CHAPTER - 3

TECTONIC GEOMORPHOLOGY

Landscape of seismically active areas show a dominating influence of structural and tectonic setup. The various geomorphic features and drainage in such areas provide evidence of neotectonic activity in response to movement along faults (Ouchi, 1985; Schumm et al., 2000). The planimetric geometry of fluvial network, in particular, is an important indicator of the morphostructural framework (Beneduce et al., 2004). Impact of vertical movements along faults and their timing can be delineated from fluvial geomorphic features and tectonic landforms (Rockwell et al., 1984; Wells et al., 1988; Ascione and Romano, 1999; Schumm et al., 2000). Well constrained study of landscape response to external forcing is necessary to understand the recent evolutionary history (Dorsey and Roering, 2006; Wesnousky, 2005). The landscape of seismically active Kachchh region is unique in the sense that it has evolved essentially as a result of several phases of tectonic movements along faults (Biswas, 2005).

The present chapter describes the results of tectono-geomorphic studies carried out along Katrol Hill Range followed by DEM modeling (Figure 3.1) to understand neotectonic activity in contemporary tectonic setting. Geomorphologic data is generated to understand the impact of tectonic structures on landscape and drainage configuration. Detailed documentation and analysis of the landscape features suggesting influence of neotectonic activity like geomorphic setup, drainage characteristics, bedrock gorges and fault scarps have been carried out. The main aim of the study is to understand the tectonic geomorphology of the Katrol Hill Range with respect to structural characteristics and provide geomorphic evidence of reactivation of Katrol Hill Fault (KHF) during Quaternary.

GEOLOGY AND STRUCTURE OF THE KATROL HILL RANGE

Most part of the Mainland Kachchh is occupied by Mesozoic rocks which represent continuous deposition from Bathonian to Santonian (Biswas, 1977; 1982). The Mesozoic sequence has been classified into the Jhurio, Jumara, Jhuran and Bhuj Formations (Biswas, 1977; 1982; 1987; 1993). The Katrol Hill Range is located to the south of KHF (Figures 3.1, 3.2) and exposes rocks belonging to the Jumara, Jhuran and Bhuj Formations. The KHF marks a distinct lithotectonic contact (Figures 2.1, 2.2) between the Bhuj Formation (Late Cretaceous) to the north and the Jumara and Jhuran Formations (Middle Jurassic to Early Cretaceous) to the south

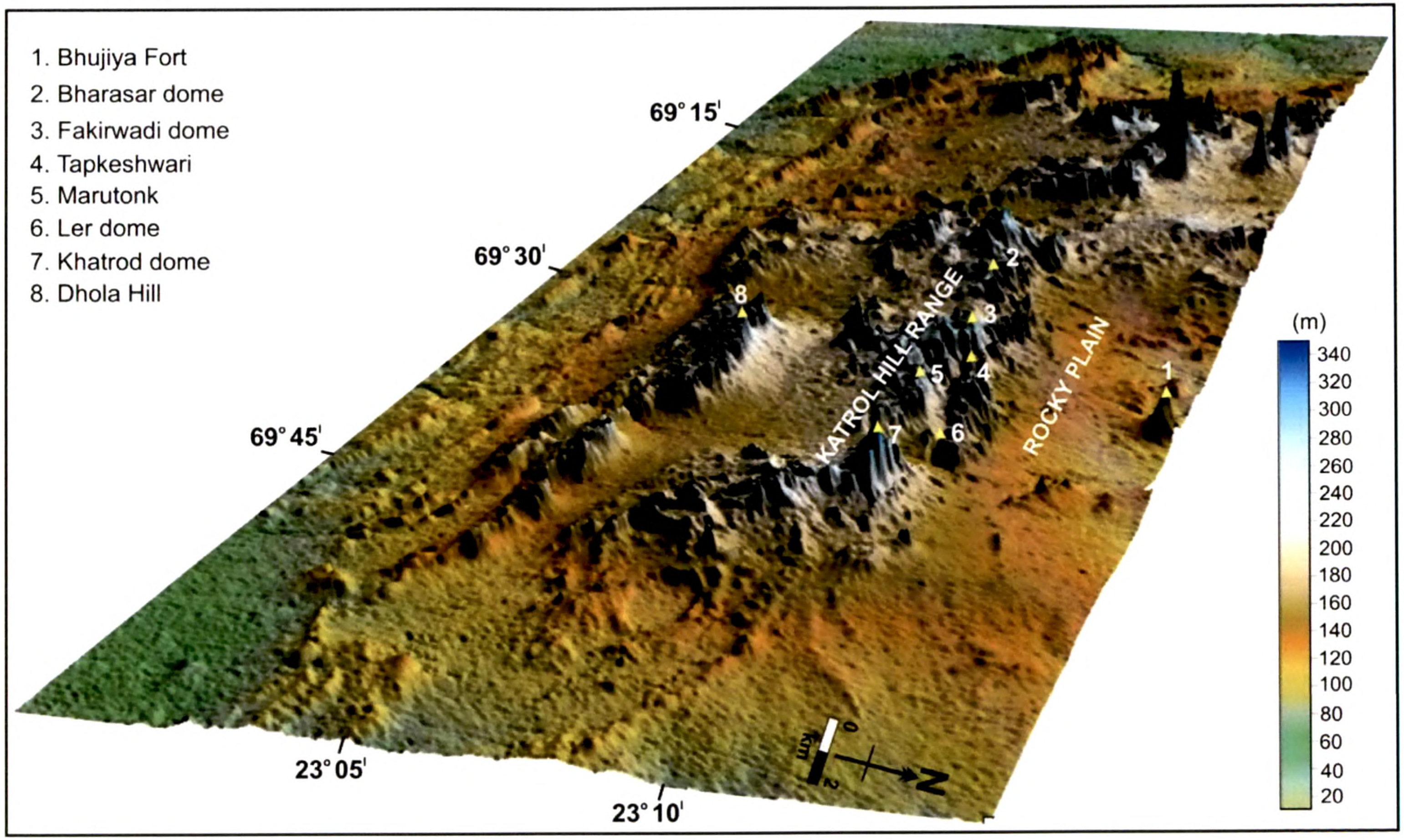

Figure 3.1 Digital Elevation Model (DEM) showing the rugged topography of the Katrol Hill Range. Note the sharp geomorphic contrast between rocky plain of Bhuj and the hilly topography of the Katrol Hill Range. Gradual decrease in the elevation towards south can also be seen.

(Biswas and Deshpande, 1970). The presence of a narrow zone of domal structures to the south of KHF is a significant feature of the Katrol Hill Range (Figure 2.2). Prominent domes are the ones located at Khatrod, Ler, Gangeshwar and to the south of Bharasar (Thakkar et al., 1999). 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 5-10^0 towards south while the northern limb is steeply dipping towards the north or is vertical. Some of these domes contain several N-S trending dykes and plugs with occasional sills in their central part. The sandstones of Bhuj Formation to the north of the KHF show broad open E-W trending anticlinal and synclinal folds. To the south, the various Mesozoic Formations dip southwards and are overlain by the Palaeocene trappean basaltic flows, Tertiary rocks and Quaternary sediments extending up to the coastline of Gulf of Kachchh (Figures 2.1, 2.2). The Quaternary deposits fill the structural valleys within the Katrol Hill Range and cover rocky pediments in the foothills. Geomorphologically, the KHF is expressed as an E-W trending line of north-facing scarps separating the rocky plain comprising sandstones of Bhuj Formation to the north and the rugged terrain of Katrol Hill Range (Figure 3.1) made up of highly deformed Mesozoic rocks older than Bhuj Formation (Patidar et al., 2007). The KHF shows right-lateral and left-lateral shifts along the transverse faults (Biswas and Deshpande 1970; Maurya et al 2003a; Patidar et al., 2007). Close examination of structural features shows that the transverse faults have been active during Quaternary (Thakkar et al., 1999; Maurya et al., 2003b).

