Chapter 4
Fluvial Sequences

Introduction

Geologists and geomorphologists have become increasingly interested in understanding the fluvial response to changing environmental conditions as the fluvial systems have capabilities to preserve it in the form of morphological, sedimentological and ecological repository (Schumm, 1977; Bull, 1991; Vanderberghe, 1993; Blum & Tornquist, 2000) Although, fluvial systems provide important information regarding the processes operative in the region, fluvial records and their morphology in Saurashtra peninsula has not received much attention as it has been in the case of the Sabarmati, Mahi and Narmada rivers of mainland Gujarat. However, Marathe (1981) has carried out basic morphometric analysis in the Hiran river basin and recognized gravelly and sandy units along with the miliolite limestone units therein. A detailed record on the geoarchaeology of the Hiran river with a geochronological constrain has been made available by Baskaran et al. (1986). Drainage basins are the fundamental unit of a geomorphic system (Bloom, 2002) and hence, should not be avoided while appreciating the regional geomorphological evolution. The response of any coastal segment either to the sea level change or to the tectonics gets reflected in its overall geomorphic characteristics, coastline as well as coastal rivers. An attempt has been therefore, made to investigate morphometric parameters and fluvial sequences from the selected drainage basins of the study area

In general, the Saurashtra peninsula shows radial drainage pattern (Fig. 1 4) The drainages of the Saurashtra are of ephemeral type and have a short period of flow following the intense rainfall. They carry maximum water and sediment load during the southwest monsoon period which onset generally between the June and continues up to the September Bhadar and Shetrunji are the two biggest river basins of the Saurashtra peninsula, the Bhadar being 185 km long. Noli, Megal, Hiran, Saraswati, Singwado and Sangwadi are the other important coastal rivers of the southwest Saurashtra peninsula (Fig. 4.1) which originates from the Gir Highlands and debouches their water into the Arabian Sea The other important coastal streams are Devka, Somat and Rupen which originate mostly in the coastal plains of the south Saurashtra and travel for a shorter distance with insignificant fluvial deposition The present chapter consists of a detailed description pertaining to various lithofacies exposed in the river bank cliff sections of these rivers

Fluvial Sequences

Changes in the climate and consequent changes in the sea level get reflected in spatial shifts of geomorphic domain, and associated sedimentary packages (Blum & Tornqvist, 2000). Fluvial landforms and associated sedimentary packages, especially of the coastal areas, provide an important continental record of change in the sea level. Rivers draining the southwestern coastal plains of Saurashtra were examined by studying the sediments exposed in the riverbanks. The sediments were denoted as individual facies by following the conventional two-letter coding scheme of Miall (1996). The characteristic lithofacies and bounding surfaces were recognized and evaluated to see their significance within and across the fluvial systems. The Bhadar river has been studied in detail to establish

