Conglomerates varying in geometry from sheet to ribbon to lens (*sensu* Friend, 1983) exhibiting trough cross-stratification are present in both the Mahi and Sabarmati valleys (Plate 4.1). The conglomerates show a range in thickness from 0.5 to 3.5 m. They occur both as solitary sets and co-sets, although the former has a rarer occurrence. Basal bounding surfaces are planar erosive regionally with local scours. Compositionally the facies comprises quartzites, basalts and calcretes in the Mahi valley whereas in the Sabarmati valley laterites, quartzites and calcretes make up the coarse-clast (framework) assemblage. In addition, silty-clay blocks and mud clasts are quite common and line the base of every conglomerate. Within the sub-angular silty-clay blocks primary lamination is seen (Plate 4.2) that dips at an high angle to the basal bounding surface of the conglomerate. These blocks though roughly cuboid at times are also sub-spherical in shape. The mud blocks vary in dimensions from 25 cm to up to 1.3 m. Mud clasts are commonly between 5 to 10 cm in size. Their shapes vary from elliptical discoids to circular discoids with smoothened surfaces. Less regular shapes are also seen occasionally.

The conglomerates reveal a great deal of heterogeneity in the relative proportions of matrix and framework grains. Whereas conglomerates in the Sabarmati valley have higher amounts of sand matrix (sandy conglomerates) those in the Mahi valley are relatively coarser framework dominated. Clast sizes vary immensely. However they are not comparable to the huge basal sediment blocks. Framework clasts range from pebbles to cobbles that are 18 cm long. Clasts of calcrete are highly irregular in surface morphology with multiple protrusions (Plate 4.3). Basalt, quartzite and laterite clasts are sub-angular to sub-rounded and are usually in the pebble grade.

The foresets are normally graded although the transition in not smooth but is a bisected abrupt change from pebble-cobble clasts to granule rich layers. At some places a complete fining upward sequence terminating in coarse sand is also seen. Foresets are tangential concave upwards and are usually 10 to 18 cm in thickness.

At Rayka (Mahi valley) a ~300 m long calcrete-conglomerate 3D outcrop was analysed in great detail. The outcropping face parallels the depositional strike while incoming tributaries of the river Mahi cut the sheet exposing the depositional dip face. It overlies clays showing vertic features such as psuedoanticlines, fissures, slickensides alongwith pedogenic indicators such as smectitic clay accumulation, rhizoliths and calcretes. The lower bounding surface is planar erosive. Local scours are also seen at places.

Troughs vary in width from about 1 m to 7 m. No clusters in width dimension is seen. The amplitude of the troughs exhibit a linear co-variance with widths (Fig. 4.1).

Amplitudes range from as little as 0.3 m (some smaller troughs ~0.15 m are observed locally) to up to 1.6 m. A first order linear regression fit gives the result:

$$\text{Amplitude} = 0.0915(\text{Width}) + 0.5542 \qquad (r^2 = 0.787)$$

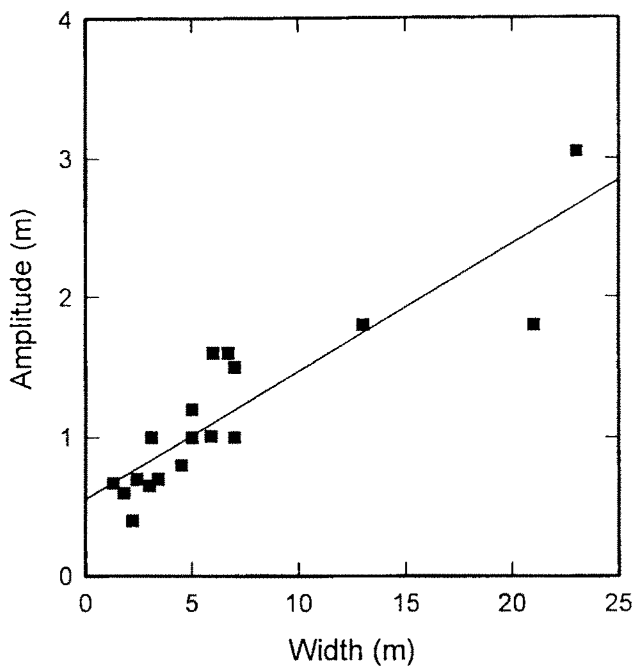

Figure 4.1: Bivariate plot showing linear covariance of trough amplitude with width.

The troughs show two populations in the dip of the foresets. One clusters between 5°-12° while the other ranges from 20°-34° (Fig. 4.2; Plate 4.4). However it is evident that a small boundary separates these groups and data from other localities across the globe may well establish a continuum. Dips are low for large values of width and low values of amplitude of troughs and increase for larger amplitude troughs (Fig. 4.3 a, b).

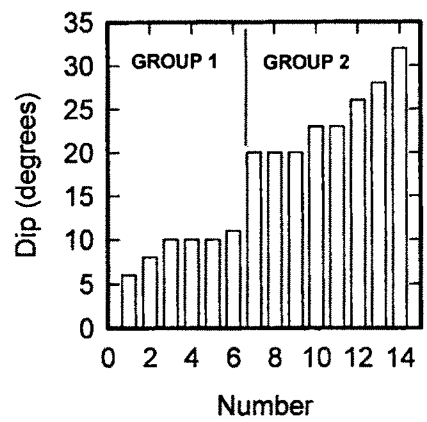

Figure 4.2: Univariate plot of dip of foresets. Two groups may be distinguished within the data set. One has values of 12 and less while the other has values 20 and above.