The study area is divisible into two main geomorphic domains- the Katrol Hill Range to the south of KHF and the rocky plain to the north of it. The N-S trending range front scarps mark the geomorphic expression of the KHF. In the following paragraphs the salient features of the Katrol Hill Range, the KHF, drainage configuration and gorges are described.

TECTONIC GEOMORPHOLOGY

The Katrol Hill Range

The Katrol Hill Range is located to the south of the Katrol Hill Fault (KHF). The Katrol Hill Range corresponds to the flexure zone to the south of the KHF (Figure 2.2) with the rocky plain of Bhuj to the north (Figure 3.1). In the Katrol Hill Range the Mesozoic rocks (Jumara and Jhuran Formations) show high degree of

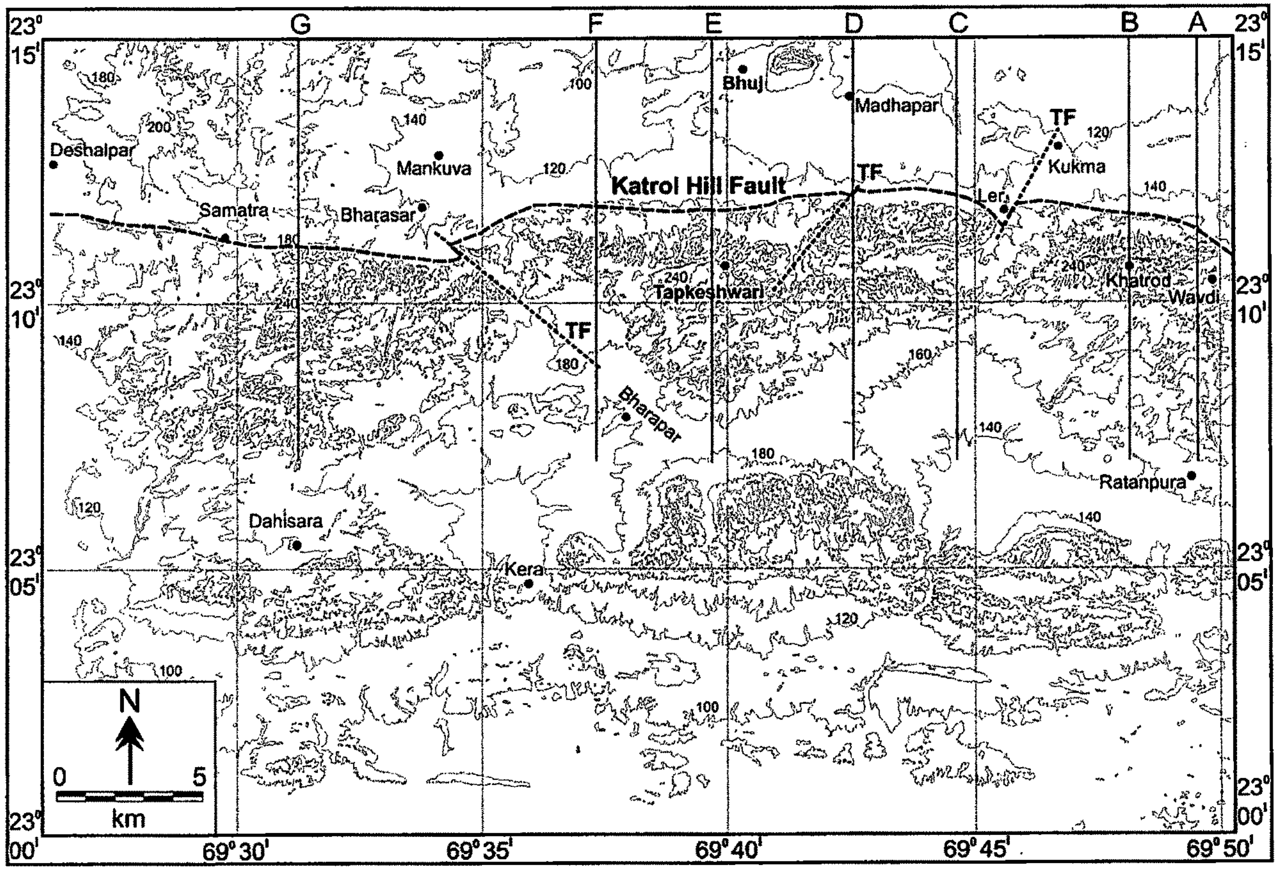

Figure 3.2 Contour map of southern Mainland Kachchh prepared from Survey of India topographical maps on 1:50,000 scale. Note the rugged topography of the Katrol Hill Range, sharp geomorphic contrast with the rocky plain to the north and the progressive decrease of ruggedness in topography and elevation towards south. Lines A-G shows the alignment of topographic sections in Figure 3.4a. The highest elevations are observed in the northern part of the range. The trace of KHF is as per the present study.(Toposheet Nos. 41E/8,12,16 and 41F/5, 9,13)

deformation as evidenced by the domal and anticlinal structures, which are truncated over the KHF illustrating the compressive stress regime. Major geomorphologic characteristics of this range include fault-controlled first-order topography, uplifted Quaternary and pre-Quaternary planation surfaces, youthful fault scarps and a structurally controlled drainage network that exhibits incised rocky valleys and gorges with scattered occurrence of Quaternary deposits (Patidar et al., 2007). The rugged and rocky landscape of the Katrol Hill Range (Figure 3.2) shows several evidence of dominating control of neotectonic activity in its geomorphic development. The range abruptly rises above the rocky plain occurring to the north (Figures 3.1, 3.3). The most impressive aspect of the area is the north facing E-W trending line of range front scarps that marks the geomorphic expression of the Katrol Hill Fault (Figure 3.3). The overall youthful topography of the Katrol Hill Range and the range front scarps indicate dominance of tectonic activity over erosional processes (Figure 3.3). Role of tectonic activity in landscape shaping of the southern Mainland Kachchh is well evidenced by the development of cyclic planation surfaces (Biswas, 1974). Five such surfaces have been recognized, which are named as the Upper Cretaceous surface, Early Tertiary surface, Mid-Tertiary surface, Late Tertiary surface and Early Quaternary surface. These surfaces are found to correlate with unconformities in the stratigraphic sequence and indicate period of tectonic events causing break in sedimentation and initiation of an erosional cycle (Biswas, 1974). Within the Katrol Hill Range, the various planation surfaces show southward tilting, which suggest episodic unidirectional movements along the KHF during the Cenozoic (Biswas, 1974). Southward tilt of the planation surfaces and southward dips of the Mesozoic and Tertiary rocks (Biswas, 1974) indicate that the southern Mainland Kachchh represents a large tilt block (Figure 2.2), delimited by the Katrol Hill Fault to the north and the Gulf of Kachchh Fault to the south (Biswas and Khattri, 2002). The rocky plain developed over the sandstone of Bhuj Formation to the north of the KHF is identified as Early Quaternary surface (Biswas, 1974).

The Katrol Hill Range shows a general decrease in topographic ruggedness towards the south (Figures 3.2, 3.3). The highest summits of this range lies close to the northern edge which is in conformity with the narrow zone of positive structural relief along the KHF (Figures 3.2 and 3.3). The crest line comprising the highest summits of this range lies close to the northern edge whereas the drainage divide to the south also lies very close to the crest line (Figure 3.4). The DEM illustrates the narrow incised region between the crest line and drainage divide marked as backvalley trending E-W within south dipping Mesozoic Formations (Figures 3.1, 3.3).

