QUATERNARY STRATIGRAPHY

Investigations of Quaternary deposits in active fault zones are crucial as they provide critical stratigraphic evidence for reconstructing neotectonic evolution of faults as demonstrated in the case of Katrol Hill Fault in the central part of mainland Kachchh (Leeder et al. 1991; Patidar et al. 2007; 2008). In this chapter, the Quaternary sediments occurring in the eastern part of the KMF zone (Fig. 3.1) are described primarily with a view to delineate its Quaternary evolutionary history. A lithostratigraphic framework supported by chronology of the Quaternary sediments is provided. An attempt is made to identify the phases of neotectonic activity along the KMF as reflected in the stratigraphic development.

The exposed Quaternary sediments in all the morphotectonic segments of the KMF zone in the study area were investigated. The locations of the studied exposed Quaternary sediments in the KMF zone are shown in Fig. 3.1b in the previous chapter. Vertical lithologs were prepared and their lateral variations in sedimentary facies were also documented. OSL dating of the samples collected was also carried out. The occurrence of Quaternary deposits along a 1-3 km wide zone between the KMF scarps and Banni plain is extremely significant (Fig. 3.1b). These deposits average 5-10 m in thickness and display wide variation in lithology, both in the northward direction and laterally along the KMF zone.

The deposits, in general, comprise coarse as well as finer gravelly deposits, sands and aeolian and fluvial miliolites. These deposits together, effectively conceal the KMF fault line below them and form a north sloping surface that merges with the Banni plain. The northward sloping surface developed over the Quaternary deposits is consistent with the decreasing depth of incision in this direction. The Nirona, Kaila, Pur and the Kaswali rivers have given rise to fan shaped alluvial deposits at their mouths near the KMF zone (Fig. 3.1b). These are formed due to dispersal of recent sandy alluvium as the river loses gradient and bifurcate into small indistinct channels before disappearing in the Banni plain. The fan shaped alluvial deposits, therefore, form the stratigraphically youngest Quaternary deposits of the KMF zone. The Quaternary deposits exposed in the cliff sections of the various north flowing streams have great significance for understanding the neotectonic
PART-B Kachchh Mainland Fault (KMF)
evolution of the KMF. The Quaternary sediments exposed in various morphotectonic
segments are described separately.

NIRONA-JHURA SEGMENT

This segment lies to the north of Jura dome and extends from Nirona in the west
to Pur river in the east (Fig. 3.1a). The segment is characterized by a northward sloping
surface developed over the Quaternary deposits. The surface abuts against the KMF scarp
in the south and gently grades into the flat terrain of the Banni plain in the north. In
general, the maximum thickness is exposed closer to the scarps corresponding to the
incision pattern which shows a northward decreasing pattern mentioned earlier. Lithologs
of the sections studied in this segment are shown in Fig. 4.2.

Figure 4.1 Lithologs of Quaternary sediments exposed in Segment-I. Location of the
lithologs is shown in Fig. 3.1b.

The maximum thickness of the sediments is exposed along the Kaila river that
PART-B Kachchh Mainland Fault (KMF)
flows along the eastern most fringe of the Jhura dome. The Quaternary sediments are exposed in continuous line of vertical cliffs on left bank from Sodha camp to Jhura village in the north (Fig. 3.1b). South of Sodha camp, the cliff exposing Mesozoic rocks of same height are observed. The Quaternary sediments rest unconformably over the northeast dipping Mesozoic sandstones which are also incised (Fig. 4.1, lithologic 1). In the upstream reach, the bottommost 2-3 m part of the cliff section comprises of Mesozoic rocks. The overlying ~12 m thick Quaternary sediments is divisible in distinct lithologic units. All units are separated by erosional contacts.

Figure 4.2 (a) Close view of clast supported bouldery gravel at the base of the exposed cliff section in Kaila river to the south of Jhura. (b) Close view of the largest boulder observed. The size of the clast is 0.6 m. (c) Tilted sediment succession of Quaternary deposits exposed in a lower order stream in segment-I. (d) View of aeolian milolite forming the floor of the incised valley shown in (c). Note the fine grained nature of the deposit and the aeolian cross bedding. (e) Close view showing the aeolian cross bedding in the milolite deposit shown in (d).

The succession starts with a 4 m thick clast supported massive bouldery gravel overlying the Mesozoic rocks (Fig. 4.2a). The average size of the boulder is ~50 cm, whereas the largest boulder is approximately 0.6 m (Fig. 4.2b). The large boulders are
PART-B Kachchh Mainland Fault (KMF)

enclosed in a matrix of cobble to pebble sized fragments. A small amount of interstitial sand appears to have been introduced subsequently. The lithoclasts are dominantly consisting of Mesozoic sandstones. The clasts are highly angular and sub-rounded. The bigger boulders are concentrated in the basal part of the unit. The vertical change in the clast size is because of the change in shear stress over the bedform. Higher sediment concentration, cohesive matrix and little internal sorting are the indicative of hyperconcentrated pseudoplastic debris flow (Miall, 1996). The higher content of bigger clast size, texture, absence of sedimentary structures indicate cohesionless, non-viscous pseudoplastic debris flow with internal bedload that deposited the poorly graded massive gravel (e.g. Blair and McPherson, 1992; Aziz et al. 2003; Garzione et al. 2003; Dorsey and Roering, 2006; Pope et al. 2008).

The basal boulder gravel unit is overlain by 5 m thick gravelly sand. This unit dominantly comprises several gravel rich layers separated by relatively thinner sandy horizons. The gravel shows angular clasts of pebble size that are enclosed in a matrix of finer gravels and sand. The intervening sands are discontinuous and of lensoid nature. The angular nature of the clasts testifies to the short distance transport which is in conformity with the geomorphic setting of the deposits. The absence of sedimentary structure and occurrence of unorganized pebbles in coarse sandy matrix suggest rapid deposition by sediment gravity flows or debris flows (Rust, 1978; Miall, 1996; e.g. Stokes and Mather, 2000; Aziz et al. 2003; Deynoux et al. 2005). The gravelly sand is overlain by 2 m thick matrix supported cobbly pebbly gravel. The individual clasts are found to be 20-40 cm size. The matrix is composed of rock fragments of smaller size. The clasts and matrix are angular in nature. The unit shows a considerable thickness along the cliff section and a general decrease in clast size towards the north. The presence of matrix suggests the cohesive, viscous nature of depositing flow whereas; the absence of sedimentary structure and the fabric indicate the sediment deposition by debris flows (Rust, 1978; Miall, 1996). All these lithofacies characteristics indicate the deposition by viscous, high strength clast rich debris flows (e.g. Blair and McPherson, 1992; Garzione et al. 2003; Dorsey and Roering, 2006; Pope et al. 2008). OSL sample collected from one of the sand lenses has yielded an age of 34±5 Ka. The top of the section is marked by 1m thick structureless sand deposited by sediment gravity flows which has given an OSL age of 4±0.5 Ka.

