CHAPTER - 7

MORPHOTECTONIC EVOLUTION OF THE BASIN

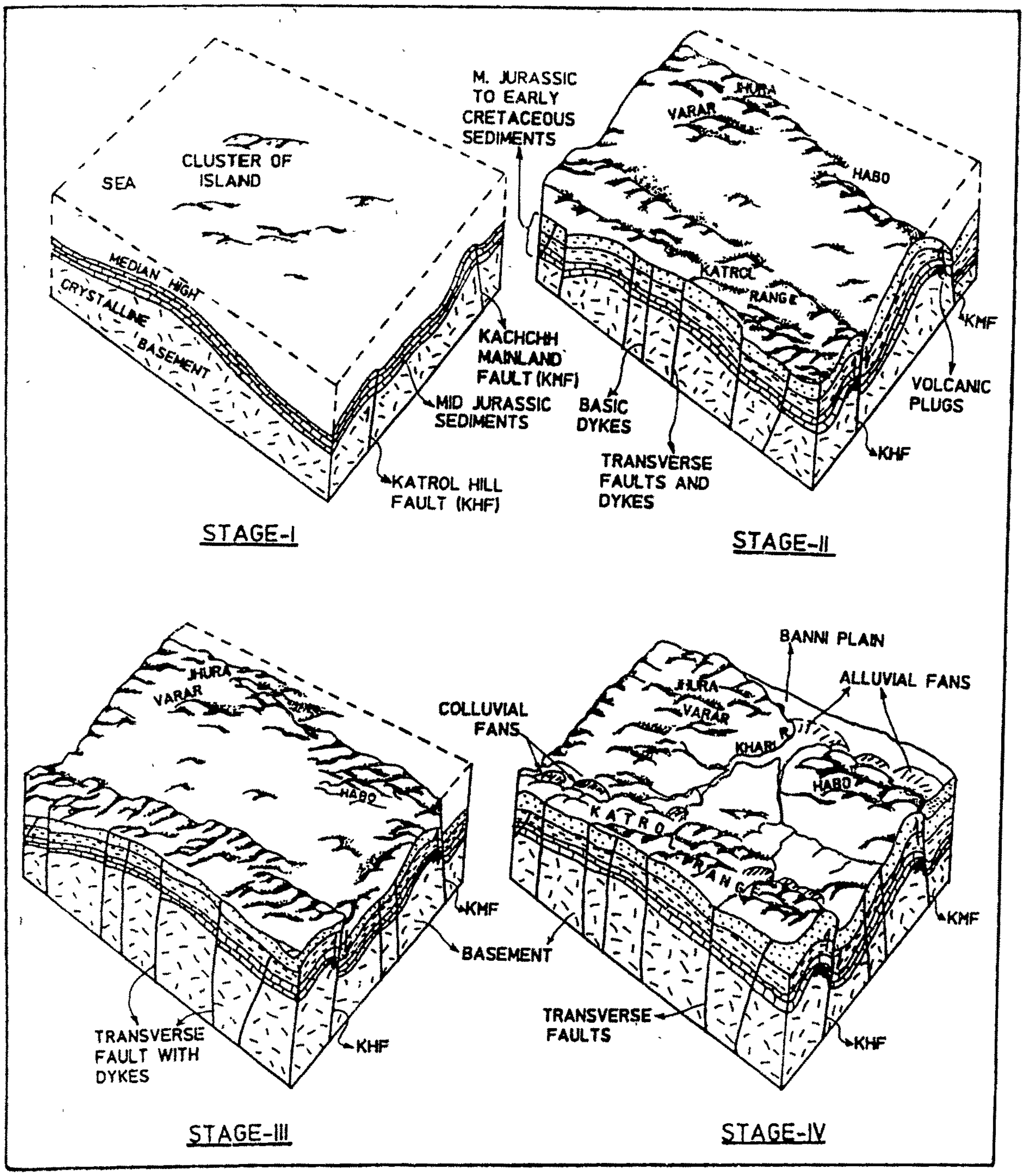
Landscape evolution in a broad sense, can be described as a function of climate, tectonism and geologic parameters such as rock type or structure. Climatic parameters tend to degrade landscapes through the chemical and physical erosive action of wind, water and ice. Tectonism, on the other hand, tents to construct landscapes through uplift and crustal warping. Rock type can influence landscape evolution through differences in erodibility, while geologic structure can influence the large scale pattern or grain of a landscape. The complex interaction of these variables directly influence the evolution of fluvial systems and thus provide information on the manner in which they carve the landscape (Schumm, 1956,1977; Keller,1986; Bull and Knuepfer, 1987; Schumm et al, 1987). Temporal or spatial changes in one or more of these variables can, therefore have profound effects on landscape evolution.