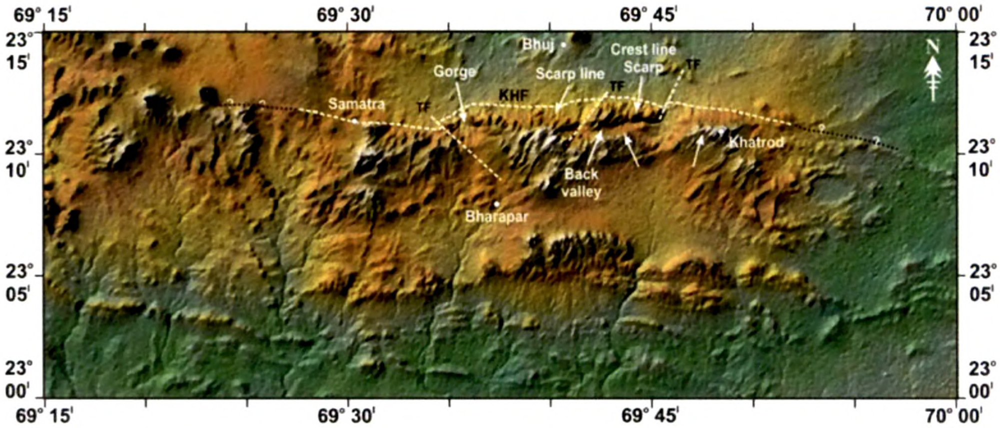

Figure 3.3 Shaded relief map of Katrol Hill Range. The location of Katrol Hill Fault (KHF) and transverse faults are marked based on field mapping and GPR, carried out in the present study. Note geomorphic contrast between the rocky plain to the north of the KHF and the rugged topography to the south of the fault. Also seen are the E-W trending back valleys and the range front scarp.

The peaks along the crest line of range front scarps have average heights ranging from 250-300 m, the highest being the Khatrod peak with an elevation of 349 m amsl located in the eastern part (Figure 3.2). The elevations progressively decrease towards south. The crest line is marked by impressive north-facing scarps (Figure 3.4) with steep slopes that show characters typical of fault-generated mountain front scarps. This E-W trending scarp line follows the trend of the KHF, however the actual fault line occurs to the north of it (Maurya et al., 2005). In some portions, several 20-30 m high scarplets occur between the major scarp line and the fault line of KHF. These scarps are found to be the remnants of the retreating free face. The presence of the crest line close to the Katrol Hill Fault and gradual reduction in the ruggedness of the topography towards south conforms to the tilt block structure of the Katrol Hill Range. The Katrol Hill Range forms the main watershed of Mainland Kachchh, the major rivers draining towards north are the Khari, Pat and Pur Rivers. Various domes situated to the south of KHF control the drainage fabric of the area. Radial drainage patterns observed within the Katrol Hill Range, are influenced by individual domes.

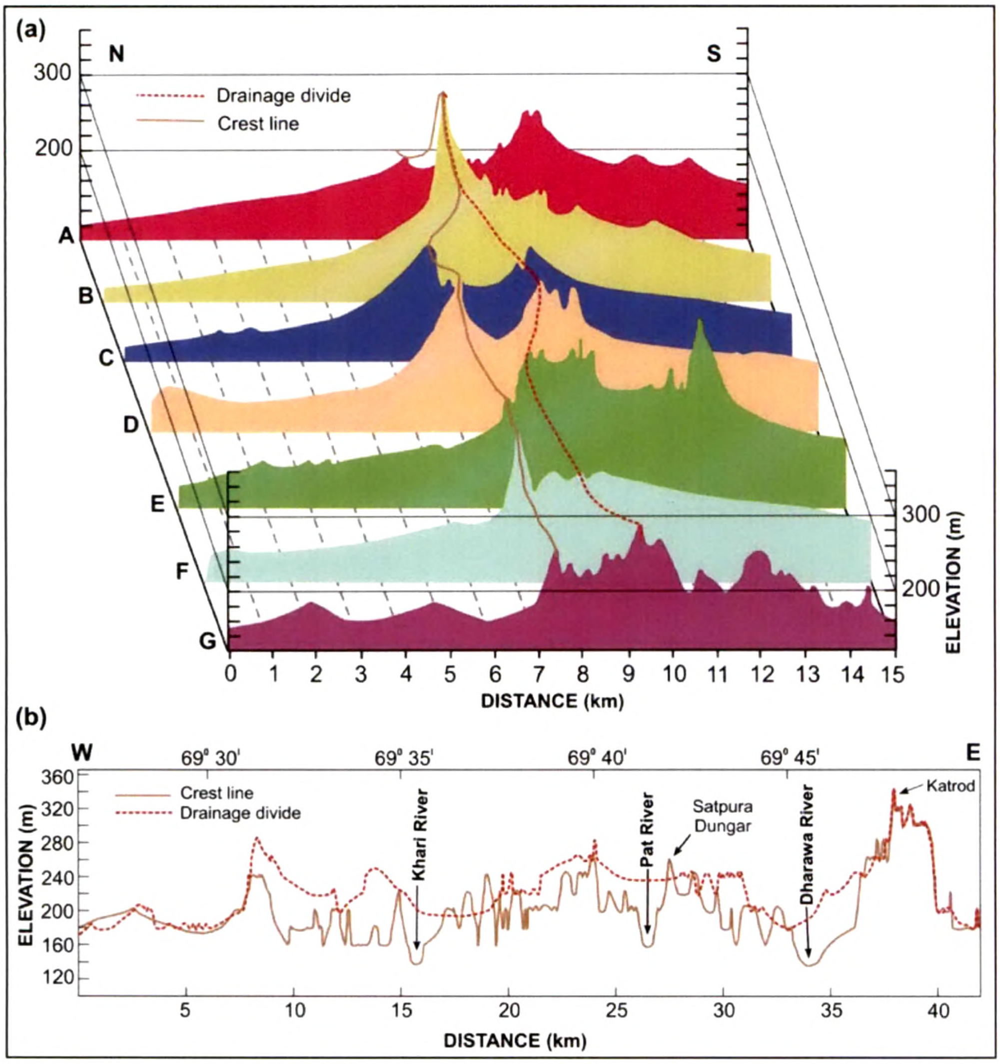

Figure 3.4 (a) Topographic sections along N-S direction showing crest line of the range front scarps and the drainage divide. Location of section lines is shown in Figure 3.2. (b) Topographic section along the crest line of the range front scarps and the drainage divide.

The Katrol Hill Fault (KHF)

The E-W trending Katrol Hill Fault (KHF) is located to the north of Katrol Hill Range of the Mainland Kachchh. The field investigations and mapping of the KHF carried out suggest significant variation in the dip and strike of the fault plane which is mapped along streams at various locations (Figure 3.5). In the eastern part, the dip of the fault is 80°S near Khatrod which decreases towards west up to 45°S at Samatra (Figure 3.5). Though the general trend of KHF is E-W, it shows significant variation in strike in the vicinity of transverse faults (Figure 3.3).

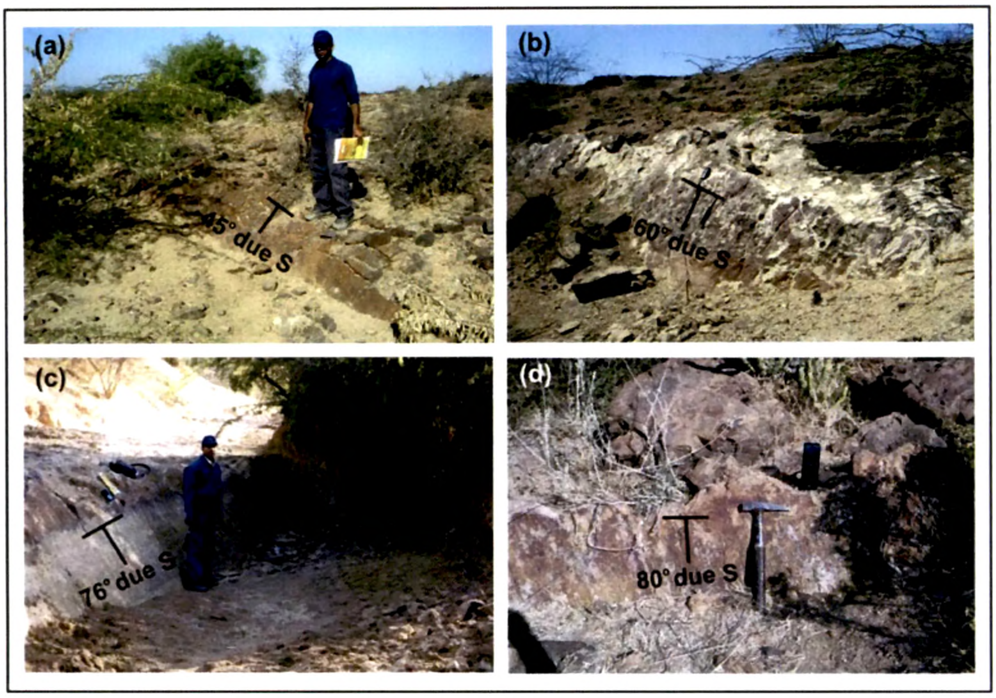

Figure 3.5 Field photographs of the fault plane of KHF showing variation in the amount of dip of the fault from west to east. (a) SE of Samatra (b) South of Bharasar (c) North of Tapkeshwari (d) North of the Khatrod peak.

