Chapter 6

DEPOSITIONAL ENVIRONMENTS

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The large congregation of data on sedimentary facies and palaeosols makes it possible to erect or visualise the nature of past depositional systems and palaeogeomorphology. It also makes it possible to analyse changes in time and space and relate them to allocyclic and autocyclic mechanisms. Comparisons of the deposits with responses of modern analogues to annual discharge patterns yields quantitative estimates of past discharge regimes.

It has been possible to recognize three phases of aggradation based on sedimentary characters discussed in chapters four and five. These phases have characters that are exclusive, and point to the fact that sufficiently different formative conditions existed during such spans. The phases are termed here as aggradation phases.

6.1 Aggradation Phase 1

This span of aggradation covers the basal deposits at most sites in which major conglomerate bodies coexist with sandier facies. The facies that represent this phase include trough cross stratified conglomerates (Gt), planar cross-stratified conglomerates (Gp), horizontally stratified sands (Sh) and trough cross stratified sands (St). Palaeosols are exclusively vertisols with varying degrees of hydromorphism.

This suite of facies indicates that rivers during this period were mixed load. The absence of lateral-accretion structures or inclined heterolithic stratification negates deposition from high sinuosity meandering rivers. The presence of Gp facies related to downstream bar accretion lends credence to the interpretation that rivers were multiple-thread and braided. Additional support comes from the section at Rayka where a conglomeratic sheet is encased on both ends by large channel troughs. Lateral stability of thee rivers was facilitated by the presence of cohesive banks (Friend et al., 1979). Resistance towards bank erosion was provided through two means. One was the development of smectite-rich vertisols and the other was the formation of laterally extensive groundwater calcretes along primary stratification planes. Additionally, vertic soils would have aided in the armouring of floodplains against erosion and were important perpetrators in preserving underlying cohesionless sediments (Retallack, 1986). Banks did collapse, and this probably effected through underscouring. This is evident owing to the presence of large boulders at the base of conglomerate sheets and the ubiquity of calcretes as the most dominant clast in such sheets. The alluvial plains exhibited a microtopograhy popularly known today as the 'mukkara' structure (Retallack, 1990). This consists of a repeated arrangement of circular topographic lows rimmed by higher ground. The latter marks areas where the soil upheaved during re-wetting while the lows correspond to the base of bowls observed in the shallow subsurface.

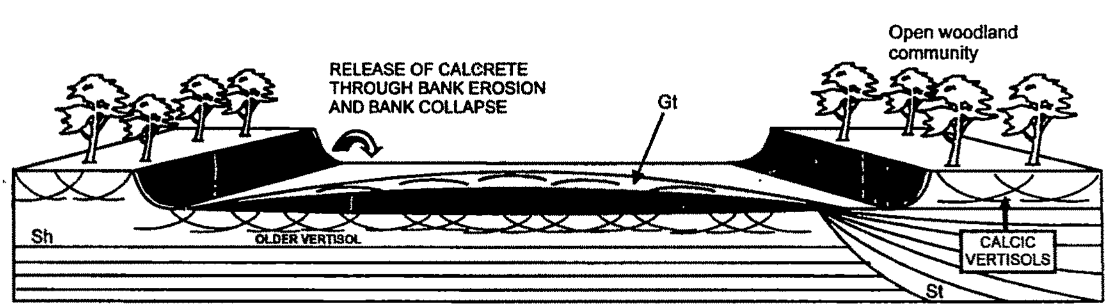

Figure 6.1: Model illustrating principal sedimentological and morphological features of rivers during Aggradation Phase 1.

The predominance of gravel dunes is important because such dunes require special hydraulic conditions for their formation and preservation in the stratigraphic record. The essential requirement being a rapid recession of flood (Carling, 1996). The rivers also experienced some months of total dryness during which evaporation led to precipitation of groundwater calcretes.

Flows were channelised except during large floods when overbank deposition (Sh facies) took place. Such flows were usually unsteady and non-uniform which is usually true for most natural conditions.

Facies models representative for the above assemblages are scarce. Our understanding of braided rivers that are mixed-load, in which transport is mediated both as suspension load and bedload is still in its conceptual stages. The river Burdekin of North Queensland, Australia (Alexander & Fielding, 1996; Fielding & Alexander, 1995), is a well documented paradigm of rivers that existed during this phase. The river has a catchment area of 1,29,000 km^2 and maximum discharges of around 26,000 m^3s^{-1}. Flood hydrographs reveal a precipitous rise during which turbid waters have high suspended load concentration. The climate varies between extremes of drought affected periods and floods (such as those mentioned above). The variability in discharge is produced by a wet summer season controlled by unpredictable tropical cyclones. To an extent the river Narmada, western India displays a striking similarity in discharge behaviour through the year (Rajaguru et al., 1995). Vegetation in the Burdekin river area is dominated by a open dry woodland community. Sedimentologically the river bed is sand dominated with particles moulded into dunes. These sands occur along with gravel patches that show antidunes (Alexander & Fielding, 1996). The river has steep banks and slump scars are common. During low stage flow mud-filled depressions show desiccation cracks and pedogenetic modification. The preservation of dunes, antidunes and gravel sheets is attributed by the authors to rapid emergence of bar surfaces subsequent to flood peaks resulting in minimal reworking.