In the foregoing chapters of this thesis the author has described the interaction of climate, tectonism, rock type and structure that influence the geomorphic processes and landscape evolution. The Khari river basin forms a crucial area of Kachchh whose evolution is closely associated with the evolutionary history of Mainland Kachchh. The geological set up indicates that the evolutionary history of the area dates back to Mesozoic times. The rocks exposed in the area comprise mainly Mesozoics with localized occurrences of Tertiary rocks. The strata show a gentle southerly dip except in the regions adjacent to folds and faults. The Mesozoic rocks belong to the Jhura, Jumara, Jhuran and Bhuj Formations. The patchy occurrences of Tertiary rocks belong to the Madh and Khari series. The trappean rocks are represented by several structurally controlled dykes and plugs in the core portions of the domes.

The evolutionary history of the area starts with the transgression of the sea during Middle Jurassic (Fig.7.1) subsequent to the formation of the Kachchh basin. During this phase, the Jhurio and Jumara Formations were deposited. The Mainland formed the main depocentre during this phase (Biswas,1981). The deposition took place in a slowly and cyclically subsiding basin. The Jhuran and Bhuj Formations were deposited during the regression of the sea which followed the first transgressive phase. These two phases are separated by an unconformity (Biswas, 1977,1981).

The Bhuj Formation, which is fluvial in the east with increasing marine influence towards west was deposited during the final withdrawal of the Mesozoic sea as a delta complex (Biswas, 1981). The basin

Fig.7.1 Diagrammatic representation of the major stages in the tectonic evolution of the area aroud Bhuj in Central Kachchh Mainland. **Stage-I** Area covered by late Jurassic sea. Median high is reflected by scattered islands. **Stage-II** Development of transverse faults and simultaneous intrusion of basic dykes before the onset of main eruptive phase. Doming was perhaps initiated at this stage due to upwelling of magma in the subsurface. The main volcanic phase and accummulation of compressive stresses on the KMF and KHF led to the formation of domes, flexures and reverse movement along KHF. **Stage-III** Post domal reactivation of transverse faults leading to lateral displacement of KHF, KMF and various domes during Eocene-Oligocene. **Stage-IV** Evolution of the present physiographic set up during Early Quaternary due to tectonic movements along KHF, KMF and related faults followed by Late Pleistocene-Recent movements along transverse faults.



SEA
CLUSTER OF ISLAND
MEDIAN HIGH
CRYSTALLINE BASEMENT
KACHCHH MAINLAND FAULT (KMF)
MID JURASSIC SEDIMENTS
KATROL HILL FAULT (KHF)
STAGE-I
M. JURASSIC TO EARLY CRETACEOUS SEDIMENTS
JHURA
VARAR
HABO
KATROL RANGE
KMF
VOLCANIC PLUGS
BASIC DYKES
TRANSVERSE FAULTS AND DYKES
KHF
STAGE-II
JHURA
VARAR
HABO
KMF
BASEMENT
TRANSVERSE FAULT WITH DYKES
KHF
STAGE-III
BANNI PLAIN
ALLUVIAL FANS
COLLUVIAL FANS
JHURA
VARAR
KHARI
HABO
KATROL RANGE
KMF
TRANSVERSE FAULTS
KHF
STAGE-IV

subsided at a faster rate during this period. The region also comes under median high (Biswas, 1982) which is responsible for the poorly developed upper and middle parts of Bhuj Formation in the area. The Mesozoic sedimentation was truncated by a phase of orogenic movements.