As mentioned earlier, the KHF is expressed as an E-W trending line of north-facing scarps separating the rocky plain comprising sandstones of Bhuj Formation to the north and the rugged terrain of Katrol Hill Range made up of highly deformed Mesozoic rocks older than the Bhuj Formation (Figures 3.1, 3.3). The DEM of Katrol Hill Range depicts the abrupt change in the elevation across the KHF (Figure 3.1). The offsetting of the range front scarps of the KHF along various transverse faults is clearly seen in the DEM. The scarp line shows three major gaps that have been formed by the northward flowing Khari River, Pat River and the Gunawari River (Figure 3.4). The free faces of the scarps show northward inclinations ranging from 50° to subvertical. The free face is characterised by longitudinal rills and notches down the free face formed by surface runoff flowing over the crest of the scarp and down the free face (Figure 3.6). A sharp discontinuity of slope is seen in the lower part of the free face where it joins the debris slope. The crest forms the original upper surface above the free face. The crest part of the KHF scarps shows different degrees of rounding, a reflection of the removal of free face by erosion. The debris slope below the free face show northward slopes ranging from 15-35°. Morphology of scarps may be controlled by erosion or deposition (Wallace, 1977). Evidence for erosional control on the morphology of KHF scarps includes gullying of the scarp face (Figure 3.6), rounding of the crests, concentration of coarse debris at the base, at places covered by miliolites, absence of fine grained alluvial deposits gullying by various streams further away from the scarps. The short and straight river courses in the direction of the tectonic slope and the incised and confined channel belts indicate vertical uplift of the area along the KHF.

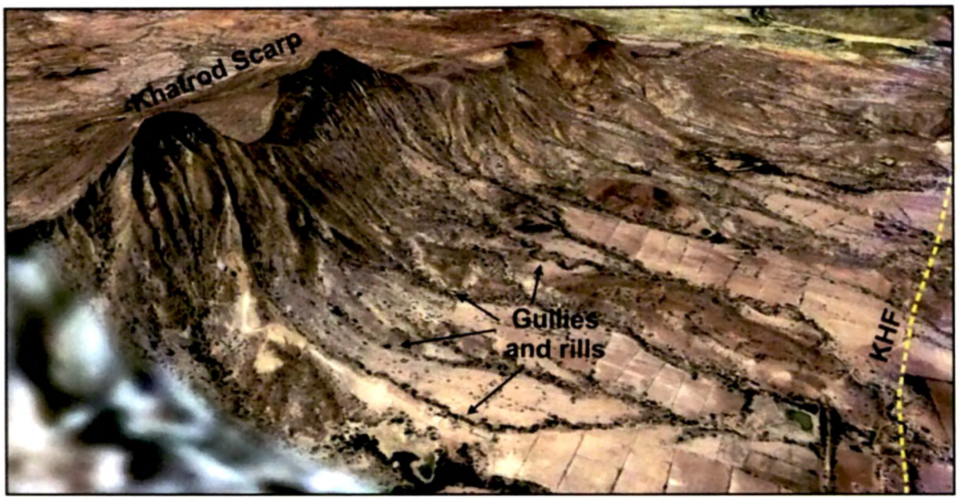

Figure 3.6 North-facing KHF scarp at Khatrod in satellite image showing gullies and rills forming the origin of lower order north flowing streams (source-www.googleearth.com). Note the location of KHF away from the scarp.

DRAINAGE CONFIGURATION

In the Mainland Kachchh, the Katrol Hill Range forms the main drainage divide between the north and south flowing drainages (Figures 1.2, 3.7). The north-flowing drainage originates within the mountainous terrain of the Katrol Hill Range and subsequently flows across the KHF, the rocky plain, the Northern Hill Range and the Kachchh Mainland Fault (KMF) before dying out in the Banni-Rann plains (Figures 1.2). Within the Katrol Hill Range almost all streams display bedrock gorges of varying dimensions. However, in the rocky plain to the north of the KHF, which is identified as part of an Early Quaternary planation surface developed all over Kachchh, the rivers show incised bedrock channels with occasional development of deep narrow gorges with multiple levels of rocky terraces and isolated pockets of alluvial deposits (Figure 3.7).