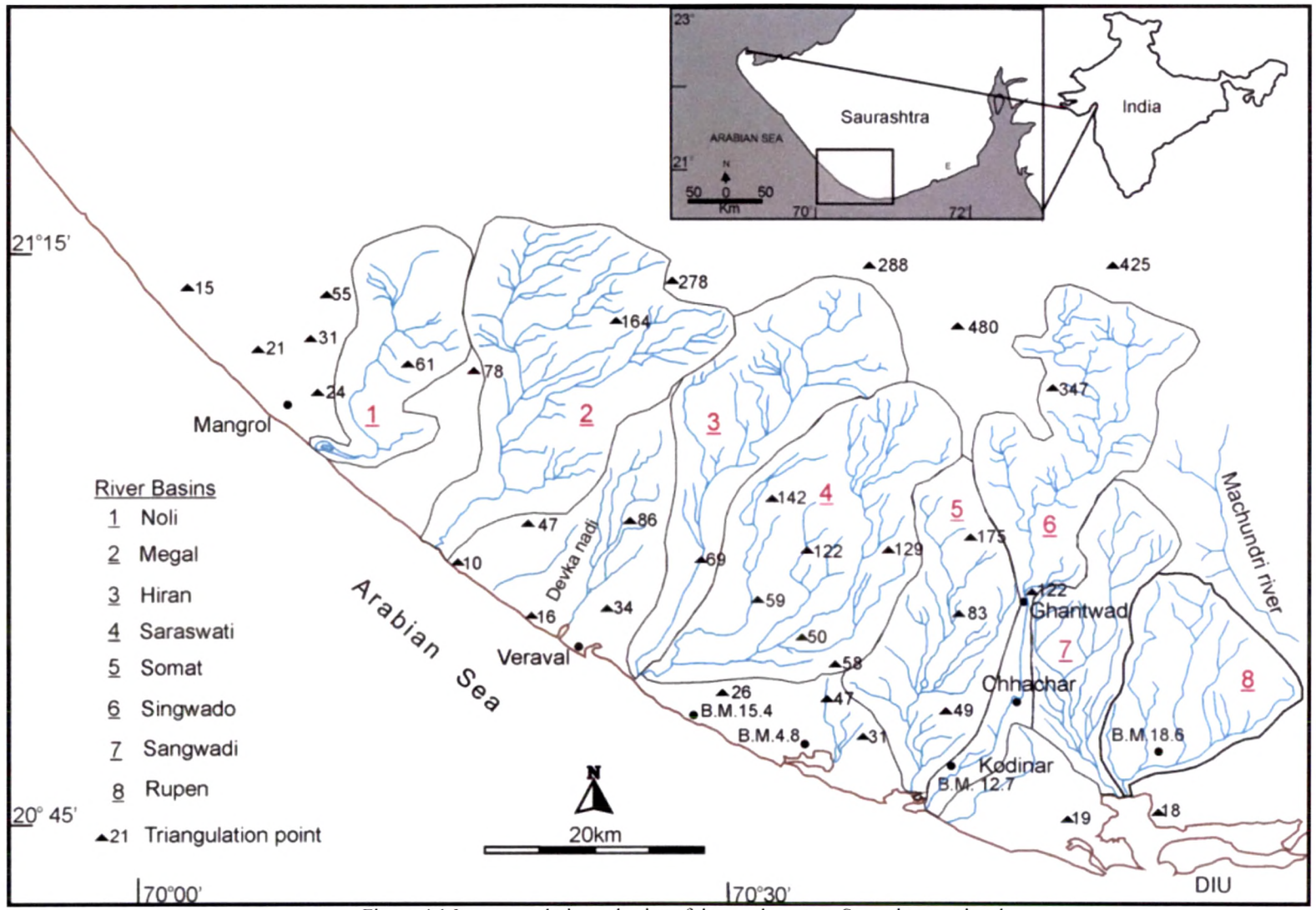

Figure 4.1 Important drainage basins of the southwestern Saurashtra peninsula.

various sedimentary sequences/facies as well as to identify marker horizons because, this is the longest river of the Saurashtra peninsula bearing all possibilities of development and preservations of the record of the fluvial sequences. Representative samples from the facies identified were also analyzed for their granulometry and carbonate content adopting the standard laboratory techniques (Folk, 1974; Ireland, 1971). The studies from Bhadar river basin were then extended to other rivers further south wards, and include Ojat river near Junagadh. Noli river near Mangrol, Hiran and Saraswati river near Veraval and Singwado river near Kodinar (Fig. 4.2, a).

Lithofacies in Bhadar River Basin

Bhadar is the longest river of Saurashtra peninsula, and its basin covers an area of about 4143.75 sq. km (Fig 4.2, b). The basin consists of nine sub-basins drained by several streams viz., Vinu, Moj, Phophal. Champavadi, Gondli, Karmali, Vasvari, Survo and Galoliya. The river originates near Jasdan and flows towards west about 185 km to meet the Arabian Sea near Navibandar Basalt and other magmatic derivatives belonging to the Deccan Trap Formation (Late Cretaceous) dominate the geology of the basin Fluvial sequences are exposed in riverbank cliffs of moderate height (8-10m) downstream of the Bhadar dam about 20 km east of Jetpur (Fig 4.2, *b*). Following the conventional two-letter coding scheme of Miall (1996), the gravelly units can be categorized in trough cross-bedded gravel (Gt) facies and crudely bedded gravel (Gh) facies. The sandy units chiefly exhibit massive sand (Sm) facies and planar cross-bedded sand (Sp) facies. These facies, in general, are overlain by silty sand facies that is designated as flood plain deposits (Fl facies). The contact between the adjacent lithofacies is sharp, and in places feeble to moderate degree of pedogenesis (P facies) is observed in the lower units.