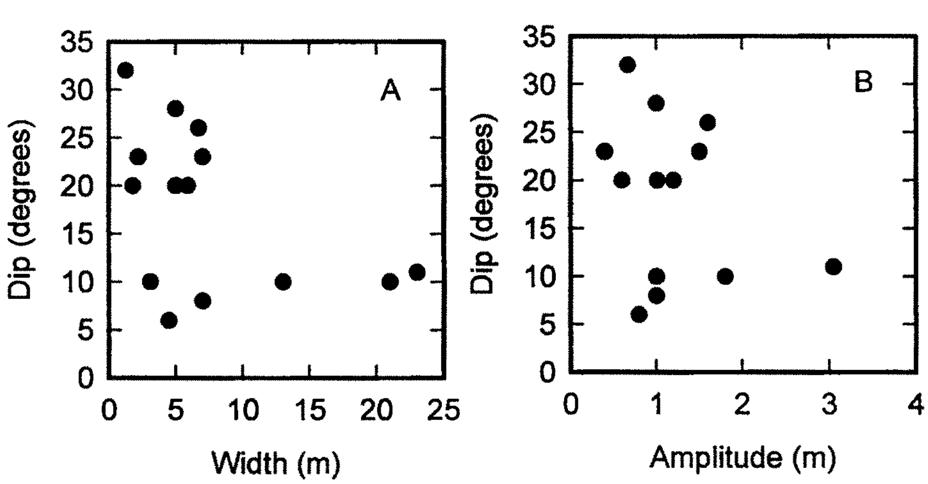

Fig. 4.3 : a] Bivariate plot of foreset dip vs. trough width. Troughs of low width have higher dip values. b] Bivariate plot of foreset dip vs. trough amplitude.

Foresets vary in thickness from 2 cm to 14 cm. Those associated with high dip strata are as a rule greater than 5 cm in thickness, typically around 10 to 14 cm. Foresets are normally graded. At places a distinct division into a lower open framework pebbly to cobbly layer overlain by matrix rich granular layer is observed. Clasts are composed of irregular shaped calcrete and subrounded basalt and quartzo-feldspathic detritus.

The foresets typically are concave-up and tangential. The bounding surfaces within each trough shallow upwards. Troughs occur within the sheet as groups (nests) of small-medium dimensions or as larger isolated troughs. At the northwestern end of the outcrop such larger troughs show a directional arrangement. In this mode a predecessor trough is partly eroded by the newly formed trough. In the 'grouped' arrangement the apices of an underlying trough meets the central depressions of overlying adjacent troughs.

Troughs, in the present case appear to be of two origins. Low dip, high width, small amplitude and large width/amplitude values characterise one group. These are inferred to be deposited as sheets or very small amplitude large bedforms in channels. The foresets are never more than several grains thick (Plate 4.4). Thus it is possible that transportation was effected as bedload sheets (Whiting et al. 1988) that migrated on low angle elongated lee slopes. Yagishita (1997) rightly points out that within channels, deposition is not mediated as a simultaneous trough fill but is probably a lag deposit. However in the present case the occurrence of low angle foresets manifests migratory behaviour, suggesting the presence of bedforms. This facies is designated as Gt_b. The third qualifier here is added to describe the formative process. In this class troughs are isolated or show a directional arrangement. Bedload sheets were observed by Whiting et al., (1988) in the Duck Creek, Wyoming, USA. Within the fine gravel channels the sheets were organised in plan view as migrating patches of sediment. The bedload sheets were delineated by coarse fronts and at times a topographic step at the advancing front of each sheet. Laboratory simulations of bedload sheets (Bennett & Bridge, 1995) have shown that crests are fine grained while troughs are relatively coarser. Discernible lee sides developed only in the largest bedforms. These bedload sheets represent incipient dunes, a stage transitional between essentially incipient motion/immobile bed conditions and a dune covered bed.

The second group contains those troughs that have high dip values, moderate width and large amplitudes, and low width/amplitude ratios (Plates 4.5). These are related to trains of migrating 3D dunes (Carling, 1996). Such troughs never occur solitarily and are always present as nests or groups. This facies is termed as Gt_d, the third qualifier describes a dune origin (*sensu* Ashley 1990). Revised bedform stability diagrams that incorporate both flume as well as field data for a larger range of grain size (Best, 1996) suggest very high shear stresses responsible for the formation of gravel dunes.

The ratio of width/amplitude has been plotted in figure 4.4 with dip values. The efficacy of the plot in demarcating troughs of differing origins is clearly evident. Gt_b troughs plot preferentially in the left-hand upper corner reflecting the larger widths of the troughs while Gt_d troughs plot in the lower right hand corner of the plot owing to higher amplitude values. A review of papers appearing in leading sedimentological journals over the past decade reveals that most authors prefer a channel-fill origin (Table 4.1).

While in the present case dip values and trough dimensions proved valuable discriminators, no such information was available usually in the articles.

