STRATIGRAPHY AND SEDIMENTARY FACIES

Stratigraphic studies on the sediments comprising the depositional surfaces in Kim river basin – the Late Pleistocene Depositional Surface (LPDS) and the Late Holocene Depositional Surface (LHDS), were carried out with a view to infer their genesis and delineate the morphostratigraphic relationship of the various surfaces. The sediments in these surfaces are exposed along the vertically incised cliffs of the Kim river and its tributaries. The study was carried out in all the three morphostructural domains.

The exposed sediments were measured and vertical logs were prepared. The physical characteristics of the individual litho-units were noted which reveals a well preserved record of changes in depositional environments. These changes as well as subsequent depositional events are marked by the marine, fluvial and fluvio-marine sediments. These sediments of diverse environments are exposed by the Kim river due to incision. Individual lithosections were measured and key horizons were identified and compared. The exposed sequences were also studied to know their lateral as well as the vertical facies variations. On the basis of the relative order of superposition and comparable lithounits overlying and underlying the marker horizon a composite litho-stratigraphy was prepared. In the upland zone (morphostructural domain –I), the deposits overlie the basement rocks and are about 10 to 15 m thick. At places the basement rocks are fractured over which occur the Quaternary sediments. In general sediments of LPDS are compact and show evidence of pedogenic activity while the LHDS sediments are comparatively less compact and show no sign of pedogenesis.

LATE PLEISTOCENE DEPOSITIONAL SURFACE (LPDS)

This Late Pleistocene Depositional Surface is a flat alluvial surface extensively developed in the morphostructural domains I and II. In morphostructural domain I the sediments of LPDS (Fig. 5.1) rest over the Deccan Traps while in the morphostructural domain II, they overlie the Tertiary rocks. The sediments comprising this surface show incision of 10-15 m along the various river valleys. The various lithosections measured are described below.

Pansim section

This section occurs in the morphostructural domain I along the left bank of Kim River (Figs. 5.1, 5.2). The Late Pleistocene sediments at Pansim directly overlie the basaltic rocks exposed in the river bed. The section exposes well bedded fluvial sediments which are about 11m thick. The sediment succession starts with a 1.5 m thick planar cross stratified gravel (Fig. 5.3). This is followed by a 1.25 m thick horizontally