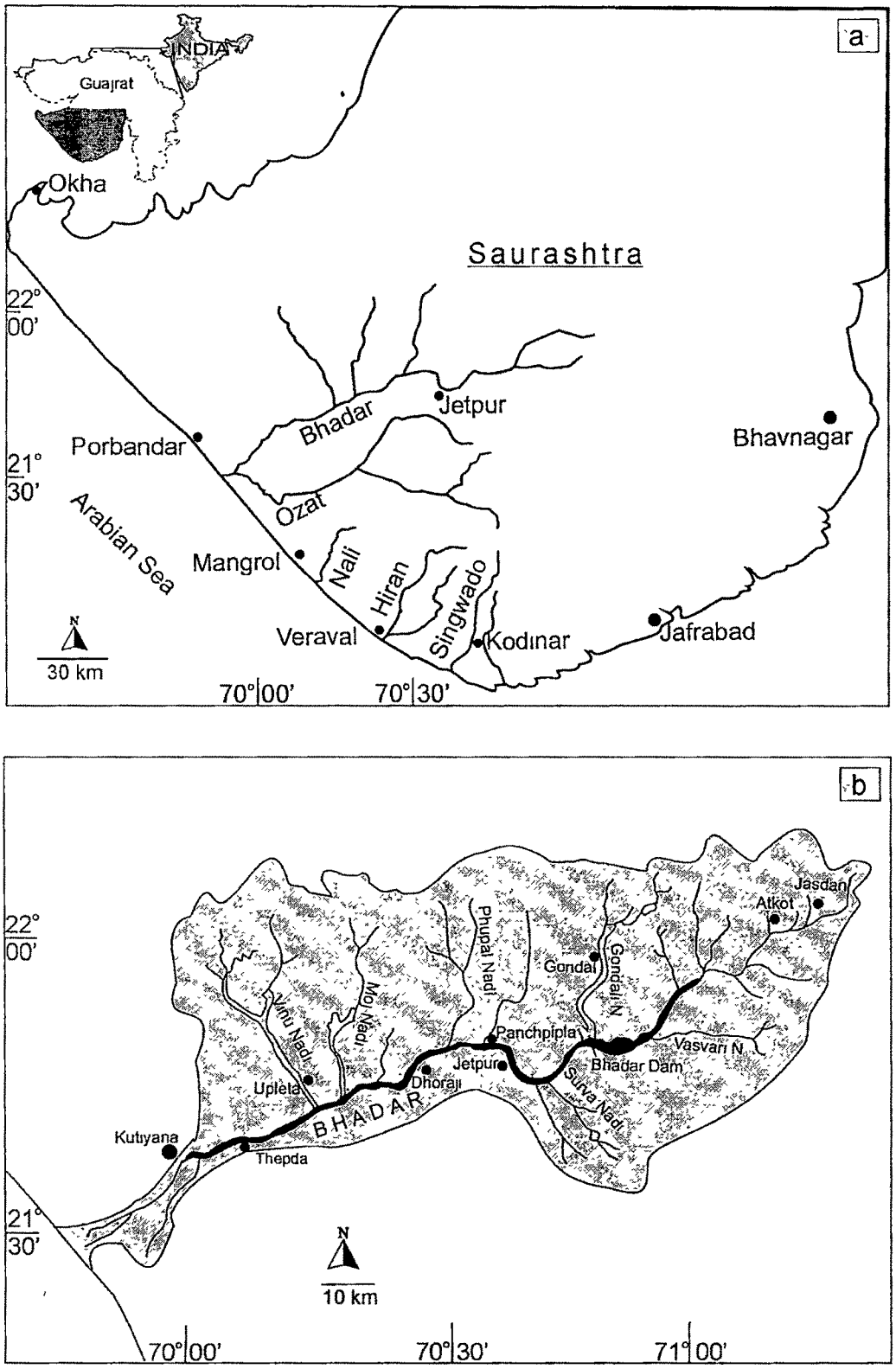

Figure 4 2 (a) Map showing the Bhadar and other rivers in the study area.
(b) A detailed map of the Bhadar river basin showing its tributaries and major locations

Palaeosol facies (P)

The prominent breaks in fluvial sequences of Bhadar basin can be seen in the form of palaeosol layers that has been designated as P-facies. Based on its stratigraphic occurrence, palaeosol developed over the pre-Quaternary substrate is referred to as P1 facies and other palaeosol layer that caps the lower gravelly unit as P2 facies (Fig 4.3).

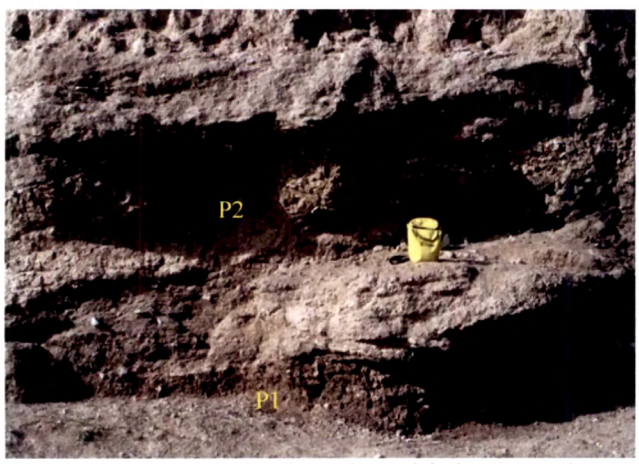

Figure 4.3 Photograph showing palaeosol facies (P1) and (P2) in Bhadar river basin. (Height of the bag 20cm)

The P1 facies in Bhadar river is developed on the Deccan Trap basalt, and is dark greyish brown (5YR 3/2-3/4) in colour. It shows vertisolic characters with numerous fractures, and subangular to angular blocky soilpeds. The fractures, in places, are filled in by calcareous matter but the, overall nature of soil is weakly calcareous as it gives very little reaction with mild HCl. The contact with substrate is clear and its lateral continuity is wavy. The soil pH is around 7.83 and EC 2.75. The organic carbon content is about 0.31%. P2 facies is developed on the Gt1 facies and Sp facies. This is light brown (5 YR 5/5) to yellowish brown (10 YR 5/2) in colour, and also shows few degree of fine to medium size mottling with faint contrast (Retallack, 1988). The soilpeds are fine granular to blocky. It is calcareous in nature. The pH is about 8.28 to 8.35 with EC value ranging from 0.37 to 0.58 the organic carbon content is about 0.39 to 0.54%. The contact between P2 and substrate gravels is gradual and its lateral continuity is broken.

Trough cross-bedded gravel facies (Gt)

The trough cross-bedded gravel facies is the most dominant lithofacies in the study area. Stratigraphically, two units Gt1 and Gt2 have been identified. The Gt1 facies, 1-4m thick, occurs unconformably either over the Deccan Trap Formation or over the palaeosol developed on it. The average length of individual trough ranges between 12 and 20m whereas, its width reaches maximum up to 7m. Average height (amplitude) of troughs is about 1.5m. The trough axes are oriented in 300°-120° direction. The average size of clasts, dominantly basalt, constituting this facies is about 2.5cm. Individual foresets in Gt1 also show normal grading (Fig. 4.4). The thickness of individual strata ranges from 2cm to about 20cm and the average dip of all the foresets is between 18°-28°. The Gt2 facies is distinctly different from the Gt1 facies both, compositionally and geometrically. This younger unit rests over the pedogenetically altered top (P2) of the Gt1 facies and planar cross-stratified sand (Sp) facies that overlies the Gt1. The Gt2 facies has trough widths of about 3m, lengths of about 6-8m and heights of about 1m with an orientation of troughs along 110°-290°. The thickness of individual strata ranges from 2 to 7cm. The average dip amount of the foresets is about 28°. Locally, the Gt2 facies grades into planar cross-stratified sand (Sp) facies (Fig. 4.5). Both, the Gt1 and Gt2 facies show multistoried stacking of the troughs.

Figure 4.4 Normal grading in the foresets of the (Gt1) facies at Panchpipla (Length of the hammer 45cm).

Figure 4.5 Gt2 facies underlain by palaeosol (P2) near Jetpur railway bridge. (Height of person 165cm)

Crudely bedded gravel facies (Gh)

The gravelly sequence also consists of a clast supported, crudely bedded and unsorted facies, which is designated as Gh facies (Fig. 4.6). The clast size ranges from 1cm to 15cm, but few boulders larger than 60cm are also observed. The majority of the clasts are angular to subangular and elliptical in shape. Basalt and other magmatic rocks are dominant clast constituents; however, the larger fragments are of limestone. Locally, the clast imbrication is in the 220° direction. The thickness of this unit ranges between 0.5 and 1.5m. Stratigraphically, this unit is equivalent to the Gt2 facies as it occurs over the same bounding surface.