AUTHORS	WIDTH	HEIGHT	DIP	REMARKS	INTERPRETATION
Ramos et al., (1986)	2-10	0.5-2	--	--	Channel-fill conglomerates
Blair, (1987)	--	0.1-1	--	--	Deposition over trough or channel shaped scours
Cavazza, (1990)	--	0.5-2	--	Intimately related with facies Gp	Unidirectional migration of megaripples across bartops or channel margins
Smith, (1990)	10	3	--	Most cosets display a scoop like geometry	Erosion and subsequent fill of scours
Pivnik, (1990)	--	--	--	Small scale trough cross stratification Large scale trough cross stratification	Small and large 3D ripples Minor channel fills
Bromley, (1991)	--	--	--	--	Minor channel fills
Evans, (1991)	--	--	--	--	Channel fills
Crews & Ethridge, (1993)	--	0.5-1	--	Isolated scour fills Cosets of trough cross beds	Channel fills Climbing of trains of sinuous crested dunes
Clemente & Perez-Arlucea, (1993)	--	0.1-0.3	--	--	Minor channel fills
Lang, (1993)	--	--	--	--	Minor channel fills
Brierley et al., (1993)	10	up to 4	--	--	Channel fills
Siegenthaler & Huggenberger, (1993)	max. 100	0.5-6	--	Lower bounding surface spoon-shaped	Confluence pools
Browne & Plint, (1994)	--	0.3-1.4	--	Cosets separated by undulating erosional surfaces	Deposition in 3D subaqueous dunes
Benaouiss et al., (1996)	--	0.5-2	--	Uniformly concave base	Grouped 3D type dunes
Keighley & Pickerill, (1996)	--	<0.5-1	--	--	Not given explicitly
Yagishita, (1997)	--	--	Low	Scour	Channel fill small scale channel dissection of longitudinal bar
Jo et al., (1997)	--	--	--	Scour	Filling of minor channels, scours and channel pools

Table 4.1 : Review of interpretations made by authors during the past decade of gravel troughs. Note that for most works it has not been possible to assess due to lack of data on width, height and dip of the troughs.

In the architectural element approach a hierarchy of building block exists. 'Bricks' of various facies build 'Walls' termed as lithosomes or architectural elements (Miall, 1996). Thus a element may be composed of one facies or of several. Channel-fill deposits usually exhibit several facies and are hence elements (CH element?). For example within the conglomerate sheet the ~20 m wide troughs are channel-fills *sensu-stricto* and arc build up of Gt_d and Gt_b facies internally. Directional arrangement demonstrates channel shifting. These channels appear to be chutes based on their location at the northwestern extremity of the outcrop. It should be remembered that channels are elongate concave-up depressions that are several channel-widths in length. Sediment is transported within these elongate depressions as bedload sheets or flow transverse bedforms. Hence in conformity with genetically specific interpretations at the facies level (e.g. Gms, Gm, Gp facies), the interpretation in facies-code tables should describe the specific process responsible for the Gt facies formation.

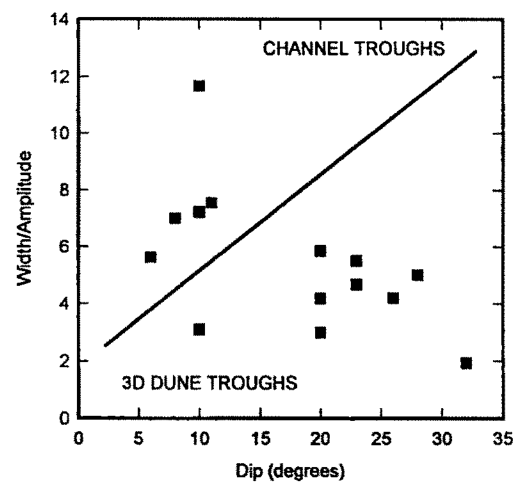

Figure 4.4: Bivariate plot of the ratio of trough width to trough amplitude vs. foreset dip. This plot helps distinguish troughs of channel and dune origin. The line drawn to distinguish the two groups is arbitrary.

In both the varieties of troughs described in this study the lower bounding surface is planar erosive. Partly this condition has arisen due to cohesion in the underlying vertic clays. Based on the attitude of the lower bounding surface a third variety of Gt has been identified by Siegenthaler and Huggenberger (1993). The troughs are 100 m wide and 0.5 m to 6 m in amplitude. These are interpreted as having originated at confluence pools in a braided stream (Siegenthaler & Huggenberger, 1993). Such facies can be identified by the spoon shaped lower bounding surface as seen in the *depositional dip* face and within-trough lateral foreset migration in the *depositional strike* face. This facies is termed here as Gt_c (c = confluence pool). Figure 4.5 illustrates the fundamental characters of these three varieties of Gt facies.