The main characteristic of these deposits is their occurrence in imposing cliffs on the left bank of the Kaila River and its dominance of highly angular coarse grained fluvial deposits. A general decrease of sediment size to the north, which is the downstream
PART-B Kachchh Mainland Fault (KMF)
direction, is very obvious. The sediments exposed in the cliffs are in complete contrast to
fine grained sandy bedload in the present day channel of the river. The section is reduced
to ~6 m to the east of Jhura village where the cliff section gradually goes below the recent
fan shaped sandy alluvium of the Kaila river further north.

To the west of Jhura, the Sonva nala stream also exposes Quaternary sediments
along its 8-10 m high incised clifffy bank (Fig. 4.1, litholog 2). The river follows a N-S
oriented gorge like incised course for about 2 km after emerging from the hilly terrain of
eastern part of Jhura dome. The stratigraphic development is restricted as compare to
Kaila River. Here the Quaternary deposits overlie the north dipping Mesozoic sediments
which form about 4m of the basal part of the cliff section. The Mesozoic rocks are
unconformably overlain by ~1 m of pebbly gravel. The gravel is matrix supported and
consists of clasts of Mesozoic sandstone. The unorganized, structureless pebbles and
abundant coarse matrix indicates the cohesive nature of depositing agent. As the
lithofacies comprises of matrix rich gravel with absence of sedimentary structures it can
be inferred that the sediments were deposited by cohesive, low strength turbulent or
laminar flow with an inertial bedload. Absence of imbrication, sorting and sedimentary
structures suggest rapid deposition by cohesive clast rich sediment gravity flows (Rust
1978, Miall, 1996 e.g. Blair and McPherson, 1992; Garzione et al. 2003; Dorsey and
Roering, 2006; Pope et al. 2008). They are overlain by coarse gravel which shows clasts
of cobble sized. The cobble gravel is 2 m thick and easily distinguishable from the lower
pebbly gravel unit by its grain size. The unit consists of cobble size clasts embedded in
matrix of medium to fine sand. The clasts comprise rock fragments of shales and
laminated sandstone and are platy in nature with their flat bases giving the appearance of
pseudostratification. The clasts show high angularity and are imbricated in the
downstream direction. Although the lithofacies have been deposited by the same
depositional process as the former one, the increased clast size indicates relatively
increased strength of the flows. The top of the exposed section is marked by compacted
valley fill miliolites. It consists of sand sized grains of miliolitic sand cemented by
calcareous matrix. The valley-fill miliolites also contain clasts of Mesozoic rocks of
varying sizes embedded within the compacted miliolites grains which points to fluvial
deposition. The valley fill miliolites owe their origin to erosion of aeolian miliolites in the
upstream area which were fluvially reworked, carrying the Mesozoic rock fragments
along with them and redeposited. This horizon brackets the underlying deposits together
with those exposed along the Kaila river as of pre-miliolite phase.
PART-B Kachchh Mainland Fault (KMF)

Further west of Sonva nala river, the Quaternary deposits continue to form a north sloping surface in front of KMF scarps up to Nirona river. The surface is extensively directed by several north flowing streams including the Badi river that arises from the core portion of the Jhura dome. Good exposures of the sediments are observed in an unnamed lower order stream to the west of it that exhibits an incised course exposing varied lithologies of the Quaternary sediments (Fig. 4.2c). Here the section starts with aeolian miliolite which forms the floor of the incised valley (Fig. 4.3d). The aeolian origin of the miliolite is evident by its laterally extensive and uniformly fine grained nature and well developed aeolian cross bedding (Fig. 4.2d). The deposits form a part of the extensive obstacle dune that was formed in front of the KMF scarps, of which, a small part is exposed in the valley floor while the rest of it is covered by the younger Quaternary deposits. The aeolian miliolite is part of the regionally extensive and prolonged phase of miliolite deposits witnessed all over the Kachchh basin from Middle to Late Pleistocene (Baskaran et al. 1989). The aeolian miliolite is overlain by 3.2 m thick gravelly sand that contains dispersed angular clasts of Mesozoic rocks (Fig. 4.1, litholog 3). The massive texture of the sand with presence of isolated clast and the absence of sedimentary structures suggest the rapid deposition of gravelly sand (Miall, 1996). It is interpreted that the structureless fine to coarse pebbly sand was deposited as sheetflood sedimentation by sediment gravity flow (Miall 1996; Stokes and Mather, 2000; Coltorti et al. 2010). This is followed by ~1.7 m thick semi-compacted valley fill miliolite that characteristically shows stratification and angular pebbles of Mesozoic rocks.

A 0.7 m thick gravel overlies the valley fill miliolite. The clasts include cobbles as well as boulders of sandstones. The large angular clasts are clast supported while the smaller ones are matrix supported. The entire sediment succession horizon shows marked tilting towards the north (Fig. 4.2c). The clasts are weakly graded, poorly sorted, and does not show imbrications and sedimentary structures which are the characteristic properties of debris flow deposits (Miall, 1996). Further, the clast supported cobbles and pebbles indicate hyperconcentrated, low strength, clast rich pseudoplastic nature of the depositing fluid (Rust, 1978; Miall, 1996). Hence, it is inferred that the sediments were deposited by low strength pseudoplastic debris flow (e.g. Elair and McPherson, 1992; Aziz et al. 2003; Pope et al. 2008). The gravel is followed by ~1.0 m thick sand which is in turn overlain by 1 m thick gravelly sand marking the top of the succession. These both lithofacies have sheet like geometry, massive texture and the absence of sedimentary structures suggests the deposition by sediment gravity flow that could be related to the sheetflood
PART-B Kachchh Mainland Fault (KMF) sedimentation (Miall, 1996; Coltorti et al. 2010). On the basis of miliolite deposits at the base, the overlying sediments are clearly the result of post-miliolite depositional phase. The tilting of the sediments provides strong evidence for reactivation of KMF in post-miliolite time.

KUNARIA- LODAI SEGMENT

This segment extends from Kunaria in the west to Lodai in the east and corresponds to the KMF zone to the north of the Habo dome (Fig. 3.1a and b). The Quaternary deposit occurs in a 2-3 km wide band to the north of the KMF scarp developed in the northern limb of the Habo dome (Fig. 3.1b; 4.3a). The major rivers are the Pur and Kaswali river that flow in the saddles to the west and east of the Habo dome respectively. Between them several unnamed streams arising from the hilly topography of the Habo dome flow northward incising through the Quaternary sediments before disappearing in the Banni Plain (Fig 3.1b). All rivers expose variable thickness of their deposits overlying the Mesozoic rocks. Maximum stratigraphic development of the deposits is seen in the Falay river (Fig. 4.4). Vertical cliff sections in the Falay river and a small tributary near Falay on its right bank reveals the heterogeneity of the dominantly coarse grained fluvial deposits (Fig. 4.4, litholog 4). The deposits unconformably overlie the vertically dipping Mesozoic strata (Fig. 4.4a). In the downstream side, several tens of meter wide zone of highly sheared Mesozoic rocks underlie the Quaternary deposits.