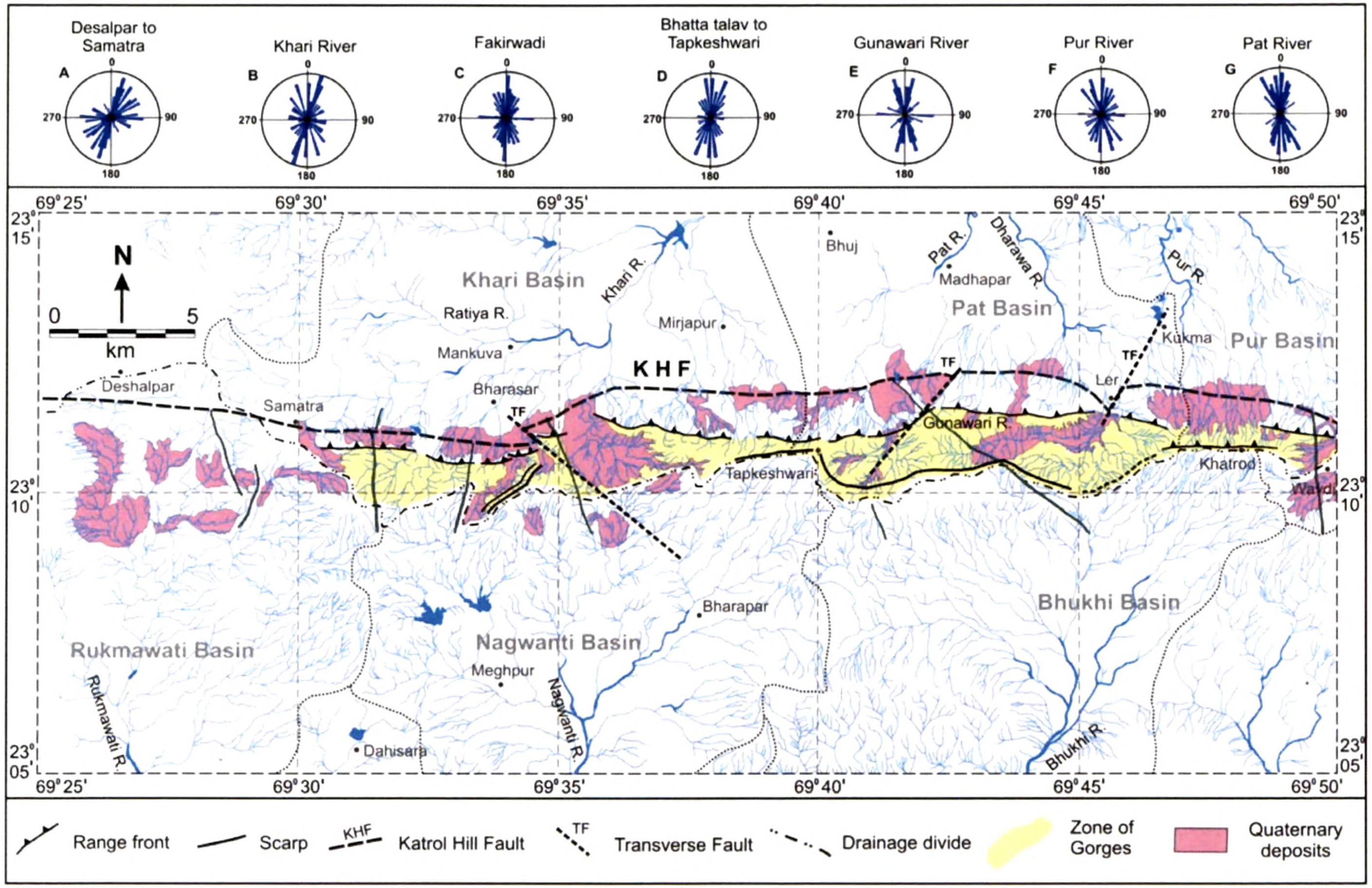

Figure 3.7 Map showing drainage network of the Katrol Hill Range. Note the E-W trending range front scarps, drainage divide between the north flowing and south flowing Rivers and the zone of gorges between them. The rosettes show stream orientation of various north flowing drainages. Dominance of the N-S transverse trend can be clearly seen.

In general, the Katrol Hill Range shows a dense network of streams which is in contrast to the hyperarid climate of the region (Figure 3.7). The present ephemeral rivers appear to be in an erosional phase as evidenced by their deeply incised courses exposing pre-Quaternary rocks with very thin and scattered occurrences of recent channel deposits (Figure 3.7). The Khari, Pur, Pat and Gunawari are the major north-flowing rivers that arise from the northern part of the Katrol Hill Range and flow towards north (Figure 3.7). The south-flowing rivers drain a major part of the Katrol Hill Range and flow along the tectonic slopes to meet the Gulf of Kachchh. The Rukmavati, the Nagwanti, the Phot and the Bhukhi are the major consequent Rivers flowing towards the south (Figure 3.7). The various Rivers flow towards north and south from the Katrol Hill Range follow deeply incised courses with several entrenched meanders. The rosetters of the streams orientations of the various rivers however shows major control of N-S oriented fracture patterns (Figure 3.7). The drainage divide is located to the south of the range front and occurs very close to the crest line (Figure 3.4). In the eastern part around Khatrod, the drainage divide follows the crest line of the range front (Figures 3.4, 3.7). The close spacing of the range front crest line and the drainage divide testifies to the overwhelming influence of neotectonic activity along the KHF and the resultant active southward tilting of the Katrol Hill Range on the drainage network.

North flowing drainages

The north flowing drainage of the Katrol Hill Range comprises the Khari, Pat, Pur and Gunawari Rivers and their dense network of tributary streams (Figure 3.7). The Pat and Pur Rivers join the Khari River further north of the Bhuj town. These incise through the rocky plain to the north of KHF and disappear in the Banni plain. These rivers flow on the Early Quaternary land surface (Biswas, 1974) implying that they have evolved late in the geological history. As mentioned above, majority of the north flowing lower order streams originate along the north-facing escarpment of the mountain front scarps. These streams originate as rills or gullies on the scarp face that are transformed to incising streams at the base of the scarps (Figures 3.6, 3.8). The longitudinal profiles of selected lower order streams arising from the scarp faces show a distinct vertical profile in the upper part, which corresponds to the steep face of the scarps (Figure 3.8). These profiles are in contrast to those of the streams originating in the back valleys, which are gentler but nevertheless show steep gradients. These streams are characterised by highly sinuous courses before they join up with higher order streams. The western half of the northern margin of the Katrol Hill Range is drained by the Khari River and its tributaries (Patidar et al., 2007, 2008).

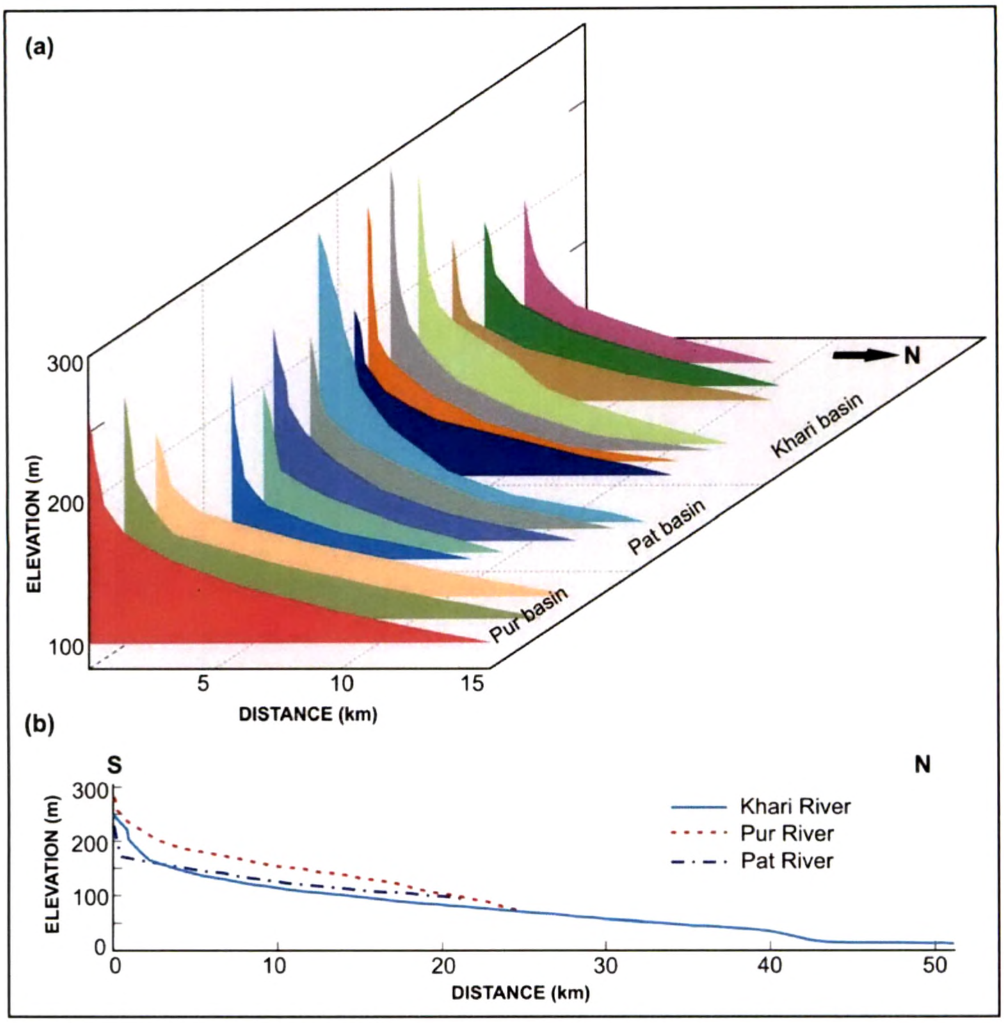

Figure 3.8 (a) Longitudinal profiles of selected north flowing lower order streams arising from the scarp faces. The upper part of the profiles corresponds to the free face of the scarps. (b) Longitudinal profiles of the north flowing Khari, Pat and Pur Rivers originating in the back valleys.

A major feature of the north flowing rivers is their deeply incised courses with intermittent gorges within the Katrol Hill Range. The source region of the north flowing drainage lies in the extremity narrow linear zone along the crest line of the range front (Figure 3.7). Though the source region of the north flowing drainage is small but the number of streams is extremely high. In comparison, the number of streams originating and draining the back valleys behind the range front is extremely small (Figure 3.7). Patidar et al. (2007) identify this as an E-W trending zone of gorges located between the crest line and drainage divide (Figure 3.7). Several gorges of varying dimensions occur within the zone between the crestline of the scarps and the drainage divide identified as the zone of gorges (Figure 3.7). This zone is located in close vicinity of the KHF and correlates with the most rugged part of the Katrol Hill Range. The back valleys have a general E-W trend that is controlled by the strike of various formations (Figures 3.2, 3.3). The Gunawari River in the western part follows such an E-W trending back valley behind the range front before it pierces through the scarp line near Ler village and proceeding further north (Figure 3.7). The Gunawari valley also marks the area where the separation distance between the crest line and the drainage divide is the largest (Figure 3.7). The drainage divide here runs along a major E-W trending cuesta scarp located to the south of the range front (Patidar et al., 2007).