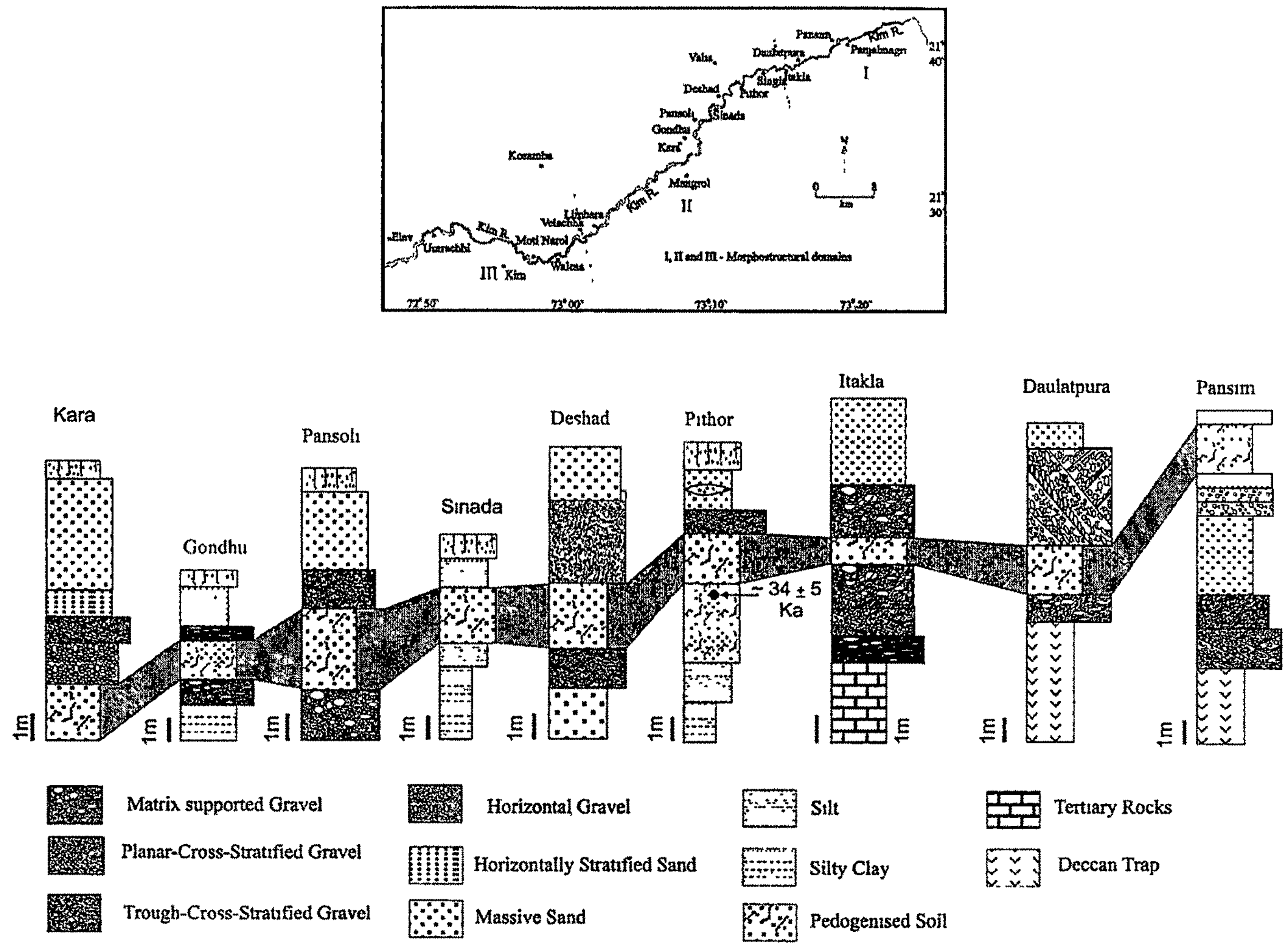

Fig. 5.1 Lithologs showing the exposed sediment succession of Late Pleistocene Depositional Surface (LPDS).

stratified gravel. The clasts comprising these gravel beds are of basalts which are subangular in shape and the encased matrix is sandy. The gravels are overlain by a

Fig. 5.2 Photograph showing the exposed fluvial sediments at Pansim.

structureless 2.5 m thick massive sand within which a few calcrete nodules are dispersed.

Fig. 5.3 Photograph showing the semi-compact planar cross stratified gravel at the base of exposed sediment succession at Pansim.

A 1 m thick sandy gravel overlies the sand horizon which is followed by a 2 m thick deeply pedogenised soil horizon. The soil is distinctly identifiable owing to the presence of abundant nodular pedogenic calcretes mainly in its upper part. The sequence is capped by a 0.5 m thick horizontally laminated coarse sand.

Daulatpura section

At Daulatpura, in morphostructural domain I the sediments of Late Pleistocene depositional surface are exposed on the left bank of an entrenched meander. These are about 13 m thick and overlie trappean basement rocks. The base of the sequence is marked by a compact highly calcretised bed of about 1 m in thickness (Figs. 5.1, 5.4) and are overlain by highly fractured and mottled pedogenised clays. The clays are characterised by the presence of abundant pedogenic calcretes and is overlain by a planar cross stratified gravel of 4 m thickness. The sequence is capped by a 1 m thick sand horizon.

Fig. 5.4 Photograph showing the compact basal gravel overlain by pedogenised clays at Daulatpura.

Itakla section

This section (Fig. 5.1, 5.5) is located about 1 km downstream of Itakla village in the morphostructural domain-II. The sediments overlie the fossiliferous Tertiary rocks. The sediment succession at Itakla shows a clear domination of gravelly facies in

Fig. 5.5 Photograph showing the exposed fluvial sediments near Itakla.

comparison to the sections exposed at Daulatpura and Pansim. This is possibily because of its close proximity to the Rajpardi Fault. The sediment succession starts with a 1 m thick massive gravel bed containing clasts of mostly trappean rocks and is followed by 2.25 m thick planar and trough cross stratified gravels capped by a 1 m thick buried soil. Towards the top the buried soil is again overlain by a 2 m thick trough cross stratified gravel and than by a 4 m thick massive sand.

Pithor section

The section occurs in the morphostructural domain II and exposes the Late Pleistocene sediments (Figs. 5.1, 5.6) along a huge entrenched meander near Pithor. The sequence starts with a 1.5 m thick silty clay horizon which is overlain by 1.5 m thick massive silts. A thick horizon of silty sands which shows calcrete pipes along the cracks and fractures occurs over the silts (Fig. 5.7). Optically Stimulated Luminescence (OSL) dating of these silts (Fig. 5.1) has yielded a tentative age of 34$\pm$5 Ka. A well developed 2 m thick pedogenised soil bed containing abundant nodular calcretes is measured at Pithor. This bed is comparable and occurs at the same stratigraphic position to that of a soil horizon observed at Pansim, Daulatpura and Itakla. This is actually a buried soil overlain by a planar cross stratified sandy gravel bed of about 1 m thickness (Fig 5.8). This gravel bed shows a distinct scoured base and is overlain by 1.5 m thick sand bed in which occur thin gravel lenses made up dominantly of calcrete clasts and is capped by a thin horizon of top soil.

Fig. 5.6 Photograph showing sediment succession of the Late Pleistocene Depositional Surface (LPDS) at Pithor. The highly calcretised soil is seen towards the upper part of the succession.