The Mesozoic rocks in the area are intruded by a number of basic dykes trending mostly N-S or NW-SE. These occur in the vicinity of faults or along the faults (Fig.7.1), suggesting syntectonic nature of the intrusive rocks (Biswas and Deshpande, 1973). The dykes occurring to the south and north of Katrol Hill Fault abruptly terminate against the fault. The Madh Series of Paleocene age is exposed north of Kukma village extending further north-eastward upto Paddhhar and is of continental origin (Biswas, 1973). The other important Tertiary unit is the Vinjhan Formation of Upper Miocene age which occurs in the form of scattered patches deposited in tidal flat to littoral environment of a transgressive sea (Biswas, 1973).

The Quaternary deposits are confined along the various river valleys and major fault lines. An extensive tract of Quaternary deposits comprising the plain of Banni occur to the extreme north of the study area. Quaternary deposits in the study area occur mainly in the form of alluvial and colluvial fans, fluvial sandbars, valley fill miliolites and fluvio-aeolian miliolite patches.

The alluvial and colluvial fans are associated with the Mainland Fault and Katrol Hill Fault. The presence of colluvial fans at the base of fault scarps are a conspicuous feature of the area. The colluvial material is suggestive of degradation of the fault scarps. Majority of the colluvial fans recorded in the area are located along the E-W faults, notably the

Katrol Hill Fault. The NNW-SSE, NW-SE, NE-SW and NNE-SSW trending transverse faults show very little or negligible colluvial material indicating a relatively fresh nature of these scarps. The colluvial fans are incised by various streams and are overlain by miliolite deposits suggesting that these deposits are of Early Quaternary age.

Miliolites occur as small inliers within the rocky area as obstacle dunes and as sheet deposits. The sheet miliolites occurring extensively in the area are studded with cobbles and pebbles suggesting a fluvial component in the origin of these deposits (Chakraborty et al., 1993). Alluvial deposits are found in patches within the various river channels. The alluvial deposits at places show faulted contacts with the older rocks. Immediately to the north of Mainland Fault in the Banni plains, these deposits show incision of 1.5 to 3.0 m.

PRE-QUATERNARY TECTONIC EVOLUTION

The area around Bhuj in Mainland Kachchh reveals an interesting structural framework which has tremendous implications for tectonic evolution of Khari river basin. The E-W trending regional faults, the Katrol Hill Fault and the Mainland Fault are prominent structural features of the area. The Katrol Hill Fault is an almost E-W regional fault which has brought the older rocks in the south over the younger rocks to the north. The fault plane near Hamadra lake is inclined steeply (55-60°) towards south and it is thus a reverse type of fault. The fault parallels the strike of the strata and is somewhat sinous rather than straight. It marks the northern limit of the Katrol range and forms a major drainage divide of the Mainland. The northern face of the fault scarp exhibit characters typical of a fault generated mountain front (Mayer, 1986, Bull and McFadden, 1978).