Planar cross-stratified sand facies (Sp)

The sandy unit that unconformably lies over the pedogenetically altered top of the Gt1 or Deccan Trap basalt, is characterized by the presence of very gently dipping (10°-15°), planar cross-stratified sand (Sp) facies (Fig. 4.7). In general, it consists of medium to fine sand. However, locally it grades into gravelly sand that occurs as a shallow scour fills that is designated to Ss facies (Fig. 4.8). This unit ranges in thickness from 1 to 2m and its top is pedogenetically altered. The palaeosol layer (P2facies) capping this unit is relatively lighter in colour and contains few rhizocretions.

Figure 4.6 A closer view of Gh facies in Bhadar river near Thepda. (Diameter of tape spool 10cm)

Figure 4.7 Typical Sp facies marked by gentle planar cross-stratification in Survo river near Jetpur. (Length of hammer 60cm)

Figure 4.8 Planar cross-stratified sand facies (Sp) with a lensoid form of locally occurring scour fill (Ss facies). Diameter of the tape spool is 10cm.

Massive sand facies (Sm)

Another significant unit of the fluvial sequences of the Bhadar river is massive sand (Sm) facies that overlies the Sp facies or Gt2 facies with a sharp contact (Fig. 4.9). This unit, 1.5 to 2m thick, comprises medium to coarse sand with faint horizontal laminations. This sand facies is characterized by significant amount of bioclastic carbonate sand (about 23%) along with the dark coloured trap sand and other detrital constituents.

Figure 4.9 Bioclastic carbonate sand dominating massive sand (Sm) facies underlain by the Sp facies as seen near Panchpipla. (Height of person 165cm)

At Thepda near Kutıyana, this unit shows horizontal cylindrical, branching and non-branching burrows with an average diameter of 2.5cm (Fig. 4.10). Texture and composition wise this unit is similar to impure miliolite limestone. The miliolite limestone (*per se*) is very fine to medium grained, well rounded to subrounded, well sorted sand (dominantly allochemical, subordinately detrital) deposit that can be designated as massive sand (Sm) facies and planar cross-bedded sand (Sp) facies due to its texture and structure, when it is found forming a part of fluvial sequences.

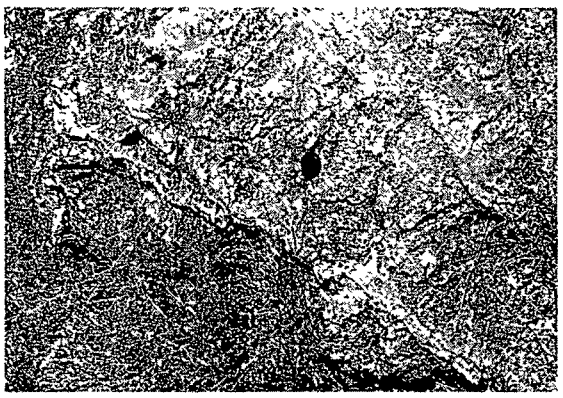

Figure 4.10 Biogenic structures in the Sm facies suggestive of its near shore deposition at Thepda (Diameter of lens cap 5cm)

As stated earlier, the Quaternary fluvial sequences are better exposed in the river bank cliffs downstream of the Bhadar dam. These river bank sections were investigated in detail and lithologs were prepared using the standardized two letter facies code scheme, and are shown in Figure 4 11. The Panchpipla section of the Bhadar river basin was sampled at 15cm interval and the grain size characteristics as well as carbonate content were measured using standard laboratory procedures. It was observed that the Gt1 facies is characterized by the mean grain size 2.97 of phi with a standard deviation to be 1.045. The average $CaCO_3$ content of this gravel facies is 23%. The gravel facies (Gt2) lying just below the massive sand facies (Sm) have shown 25% $CaCO_3$ content with the mean grain size of 2.1phi with a standard deviation value 0.952.