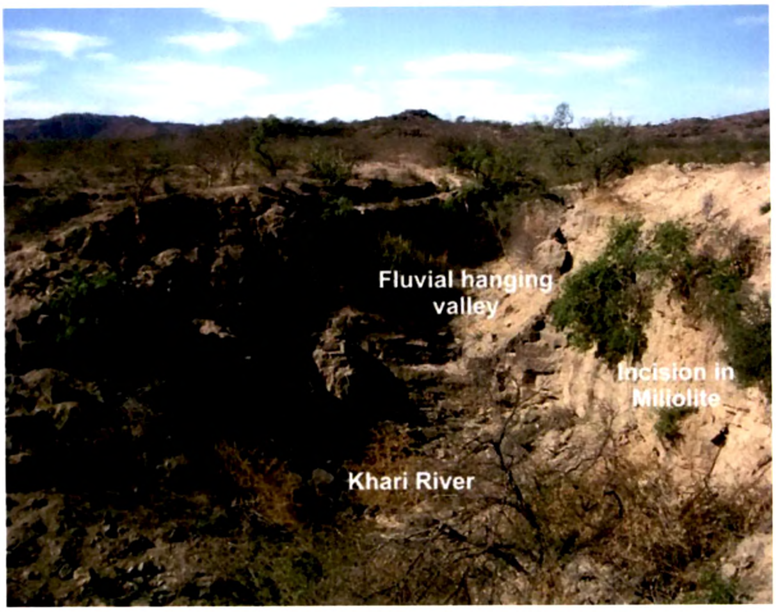

Figure 3.9 View of the hanging tributary valley formed within valley fill miliolites located in the back vallev reach of the Khari River.

All gorges occur in close vicinity of the KHF and are at several places associated with minor intra-range faults. The directional analysis of the north flowing lower order streams shown in Figure 3.7, testify the dominance of transverse faults in their formation. Within the hill range, the Gunawari River flows along a general E-W trending back valley forming a 10-15 m deep narrow incised valley with several prominent gorge reaches. The incised valley walls and gorge walls expose Mesozoic rocks and Quaternary deposits. Similarly, the Khari River in its proximal reach flows through a E-W trending back valley incising through Quaternary miliolite deposits and underlying Mesozoic rocks. Several of its lower tributaries in this reach show 10-20 m deep gorges. One of the tributaries is observed to have formed a fluvial hanging valley (Figure 3.9). This first order tributary exhibits extremely narrow ~7 m deep channel within the Quaternary miliolite deposits which is located about ~8 m above the valley floor of the trunk stream. Several streams located in the area between the scarp line and the drainage divide show extremely narrow gorges with more or less similar geomorphic setting. The incised channels, gorges within the structurally controlled back valleys testify to tectonic uplift in recent times. The presence of gorges in close vicinity of the KHF points to the obvious role of neotectonic uplift of the range along the KHF in their Formation.

South flowing drainages

The south flowing drainage occupies a major part of the Katrol Hill Range (Figure 3.7). As stated earlier, these drainages originate very close to the crest line and flow southward in incised channels along the backslopes (dipslopes) of the range. Though these channels are deeply incised, the gorges are generally rare. The various streams display rocky channels with steep gradients and general absence of alluvium. The various streams comprise the source area of the Bhukhi, Phot, Nagwanti and Rukmavati basins (Figure 3.7). A remarkable correlation between the depth of River incision by south flowing Rivers and the tilt block structure is observed. This is brought out well by the change in the depth of incision observed in the Rivers flowing southwards (for example, Rukmavati, Nagwanti, Phot and Bhukhi). A marked decrease in the depth of incision is noted as these Rivers flow southwards in the direction of the tilt. This suggests that active tilting of the block due to differential uplift along the E-W trending Katrol Hill Fault (KHF) has controlled the degree of incision along the south flowing fivers. The south-flowing fivers incise through a narrow coastal alluvial plain consisting of Late Quaternary deposits before debouching in the sea (Maurya et al., 2003b, 2003c, 2008).

GORGES AND THEIR NEOTECTONIC SIGNIFICANCE

Bedrock gorges are spectacular geomorphic features that result from high-intensity fluvial erosion. With in the study area, development of gorge provides evidence in respect of uplift of the area along the KHF and other associated faults. The gorges and incision by the various north flowing Rivers provide an important geomorphic evidence for differential uplift of the blocks to the south as well as north of the KHF. Four main gorges (Figure 3.7) developed within the hilly terrain of Katrol Hill Range are studied in view to understand the neotectonic behaviour of the area. These occur in the vicinity of the KHF and are associated with transverse faults. The bedrock gorge has developed in Cretaceous sandstones near Bharapar village south of the KHF along a transverse fault (Figures 3.7, 3.10). Southern part of the gorge trends N 20° E while northern part is oriented N 40° W. Two distinct tectonic terraces are observed but none of them contains flutings and potholes. However, the gorge walls have a sinuous profile formed due to torrential flow of water (Figure 3.10).

Figure 3.10 Narrow gorge developed in Cretaceous sandstone near Bharapar village. The gorge follows the N-S transverse trend.

The general slope of the area is due south. A significant south-dipping reverse fault parallel to the gorge has observed. Another bedrock gorge, along the Khari River (Figure 3.7) located towards north of KHF, exhibits a locally developed deep gorge (~400 m long) with bedrock terraces (Figure 3.11). A basic dyke runs along the N100° trend across the channel confining a pond to the downstream side of the gorge. Also seen is a prominent vertical normal fault trending N50°. The general trend of the gorge is N 40° E with ~18-21 m deep vertical walls which confines an extremely narrow 1.5-4 m wide channel (Figure 3.11). The narrow gorge is followed upwards by