Structurally, the formation of the domes has influenced the geomorphology of the area. These domes constitute the northern hilly ranges-the Habo and the Jhura hills and the Katrol Hill range in the central highland. The Habo and Jhura domes flank the Mainland Fault. Katrol Hill Fault also shows domes or half anticlines. The various domes associated with the Katrol Hill Fault are Ler dome, Gangeshwar dome, ShivParas dome (Lakki dungar dome), Khatrod dome and Chadwa dome. The northern limbs of the domes occurring to the south, are truncated by the Katrol Hill Fault. The southern limbs of the domes are gently inclined, as little as 5-10° towards south while the northern limb is steeply dipping towards the north or is vertical. At places, the northern limbs are seen overturned with a steep dip due south. Some of these domes contain basic rocks in their central portions, several N-S dykes and plugs with occasional sills. The eastern and western limits of the domes are marked by N-S transverse faults. The N-S and NW-SE fractures are occupied by basic igneous dykes. The fact that some of the transverse faults cut across the Katrol Hill Fault is significant.

Biswas (1982) opined that the parallel E-W trending basin bounding faults are related to the origin of the Kachchh basin. The subsequent tectonic movements along these faults including the Katrol Hill Fault resulted in the present geologic and geomorphic configuration. North of this fault several similar faults including minor and major faults show step faulting towards north. These faults are responsible for the gentle anti-dip tilt of the area towards north.

The period of tectonic upheaval following the cessation of Mesozoic sedimentation is responsible for the complications in the structural set up of the area which are manifested in the present landscape. The Katrol Hill Fault and the Mainland Fault are displaced by several NNW-SSE, NW-SE, NE-SW and NNE-SSW transverse faults. Close association of the transverse fault trends and the intrusive dykes of the area suggest that these events are related to each other and are coeval.

According to Biswas and Deshpande (1973) the intrusives with the exception of plugs belong to a pre-Deccan trap phase. This seems to be distinct possibility since the area around Bhuj shows a large number of dykes, but no outcrop of Deccan traps is seen even though the area is a structural and physiographic depression and Madh series of Palaeocene and Khari Series of Miocene age are preserved. This suggests that the transverse faulting and intrusion of dykes took place sometime after the deposition of Bhuj Formation but before the onset of Deccan trap volcanic activity (Fig.7.1).

The phase of transverse faulting and intrusion of dykes was followed by a major diastrophic cycle which accompanied the main trappean volcanic activity. This phase gave rise to several domes and flexures described earlier along the Kachchh Mainland Fault and Katrol Hill Fault. The localization of folded zones along the Katrol Hill Fault and Mainland Fault points to the significant role played by these faults in the formation of the fold zones and suggests accumulation of compressive stresses along these fault planes. These compressive stresses possibly led to reverse movement along the Katrol Hill Fault.

The presence of volcanic plugs related to the eruption of trappean lavas (Biswas and Deshpande, 1973) in the central portions of the domes indicate syntectonic volcanic activity. The formation of domes, folds and flexures is thus the result of intricate interplay of localized stresses in fault zones and simultaneous volcanism. The major uplift zones of the area came into existence as a result of differential uplift along the E-W faults during this phase. In Cretaceous period Indian plate was passing over a hot spot called reunion which resulted in massive effusion of Deccan lava in India (Raval, 1995). The extrusion of the Deccan Traps is a late synrift event as evidenced by the age of the Traps, ~65 Ma, and the oldest sea floor-spreading magnetic anomalies observed in the Arabian sea, 59.0 to 63.3 Ma (Condie et al., 1989). The trappean lavas mainly erupted from Hawaiian type shield volcanoes (Biswas and Deshpande, 1973) and most of the domes and anticlinal structures evolved at that time. This phase of tectonic upheaval ceased before the onset of Tertiary as evidenced by the very gently dipping Tertiary rocks which overlie the eroded Mesozoic folds in E and SE part of Mainland Kachchh (Biswas, 1982).

The dykes do not cross the Katrol Hill Fault on either side whereas the transverse faults are seen displacing, both the Katrol Hill Fault and the Mainland Fault. The strata in the various domes also show lateral displacement along these faults. This suggests a later phase of reactivation of transverse faults with dominantly strike slip movement as evidenced by the horizontally displaced fault scarps of Katrol Hill Fault and Mainland Fault sometimes during Tertiary. This event is possibly related to Stage 5 of the drift history of the Indian plate described by Biswas (1982). According to him, the Stage 5 constitutes the Eocene-Oligocene period when the final welding of Indian and Eurasian plate took place resulting in slowing down of the northward drift and anticlockwise rotation of about 9° (Biswas, 1988).