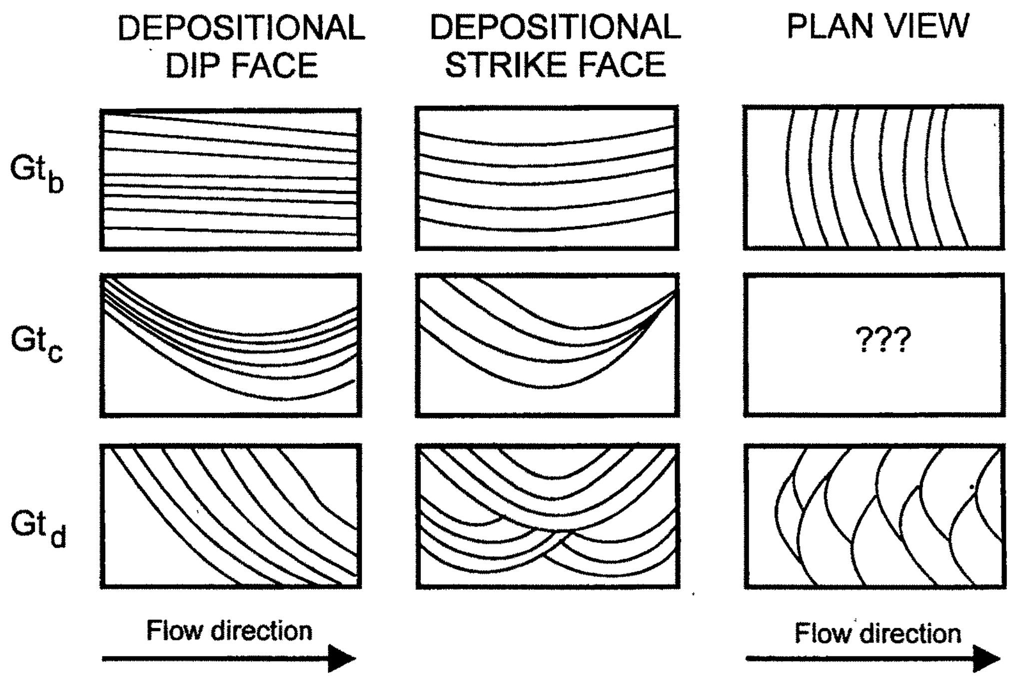

Figure 4.5: Primary distinguishing characteristics of the three varieties of Gt facies.

The transition from pebbly to cobbly openwork textures to matrix filled layers to coarse sand may be effected through complex sorting mechanisms at various stages of dune advancement. In a flume experiment Carling (1990) assessed the role of particle overpassing over bar tops. His results point to entrainment of gravel particles with low pivoting angles at the initial stages of incipient motion. In the experiments foreset angles ranged between 20° and 34°. With increasing bed shear stress fine sand entered the suspended load which in turn led to a net increase in gravel transport. The supply of sediment on the stoss may come in pulses of bedload sheets. These sheets typically have coarse fronts and fine towards the tail. The cyclic character of the foresets necessitates a continuous sediment supply or in rapid successive pulses. These pulses are later sorted either through selective entrainment or distrainment (Whiting, 1996). During entrainment more mobile grains get carried away in the flow leaving behind a lag. Ideally as the critical boundary shear stress increases with particle diameter the coarsest sediments should form the lag. But in a heterogeneous mixture the shear stress required to entrain a particle whose diameter is smaller than the median, is greater than what it would have been, were it on a surface of smaller particles. Hence overpassing particles which are coarser arrive at the crest earlier forming a basal open framework sub layer at each foreset as observed in the present study.

The arriving sediments also stand a prospect for further sorting as they fall over dune fronts or bar fronts. Due to differing particle sizes larger particles would tend to have shorter trajectories of distrainment than the finer fraction. This can result in coarser grains accumulating near the crest of the dune leading ultimately to normal graded foresets. The presence of sand layers (Plate 4.4) seen along with the coarser clasts suggests deposition from the re-circulating flow as the bed shear stresses reduced in magnitude.

The high irregularity in the case of clasts when calcretes dominate the composition leads to coarse clasts forming a barricade at the lee of the dune behind which smaller particles (granules) are trapped. This clustering is effected by clast interlocking akin to pieces of a jigsaw puzzle.

4.2 Planar cross-stratified conglomerate (Gp)

The facies (Plate 4.1) occurs both as solitary sets and cosets and varies in thickness from 2 to 5 m. It usually forms discontinuous bodies or lenses. Most conglomerates are matrix rich, exceptions being those seen at Poicha (Plate 4.6) and Muhammedpura (Mahi basin). Foresets are normally graded with thickness in the range of 5-14 cm. Compositionally clasts are made up of calcretes, quartzites and basalts in the Mahi basin whereas in the Sabarmati basin laterites, calcretes and quartzites are present. Most clasts are in the pebble to cobble grade. Where foresets may be observed in the depositional dip direction, they are concave up and dipping at an angle between 15^{0} and 25^{0}. The conglomerates are sometimes intimately interlayered with coarse stratified sands. Lower bounding surfaces are as a rule planar erosive. In the more sandier varieties planar cross stratified conglomerates consist of foresets in which only the bases are lined with disconnected pebbles. Clasts again as in the case of Gt facies are subrounded to subangular when composed of quartzite, basalt or laterite and highly irregular when composed of calcrete.

The facies is interpreted as the product of flow transverse 2D bedforms or bar migration. Flows may have been unsteady and uniform as reflected in the two dimensionality of the bedform. Aggradation took place due to progressive downstream accretion of avalanching slip faces. Thickness of upto 3 m suggest bankfull flows of having flow depths around 10 to 12 m. The presence of intervening sand indicates low-stage sedimentation. This facies has been very well documented through out the world from modern river deposits (Miall, 1996) and fluvial successions of various age groups

(Massari, 1983; Steel & Thompson, 1983; Smith, 1990; Clemente & Perez-Arlucea, 1993)

4.3 Horizontally stratified sand (Sh)

Laterally extensive silty sands are developed extensively throughout both the basins (Plates 4.1, 4.7, 4.8). The sands are bound by planar non erosive surfaces that extend for several hundred metres. Individual units may be recognised by the development of well cemented layers close to the bounding surfaces. Individual units range in thickness from 0.3 to 0.5 m. At Rayka it was possible to observe planar lamination that was in part obscured by vertical discordant tubes. Elsewhere carbonate nodules are seen dispersed in sub parallel bands. Fining upward units are separated by carbonate cemented zones. In some cases the facies pinches laterally to form a trough like feature. Weak pedogenesis is seen at the top of some graded units although exact demarcation is very difficult. Grain size histograms of this facies shows significant concentrations of silt (Fig. 4.6).