Fig. 5.7 Photograph showing calcrete precipitated along cracks and fractures of the silt horizon at Pithor.

Fig. 5.8 Photograph showing planar cross stratified sandy gravel overlying the buried soil at Pithor. Note the sharp erosional contact.

Deshad section

This section is exposed on the right bank of a large entrenched meander in the morphostructural domain II at Deshad. At the base of the sequence occurs a 2 m thick sand horizon, overlain by a trough cross stratified gravel of about 1.5 m thickness. A 2.5 m thick deeply pedogenised sand showing development of nodular calcretes overlie the gravels. A second horizon of about 3 m thick trough cross stratified gravel overlies the pedogenised sand (Figs. 5.1, 5.9). The gravel clasts are rounded to subrounded and are dominantly of trappean basalts and Tertiary rocks. A fluvial sand of about 2 m thickness marks the youngest horizon of the sequence.

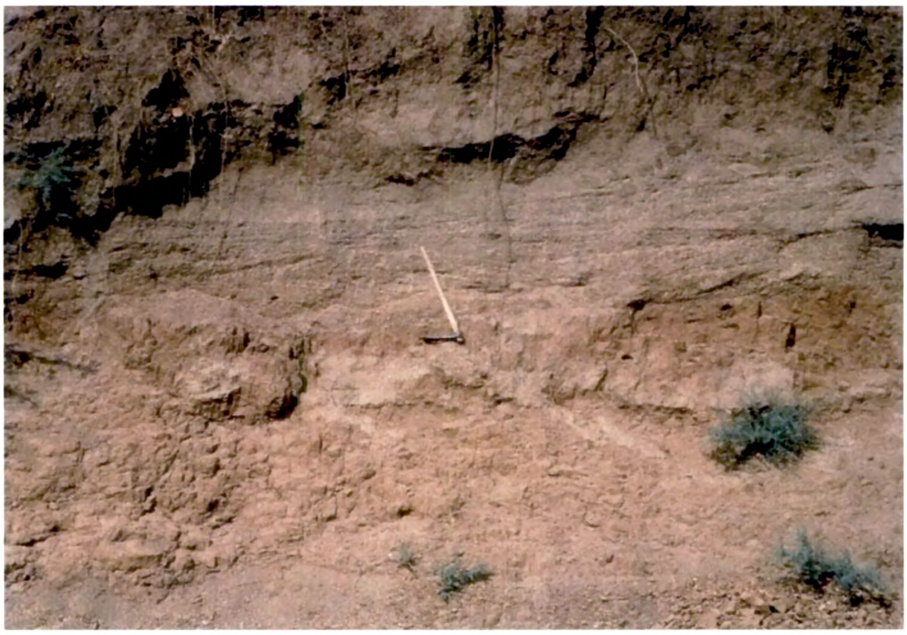

Fig. 5.9 Close view of the section at Deshad showing pedogenic horizon overlain by stratified gravel. Note the scour and fill structure at the contact.

Sinada section

This section is located about 1 km upstream of Sinada village in morphostructural domain II (Figs. 5.1, 5.10). The sediments are exposed on incised cliffs of the left bank of the Kim river. The sediment succession comprises a 3 m thick silty clay at the base which is followed by a 1 m thick horizontally bedded silts. This is overlain by 2.5 m thick highly calcretised buried soil. The calcretes are present in the form of nodules which tend to increase towards the top of the soil horizon. The sequence is capped by a 0.5 m thick top soil.

Fig. 5. 10 Photograph of the incised cliff showing sediment succession of Late Pleistocene Depositional Surface at Sinada.

Pansoli section

This section is exposed on the right bank of Kim river at Pansoli village and forms a part of the morphostructural domain-II. At the base occurs a compact matrix supported gravel bed of about 2 m thickness, followed by a brownish reddish coloured buried soil of about 3 m thickness (Fig. 5.1). A 1.5 m thick trough-cross-stratified gravel and 3 m massive structureless sand horizon rest over the buried soil.

Gondhu section

At Gondhu village the sediments that make up the Late Pleistocene Surface (LPDS) are exposed on the right bank of the Kim river in the morphostructural domain II. The base of the sequence is marked by a 1.5 m thick silty clay which is overlain by a large poorly stratified lensoidal body of gravel (Figs. 5.1, 5.11). The lensoid body extends for about 35 m and has a maximum thickness of 1 m. The gravel is overlain by a distinct soil

Fig. 5.11 Photograph showing exposed sediment sequence at Gondhu.

horizon characterized by abundant calcretes nodules. The buried soil is overlain by another lensoidal body of structureless gravel. Towards the top, the sequence consists of 1.5 m thick silt followed by 0.5 m top soil. In addition to the large lensoid body of gravels, small scale scour and fill structures are also commonly seen.