Rivers of the humid and sub-humid tropics also possess a channel-in-channel geometry. Inset channels are maintained by discharges of magnitudes lower than annual maximum discharges. The latter are instrumental in governing the shape of the larger channel. Gravel-dune bedforms suggestive of high bed shear stresses (Best, 1996) apparently form exclusively during extreme discharge events whereas sands are mobilised within both the smaller inset channels during most of the year and also during extreme floods. Vegetative disruption of desiccated mud drapes in depressions result in a complex interlayering of gravel and clays (showing shrinkage and swelling features).

Soil maturity is strongly governed by the degree of sediment input for that particular area. Long periods of sedimentation quiescence assists in organo-chemical breakdown of mineral and rock particles (e.g. basalt, feldspars, micas etc.) to form clay minerals. In fact Bown & Kraus, (1987) illustrated a systematically increasing maturity in soil development away from the principal channel tract. A similar control of clastic-sediment poisoning on pedogenic carbonate was also shown by Leeder, (1975). This implies that areas on floodplains which depict mature soils indicate that a significant quanta of time elapsed between successive sedimentation events. Deep soil development during the Phase 1 testifies towards either infrequent floodplain inundation or low avulsion frequencies. The former is characteristic of tropical rivers because of the channel-in-channel arrangement. It is only during peak discharges that floodplains get inundated whereas during a major portion of time within-channel sedimentation takes place.

6.2 Aggradation Phase 2

The central portions represented by silty sands comprise this phase which overlies Aggradation Phase 1. This phase is represented by sand facies Sh and St and occassional planar cross-stratified gravel in the Sabarmati basin. Widespread sheetflood deposits are very characteristic of ephemeral rivers, which is well summarised in Bull (1997), Stear (1985), Graf (1988). The rivers were suspension load dominated, although areas proximal to mountain-fronts experienced bedload transport leading to localised bar formation. Incipient pedons cap each normal graded unit.

This reflects closely spaced sedimentation events or drier climates disadvantageous to the proliferation of vegetative growth. The latter alternative appears more feasible in light of the frequency of such sheetflooding events in present day ephemeral rivers. The rivers were very shallow with large width/height ratios. Banks obviously were poorly defined.

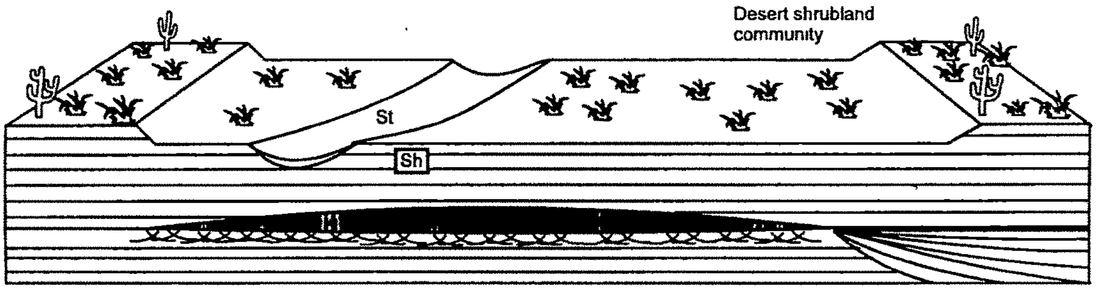

Figure 6.2: Model illustrating principal sedimentological and morphological features of rivers during Aggradation Phase 2.

A local poorly described paradigm is the Luni river basin of Rajasthan. It covers an area of 34,866 km^2 (Sharma & Murthy, 1994). The annual precipitation ranges from 600 mm in the south-eastern regions to 300 mm in the north-west with days that experience rain being around fourteen. Yearly pan evaporation of 2640 mm renders streamflow practically non-existent for the major part of the year. The channel widths vary between 68 m to 658 m with slopes of 0.0016 and 0.0006 respectively. Mean grain size typically falls in the fine sand to silt grade. From the year 1960 onwards there have been years of exceptional rainfall that caused extensive sheetfloods in the river (Ghose et al., 1980). However no properly documented sedimentological data is available for this basin.

Ephemeral rivers are typified by the large width to depth ratios (Reid & Frostick, 1989). Another character typical of ephemeral streams is the steepness of flood recession in their hydrographs. In the river Gash, Sudan (Abdullatif, 1989) for example, which has channel depths from 1-2 m and width variations from 100-800 m, discharge losses are up to 50%. Hydrographs for the year 1907-1980 show periods of high annual maximum discharges separated by years of less powerful flow. The differences are usually to the tune of several magnitudes. Another insight on the nature of these riverine systems comes from the example of the Santa Cruz river, Arizona (Graf, 1988). During a major flood in 1983, the waters formed a sheet 4.8 km wide and less than 1.5 m deep. It is thus probable that several streams emanating from mountain fronts formed the alluvial aprons on the flat alluvial plains.