Normal graded units form as the intensity of the river flow recedes. Such extensive sheets of normally graded beds are recorded in areas where sheetflood processes operate (McKee et al., 1967; Picard & High, 1973; Turnbridge, 1981; Parkash et al., 1983; Stear, 1985; Abdullatif, 1989; Reid & Frostick, 1989; Bull, 1997). The presence of internal lamination in occasional cases reflects deposition in upper plane bed flow regime (Turnbridge, 1981; Stear, 1985).

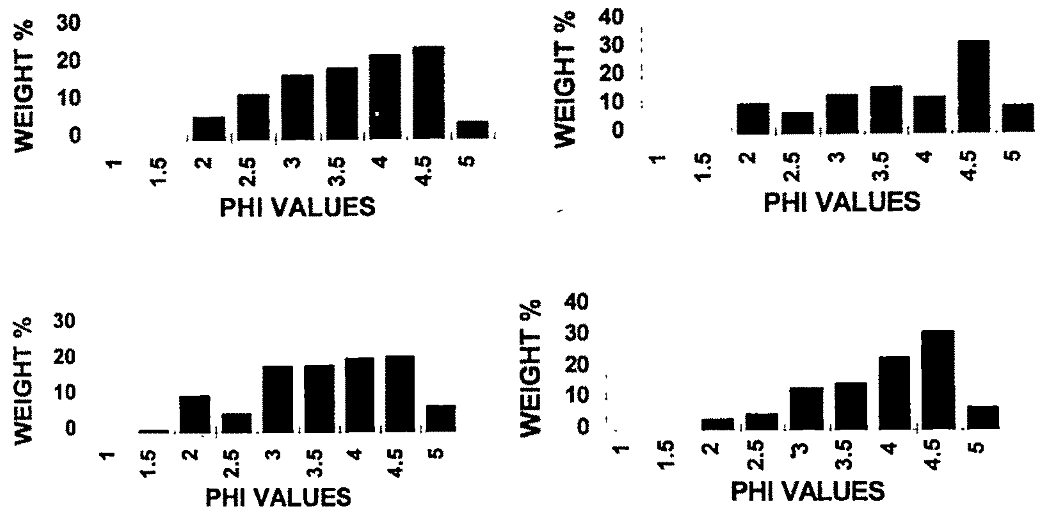

Figure 4.6: Grain size histograms for the Sh facies. Note that apart from sand the facies contains quite large amounts of silts also.

The non preservation could well be due to sediment homogenisation through root activity. Deposition from sheet floods takes place in unconfined flows. This unconfinement is achieved under two conditions. One is the absence of a well defined channel margin (Friend, 1983; Graf, 1988) and the other is when the discharge exceeds the channel's capacity leading to overbank flows (Bridge, 1984). In both situations normal graded units form as the flood recedes.

Turnbridge (1981) observed that such sand sheets extended for over hundreds of metres and had nearly parallel bases and flat tops. Abdullatif (1989) carried out a detailed facies analysis of the river Gash sediments of Sudan. In this river 'Sh' consisted of fine to medium sands with pebbles and wood debris at the bases. Average thickness of the facies was 40 cm but also reached a maximum of up to 120 cm. Similar deposits have been described by Stear (1985). The sediments which varied in thickness from 2-3.5 m were horizontally laminated. The deposits formed in response to the Laingsburg flood in the Karoo region and spanned 7 hours.

are few
Intense documentation's of spatially large sheetflood events. One such example is provided by Graf (1988) in which flows become unchannelised as the stream emerges from mountain fronts on to the alluvial aprons in the United States. The sheetflood recorded was 600 m wide and flowed for a length of 3 km.

4.4 Trough cross-stratified sand (St)

The facies comprises troughs that vary in amplitude from 0.45 m to 1.5 m and show width of upto 8 m. The facies shows fine internal stratification. The lower bounding surface is erosional. There is a progressive drop in concavity of the bounding surfaces. At one site wide shallow troughs (~42 m wide) are observed stacked laterally next to each other. In this case one of the sides of the predecessor-trough is scoured by the subsequent trough. Calcium carbonate rich bands are common and occur repetitively through the facies and develop along stratification planes. At some intervals centimetre size clasts of mud are observed. The sediments are dominantly medium to fine sand. The sediment package shows 45-48% of medium to very fine sand, 40-44% of silts and 8-10% of clay.

This facies is interpreted as deposits of shallow sub-channels (Miall, 1985; 1988) within the main river channel. The fine laminations along with grain size distributions within the facies may be due to the sediment being transported in suspension and deposited as a suspension fall-out. Suites of channels positioned next to each other may be interpreted as the result of palaeoflood induced avulsions as has been shown by Malik and Khadkikar (1996). Calcification of the facies points to periods of dryness during which groundwater evaporation led to precipitation of calcium carbonate along stratification planes.