Kara section

The Kara section occurs on right bank and is located few metres downstream of the confluence of the Kim and Tokri rivers. At the base of the sequence occurs a deeply pedogenised silty clay (Figs. 5.1, 5.12), which is overlain by a 2.5 m thick deeply scoured stratified gravel. The gravel becomes planar cross stratified in the upper part which shows large aggregates of underlying clays (Fig. 5.13) implying very short transport. Overlying this horizon is a 4 m thick massive sand capped by 0.5 m top soil has been documented.

Fig. 5.12 Photograph of the basal part of the sediment succession of Late Pleistocene Depositional Surface at Kara.

Fig. 5.13 Close view showing large aggregates of clay in gravels derived from the underlying horizon. Note the sharp erosional contact.

LATE HOLOCENE DEPOSITIONAL SURFACE (LHDS)

The Late Holocene Depositional Surface occurs as a low terraced surface and is bounded by the river channel on one side and the other older surfaces away from the river. The sediments comprising this surface are exposed as low incised cliffs of 4-8 m. As described in the earlier chapter, the Late Holocene Depositional Surfaces occur in all the three morphostructural domains. Although there is a great variability in sedimentary characteristics of these surfaces in the three morphostructural domains, its geomorphologic setting remains the same all over the Kim river basin. The sediment record of these surfaces in the morphostructural domain I and II comprises mainly of fluvial silts, sands and gravels (Fig. 5. 14) whereas in morphostructural domian III, they