The dominantly coarse nature of the Quaternary deposits is very striking (Fig. 4.4). Overlying the Mesozoic rocks is clast supported bouldery gravel which shows a maximum thickness of ~6 m (Fig. 4.3b, c). The thickness varies along the river as it overlies the uneven topography of the underlying Mesozoic rocks. The unit shows several phases of deposition of very coarse gravel as separated by 0.3 - 0.5 m thick discontinuous lensoid sand bodies of variable thickness within the gravels. The bottommost sand body is massive in nature and shows extensive development of nodular calcrites. The clasts size is mostly cobbly but boulder size fragments also regularly occur. All clasts are highly angular and indicate very short transport. The general appearance is that of typically unsorted colluvium deposits, however fluvial reworking is indicated by distinct aggradation phases and intervening sandy layers. The extremely short transport is implicit from the geomorphic setting as the source area is less than a kilometre to the south in the hilly terrain of the Habo dome (Fig. 4.3a). We interpret these as debris flows deposit as they are weakly graded, poorly sorted, and does not show imbrications and sedimentary structures. The occurrence of bigger clasts in large amount and massive texture indicate
PART-B Kachchh Mainland Fault (KMF)
deposition by hyperconcentrated, low strength, clast rich pseudoplastic debris flows (Rust, 1978; Miall, 1996; e.g. Blair and McPherson, 1992; Aziz et al. 2003; Pope et al. 2008). A sand lens from this horizon has yielded an OSL age of 100±7 Ka.

Figure 4.3 (a) Panoramic view of the KMF zone showing the field setting of the Quaternary colluvio-fluvial deposits along the Falay River. Note the flat surface formed over the colluvio-fluvial deposits exposed along the incised cliff of the river. Also seen are the vertical to subvertical sheared Mesozoic rocks in the river bed and the sharp unconformable contact with the overlying stratified colluvio-fluvial deposits. (b) Close view of the colluvio-fluvial deposits resting unconformably over the Mesozoic rocks in Falay river. (c) View of the clast supported gravel in Falay river. Note the coarse nature of the deposit and the angular nature of the clasts. (d) View of a knick point in Falay river showing the sedimentary succession. Note the valley-fill miliolite dividing the colluvio-fluvial deposits into two distinct phases. Location of the knick point is about half kilometer upstream of the photographs in (a), (b) and (c).

The thick colluvio-fluvial unit is overlain by 2-3 m thick valley fill miliolites (Fig. 4.3d). The miliolite contains dispersed clasts of pebbles to large boulder size pointing to
PART-B Kachchh Mainland Fault (KMF)
fluvial origin of the miliolite. The miliolite is again overlain by 2 m thick colluvio-fluvial
deposit represented by matrix supported gravel (Fig. 4.3d). This unit shows finer clast
size than the thick colluvio-fluvial deposits underlying the valley-fill miliolite. The
presence of medium to coarse grained sandy matrix indicates cohesive nature of the
depositing agent. The gravels unimbricated, poorly sorted and massive which suggests
rapid deposition by sediment gravity flows (Rust, 1978; Miall, 1996). Overall, the
presence of matrix and fabric suggest that the sediments deposited by cohesive, clast rich
debris flow (e.g. Blair and McPherson, 1992; Garzione et al. 2003; Dorsey and Roering,
2006; Pope et al. 2008). This unit has yielded an OSL age of 41±6 Ka.

**Figure 4.4** Lithologs of Quaternary sediments exposed in Falay river in Segment-II.
Location of the lithologs is shown in Fig. 3.1b. The vertical scale is in meters.

About one km downstream, a 15 m thick section is exposed in a deeply entrenched
meander (Fig. 4.4, litholog 5). The sediments are markedly finer than the above described
section. A 3 m thick matrix supported gravel forms the base of sedimentary succession
which shows large scale cross stratification. The clasts comprises pebble size rock
fragment. The pebbles are supported by medium to coarse sand which indicates cohesive,
viscous property of depositing medium whereas the presence of cross stratification
indicates that the sediments could have been deposited as lag deposits (Miall, 1996). It
PART-B Kachchh Mainland Fault (KMF)
could be inferred that the sediments are lag deposits that were deposited by cohesive
debris flow (Miall, 1996; Garzione et al. 2003; Dorsey and Roering, 2006). Overlying this
is a 0.5 m thick sand followed by 2m thick cobbly gravel which shows sparsely
distributed boulders as well. Above this unit lies 1 m thick sand followed by 0.5 m thick
pebbly gravel. The sand facies is characterized by massive texture, lack of
sedimentary structures and poor sorting which indicates deposition by sediment gravity
flows (Miall, 1996; Stokes and Mather, 2000; Coltorti et al. 2010). The overlying cobbly
pebbly gravel lithofacies comprises subangular to subrounded, poorly sorted, coarse
matrix supported gravels. The absence of sedimentary structures, poor grading and lack of
sorting suggest the deposition by clast rich debris flows (Miall, 1996; Blair and
McPherson, 1992; Dorsey and Roering, 2006; Kallmeier et al. 2010). This is followed by
4 m thick horizontally stratified gravelly sand. The sand shows several gravel rich lensoid
bodies. The gravels are of pebble size, subrounded and show horizontal stratification. On
the basis of structure and sediment fabric we interpret that the lithofacies was deposited
by clast rich laminated debris flow (Rust, 1978; Miall, 1996; Pope et al. 2008; Kallmeier
et al. 2010; Coltorti et al. 2010).

The top of the succession is marked by 3 m thick clast supported bouldery gravel.
The poor sorting and grading, massive texture and the absence of sedimentary structures
indicate deposition by viscous, hyperconcentrated clast rich debris flow (Rust, 1978;
Miall, 1996; Aziz et al. 2003; Pope et al. 2008; Kallmeier et al. 2010). The overall finer
nature of the sediments is in conformity with the fact that the section is located
downstream of the previously described section. Further downstream, a 11 m thick cliff
section shows increasing content of sand and prominent decrease in clast size in the
various gravelly layers (Fig. 4.4, litholog 6). However, the sediment succession is
stratigraphically comparable. About a kilometer further downstream in the north, the cliff
section is reduced to 6m. The section exposes 1 m thick clast supported gravel at the base
followed by 3 m thick sand (Fig. 4.4, litholog 7). This is overlain by 0.5 m sandy gravel
and 1.5 m thick sand at the top.