4.5 Massive silt (Sim)

An extensive blanket of silty deposits occurs throughout the basins (Plates 4.9, 4.10). These, at all sites (Plate 4.1) cap the succession. The thickness of these sediments vary from about 2 m to up to 10-12 m. The sediments are light yellow in colour and overlie Sh facies along a non-erosional planar to sub-planar contact. Recognition of these silts in the field is facilitated by the development of steep vertical bluffs. The bluffs are seen as vertical faces running parallel to the river reach. If seen as a profile perpendicular to the reach the bluffs form a negative topography while the underlying carbonate cemented Sh facies jut out giving rise to discontinuous perched benches at some localities. Elsewhere owing to recent undercutting such features are not succinct. Convex-up mounds is a common geomorphic expression which is both primary in origin in the north but more commonly it arises due to ravine erosion. The facies exhibits a total absence of primary stratification structures and is massive. Representative samples analysed for grain-size distribution characters yield high amount of silt ranging between 58-64% (Fig. 4.7).

The absence of stratification coupled with the predominance of silts suggests an origin from wind blown suspended sediments or dust (Pye, 1987 and references therein). These sediments are comparable to loess deposits, an observation earlier made by Pant (1993). Local reworking by sub-aqueous processes alter the distribution curve (Sareen & Tandon, 1995) but on a regional scale the larger population of silts persists (Allchin et al., 1978). In cases where the sand content exceeds 20% the term sandy-loess has been proposed by Pye (1987) and this term is adopted in this text. Large thickness of the deposits indicates that a constant sediment (dust) supply along with vegetation-aided trapping. Such sources may well be local. In the present case silts may have been derived from underlying sheetflood deposits that show a high concentration of silts (Fig. 4.6).

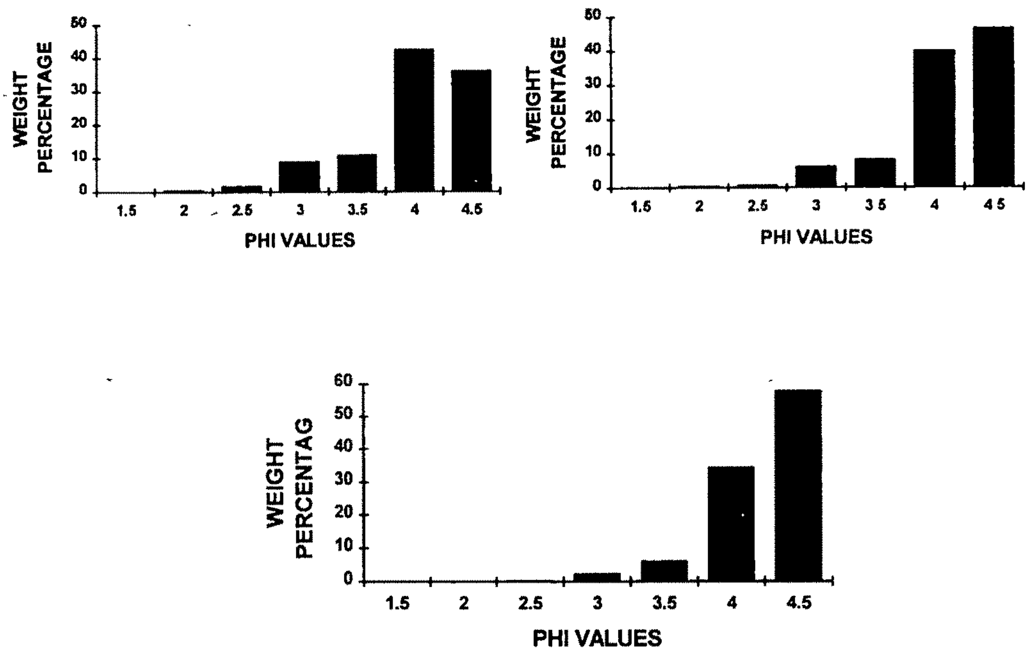

Figure 4.7: Grain size histograms for the Sim facies. Note that the facies contains quite large amounts of silts that classifies it as sandy loess.

Non cohesive nature of these sediments led to large scale remobilization during ancient dust storms. Preferential entrainment of silt is supported by numerous studies carried out on grain size distributions of particulate material and its fluxes (Nickling, 1983; Pye, 1987; Nickling & Gillies, 1993) during present day dust storms. These studies point to progressive fining of entrained particles from the ground surface with better sorting of suspended particles than those transported by either creep or saltation and concentrations of around 1 x 10^5 $\mu g\ m^{-3}$.