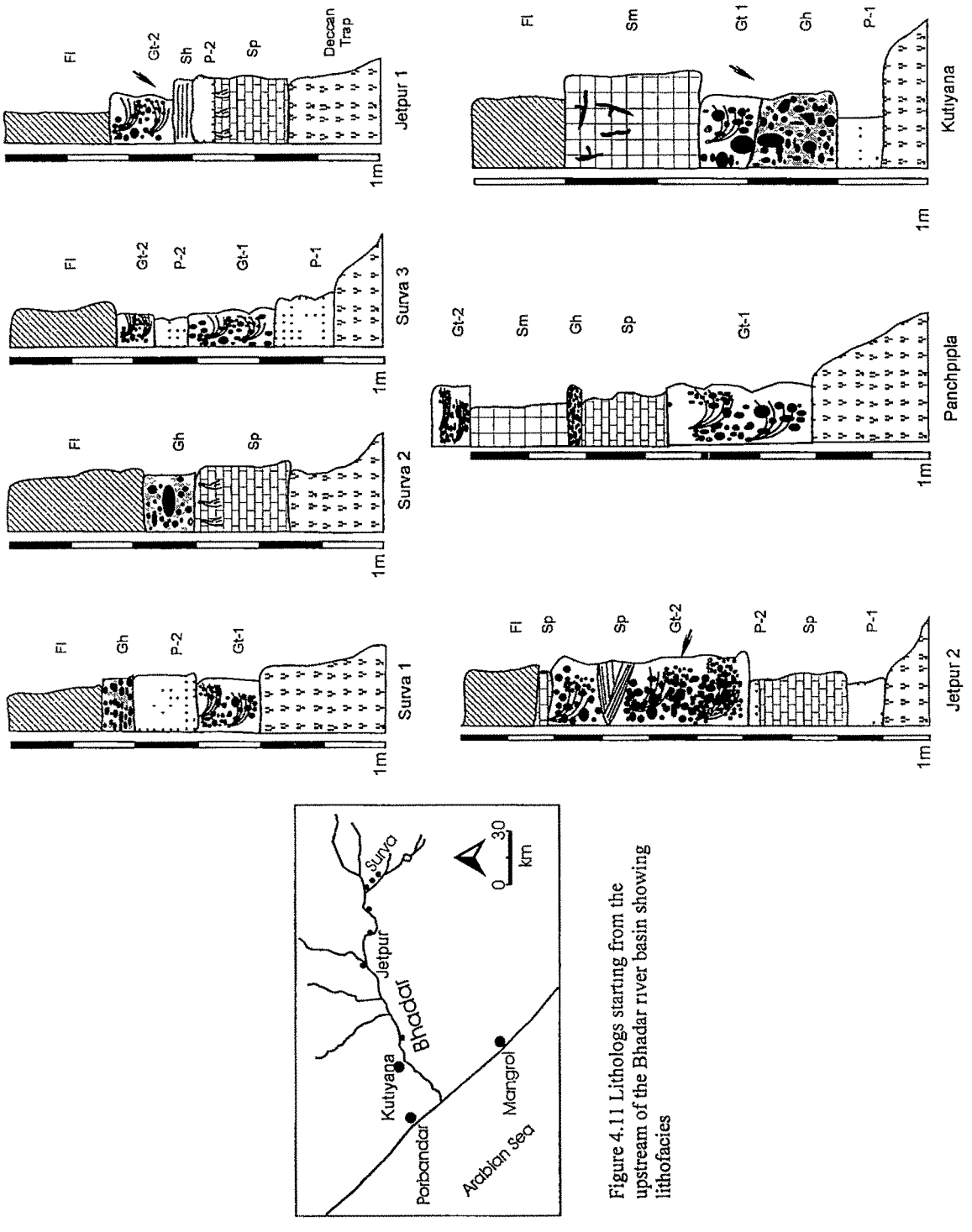

Figure 4.11 Lithologs starting from the upstream of the Bhadar river basin showing lithofacies

Lithofacies in Ojat River Basin

The Ojat river, the second longest river of SW segment of Saurashtra peninsula, drains through the Girnar hill ranges and runs for about 160km before meeting the Bhadar river almost near its mouth. The Ojat has a conspicuous appearance on the satellite imagery due to its wide valley as compared to the rivers other than the Bhadar, however the present channel is a very narrow one and misfits with the basin geometry. It takes an abrupt northward turn near Ghed Bagasra, and flows parallel to the present coastline to meet the Bhadar near Navibandar (Fig. 4.12). A prominent palaeo river mouth related to the ancient Ojat river can be seen near Madhavpur, that is partially drained by the newly born stream of the Madhuvanti river. The Ojat river basin consists of Uben, Utavali and Dhrafad sub-basins which are prominent. Various lithofacies exposed in the moderate to high (10m) riverbank cliffs of Ojat river have been recorded and correlated with earlier mentioned lithofacies of the Bhadar river. A type section in the Ojat river near Anandpur (about 15km south of Junagadh) exposes well developed lithofacies like trough cross-bedded gravel facies (Gt) and massive sand facies (Sm) with subordinately developed Gh, Sp and St facies (Fig. 4.18).

Trough cross-bedded gravel facies (Gt)

Like Bhadar river, the trough cross bedded gravel (Gt) is the dominant facies in the Ojat. river also Total thickness of this multi-stacked facies is found to be about 3-4m near Anandpur (Fig. 4.13). The orientation of trough axis here is 290° with 1-2cm thick individual foresets showing normal grading. The dominant clasts composition in the Ojat also is of the Deccan Trap basalt. Locally, this facies shows alternating sand and gravel layers (Fig. 4 14). The other derivative of gravelly facies is the clast supported crudely bedded gravel (Gh) facies. Conspicuous occurrences of rhizocretions with about 20cm

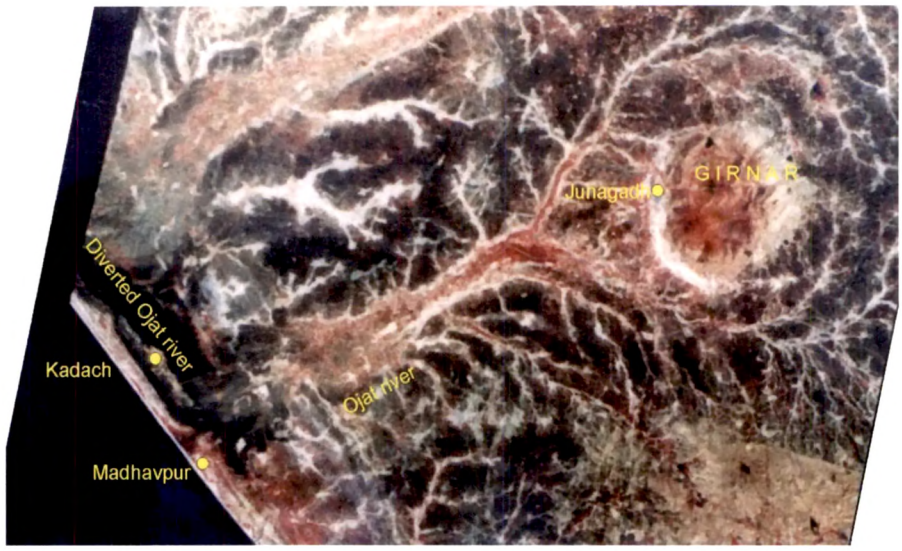

Figure 4.12 A part of Landsat image showing conspicuous valley width and abandoned sediment lobe of the Ojat river basin.