Following Deccan volcanism, the northward motion of the Indian plate was slowed down by collision with Eurasia. Most workers place the age of initial collision in the Eocene to Early Oligocene, based on decrease in plate velocities recorded in sea floor-spreading marine magnetic anomalies (Norton and Scalter, 1977; Klootwijk, 1979; Besse et al, 1984; Patriat and Achache, 1984; Besse and Courtilliot, 1988; Coward et al, 1988; Dewey et al, 1988,1989). The collision obstructed the northward movement of the Indian plate and the increasing forces and stresses threw the Mesozoic sediments and their structures onto the surface in different episodes during Tertiary. The abrupt slow down of the Indian plate after a very rapid northward movement and the anticlockwise rotation possibly realigned the tectonic stresses and reactivated the transverse fault systems resulting in strike slip movement.

The pre-Quaternary erosional surfaces E_1 and E_2 occurring at an altitude of 300 m and 240 m are mostly seen within the Katrol hill range of the study area. There is only one hill that crosses 300 m altitude which is correlatable with the Upper Cretaceous surface of Biswas (1974). A number of scattered hills ranging in altitude between 240-300m occur in the area. These are at places represented by discontinuous ridges and plateaus such as Khatrod ridge (280-342m) at Khatrod village, and Satpura plateau (260 m), south of Madhapar village. These landsurfaces in the Katrol hill range show steep mountain fronts.

The E_3 surface is distinguished from E_2 surface by flat hill tops, discontinuous ridges, plateaus and cuestas which generally fall between an altitude range of 160-200m. The youngest pre-Quaternary erosional land surface is marked by gently sloping piedmonts, residual hills, flat stony surfaces, plateaus, cuestas, mesas and terraces. The surface is drained by the second and third order streams. All the pre-Quaternary surfaces show a southerly tilt which points to an unidirectional movement along E-W Katrol Hill Fault. Biswas (1974) also recognized similar kind of tectonic movements along basement faults in Kachchh. The erosional surfaces show a wavy configuration which could be attributed to the differential movements along various fault systems and varying degree of erosional processes.

The series of erosional surfaces have constituted a stepped topography where the oldest surface occurs at the top and the youngest at the bottom. These surfaces have formed by lateral planation followed by intermittent uplift due to repeated reactivation of basement faults. The general slope of these surfaces is towards south, suggesting a unidirectional tectonic movement from time to time causing periods of tectonic instabilities and stabilities leading to the formation of polycyclic landscape. Biswas (1974) correlated these surfaces with the unconformities or hiatuses in the sedimentary sequence exposed in the bordering coast land.

A major gap exists in the study area as the Tertiary rocks are largely absent except for a few patches. However episodic tectonic movements during Tertiary are recorded from the studies carried out in other parts of Kachchh (Biswas, 1974, 1982). These tectonic movements (Early Tertiary and Mid Tertiary), only reactivated the pre-existing faults and threw the earlier land surface at a bit higher elevation and also exposed new surfaces for sub aerial erosion. The post-Palaeocene and post-Miocene movements uplifted the Early and Mid-Tertiary erosional surfaces (Biswas, 1974). Evidence of this tectonic uplift is seen in the form of the above mentioned surfaces occurring at higher levels in the area.