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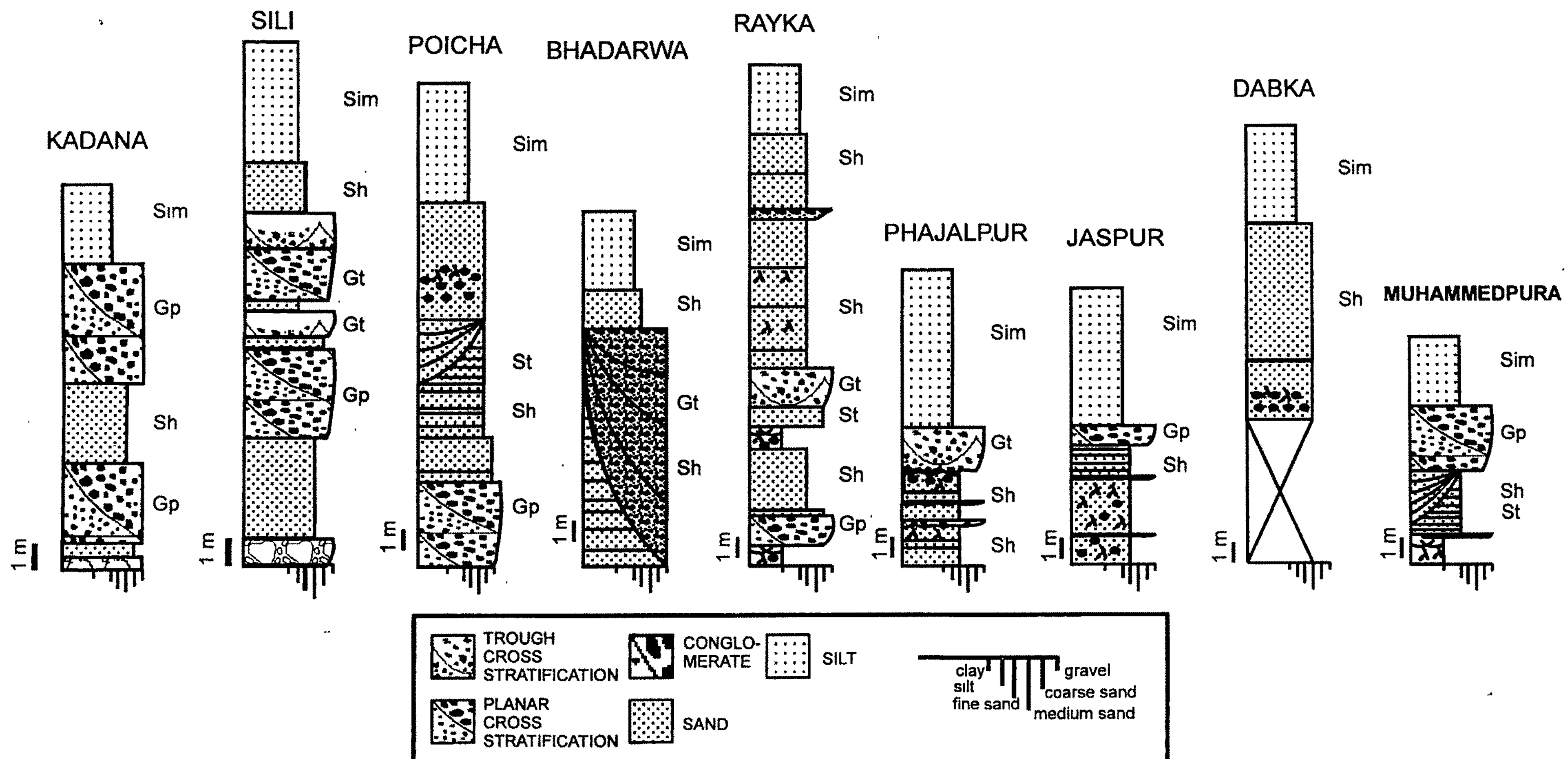