Over all, the Quaternary sediments of the Falay River typifies the occurrence of
these deposits in the KMF zone. The sedimentary characteristic reveals that the deposits
are reworked colluvial deposits. The colluvium was generated in the hilly region
comprising Mesozoic sedimentary formation in response to neotectonic uplift of the hill
range along the KMF. These were later reworked by fluvial agencies and redeposited in
front (to the north) of the range front scarps.
PART-B Kachchh Mainland Fault (KMF)

Another notable section exposing Quaternary deposits is found in an unnamed stream between Dhrang and Lodai. The section is ~6 m in height is exposed on the left bank close to the scarp line (Fig. 4.5, litholog 8). The lower~2 m of the incised section exposes steeply dipping Mesozoic shale over which the Quaternary sediments were deposited with a distinct unconformity. The Quaternary deposits are divisible into distinct aggradation phases; however, internal stratification is obscure. Overall, the section shows ~5 m thick horizontal to sub-horizontal layers of gravelly to pebbly sediments with elongated lensoid bodies of sand. The bottom most matrix supported cobbly gravel unit is the coarsest with occasional clasts of boulder size. The matrix supported massive nature of cobbly-bouldary gravels indicate cohesive, viscous property of depositing medium whereas, the cross stratification structure suggests that may have been deposited in form of lag deposits (Miall, 1996). It is inferred that the sediments are lag deposits that may have been deposited by debris flows (Miall, 1996; Blair and McPherson, 1992; Garzione et al. 2003; Dorsey and Roering, 2006; Pope et al. 2008). This is followed by stratified sandy gravel which shows increased content of sand. The gravels are of pebble to cobbles size, poorly sorted and graded, supported by sandy matrix suggest cohesive, viscous debris flow. It displays horizontal stratification indicating the deposition by laminated debris flow (Miall, 1996; Pope et al. 2008; Xallmeier et al. 2010; Coltorti et al. 2010). Towards the top, a distinct 0.5 m thick sandy body of massive nature is seen. The massive texture, lack of sedimentary structures and poor sorting indicate deposition by sediment gravity flows (Miall, 1996; Stokes and Mather, 2000; Coltorti et al. 2010). The top of the succession is marked by pebbly gravel that shows several boulders size clasts embedded in sandy matrix. The largest boulder measured is ~0.60 m. The presence of matrix indicate the cohesive nature of depositing agent, while absence of imbrication, poor sorting and sedimentary structures which suggest the rapid deposition of sediments by sediment gravity flow (Rust 1978, Miall, 1996). These sediments show a rapid fining of clasts within a short distance of less than a kilometre in the downstream direction. Near the Banni plain the stream show fine sandy alluvium exposed along the vertical cliffs of ~1 m height.

About 1 km south of Lodai, the sediments are exposed along a small stream that rises from the eastern flank of the Habo dome and meets the Kaswali river. The stream exposes 2 m of basement Mesozoic rocks (Fig. 4.5, litholog 9). The Quaternary section starts with a 0.7 m thick structureless clast supported bouldery gravel. The bigger angular clasts are encased in matrix of pebble size clasts. The facies exhibits bigger clasts in
PART-B Kachchh Mainland Fault (KMF) noticeable amount, massive clast supported structure, poorly sorted fabric, absence of stratification, imbrications and weak grading suggests deposition by low strength hyperconcentrated clast rich debris flow (Rust, 1978; Miall, 1996; Aziz et al. 2003; Pope et al. 2008; Kallmeier et al. 2010). This is overlain by 1.7 m thick massive sand with thin lenses of fine gravel. The massive texture, lack of sedimentary structures and poor sorting indicate deposition by sediment gravity flows (Miall, 1996; Stokes and Mather, 2000; Coltorti et al. 2010). The top 3.5 m is composed of well stratified matrix supported gravel. The gravels are of pebble to cobble size and supported by fine to coarse sandy matrix; poorly sorted and weakly graded indicate sediment gravity flow; whereas, the presence of horizontal stratification, indicate the deposition by high strength, clast rich laminated debris flow deposits (Miall, 1996; Pope et al. 2008; Kallmeier et al. 2010; Coltorti et al. 2010).

Figure 4.5 Lithologs of Quaternary sediments in Segment-II. Location of the lithologs is shown in Fig. 3.1b. The vertical scale is in meters.

Further south of this section, about one kilometre in the upstream direction of the Kaswali river, the Quaternary sediments are exposed in the long N-S trending cliff section on the left bank of the river. The deposits form a distinct terraced surface that is incised by >6 m (Fig. 4.5, litholog 10). The vertical section shows ~2 m of steeply dipping Mesozoic rocks that are part of the eastern flank of the Habo dome. Overlying it is a 1.5m thick boulder bed with a sharply erosional basal contact. The horizon shows large highly
PART-B Kachchh Mainland Fault (KMF)
angular boulder sized clasts which are crudely imbricated in the downstream direction. The matrix consists of finer clasts of Mesozoic rocks. The matrix supported texture indicates cohesive, viscous property of depositing medium whereas, the crude stratification indicate that the sediments could be deposited in form of large longitudinal bar deposited by debris flow (e.g. Miall, 1996; Garzione et al. 2003; Dorsey and Roering, 2006). This is followed by a horizontally stratified sandy horizon containing sparsely distributed gravel clasts. The horizontal stratification, occurrence of floating gravels and poor sorting indicate transverse bedform sedimentation by laminar sediment gravity flows (Miall, 1996; Stokes and Mather, 2000; Colorti et al. 2010). The sand is overlain by a coarse gravel layer consisting of pebble sized clasts. This is capped by finer structureless gravel. The absence of sedimentary structures, weak grading, poor sorting and absence of imbrications suggest that gravels deposited by low strength, hyperconcentrated clast rich debris flow (Rust, 1978; Miall, 1996; Aziz et al. 2003; Pope et al. 2008; Kallmeier et al. 2010); whereas the decreased clast size of the overlying gravelly lithofacies may attributed to change in hydraulic properties of the depositing flows (Miall, 1996). The deposits are overlain by thin veneer of aeolian miliolite most part of which is eroded away. The exposed sediments are therefore bracketed as of pre-miliolite phase.

LODAI-JAWAHARNAGAR SEGMENT

This segment extends from the Lodai to the west and Jawaharnagar in the east. Here the scarps are developed in the Mesozoic rocks that form small domes forming a chain of small hills (Fig. 3.1a). South of these small hills is marked by the imposing presence of E-W trending Kas hill escarpment. The Kas escarpment is prominently visible up to Jawaharnagar (Fig. 3.1a). The north facing Kas escarpment is a scarp face of a large cuesta that is formed in the south limb of the large Kas anticline. Biswas (1993) describes the domes between the KMF and the Kas escarpment as small domal closure within the large Kas anticline. Prominent domes amongst these are the Wantra and Lotia domes.