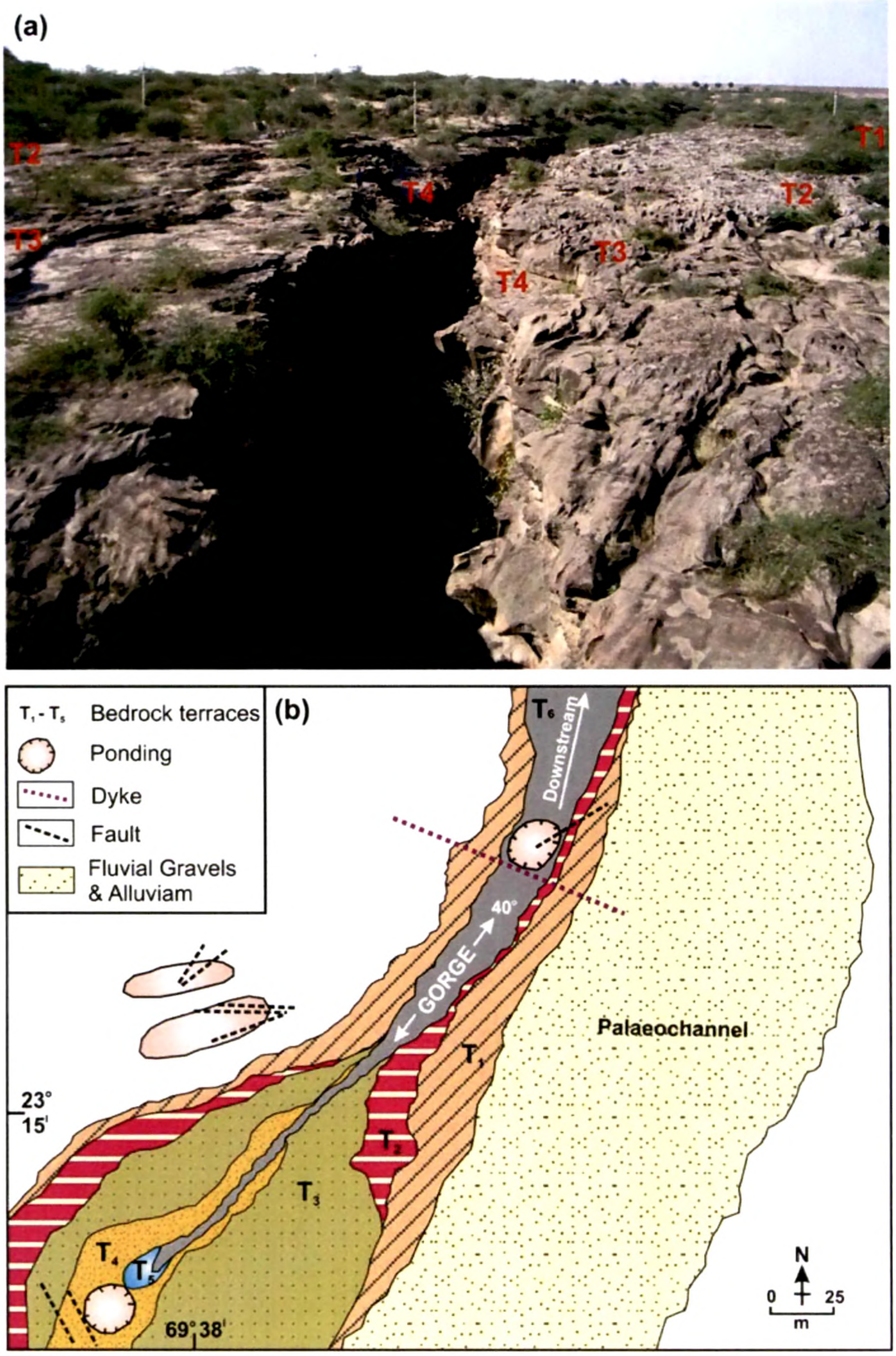

Figure 3.11 (a) Panoramic view of Khari gorge located 4 km west of Bhuj. Note the rocky terraces on both sides of the gorge. (b) Morphotectonic map of Khari gorge site showing bedrock terraces T_1 to T_5 and the palaeochannel. T_6 is the lowest terrace within the gorge having negligible aerial dimension. Ponds bounded by faults at both ends of the gorge are marked by circles.

a succession of paired rocky terraces of varying morphologic characteristics, some of which are studded with numerous large potholes and prominent directional erosional structures like flutes and longitudinal ridges and grooves. A total of six bedrock terraces have been mapped at the gorge site (Figure 3.11b), each of which exhibits characteristic morphologic features, especially in terms of the size of potholes. The total number of potholes and flutings with their average size and orientation on each bedrock terrace are given in Table 3.1. The uppermost strath has been identified as T_1, while the lowermost with smallest surface area as T_6 along the gorge. T_1 and T_2 are distinct planar surfaces with typical terrace morphology occurring at 21.3 m and 18.6 m respectively. These terrace surfaces are weathered and do not show definite erosional fluvial forms as observed in other terraces. The T_3 is the most prominent and widest terrace, which is characterised by the occurrence of many potholes and flutings (Figure 3.12). The potholes have an average diameter of 45 cm and an average depth of 75 cm. The flutings show a general NE trend that is consistent with the present day flow direction.

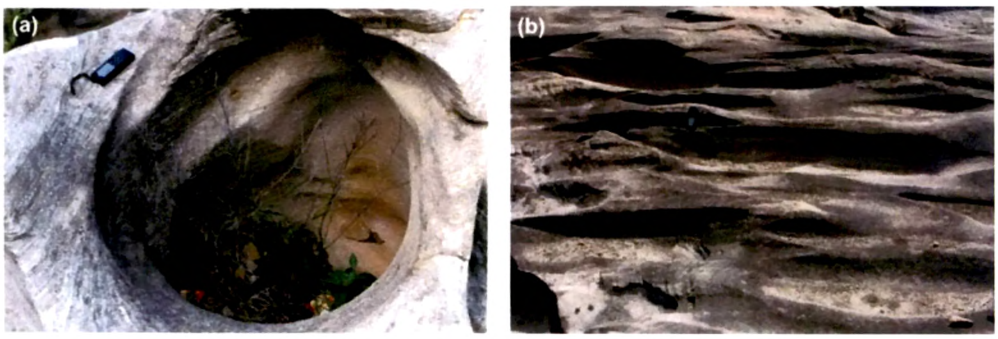

Figure 3.12 (a) Close view of a large pothole on T_3 bedrock terrace. (b) Flutings with orientation on the T_3 terrace.

A terrace 1.8 m lower than the T_3 is observed to be more pitted and highly eroded than the earlier terraces and is termed as T_4. Coalescing of potholes has resulted into mushroom shaped rocky projections on this terrace and the dimension of potholes is much larger than those seen on terrace T_3. The average diameter and depth of the potholes occurring on terrace T_4 are 55 cm and 85 cm respectively (Table 3.1). Terrace T_5 occurs 4.2 m below the T_4 and shows still larger potholes with an average diameter of 160 cm and depth 110 cm (Table 3.1). The largest potholes observed and averaging 225 cm in diameter with average depth of 225 cm (Table 3.1) occur at the levels between average water level and the T_5 surface. This indicates a phase of intense down-cutting that resulted in the formation of a deep narrow gorge. However, the varying nature, distribution and abundance of these features on different terraces suggest episodic nature and varying intensity of the fluvial processes involved in the formation of the large erosional features.

Table 3.1 Data on potholes and erosional grooves developed on various bedrock terraces of the Khari River gorge (Thakkar et al., 2006).

Sequence of Terrace	Height from Valley Floor (in metre)	Terrace height (in metre)	No. of Pot holes	Diameter of pot holes (cm)			Depth of pot holes (cm)			Number of groove marks of the length 50-300 cm	
				Min	Max	Avg	Min	Max	Avg	Number	Orientation
T_1	21.3	2.7	00	-	-	-	-	-	-	00	-
T_2	18.6	1.5	00	-	-	-	-	-	-	00	-
T_3	17.1	2.1	27	10	70	40	5	150	75	45	40^0
T_4	15.0	1.8	15	10	100	55	20	150	85	13	40^0
T_5	13.2	4.2	06	70	250	160	50	170	110	00	-
T_6	9.0	9.0	05	150	300	225	150	300	225	00	-

A transverse-trending (N 40° E) gorge near Bharasar village (Figure 3.7), has developed along a stream which exposes miliolites underlain by Mesozoic rocks along the valley walls (Figure 3.13). The gorge is 5 m deep at its upstream end near the transverse fault and rapidly attains a depth of 12 m within a distance of 500 m towards NE. The abrupt level difference of the valley floor, when traced on the surface coincides with an E-W trending fault, which is one of the several sympathetic faults parallel to the KHF. Further downstream the gorge attains considerable depth (~15 m) and meets a wide valley. At this level several of lower order tributaries form fluvial hanging valley (Figure 3.9) within Quaternary deposits.