QUATERNARY TECTONIC EVOLUTION

The first order topography of the area together with the evidences described above suggest tectonic instability of the area during Quaternary (Kar, 1993). Neotectonic uplift along various faults has been responsible for the present landscape of the area. The uplift took place in two major phases. These two phases are separated by the depositional phase of miliolites. The pre-miliolite phase took place in Early Quaternary while the post-miliolite phase occurred during Late Pleistocene which is perhaps continuing at present. The Early Quaternary tectonic activity took place along the E-W trending faults while the Late Pleistocene phase took place along the NNE-SSW to NNW-SSE trending transverse faults. The E-W trending faults including the Katrol Hill Fault were more active during Early Quaternary as suggested by the colluvial fans along this fault which underlie the miliolite deposits. This suggests that the present configuration of the landscape came into being during Early Quaternary due to neotectonic activity along E-W faults. Biswas (1974) also identified the rocky plain of Bhuj as Early Quaternary landsurface.

The Early Quaternary physiographic set up has been modified by the Late Pleistocene-Holocene tectonic activity along transverse faults. Biswas (1974) also postulated a displacement of at least 30 m along the

Katrol Hill Fault during Quaternary based on the occurrence of Early Quaternary surface at different levels on either side of the fault. A major portion of this displacement occurred during Early Quaternary. However, the total Quaternary uplift of the Mainland Kachchh could be much more. The differential uplifts are part of the regional uplift due to which the entire Kachchh region including the Rann and Banni plains have been elevated (Biswas, 1974). The basin of study falls on the middle block (Suthri-Bhujpur block) of the Mainland which has been elevated more than the other two blocks (Sharma,1991).

Late Pleistocene tectonic activity along transverse faults is evidenced by the faulting in the Late Pleistocene fluvial deposits, tilting of sheet miliolites in the vicinity of these faults and a very youthful fault scarp morphology. The present day tectonic instability of the area as evidenced by the high degree of seismic activity (Johnston and Kanter, 1996) is perhaps due to tectonic movements along these transverse faults. In the Himalayan region, the neotectonic movements along thrust planes are transmitted to various transverse faults which account for the present day seismicity (Valdiya, 1976). It is possible that the compressive stresses accumulating on the E-W latitudinal faults of Mainland Kachchh due to locking up of the Indian plate in the NE are being transmitted to the NNE-SSW and NNW-SSE transverse faults after being transformed to tear movements along these strike-slip faults in a similar manner. The tectonic rejuvenation of peninsular India during Quaternary (Radhakrishna, 1993) is also attributed to repeated tectonic movements along various transcurrent faults (Valdiya, 1998).

The present day landscape of the area is an end-product of various processes like sub-aerial erosion, pediplanation and tectonic activities. The two prominent Quaternary surfaces (E_5 and E_6) at an altitude of 80-120m and 0-20m are easily recognizable. The E_5 surface ranging in altitude between 80-120m is dominant in the central part of the basin. It is marked by low residual ridges, mesas, flat rocky and sandy pediments and rocky river terraces. This land surface slopes towards north opposite to dip, this phenomenon could be due to the vertical upliftment of the Central Kachchh Highland due to differential movement along Katrol Hill Fault during Quaternary. This landsurface is traversed by higher order streams which have incised the surface and given rise to tectono-erosional terraces. The deeply incised valleys, gorges and ravines of the Khari river basin indicate neotectonic activity during Quaternary. Biswas (1974) has reported a displacement of about 30-35m in the elevation of this surface on either side of the Katrol Hill Fault during Early Quaternary.

The latest erosional surface (E_6) occurring at an altitude of 20m is marked by boulder and gravel beds in river valley terraces at levels higher than the valley floor, the depositional terraces within the Katrol hill range, the rubble deposit 1-15 m high above the valley floor, the clay and rubble terraces 8-9m above the river bed and the Banni plain. The Banni deposits at the mouth of Khari river near Sumrasar village are cut by streams and gullies up to a depth of 0.3-1.5 m. All these characteristics are indicative of Recent uplifts.