Flows in ephemeral rivers are turbulent and the rise of the flood hydrograph usually takes 4-16 minutes. The efficiency of ephemeral rivers as carriers of bedload was demonstrated by Laronne & Reid (1993). Based on their comparative study of two Wadis of the Negev Desert, Israel with Oak Creek (Oregon, USA) they showed that for lower specific stream powers ephemeral rivers ably transport more sediment as bedload; this being several orders of magnitude than the perennial counterpart.

Within this phase the red beds represent an interlude within the general ephemeral river depositional regime. This deviation from the norm resulted in the development of ferralsols. The soils commonly form in vegetation communities represented by wooded shrubland (Retallack, 1990). Discharges would probably have been much higher but owing to poor channel development prior to this period flows remained unchannelised. However in some areas in the Sabarmati basin channels were defined and led to development of 2D bedforms of bars. Following this interlude the conditions deteriorated back to a regime in which flash floods dominated.

6.3 Aggradation Phase 3

The final phase of sedimentation in the Mahi and Sabarmati basins culminated with the deposition of massive silts (facies Sim). These wind blown sediments, more commonly found in China and Kashmir (Pant, 1993) are also seen bordering margins of major deserts (Pye, 1989). Pye (1989) provides a useful review of such aeolian dust sediments and the paradigm is largely derived from this work.

Strong winds that lead to these deposits form under a range of meteorological conditions. Dust devils are vortices in areas of strong heating of the ground which forms a layer of superheated air. These vortices are up to 100 m high but can ascend to as much as 1000 m also. Downdraught haboobs (haboob=violent winds in Arabic) generate by the outward flow of cool air from a cumulonimbus cloud. This flow is then sustained by genetically related horizontal density gradients. Haboob frequency is about 24 a year and travel at 50 $kmhr^{-1}$ for 30 minutes to an hour.

In Gujarat such winds locally reworked underlying flashflood sediments of aggradation phase 2. A net moisture deficit may be responsible for the reworking of sediments coupled with absence of persistent vegetation cover in the region. Buried soils are absent in this phase. The only indicators of periods of increased-moisture conditions are manifested as vadose-zone calcretes. No estimate of the vegetation density can be arrived at owing to lack of rhizogenic features within the sandy-loess silts. However, topsoil related rhizogenic activity is more common. The landscape during this phase was in all probability flat to gently undulating. Some of the sandy-loess were arrested locally during their movement to form mounds. These mounds are more commonly found in the northern parts of the Sabarmati basin (e.g. Langhnaj, Akhaj). Some of the loess was also trapped on the windward side of topographic highs.

Amorphous dunal mounds trending southwest-northeast are present on either side of the Mahi and also north of Ahmedabad (Allchin & Goudie, 1971). At Pavagarh a 2 km long and 1 km wide massive windward deposit attains a maximum thickness of 30 m. The sediment is fine sand and compares well with dune sands at Jalore (Allchin & Goudie, 1971).

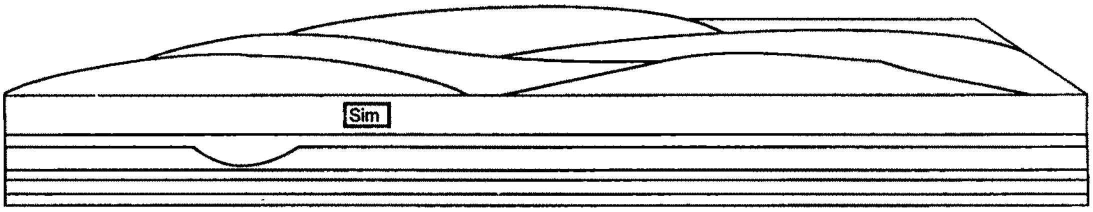

Figure 6.3: Model illustrating principal sedimentological and morphological features of dunes during Aggradation Phase 3.

Rao et al., (1989) investigated the foraminiferal content of these aeolian sediments right from Langhnaj and Ahmedabad in the south to Bikaner in the north. They identified eighty two species of foraminifera belonging to nineteen families and thirty two genera from forty two dune samples. At Ahmedabad and Langhnaj, *Ammonia beccarii* and *Asterorotalia* were more in number along with *Cibicides refulgens* and *Hauzawaia concentrica*. Diametrically the foraminiferal tests ranged between 109-445 um. They interpret that the foraminifers were blown in the suspension load of haboobs or dust-devils. Further they argue that saltation transport was not probable as it would have led to loss in ornamentation or test breakage. These foraminifers were derived from the coastal margins of Gujarat, indicating that the dunes formed not due to northeastern winds (winter monsoon) but due to southwest monsoon winds.

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