A deep, narrow gorge trending N40°E is found along the Gunawari River cutting miliolites (Figures 3.7, 3.14). The Gunawari River is a second-order stream with a general E-W course in the hilly terrain of the Katrol range about 5 km south of Madhapar village (Figure 3.14). Though the gorge does not show distinct terraces in Quaternary deposits, it is associated with a couple of transverse faults, showing

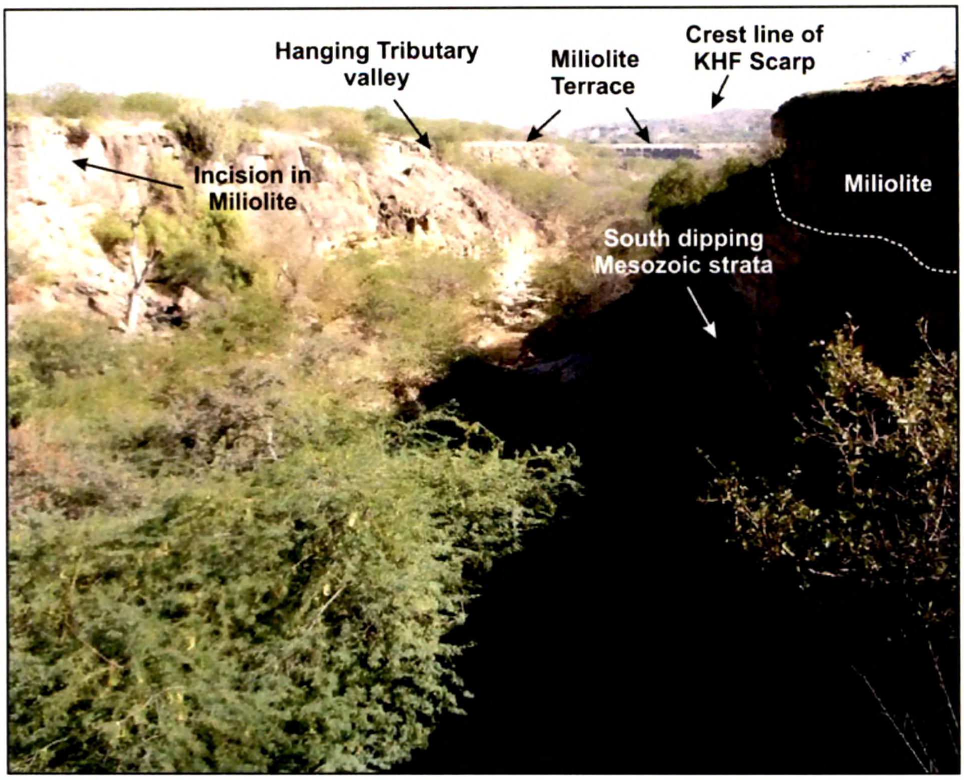

Figure 3.13 Northward view of a gorge developed along a back valley within the Katrol Hill Range by a tributary stream of Khari River. At the far end, the crest line and terraced surface of the valley fill miliolite is seen. Location of the hanging tributary valley shown in Figure 3.9 is also shown. The vertical cliffs on the left expose miliolites only while the cliff on the right side exposes south dipping Mesozoic rocks overlain by miliolites.

surfaces with slickensides indicating left-lateral movements. The valley floor of Gunawari River shows three distinct levels, all with distinct characteristics along its channel. South of the mountain front scarps within the Katrol Hill Range, the river forms a very narrow gorge in Quaternary deposits and, after crossing a prominent knick point along a transverse left-lateral fault, enters into a wider valley where Jurassic rocks are incised. Further downstream in the same direction (N 40^{o} E) the channel is extremely narrow and fluvial miliolite deposits are incised by 12-15 m forming vertical River cliffs (Figure 3.14).

In general, the gorges, deeply incised fluvial valleys and the large potholes along the gorges appear as a 'misfit' in the present-day hyper-arid climate of the region. All the gorges occurring to the south of the KHF exhibit a close association with the transverse tectonic trends. The exposure of transverse fault at Gunawari gorge marks a youthful scarp with left-lateral movement, while a reverse and south-dipping transverse fault near Bharapar gorge suggests neotectonic activity (Thakkar et al., 2006). Several parallel to sub-parallel transverse faults at various levels may be responsible for the development of the Bharasar gorge near the central axis of the Katrol Hill Range. Two abrupt level changes of the valley floor along the gorge, a sudden change in the geomorphic surface and entrenched meanders at lower reaches of the valley coincide with faults, which suggest uplift in the recent past (Patidar et al., 2007, 2008).

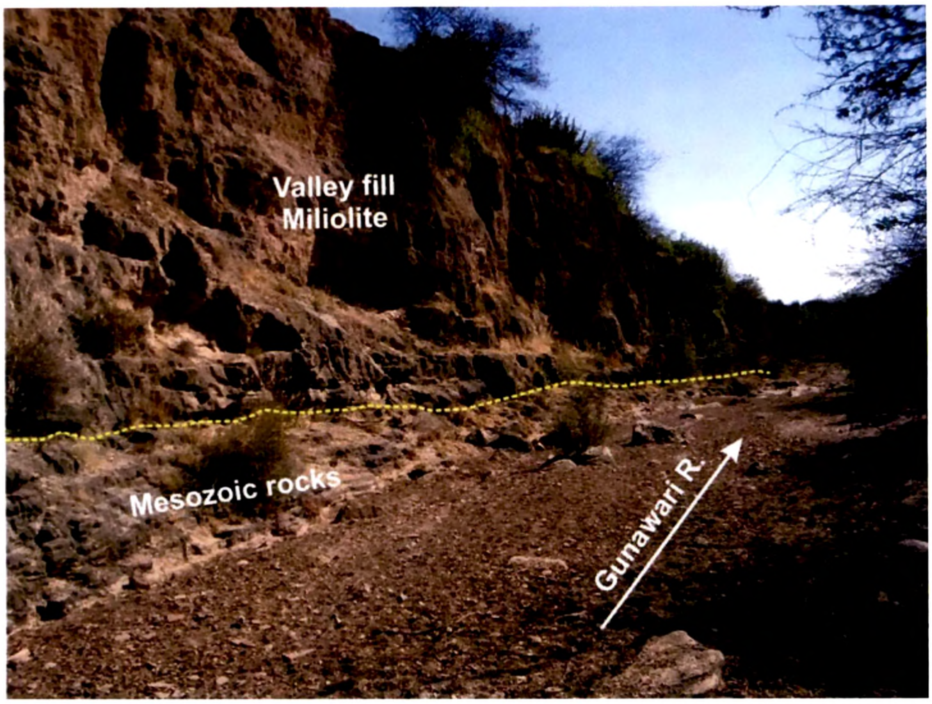

Figure 3.14 Vertical cliff of valley fill miliolite in Gunawari River along the back valley of Katrol Hill Range. Note the extremely narrow channel of the river.

The Katrol Hill Range is characterised by highly rugged rocky landscape with a series of E-W trending north-facing scarps at its northern margin that mark the seismically active Katrol Hill Fault. The study includes evidence of neotectonic activity based on a detailed geomorphological study of the Katrol Hill Range for delineating the characteristics of Katrol Hill Fault, located in the southern Mainland Kachchh. Several lines of geomorphic evidence suggest periodic reactivation of the KHF through out Quaternary period. The overall geomorphic set up is controlled by the south oriented tilt block structure of the range as evidenced by its pronounced influence on the morphology and drainage network. The close association of the crest line and the drainage divide, progressive reduction in the topography, and incision by south-flowing rivers suggest southward directed neotectonic tilting of the range due to movements along the KHF. The effect of neotectonic tilting of the southern block due to vertical movements along the KHF in shaping of the landscape of the Katrol Hill Range is implicit from the evidence documented in the present study. The drainage comprises north flowing and south flowing rivers with the drainage divide located close to the northern edge of the range which also marks the highest topographic elevations. The narrow zone between the crest line and the drainage divide has been identified as the zone of gorges where gorges and deeply incised fluvial valleys have been formed within Quaternary sediments by the various north flowing streams. The E-W trending back valleys, the sharp division of the drainage system into south-flowing and north-flowing rivers, the incised nature of the drainage and development of gorges suggest movement along the KHF in recent past. The geomorphic setup and the drainage of the Katrol Hill Range provide several lines of evidence for neotectonic activity and differential upliftment along the KHF. The general tectonic setting of the study area indicates neotectonic activity in response to accumulation of compressive stresses along the KHF. The occurrence of gorges in the vicinity of the KHF within the Katrol Hill Range, and in the low relief rocky plain suggest the dominant control of tectonics on the geomorphic evolution of the area.