The study of drainage basin morphometry suggests strong proof of episodic upliftment of the landmass. Morphometric study of other related drainage basin parameters like longitudinal stream profile, valley height and width ratio and mountain front analysis was undertaken. The Khari river has been identified as a sixth order channel. Total channel length of all the stream orders indicate stream richness in the basin. The length and number of the lower order streams in the basin suggests moderate to high relief head-water area. However, the lesser number and lesser length of the higher order streams suggest s mall extent of the basin. Ruggedness number in the present basin is less than 1.00 (i.e. 0.796), which suggests low relief and moderate density and points towards semi-arid and arid climatic condition.

The mature surface shows higher number of streams (mostly lower order streams), while younger surfaces have lesser streams but quite broad valleys. Matching with the erosional surfaces, longitudinal stream profiles also show different stages of upliftment of the landscape. Each and every stream can be divided into different segments from source to the base level. The segments on each stream are uniform i.e. at uniform height interval. Highly concave upward profile suggests that the area is tectonically very active.

The gradient index values of each segment of the streams have obvious similarity except in the Khatrod streams where each value is quite high. Such highly variable gradient indices are typical in areas experiencing an intermediate to high rate of uplift (Rhea,1993). It is in conformity with the field observations around Katrol hill where the tectonic uplift is indicated by fault scarps, triangular and narrow fans , fault breccias and synclinal troughs. The gradient value and gradient index values vary in different segments, but the corresponding segments in each stream has nearly similar values. Moreover, the curves of longitudinal stream profile shows rapid decrease or increase in gradient, while passing from one segment to another. This suggests that basically the tectonic movements that took place time to time were responsible for the evolution of Khari river basin and the landscape of Mainland Kachchh at certain intervals from Early Cretaceous to Late Quaternary.

All the streams have very low Vf ratio near their source in the hilly region, while a few kilometers away from the source, the ratio is quite high due to the broad valley morphology. At places it becomes very low, as valley incision is quite high for a particular part of the area, indicating periodic tectonic activity during the Quaternary. The results of sinuosity parameters of the Khari river basin suggest thac they are controlled dominantly by tectonism. The evolution of the Khari river basin in the later phase of tectonism is indicated by the sinuosity indices.

Most of the mountain front sinuosity values fall in the range between 1.0 to 1.6 in class-1 of Bull (1978) suggesting that the area has experienced active tectonism. Mountain fronts associated with Kachchh Mainland Fault trending in E-W direction show moderate values of Mountain front sinuosity falling in class-2 which indicates moderate to slightly active tectonism along the Kachchh Mainland Fault during Quaternary. Some of the segments of Katrol hill range formed due to the transverse shifting show unusually low values of mountain front sinuosity suggesting high degree of tectonic activity during Recent time. The values of mountain front sinuosity associated with the transverse faults (i.e. NE-SW, NW-SE, NNW-SSE, NNE-SSW, N-S and WNW-ESE) are unusually low. Mountain front sinuosity values between 1.1 to 1.27 suggest the activeness of transverse faults. At places the values indicate that these have been more active than the Katrol Hill Fault. Overall, the mountain front sinuosity values indicate that the Khari river basin has been tectonically active during Quaternary.

The latest tectonic episode in Quaternary period formed many interesting features like boulder and gravel beds in river valley terraces at level higher than the valley floor. In the regions of considerable uplift (i.e. Khatrod Dungar near Kukma village, hills near Ler and Gangeshwar, Marutonk Dungar, Lakki Dungar near Shiv Paras temple) deep gorges are seen with at least three terraces at different levels. Such terraces are seen in the wide valleys (generally parallel to faults) within the hilly region. The earliest stand at about 30 m above the river bed and consists of fluvio-aeolian miliolite rocks seem to be a Late Pleistocene to Early Holocene deposit (Biswas, 1974). Other two later terraces found at 1-10 m level above the river bed and are mainly consists of clay and rubble material. The terraces are depositional terraces found in the hilly regions of Katrol-Charwar range, Jhura and Habo hills, while on the Early Quaternary land surface tectonic terraces are developed due to the Late Quaternary episodic uplift.