The Quaternary sediments in this segment are lithologically very distinct from those of previously described sediments in segment-I and segment-II. East of Lodai to Wantra, the sediments form a continuous alluvial cover. At Wantra, a stream coming out of the Wantra dome exposes ~9 m of the Quaternary alluvial sediments on its right bank (Fig. 4.6, litholog 11). The base is marked by 1.5 m stratified sand. Overlying this is a 1 m thick semi compacted gravel. This is overlain by 1 m sand. Sand is further followed by 3.5 m thick sandy gravel which show several thin gravel rich layers. The gravel clasts are angular and unsorted. A 0.5 m structure less gravel overlies this. The top of the section is
PART-B Kachchh Mainland Fault (KMF)
marked by 1.0 m thick sandy gravel. The overall sediment nature is finer as compared to
the dominantly coarse grained sediments in segment-I and II to the west. Further
upstream, aeolian miliolites abutting against the scarps are found to occur along the river,
though they do not form vertical cliffs and are covered by dense vegetation. The aeolian
miliolite outcrops become more extensive eastward along the scarps and occurs
discontinuously for few kilometres directly overlying the Mesozoic rocks. The
géomorphological setting suggests that the deposition of miliolite took place as obstacle
dunes against the scarps Mesozoic rocks. The alluvial sediments described above
therefore belong to post-miliolite phase of fluvial deposition. Further east of Wantra, a
tongue of flat Banni plain is found to extend up to the scarps.

The Lotia stream branches into two channels as it emerges from the hills. The
western branch exposes continuous cliff section of Quaternary sediments overlying the
Mesozoic rocks. It flows towards WNW and further towards NNW in the downstream
before disappearing in the Banni plain (Fig. 3.1b). Mesozoic strata exposed in the river
channel shows vertical dips. In the downstream the basement rocks are replaced by near
horizontal Tertiary shales. The river exposes mainly fine sandy alluvium with gravel layer
overlying the sheared Mesozoic and Tertiary rocks (Fig. 4.6, litholog 12). Overlying the
basement rocks is a 1.5 m thick gravel with an erosional contact. This is overlain by 1.7 m
fine to medium sand that passes upward into gravelly sand which is 1.3 m thick. A
prominent 3 m thick sand horizon with indistinct stratification follows. Overlying this
thick sand is 0.5 m sandy gravel that is capped by 2.5 m sand marking the top of the
section. OSL date from the top of this unit suggests an age of 17±2 Ka. Though the
gravels are relatively less, lithologically they appear to be similar to the gravel horizons in
the Wantra section. The deposits represents post-miliolite phase of alluviation as revealed
by extensive miliolite deposits overlying the Mesozoic rocks to the east of Wantra and
near Jawaharnagar in the west.

To the west of Jawaharnagar, a north flowing stream bifurcates into two channels
which flow further northward as independent streams to meet the Banni plain (Fig. 3.1b).
The western channel follows a deeply incised channel exposing Quaternary sediments.
The channel shows two major knick points within a distance of 1 km that show a vertical
drop of 6 m and 5 m respectively away from the scarp. The Quaternary deposits exposed
along the cliffy banks of the stream consists of 8 m thick aeolian miliolite, followed by ~2
m thick valley fill miliolite capped by discontinuous ~1 m thick fine alluvial sand (Fig.
4.6, litholog 13). The aeolian miliolite appears to have been deposited as a large obstacle
PART-B Kachchh Mainland Fault (KMF)
dune in front of the scarp line as evidenced by an extensive mound like morphology of
the deposits. The western fringe of the dune is buried by alluvial deposits exposed in
Lotia stream. The WNW orientation of the Lotia stream is possibly controlled by
neotectonic uplift of the miliolites with dunal morphology. The eastern margin of the
presumed obstacle dune is buried under thick alluvial deposits to the east of Jawaharnagar
described later. Near the scarp line on to the left bank of the stream the miliolite strata in
contact with the Mesozoic rock shows vertical dips. The youthful topography, several
knick points and vertically inclined miliolites near the scarps indicates post-miliolite
reactivation of the KMF.

Figure 4.6 Lithologs of Quaternary sediments in Segments III and IV. Lithologs 11-13
are from Segment-III while lithologs 14-15 are from Segment-IV. The vertical
scale is in meters.

The significance of the Quaternary sediments in segment-III is that they are
comparatively finer and contain a higher amount of sand than that of segment-I and II.
The sedimentary succession comprises multi-storeyed bodics of gravel and sand. The
constituent lithofacies are sandy gravel, sand and gravelly sand lithofacies. Thick sandy
gravel facies comprises of well organized pebble clasts and fine to coarse grained sandy
matrix. The lithofacies show moderate sorting and good lateral continuity. The alternating
sand and gravelly sand lithofacies is composed of moderate to poorly sorted, massive and
PART-B Kachchh Mainland Fault (KMF)
weakly stratified sand and gravel. The matrix varies from fine to coarse grained sand wherein floating pebbles are embedded.

Because, the gravelly facies are well stratified and include clasts which are moderately imbricated, these can be interpreted as longitudinal bar deposits that filled up relatively shallow braided gravelly channels (Hein and Walker, 1977; Garzio et al. 2003). The sand may have been deposited on the top or flanks of bar during waning flow. In contrast to the alluvial fan lithofacies of segment I and II, these facies are finer and shows better sorting as well as increased sand content. Furthermore, facies bases tend to be sharp and exhibits sheet geometry. Overall the sediments represent deposits of infrequent sheet floods in shallow braided stream channels (Rust, 1972; Miall, 1977; 1996; Hein and Walker, 1977; Garzio et al. 2003; Kallmeier et al. 2010).

JAWAHARNAGAR-KHIRASARA SEGMENT

This segment lies between Jawaharnagar in the west to Khirsara in the east (Fig. 3.1a). The Quaternary sediment cover comprises mostly fine sandy alluvium that shows greatest thickness in the central part of the segment. The best exposure of Quaternary sediments is observed along a large entrenched meander of a stream flowing in the central part of the segment (Fig. 4.7a). The deeply incised meander is developed in alluvial sediments. The incision is however found to decrease rapidly to less than a metre near the Banni plain (Fig. 4.7b). The exposed sediments show a total thickness of ~11 m (Fig. 4.6, litholog 14). The sequence starts with a 1.0 m thick semi compacted massive sand. The compacted nature of sand is presumably because of the calcareous content derived from the older miliolite deposits well exposed near Jawaharnagar. This sand is overlain by 0.5 m thick semi-compacted clast supported lensoidal body of gravel. The gravel is followed by ~1 m thick sandy gravel which is overlain by 2.6 m massive and unconsolidated fine to medium fluvial sand. The unit has yielded an OSL age of 52±9 Ka.