Figure 4.13 A typical Gt facies of Ojat river resting on an undulatory surface characterizing its typical channel fill nature near Anandpur. (Height of person 165cm)

Figure 4.14 A part of the Gt facies showing alternation with thin sand layers in Ojat river near Anadnpur. (Length of hammer 30cm)

length and 3-5cm diameter have been encountered in the relatively sand rich lower portion of this unit (Fig. 4.15) that indicates stabilization and pedogenesis of this facies prior to the development of the overlying unit.

Massive sand facies (Sm)

This is another important facies developed at many places in the Ojat river basin, attaining its maximum thickness of about 4-5m. The Sm facies of this river consists of considerable amount of the Deccan Trap derived material, but also the carbonate sand, especially in its finer fractions. Locally, the facies grades into planar cross-stratified (Sp) and trough cross-stratified (St) facies. Occurrence of about 0.5m thick clayey sand layer sharply differentiates two carbonate rich sandy (miliolitic) units in the upper most part of the cliff near Anandpur (Fig. 4.16). This thin horizontally laminated moderately sorted clayey sand unit belongs to the Fl facies signifying a palaeo floodplain deposit in the fluvial sequences of the Ojat river.

Sukhpur, about 6km in the downstream of Anandpur, is another place where lithofacies were recorded in about 10m high river bank cliff. Unlike at Anandpur, the carbonate sand dominating Sh and Sm facies form a major thickness of the sequence here (Fig 4.17). The unit also has a minor development of trough cross-stratified (St) facies, and is underlain by a prominent palaeosol facies. The bed rocks (basalt) are overlain by about a meter thick Gh facies unit made up of unsorted boulders and pebbles of the volcanic rocks that shows fining upward nature. This unit is overlain by about 1-1.5m thick prominent Gtl facies which is in turn overlain by the above described carbonate sand unit with a palaeosol layer in between (Fig. 4.18).

Figure 4.15 Rhizocretion in the basal unit of fluvial sequence exposed in Ojat river near Anandpur. (Length of hammer 30cm)

Figure 4.16 Alternating carbonate sand and sandy clay units in the upper part of the fluvial sequence of Ojat river near Anandpur.(Height of person 165cm)

Figure 4.17 Gt facies in Ojat river near Sukhpur. The overlying palaeosol and Sm facies can be seen in the background. (Height of person 165cm)

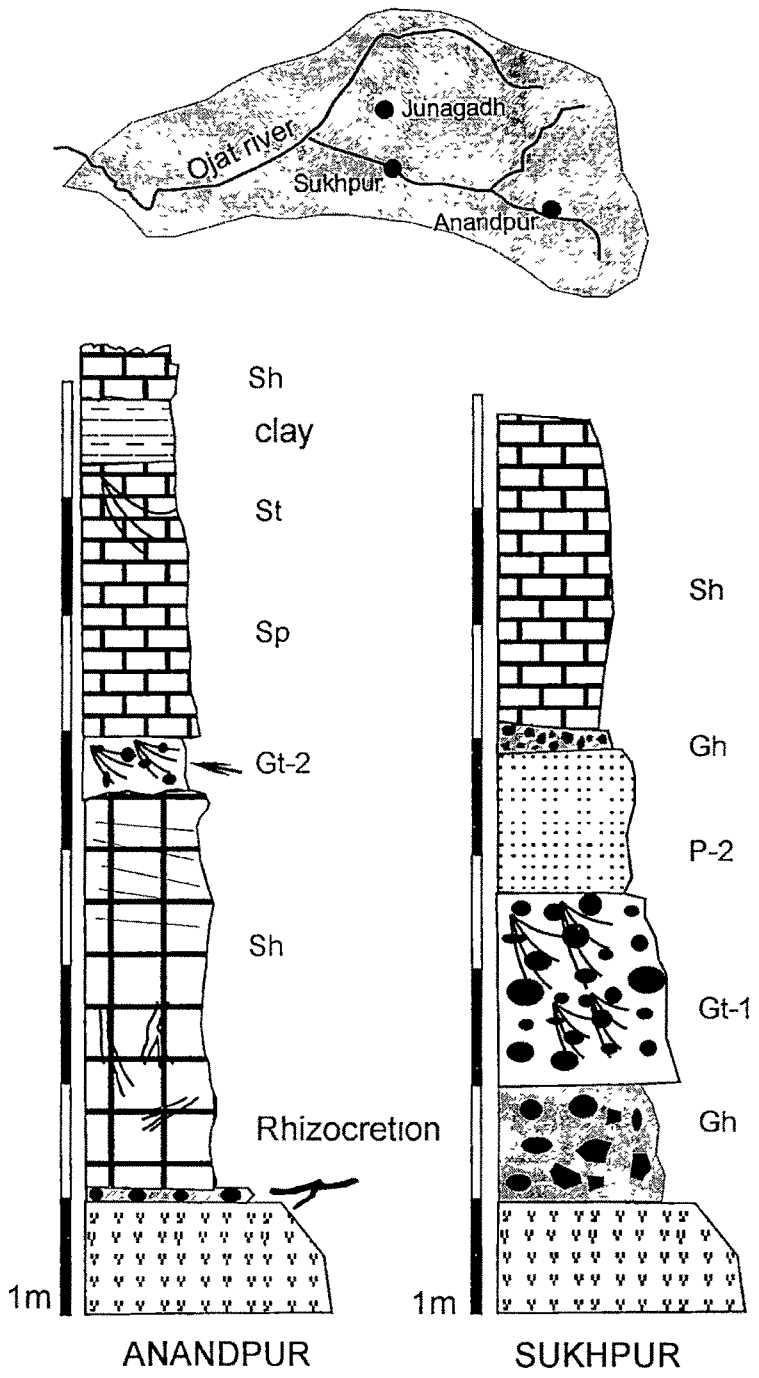

Figure 4.18 Lithologs showing various facies in the Ojat river basin.