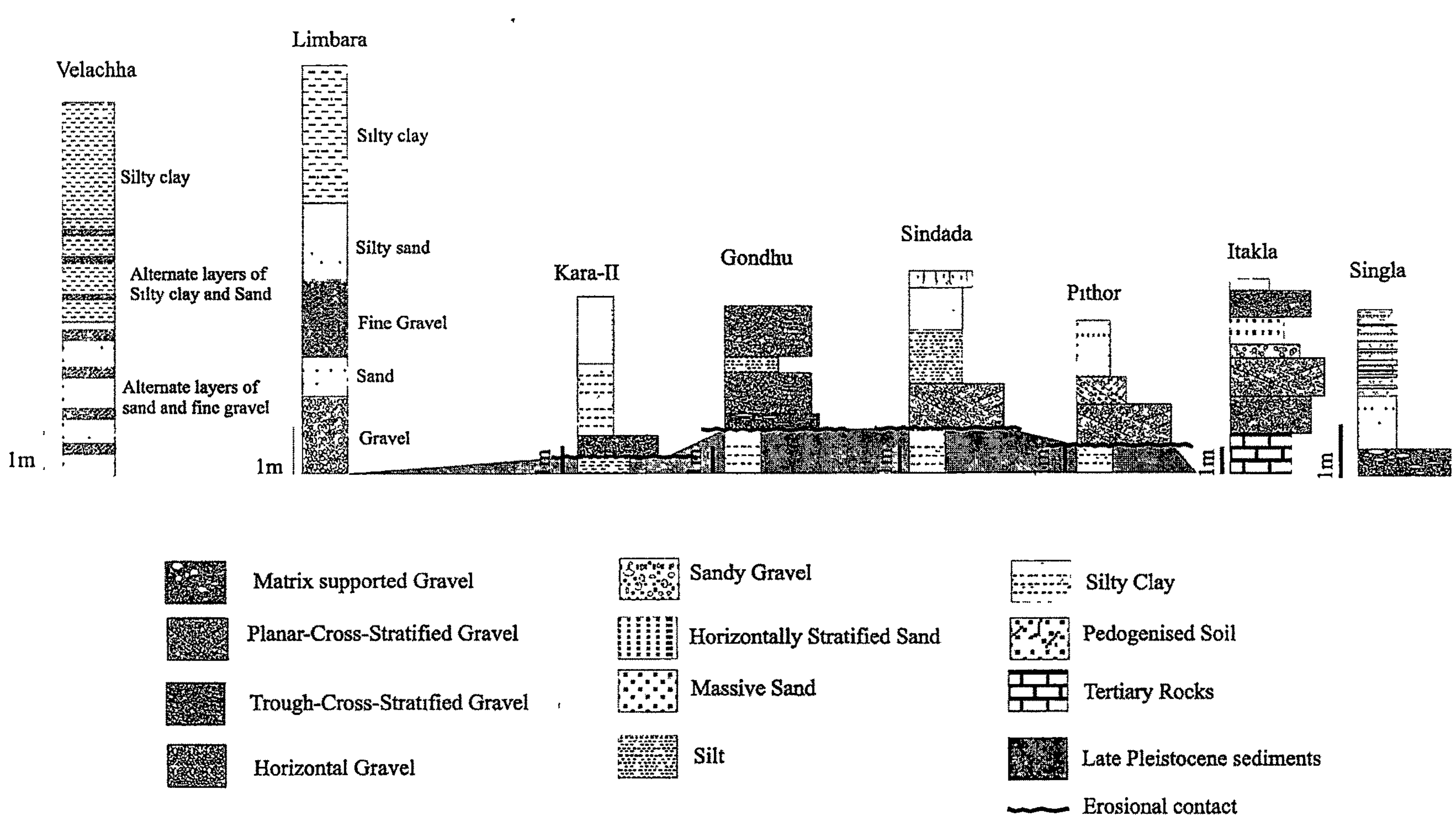

Fig. 5.14 Lithologs showing fluvial sediment succession of Late Holocene Depositional Surface in the Kim river basin. Locations of the studied sections are shown in Fig. 5.1.

are generally of estuarine-tidal environment. The sediment sequences of the Late Holocene Depositional Surface are described below.

Fluvial Sediments

The fluvial sediments forming the Late Holocene Depositional Surface (LHDS) are observed in morphostructural domain I and II only. Good sections of these sediments are exposed at Itakla, Pithor, Sinada, Gondhu, Singla, Kara, Limbara and Velachha (Fig. 5.14). In morphostructural domain – I, the sonstituent sediments of LHDS are homogenous and stratified to unstratified fine sands and silts. However, downstream of the Rajpardi Fault in morphostructural domain – II, marked increase in the grain size is observed and show multiple beds of coarse gravels. At Itakla these overlie either basaltic rocks or Tertiary rocks (Fig. 5.15). The sediments here entirely consist of stratified and unstratified gravels. The second section is located about ~300 m downstream which shows a greater

Fig. 5.15 Photograph showing Late Holocene Depositional Surface overlain by Deccan Trap at Itakla.

degree of heterogeneity in terms of lithology (Fig. 5.16). The gravels are about 3 m thick and mainly comprise unstratified gravel overlain by planar cross stratified gravel. Towards the top the gravel becomes massive and terminate into a sand horizon. The predominance of the gravels points to tectonic activity along the Rajpardi Fault.

Fig. 5.16 Close view of the planar cross stratified gravel horizon at Itakla.

At Pithor on the right bank of a large meander a good section of about 6 m is exposed. At the base, sediments of LPDS are exposed which show an erosional contact with the overlying Holocene sediments (Figs. 5.14, 5.17). The Late Holocene sediments above are mainly characterised by planar-cross-stratified gravel and planar-cross stratified sand which altogether is about 2.5 m thick and in turn followed by 2 m thick massive silt bed which shows no primary sedimentary structures.

Fig.5.17 Photograph showing sediment succession of the Late Holocene Depositional Surface at Pithor. Note the erosional contact with the basal silts of Late Pleistocene age.

At Sinada in morphostructural domain II, the sediments of LHDS rest over the sediments of Late Pleistocene Depositional Surface (Figs. 5.14, 5.18). The contact is highly irregular and erosional. Above the deeply eroded surface occurs a planar cross-stratified gravel of about 1.5 m thickness which is overlain by 2 m thick stratified silts which comprise several 8-10 cm thick individual strata. A massive silt which show pedogenises in its upper parts form the younger Holocene deposits.

Fig. 5.18 Photograph showing sharp erosional contact between Late Pleistocene Depositional Surface and Late Holocene Depositional Surface at Sinada.

Another important section of LHDS located at Gondhu shows a matrix-supported gravel of about 0.5 m thickness at the base. This massive gravel bed is overlain by large scale trough cross-stratified gravel bed (Fig. 5.19). A stratified silt bed overlain by a 2 m thick sandy gravel showing well developed cross-stratification comprise the upper part of the section.

Fig. 5.19 Photograph showing large scale cross-stratification in the sediments of Late Holocene Depositional Surface at Gondhu.

At Singla the Late Holocene sediment succession starts with a massive gravel at the base (Figs. 5.14, 5.20) which is overlain by 1m thick poorly stratified sands. The upper part of the succession shows alternate strata of laminated silty clay and sand (Fig.

Fig. 5.20 Photograph of Late Holocene Depositional Surface sediment succession at Singla.

5.20). Individual strata vary from 5 to 15 cm in thickness.

Estuarine-tidal sediments

In morphostructural domain – III, the LHDS is found to consist of estuarine- tidal sediments. Lithologically, these comprise alternations of sands, silts and laminated clays (Fig 5.21).