Overlying this is a 1.2 m crudely cross stratified pebble gravel with sandy matrix and a scored base. This unit is overlain by 1 m thick fluvial miliolite. This is again overlain by 3.5m thick well stratified and unconsolidated sandy gravel with lenses of sand. The top is marked by 0.5 m thick sandy gravel. The unit has been dated to 16±2 Ka. Overall the coarser gravelly layers show lensoid nature while the sandy horizons are more consistent. Towards north in the upstream direction, a condensed section of ~10m is exposed in a small but tight meander. The sediments are similar but are notable for the increased size of the gravel clasts.
PART-B Kachchh Mainland Fault (KMF)

Figure 4.7 (a) Downstream view of large entrenched meander formed in Quaternary deposits to the north of the KMF scarp in Segment-IV. Note the deep incision and overall fine grained nature of the sediment succession exposed in the cliff which is in contrast to the sediments in segments to the west shown in earlier photographs. (b) View of a small incised meander in close to the Banni plain. The KMF scarp is seen in the background. Note the sharp decrease in incision as compared with the incision shown in a. Rapid decrease in depth of incision in less than two kilometers suggests that neotectonic movements along the KMF are responsible for the incision of Quaternary sediments.

Another stream in the east exposes a maximum thickness of ~6 m Quaternary sediments in an entrenched meander. The sequence overlies the uneven surface of the Mesozoic shale that forms the basal 1m of the vertical section (Fig. 4.6, litholog 15). The basement rocks are overlain by 2 m thick horizontally stratified sand followed by 0.5 m
PART-B Kachchh Mainland Fault (KMF)

thick fine basal gravel. This is overlain by 3 m thick massive sand followed by 1 m thick brown coloured sand. Further east the exposed alluvial thickness rapidly decreases, while at Khirsara the sediment cover is less than a one meter. Overall, the Quaternary sediments of this segment are sandy in nature and are in complete contrast to the coarse grained sediments exposed in other segments to the west. The unconsolidated nature and field relationship suggests that the sediments are younger than the miliolite depositional phase.

In this segment the sediments are composed of two lithofacies association, sand and sandy gravel. The sand lithofacies exhibit sheet like geometry, good lateral continuity, moderate sorting, massive or weakly horizontally stratified. Massive to moderately stratified structure of sand represent the deposits of sheet flows or highly concentrated flows (Rust, 1972; McPherson et al. 1987; Miall, 1977; Garzione et al. 2003). The thick sandy gravel comprises of well organized pebble clasts and fine to coarse grained sandy matrix. It shows cross to horizontal stratification and scoured base which are the indicators of confined channel deposits (Miall, 1977). Stratification, moderate sorting and organized gravel clasts in sandy gravel lithofacies indicate transport and deposition by sheet flows in braided stream channels (Rust, 1972; Miall, 1977; Aziz et al. 2003; Kallmeier et al. 2010).

KHIRSARA-DEVISAR SEGMENT

This segment includes the eastern most part of the KMF zone from Khirsara in the west to Devisar and further east. The general relief of the hill range in this segment is lower than other segments (Fig. 3.1a) but remains rugged as evidenced by the deeply incised river courses in the bedrock. The Quaternary sediment cover in front of the scarp is very thin. The Quaternary sediments forms a thin blanket of structureless and unconsolidated alluvial sands and fine gravels averaging 1-2 m in thickness covering the Mesozoic and Tertiary rocks. Major Quaternary aggradation phases evident in other segment are absent though the drainages appear to be of similar characteristics. It is surprising that this segment escaped significant Quaternary sedimentation in an identical geological setting where other segments to the west of it show stratigraphically well developed Quaternary sedimentary sequences. It can be inferred that this particular segment has had much lesser or subdued relief during much of the Quaternary period which did not provide sites for deposition and source area for generation of sediments as well. This also suggests that the segment-V attained the present relief later than other segments which can be attributed to eastward propagation of the KMF.
PART-B Kachchh Mainland Fault (KMF)

LITHOSTRATIGRAPHY

The Quaternary sediments occur in a thin band (1-3 km) in front of the north facing range front scarp marking the physiographic expression of the KMF. The scarp is an erosional remnant that owes its origin to faulting along the KMF. The Quaternary sediments form a northward sloping and highly dissected surface that gradually merges with the flat terrain of the Banni plain in the north. The sediments are obviously derived from the hilly terrain of the Northern Hill Range comprising deformed Mesozoic rocks and deposited by various streams in front of the scarps. The Quaternary sediment cover though thin, exhibits wide variation in lithology vertically as well as laterally along the KMF zone. All segments of the KMF zone investigated in the present study, show excellent stratigraphic development, except in the easternmost segment-V. OSL dating of the samples taken from selected horizons was also carried out (Table 4.1). The sediments are well exposed along the incised cliffs of north flowing small streams. In general, the maximum exposed thickness is found near to the scarps where the incision is also maximum which rapidly decreases towards north.

Table 4.1 OSL ages of the exposed Quaternary sediments. Sample PCH-1 is from the Pachcham island while the rest are from the Quaternary sediment successions exposed in the KMF zone.

<table>
<thead>
<tr>
<th>Field No.</th>
<th>Lab No.</th>
<th>U (ppm)</th>
<th>Th (ppm)</th>
<th>K %</th>
<th>Cosmic ray</th>
<th>Water content (%)</th>
<th>Wt. mean Ed</th>
<th>Wt. mean Age(Ka)</th>
<th>Dose Rate (Gy/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAL-1</td>
<td>LD1203</td>
<td>1.5</td>
<td>10.4</td>
<td>0.6</td>
<td>150±30</td>
<td>15±5</td>
<td>65±9</td>
<td>41±6</td>
<td>1.6±0.1</td>
</tr>
<tr>
<td>FAL-2</td>
<td>LD1204</td>
<td>1.6</td>
<td>13.6</td>
<td>1.0</td>
<td>150±30</td>
<td>15±5</td>
<td>75±13</td>
<td>35±6</td>
<td>2.1±0.1</td>
</tr>
<tr>
<td>FAL-3</td>
<td>LD1205</td>
<td>1.6</td>
<td>12.1</td>
<td>0.7</td>
<td>150±30</td>
<td>15±5</td>
<td>180±7</td>
<td>100±7</td>
<td>1.8±0.1</td>
</tr>
<tr>
<td>PCH-1</td>
<td>LD1209</td>
<td>1.4</td>
<td>8.1</td>
<td>1.1</td>
<td>150±30</td>
<td>15±5</td>
<td>68±10</td>
<td>37±6</td>
<td>1.8±0.1</td>
</tr>
<tr>
<td>JWN-1</td>
<td>LD1210</td>
<td>1.1</td>
<td>6.5</td>
<td>0.3</td>
<td>150±30</td>
<td>15±5</td>
<td>16±2</td>
<td>16±2</td>
<td>1±0.1</td>
</tr>
<tr>
<td>JWN-2</td>
<td>LD1211</td>
<td>1.4</td>
<td>11.8</td>
<td>0.45</td>
<td>150±30</td>
<td>15±5</td>
<td>80±12</td>
<td>52±9</td>
<td>1.5±0.1</td>
</tr>
<tr>
<td>KAI-1</td>
<td>LD1212</td>
<td>2.2</td>
<td>17.4</td>
<td>0.94</td>
<td>150±30</td>
<td>15±5</td>
<td>10±1</td>
<td>4±0.5</td>
<td>2.4±0.2</td>
</tr>
<tr>
<td>KAI-2</td>
<td>LD1213</td>
<td>1.1</td>
<td>4.1</td>
<td>0.4</td>
<td>150±30</td>
<td>15±5</td>
<td>32±4</td>
<td>34±5</td>
<td>0.9±0.1</td>
</tr>
<tr>
<td>LOT-1</td>
<td>LD1215</td>
<td>1.3</td>
<td>9.4</td>
<td>0.4</td>
<td>150±30</td>
<td>15±5</td>
<td>22±2</td>
<td>17±2</td>
<td>1.3±0.1</td>
</tr>
</tbody>
</table>