Lithofacies in the other rivers

Lithofacies and marker horizons are identified in the fluvial sequence of Bhadar and Ojat river basins. The record from Bhadar seems to be most complete and hence, fluvial records of the other rivers like Noli, Hiran, Singwado and Saraswati (Fig. 4.19) has been compared with that of the Bhadar river to recognize the lithofacies and bounding surfaces.

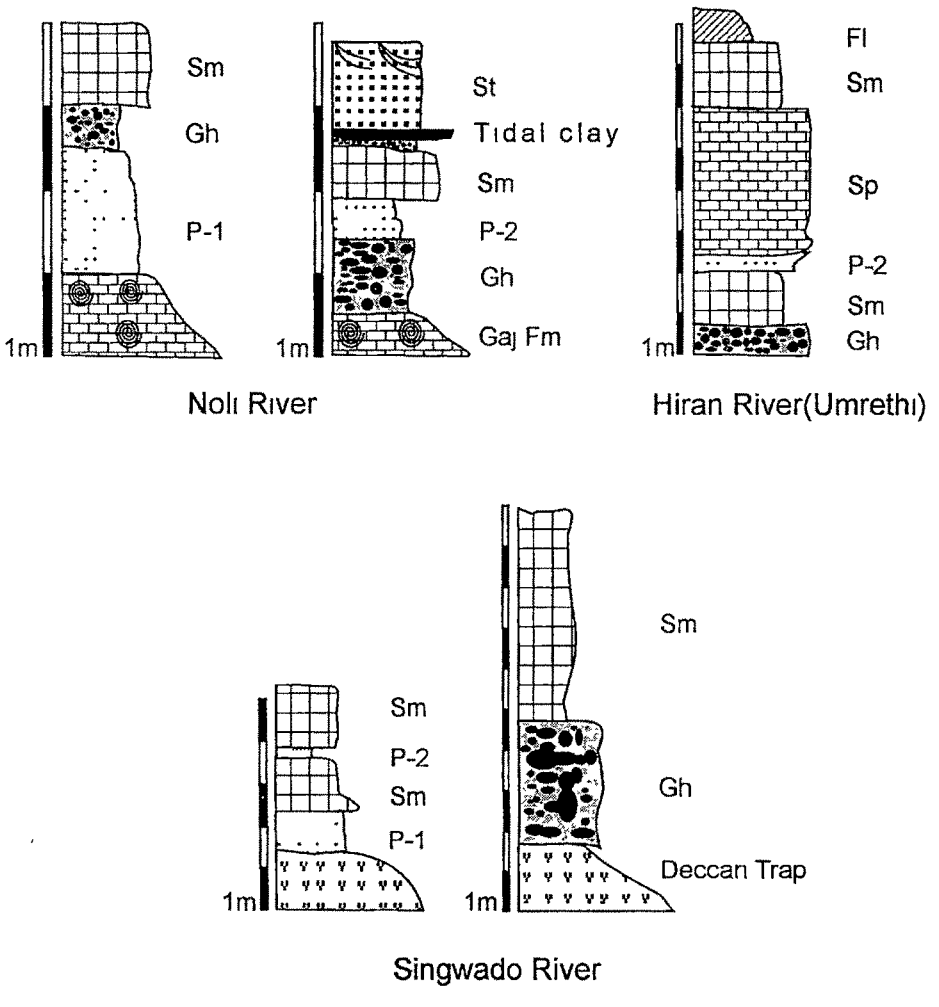

Figure 4 19 Lithologs of the other rivers of the southwestern Saurashtra.

The fluvial sequence of the Noli river consists of mainly crudely bedded gravel (Gh) facies that lies over the limestone of Gaj Formation (Miocene) with either a sharp erosional contact or a palaeosol layer in between. The palaeosol unit, about 0.5 to 1 m thick, extends upstream wards where it caps over the basalt of the Deccan Trap Formation. It shows dark brown (5 YR 3/5) to light olive brown (5 Y 5/6) colour. The palaeosol developed over the Gaj limestone is strongly calcareous in nature, and exhibits gradual contact with the substrate. This unit is correlated with the P1 facies of Bhadar river because of its pre-Quaternary substrate. The Gh facies of Noli river attains a maximum thickness of about 2 m, and locally grades in to Gt facies. The clast size ranges between 2 cm and 25 cm. The larger clasts are of mostly limestone, but those of the basalt are dominating. The top of Gh facies is pedogenetically altered. This has been designated as P2 facies. It is yellowish to brown (10 YR 6/6 to 6/5) in colour and calcareous in nature. This is overlain by massive sand (Sm) facies that is about 2 to 3 m thick. Texture and composition wise this unit is similar to the Sm facies of Bhadar river. At Kamnath, 10 km east of Mangrol, signatures of marine flooding can be seen in the form of a compact calcareous tidal clay unit (Fig. 4.20) at an elevation of about 18 m amsl. This unit grades upstream wards into trough cross-bedded sand (St) facies composed of bioclastic carbonate sand. The St facies can be designated as miliolite limestone, as it is referred to in the literature.