Plate 4.1: Lithologs of the Mahi basin showing distribution of clastic facies

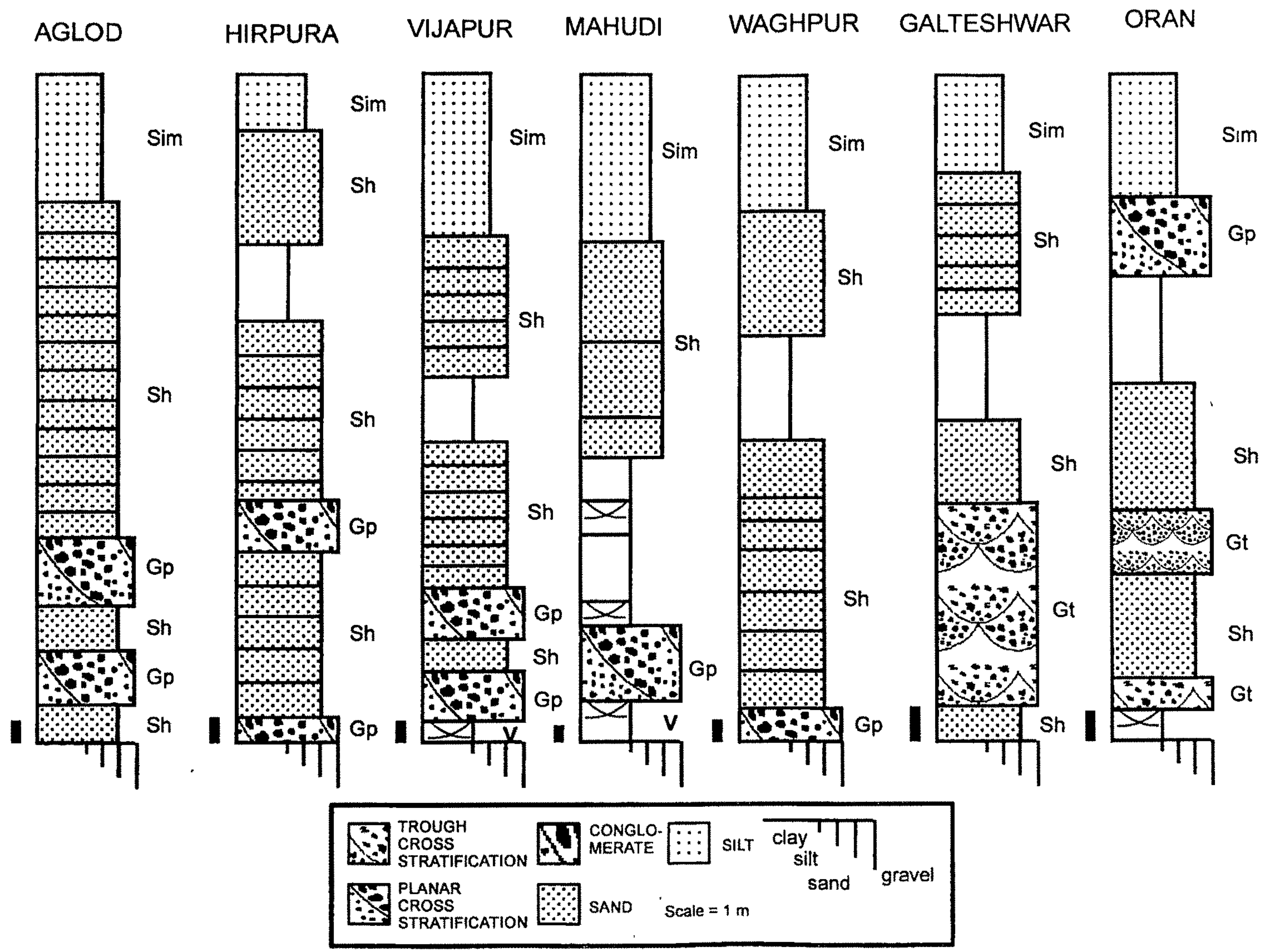

Plate 4.1(contd.): Lithologs of the Sabarmati basin showing distribution of clastic facies

Plate 4.2: Internally stratified silty sand block lining the base of the conglomerate sheet at Rayka (Mahi basin). Scale is 1 m long. Note the vertical orientation of the stratification.

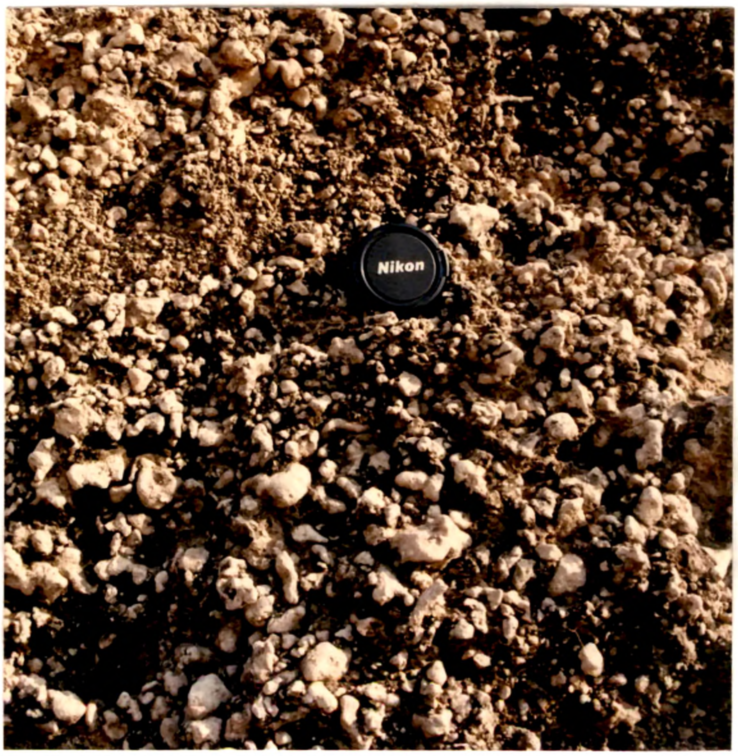

Plate 4.3: Irregular clast morphology of calcretes at Rayka (Mahi basin). Camera lens cap is 5.5 cm in diameter.

Plate 4.4: Juxtaposition of Gtb facies over the underlying Gtd facies. Gtb foreset beds are only several grain thicks while Gtd foreset beds are much thicker. Diameter of the lens cap is 5.5 cm. Location = Rayka, Mahi basin.

Plate 4.5: Gravel troughs of 3D dune origin. Location = Rayka, Mahi basin.

Plate 4.6: Planar cross-stratified gravel facies at Poicha, Mahi basin. Scale is 1 m long.

Plate 4.7: Horizontally stratified silty sands associated with the conglomerate facies. Unit in the foreground is 2 m thick. (Location = Rayka, Mahi basin).

Plate 4.8: Sh facies of sheetflood origin. Note the continuous extent of horizontal parallel stratification in the sediments above the author. (Height of the author is 1.56 m). Location is Hirpura, Sabarmati basin.

Plate 4.9: Sim facies (massive silts) seen capping deposits of sheetflood origin (Sh facies) at the top of the section. Thickness of red horizon at the left end of the photograph is 3 m (Location = Dabka, Mahi basin).

Plate 4.10: Massive silts (Sim) forming characteristic vertical bluffs due to absence of internal stratification at Mahudi, Sabarmati basin. Bluff of the right is 7 m thick.