The prominent development of the miliolite phase in the study area can be considered as a marker horizon which can be used in correlation of the underlying and overlying phases of the sedimentary record (Fig. 4.8). The Quaternary sediments of the KMF zone can be classified into three major aggradation phases (Fig. 4.9). The oldest
PART-B Kachchh Mainland Fault (KMF) phase includes the sediments occurring below the miliolites. The second is the miliolite phase that includes the aeolian miliolites and valley-fill fluvial miliolites. The youngest phase is the post-miliolite phase that includes all deposits younger than miliolite. The deposits older than the miliolite phase are well exposed mainly in segment-I and segment-II to the north of Jhura and Habo domes respectively (Fig. 4.8). These deposits are dominantly coarse grained and are composed of clast supported to matrix supported gravels. The striking feature of these deposits is the large size of the clasts that ranges from boulder to pebbles (Fig. 4.8). The basal clast supported bouldery gravel seen in the cliff section of the Kaila and Kaswali rivers overlying the uneven surface of the underlying Mesozoic rock from the oldest Quaternary deposits of the KMF zone. This is overlain by several depositional phases of various kinds of gravel deposits. These deposits are unsorted and contain large angular clasts of Mesozoic rocks. The deposits underlying the miliolites imply short transport of the colluvial debris generated in the hilly region presumably due to uplift of the source area in response to neotectonic activity along the KMF. The pre-miliolite sediments can therefore be categorized in general as colluvio-fluvial deposits, which correspond to the pre-miliolite phase of neotectonic activity along the KMF. These deposits are in sharp contrast to the present day sandy bed load of the various streams and large rivers like the Kaila and Kaswali rivers.

The miliolite phase is the most characteristic Quaternary depositional phase of the region which includes both the aeolian as well as fluvial deposits. These comprise medium to coarse grained semi-compacted clastic limestones with higher lithic content than the comparable and more intensively studied miliolite rocks of Saurashtra (Biswa, 1971). These are described as originally carbonate rich sediments blown by wind from coastal area and deposited as scattered obstacle dunes along the rocky slopes within the hill ranges and in part of the scarps (Biswa, 1971). The miliolites are the only dated Quaternary sediments of Kachchh which have regional distribution. Since the lithologic and chronologic correlatability of the miliolites of Kachchh with their more well developed and more intensely investigated counterpart in Saurashtra is already well established and accepted (Baskaran et al. 1989; Chakrabarti et al. 1993; Somayajulu, 1993), they form important reference point for the interpretation of other Quaternary deposits in Kachchh especially in those occurring in the known active fault zones and for which no chronological data is available. (e.g. Patidar et al. 2007).
Fig. 4.8 Lateral correlation of the Quaternary sediments exposed in the KMF zone. Note the clear distinct three phases of aggradation. The vertical scale is in meters.
PART-B Kachchh Mainland Fault (KMF)

However, almost all dates of miliolites are reported from the central mainland Kachchh and none from the KMF zone. $^{230}T_{h}^{234}U$ ages of the Kachchh miliolite ranges from 30 to 130 ka (Baskaran et al. 1989; Catakabarti et al. 1993; Somayajulu, 1993). The miliolite phase therefore represents an extensive depositional phase all over the Kachchh basin from middle Pleistocene to late Pleistocene. Aeolian miliolite comprises fine grained texture while in reworked fluvial miliolite, the presence of varying sizes of clasts of Mesozoic rocks and horizontal stratification is seen. The thickest aeolian miliolite deposit is seen in the Jawaharnagar stream where $\sim$8 m thick deposit forms dunal morphology and abuts against the KMF scarp where it shows the vertical dip near the scarp. This suggests post-miliolite phase of neotectonic activity along the KMF. Reworking of the aeolian miliolite by fluvial agencies has resulted in the formation of valley-fill miliolite or fluvial miliolite (Biswas, 1971; Patidar et al. 2007). The maximum exposed thickness of the valley fill miliolite is seen in the Falay river where the maximum thickness of these deposits is $\sim$3 m.

The post-miliolite phase is represented by the alluvial deposits overlying the miliolites. Typical exposures of the sediments younger than miliolite are found at Wantra and in large incised meanders to the east of Jawaharnagar. These sediments also show lithological heterogeneity along the length of the KMF zone. In segment-I these consist of cobbly-pebbly gravel with sands where they overlie the miliolite and are tilted. In segment-II this phase is separated by matrix supported gravel overlying the valley fill miliolite in Falay river. The clast size here is of pebble size. Further east in segment-III at Wantra, clast size is visibly reduced and the sand content is found to increase. The Wantra section exposes the post-miliolite deposit; the sediments are unconsolidated and characterized by relatively less amount of gravel deposits. Since the source area is the same, the relatively finer nature of the deposits could be indicative of comparatively less intense neotectonic activity along the KMF during the deposition of post-miliolite sediments. However, the tectonically controlled incision of the Quaternary deposits observed in all the segments indicates a post-depositional tectonic activity along the KMF.

The sedimentary characteristics and stratigraphic set up of the Quaternary sediments of the KMF zone described earlier are suggestive of very specific depositional processes. The geomorphic setting, proximity of the source area and the fact that the deposits overlap an active fault zone are further strong indicators of the nature of sedimentary processes that operated during the deposition of these sediments. The
PART-B Kachchh Mainland Fault (KMF)

deposits are in sharp contrast to the present day sedimentation that occurs by the seasonally active rivers and the resultant deposits are sandy.