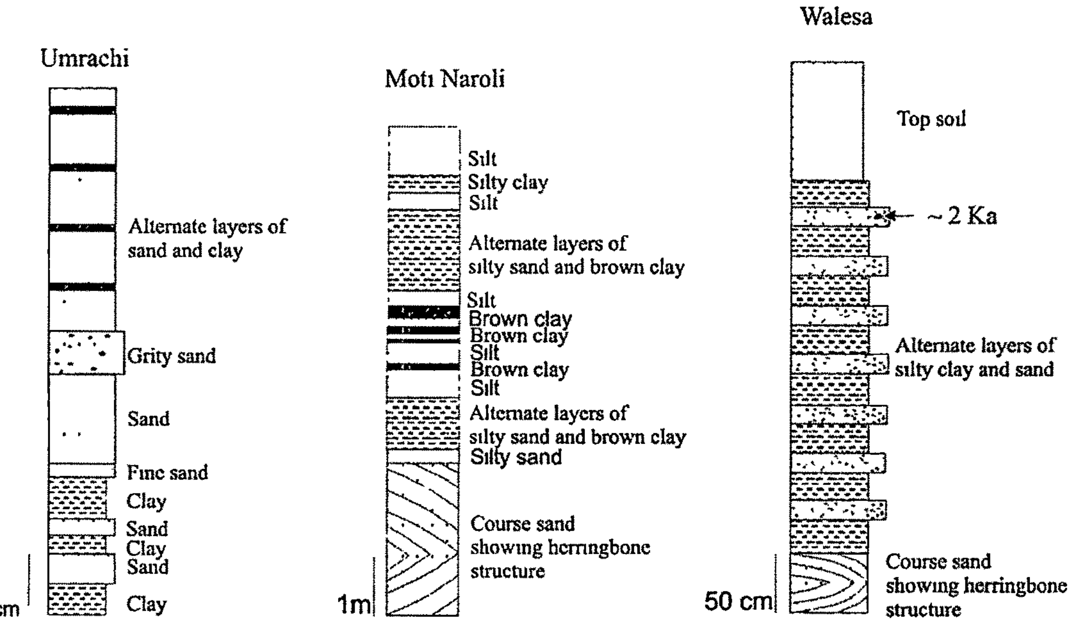

Fig. 5.21 Lithologs of stratigraphy of Late Holocene Depositional Surface in the estuarine zone.

At Walesa, the Late Holocene section is exposed on the left bank of the Kim River in the estuarine part of the morphostructural domain-III. A 0.50 m thick sand bed forms the base of the Late Holocene succession. The sand bed shows typical bi-directional cross beddings termed as herringbone structure. The presence of bi-directional cross stratification is indicative of estuarine environment. This is overlain by 3 m thick alternating beds of silts and clays rich in organic matter (Figs. 5.21, 5.22). Optically Stimulated Luminescence (OSL) dating of the silts in the upper part has yielded a tentative age of ~2 Ka. A thick surface

Fig. 5.22 Photograph showing alternate layers of silt, sand and finely laminated clay in Late Holocene Depositional Surface at Walesa.

soil marks the top of the exposed sediment succession. Overall, the sediment characteristics are typical of tidal-estuarine environments.

At Moti Naroli the morphostructural domain III, these sediments occur on the left bank of the Kim River. The base of the section is marked by a 2 to 3 m thick sand bed which shows well developed planar cross stratification. The foresets are found to dip in downstream as well as in upstream direction (Figs. 5.21, 5.23). Such bidirectional

Fig. 5.23 Photograph showing bi-directional cross bedding in sands at Moti Naroli. In the upper parts the foresets dip in downstream direction while the at the bottom, the foresets are seen to show upstream dips.

foresets typically point to their deposition in an estuarine environment.

This bed is overlain by a thin layer of silty sand of about 0.25 m. The silty layers alternate with clays and show well developed horizontal laminations. Such alternations occur all throughout the section (Figs. 5.21, 5.24). The total thickness of this sequence showing alternations of silts and clays is about 2.5 m. The clay layers are found to be rich in organic matter and show fine internal laminations. The succession is capped by 0.5 m thin sand bed which shows a well developed top soil. Similar lithological characteristics are observed in the estuarine sediments exposed at Umrachhi. In general, the muddy sediments accumulate mainly in the tidal flats while sands are deposited in tidal channels running along the estuary (Woodroffe et al. 1989; Darymple et al. 1992).

Fig. 5.24 Photograph showing alternate lithologies of sand, silt and clay at Moti Naroli.

SEDIMENTARY FACIES

Sedimentological studies were carried out to delineate the depositional environments of the sediments comprising the surfaces (LPDS and LHDS) in the Kim river basin. The exposed sediment sequences provide vital information on the various sedimentary processes and related depositional environments (Miall, 1996). The physical characteristics of individual lithounits were identified in the field which helped in assigning the facies codes. The following facies were identified using the facies codes of Miall (1985).