Figure 4.20 Compact tidal clay unit underlain by a prominent pedogenised Gh facies as seen in Noli river at Kamnath. (Height of the person 165cm)

The fluvial sequence of Hiran river near Veraval has also been investigated by other workers (Marathe, 1981; Baskaran et al., 1986) with special reference to the

miliolite problem. This sandy facies lie over the gravelly (Gh) facies that has yielded Early Acheulian tools in the Hiran valley (Marathe, 1981). Fluvial sequence of the Singwado river near Ghantwad and Chhachhar, 12 km north of Kodinar, is composed of mainly gravelly and sandy units (Fig. 4.21). The gravels are poorly sorted, subangular to subrounded and crudely bedded (Gh facies). The clasts, dominantly basalt, range in size from 1 cm to 15 cm. The sandy unit is locally horizontally bedded (Sh facies), but major part appears massive (Sm facies). This unit is also consisting of bioclastic carbonate sand; the sedimentary structures and biogenic structures therein are suggestive of the marine flooding The palaeosol (P1 facies) developed over basalt substrate and exposed at the base of a section near Ghantwad shows similar characteristics to the P1 facies of Bhadar and Noli rivers, however, the vertisolic characters are much distinct here (Fig. 4 22). This palaeosol unit is overlain either by Gh facies or directly by Sh and Sm facies A palaeosol layer (P2) that is developed over the Sh facies separates two sandy units. This light yellow coloured granular soil is calcareous in nature, and shows rhizocretions in its upper part The fluvial sequences of these rivers of south Saurashtra are correlated based on the marker horizons like the palaeosol developed over pre-Quaternary substrate, extensive gravelly facies and the characteristic carbonate dominated sand facies. As described in the previous chapter, the erosional surfaces have been traced out in the region not only in the fluvial record, but also in the coastal deposits.

Table – IV 1 summarizes the facies identified in the fluvial sequences of southwestern Saurashtra and also its probable time range. In general, the fluvial sequences of the study area suggest two distinct aggradational phases separated by a profound break. The Gt facies has manifested this, and so it is subdivided into Gt1 and Gt2 facies on stratigraphic consideration. The Quaternary record begins with the P1 facies exhibiting typical vertisolic characters, over the pre-Quaternary substrate

Figure 4.21 Horiozontally bedded bioclastic carbonate rich sandy unit (Sh facies) underlain by poorly sorted gravelly (Gh facies) unit. (The cliff height is 4.5m).

Figure 4.22 A palaeosol unit (P1 facies) developed over the basalt showing a typical vertisolic character (Height of the person 165cm).

a stable landscape that allowed a fair degree of pedogenesis of the late Cretaceous volcanic rocks and the Neogene sediments. The Gt1, sharply overlying this palaeosol unit, is related to the first phase of fluvial aggradation during Quaternary time. In absence of any geochronological data from the equivalent unit in the region, it is difficult to ascertain the age difference between the pedogenesis and deposition of these gravels.

Table – IV 1 Summary of the lithofacies of fluvial sequences of south Saurashtra

Lithofacies	Description	Remarks
Fl	Mainly consists of silty sand facies, feebly pedogenetically altered at top. Mostly structure less semi-consolidated in nature.	Related to the youngest fluvial aggradation. (Holocene to Recent)
Gt2	Relatively thicker unit dominated by basalt clasts, and few chalcedony and limestone clasts Grades locally into Sp facies.	Has yielded Middle Palaeolithic tools at Jetpur older than 56.8 ka.(Baskaran et al.,1986)
Gh	Mainly basaltic and limestone clasts.	Locally developed facies
Sm	Medium to coarse sand, dominated by allochems Biogenic structures are present. It is similar to the miliolite limestone.	Equivalent miliolites have U-series age range 75-115 ka. (Baskaran et al., 1989)
P2	Pedogenetically altered top of the Sp facies shows presence of rhizocretions Lighter in colour and also occurs above Gt1 facies.	Lower Palaeolithic tools are reported from this unit from south Saurashtra coast. (Marather et al., 1998)
Sp/Ss	Medium to fine sand locally occurs as scour fill gravelly sand	Associated with Gt1 facies.
Gt1	Comprising mainly of basaltic clasts.	Early Acheulian tools recovered in Hiran river are dated >196 ka. (Baskaran et al., 1986)
P1	Mainly vertisol developed over the Deccan Trap basalt, and in places, over Gaj limestone.	Oldest palaeosol found on pre-Quaternary substrate.

This facies is associated with the Sp facies that does not contain bioclastic carbonate sand Together, Gt1 and Sp facies constitute a sequence typically of ephemeral stream that could deposit the gravels as channel-fills and sand as overbank deposits (Miall, 1996) P2 facies suggests termination of this, however, its limited extent and less prominent soil peds with absence of any pedo-horizon are perhaps suggestive of a lesser degree of pedogenesis and/or drier climate. This palaeosol unit is capped by a prominent marine flooding event recorded in the form of bioclastic carbonate dominated sand (Sm facies), biogenic structures, tidal clays, coarse grained bioclastic limestone, etc. The elevations of the occurrence of such lithological units suggestive of marine flooding are clustered around 10 to 15m amsl. A palaeosol unit, equivalent to P2 facies in the rivers studied, has been reported occurring at the base of coastal miliolite sequence of south

Saurashtra; the Late Acheulian tools occurring over this soil unit were considered to be of late Middle Pleistocene age (Marathe et al., 1998; Patel and Bhatt, 1995). The gravelly unit (Gh facies) at the base of Hiran river sequence has yielded Early Acheulian tools that has been dated older than 196 ka (Baskaran et al., 1986). This unit is correlated with the Gt1 of Bhadar river. The U-series ages of the carbonate sands – miliolite limestone (M-II 75 to 115 ka) lying above the Gt1/Sp and P2 facies suggest linkage to higher sea level of perhaps MOI substage 5e, if the ages are an underestimate. This has been followed by another phase of fluvial aggradation recorded in the form of Gt2 facies that shows local variation in to Gh and Sp facies of limited extent. The sequence is covered by Fl facies, commonly occurring in the rivers of study area that can be linked to the late Holocene fluvial aggradation.