![Diagram of lithostratigraphic log]

**Figure 4.9** Composite lithostratigraphic log of the Quaternary sediments occurring along the KMF zone in the study area. The vertical scale is in meters.
PART-B Kachchh Mainland Fault (KMF)

NEOTECTONIC IMPLICATIONS

Neotectonics is the prime factor that governs the sedimentation pattern and geomorphic evolution in active fault zones. The Quaternary deposits occurring in the seismically active KMF zone provide important clues for neotectonic evolution. The lateral continuity and excellent stratigraphic development of the deposits in the KMF zone are in a way contrasting with the dominantly rugged rocky landscape of the Kachchh developed over Mesozoic rocks with negligible Quaternary sediment cover. The confinement and deposition of Quaternary sediments in front of the scarps along the KMF zone points to the primary control exerted by neotectonic activity in the generation and deposition of the Quaternary sediments. The rugged hilly terrain of the Northern Hill Range consisting of deformed Mesozoic rocks acted as the source area for the generation of sediments which were transported and deposited in front (north) of the scarps. Tectonic uplift of the hill ranges due to neotectonic activity along the KMF led to the generation of vast amounts of colluvial deposits which were reworked by fluvial agencies and transported northwards. The multistoreyed sedimentary architecture of the sediments indicate deposition in the form of small coalescing alluvial fans by multi-distributary channel systems in the backdrop of an active fault controlled range front. The dominantly coarse grained nature of the pre-miliolite deposits are particularly well developed in segments I and II, and the sedimentary characteristics indicate that deposition occurred in phases mainly by debris flows and sediment gravity flows as discussed in the previous section. Available chronological data suggests that the overlying miliolite deposits represent a prolonged period from middle to late Pleistocene (Baskaran et al. 1989) thus bracketing the neotectonic activity represented by the colluvio-fluvial deposits to early to middle Pleistocene.

Broadly, the overlying aeolian and fluvial miliolites are stratigraphically and lithologically comparable with their more extensively developed and studied counterpart in Saurashtra (Baskaran, 1989). The aeolian miliolites were deposited as scattered obstacle dunes within the Northern hill range and also in the KMF zone in front of the north facing scarps. These were fluvially reworked and deposited over the colluvio-fluvial deposits possibly during the early Holocene. Similar valley fill miliolites in the Katrol Hill Fault (KHF) zone in central part of the mainland Kachchh have been related with the humid phase of the early Holocene (Patidar et al. 2007). The nature of neotectonic activity during the deposition of miliolite is not clear as the deposits are scattered and fine grained by virtue of their aeolian origin. Moreover, no fluvial deposits within aeolian
PART-B Kachchh Mainland Fault (KMF)

Miliolites are observed or reported from elsewhere in Kachchh by previous workers. However, vertically disposed aeolian miliolite near the scarps and tilted gravel layers overlying fluvial miliolites indicate post-miliolite tectonic activity along the KMF.

The interlayered sandy gravel and sand deposits overlying the miliolites are striking finer than the pre-miliolite colluvio-fluvial deposits. The finer nature of the deposits, well exposed in segments III and IV, is evidenced by the increased sand content and pebble sized clasts in the gravel. The sediments were deposited dominantly as sheet floods in shallow braided stream channels. Since the source area for the generation of sediments remained the same, the relatively finer nature of the deposits could be indicative of comparatively less intense neotectonic activity along the KMF in the post-miliolite time. Based on the sedimentary facies and multistoreyed architecture, we infer braided multi-distributary channel systems for the deposition of the post-miliolite Quaternary sediment succession along the KMF zone.

The present day setting of the KMF is in contrast to the one indicated by the exposed Quaternary sediments. Presently, the Quaternary deposits form a narrow 1-3 km wide highly dissected northward sloping surface along the length of the KMF zone. The drainages are deeply entrenched with narrow ephemeral sandy stream channels bound by vertical cliffs exposing the sediments. The depth of incision is maximum near the scarps which rapidly decreases northward as the streams disappear into the Banni plain. This suggests post-depositional tectonic activity along the KMF that resulted in tilting of the Quaternary sediment surface away from the scarps and tectonically controlled fluvial incision and dissection of the sediment sequences.

The variable geomorphic response to neotectonic activity along the KMF is interesting. Many studies exist which describe controls of tectonics and climate on sedimentation and incision but studies that discuss factors that trigger change from deposition to incision under tectonically active conditions are rare. It is difficult to determine the precise causes of change from deposition to incision in the study area even though the KMF continues to be tectonically active as evidenced by the tectonically controlled incision and occurrence of several earthquakes. The role of climate change is ruled out as Kachchh falls in the hyper-arid climatic belt of western India that includes the Thar Desert to the north as well. The scanty rainfall means that the present discharge and stream power alone cannot account for the amount of incision observed. Moreover arid conditions do not favour generation of large amount of sediments in source areas. The sand dominated floor of the present day rivers even within the hill ranges testify to the
PART-B Kachchh Mainland Fault (KMF)

low degree of sediment generation, stream power and sediment carrying capacity. We therefore believe that marked reduction in sediment supply could be the reason for transformation of rivers from depositional to erosional under uniformly tectonically active conditions. Modelling of changes in sediment flux and incision in tectonically active conditions show that reduction in supply of sediment leads to river incision and/or diversion (Humphrey and Konrad, 2000). This also shows that in tectonically active environment incision is favoured during phases of enhanced tectonic activity (Chen et al. 2011). It is inferred that, continued neotectonic activity along KMF that continues at the present time is the prime factor responsible for causing incision and dissection of the Quaternary sediments while climate may have played an indirect role in switching off the sediment supply. However, while the role of neotectonic activity is very obvious, the role of climate change needs to be substantiated by further studies.

The inferences of the present study are consistent with previous studies in active fault zones in Kachchh and other parts of the globe which identify variation in rates of tectonic activity as the first order influence on sedimentation and erosion. Tectonically controlled Quaternary deposition reported previously from Kachchh include the vast basin of the Ranns, the coastal plain along the Gulf of Kachchh in the south and the Katrol Hill Fault (KHF) zone in the central part of Mainland Kachchh (Biswa 1974; Thakkar et al. 1999; Maurya et al. 2003b; 2008; Patidar et al. 2007; 2008). These sediments were deposited in structurally controlled sites/basins and have provided vital stratigraphic and geomorphic evidences for reconstructing neotectonic evolution of the respective areas (Merh 2005; Maurya et al. 2008; Patidar et al. 2007; 2008). This indicates the significant role played by neotectonic activity along various active faults including the KMF in controlling the Quaternary sedimentation and geomorphic evolution in the Kachchh basin.