Matrix supported gravel (Gms)

The Gms facies are found mostly in the sediment sequences of morphostructural domains I and II. Both LPDS and LHDS sediments show occurrence of Gms facies. The sediment sequences of Late Pleistocene Depositional Surfaces (LPDS) show presence of Gms facies at Daulatpur, Itakla, Pansoli and Sinada, while in the Late Holocene Depositional Surface (LHDS) it is well developed at Limbara and Velachha. The Gms facies in the LPDS rests on the basement rocks in the morphostructural domain-I, while in the morphostructural domain-II, it overlies the intensely pedogenised fractured clay horizon (vertisol) and/or massive sands. The facies is comprised of subrounded to subangular basaltic clasts (3 to 6 cm) with sand as matrix in the morphostructural domain I. In the morphostructural domain-II, the Gms facies consists of rounded to subrounded clasts of Tertiary rocks with sand as matrix (Fig. 5.25). The thickness varies between 1 to 3 m. The Gms facies in the LHDS is well developed in the sections exposed at the western end of morphostructural domain-II. These facies are less compact and it comprises clasts of both basaltic and Tertiary rocks. The Gms facies has been interpreted as a debris flow deposit (Karpeta, 1993; Sroka and Kowalska, 1998) related to gravity slumps of clastic material (Blair, 1987).

Fig. 5.25 Close views of the matrix supported gravel at Kara.

Planar cross-stratified gravel (Gp)

This facies is characterised by gravel clasts which are relatively small in size and show planar cross-stratification and moderate to poor sorting (Fig.5.26). Clast

Fig. 5.26 Photograph showing planar cross stratified gravel facies at Gondhu.

imbrication is common. These units are 0.5-3 m thick and show erosional bases. Grain size changes are abrupt and show no particular trends. The foresets occasionally show steep dips upto 40^{o}

The Gp facies has better developed in the morphostructural domain-I in the sections of LPDS at Daulatpura and Itakla. The facies is highly compact and rests on the intensely pedogenised fractured clay horizon (vertisol). The clasts (1 to 6 cm) of this facies are rounded to subrounded and basaltic in composition. The thickness of the Gp facies varies from 1 to 4 m. The foresets of this facies at Daulatpura are normally graded and dip at an angle of 24^{0}-27^{0} due SW. The grading is well marked by coarse and fine beds ranging in thickness between 20 to 25 cm and 6 to 8 cm respectively. In the morphostructural domain-II and III, the Gp facies is not exposed. The facies has been interpreted as formed due to downstream accretion of avalanching slip faces on an advancing channel bar (Smith, 1990; Jo and Chough, 2001). Such facies have been interpreted as representing migrating straight crested transverse bars (Clemente and Perez-Arlucea, 1993; Collinson and Thompson, 1989) and indicate deposition under waning flood conditions (Miall, 1985). Cementation of this facies may be attributed to local dissolution of the calcrete clast bedload and reprecipitation in the interparticle voids (Khadkikar et al. 1998).

Trough cross-stratified gravel (Gt)

The Gt facies is well exposed in morphostructural domains I and II (Fig. 5.27). In the morphostructural domain- II, the Gt facies is well exposed in sections of LPDS at Itakla, Deheli, Pansoli and Kara. The facies rests on the Gp facies in the morphostructural domain-I, while in the morphostructural domain-II, the Gt facies overlies the massive sand (Sm) and at places the intensely pedogenised fractured clay horizon. In the morphostructural domain-I, the Gt facies is comprised of subrounded to subangular basaltic clasts (1 to 3 cm) with sand matrix, while in the morphostructural

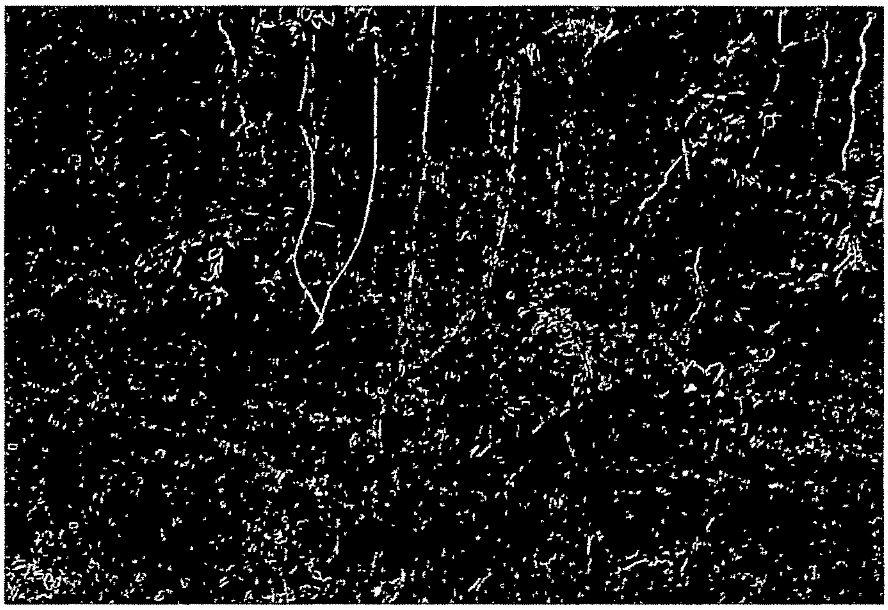

Fig. 5.27 Photograph showing trough cross stratification gravel at Gondhu. The troughs can be seen gradually changing over to horizontal stratification towards the top.

domain-II, the Gt facies is comprised of rounded to subrounded clasts of Tertiary rocks. The Gt facies at Deshad are laterally and persistent and occurs as 'ribbon like' bodies. The facies thickness decreases laterally on the either sides and merges with the horizontally stratified fine sand facies. The lower bounding surface of this facies is erosive with respect to the underlying mottled clay horizon at Deshad and Pansoli. The amplitude of the trough varies between 0.5 m to 1.5 m and are 1.5 m to 20 m wide. The foresets are normal graded and dip at an angle of 18^0-19^0 due ENE-WSW. The grading is marked by coarse and fine beds. The coarser beds range in thickness between 12 to 15 cm while finer beds are of 6 to 9 cm in thickness.

The Gt facies normally form by the downstream migration of trains of mega sinous crested dunes in a deepest part of the channel (Miall, 1978; Rust, 1978; Billi et al. 1987; Todd and Went, 1991). The change in foreset dips from high (18^0-19^0) passing into almost horizontally bedded gravel bed suggests deposition near the transition to upper stage plane beds (Smith, 1990). The maximum thickness of 4 m suggests flow depth of a similar magnitude. The change in trough dimension indicates fluctuating flow regime.

Horizontally stratified gravel (Gh)

This lithofacies consists of clast-supported pebble and cobble gravel with crude horizontal stratification (Miall, 1996). The facies has been documented in Pansim, Itakla and Kara (Fig. 5.28) sections. Here, the clasts are moderately to poorly sorted and the

Fig. 5.28 Close view of the horizontally stratified gravel facies at Kara.

clasts range in size between 5-10 cm. Clasts are commonly imbricated. The facies is a result of repetitive deposition beneath the turbulent flows that carry abundant sediments (Hein and Walker, 1977; Miall, 1996).

Horizontally stratified sand (Sh)

This facies shows thinly stratified or horizontally laminated coarse to fine sand units. The individual lamina is 0.2-0.3 m thick. The facies overlies the Gms and Gm facies. The sands were deposited in upper flow regime plane bed conditions. The horizontal lamination and lack of channel structures are indicative of sporadic shallow sheet flows (Balance, 1984). The Sh is interpreted as a product of relatively high energy conditions, at the transition from lower to upper flow regime, in the shallow channels of a braided river (Sroka and Kowalska, 1998; Boothroyd and Ashley, 1975; Harms et al. 1982).

Massive sand (Sm)

This facies occurs as tabular sand sheets of 0.20 to 3.0 m thickness. The contacts of the individual beds are sharp and are traceable laterally. It occurs within the Gms and Gp facies as medium to coarse sand sheets. The facies represent overbank deposits as in crevasse splays (DeCelles et al., 1991). These represent rapid deposition from heavily sediment laden flows from waning floods (Todd, 1989; Maizels, 1993).

Laminated Sand, Silt and Mud (Fl)

The Fl facies contains mainly medium or fine sand, silt and mud. Its gravel admixture is negligible. The sorting is moderate and skewness of grain size distribution is negative. Units of Fl are 0.2-0.5 m thick. The main depositional structure is horizontal lamination with sets of small scale cross bedding. Very small-scale ripples may be present in the sand and silt beds. Undulating bedding, scattered bioturbation (including animal foot-prints), desiccation cracks, plant roots, coal streaks and scattered pedogenic nodules may be present in this facies. Typical thickness of continuous Fl deposits range from a few centimeters to many meters, depending on sediment supply, fluvial style, and basin subsidence rates. Careful observation may indicate that units are organized into thin fining-or-coarsening-upward successions (Miall, 1996). The Fl facies represents overbank deposits formed in a very low energy regime, probably during waning flood conditions (Sroka and Kowalska, 1998; Miall, 1996). The sand and silts indicate plane bed deposition either under high or low flow regime (Harms et al. 1982; Bridge and Best, 1988; Best and Bridge, 1992). The muds have been deposited primarily in standing water, later modified by bioturbation (Friend, 1966; Miall, 1977; Turner, 1980).

Palaeosol

A prominent deeply pedogenised buried soil is observed in upper parts of the exposed sediments of LPDS. The soil is readily identifiable owing to its deep brown colour. The soil shows abundance of calcrete nodules. The relative abundance of calcrete nodules increases towards the top of the soil profile. The soil shows extensive fracturing giving rise to blocky aggregates. Since the soil occurs at the same stratigraphic position and is invariably observed in all the exposed sections, it has been found useful for establishing stratigraphic relationships of the sediments forming the Late Pleistocene Depositional Surface (LPDS).