CHAPTER 6

GEOMORPHIC EVOLUTION

Landscape evolution of a basin is the function of climate, tectonism and geologic parameters such as gross lithology and structure. Climatic parameters tend to degrade landscapes through the chemical and physical action of various agents. Tectonism, on the other hand, tends to construct landscapes through uplift and crustal warping.

Structural style of Kachchh Rift Basin is unique in India but the numerous Late Cretaceous uplifts associated with plutonic bodies and intervening Tertiary basins can be compared with the Laramide structures of the Colorado Plateau, Central Montana Rockies of North America (Eardly, 1962; Prucha, et al., 1965) and structures of Russian Platform (Beloussov, 1962).

The development of Kachchh basin has been described by Biswas (1982, 1987) and Gombos et al. (2005). According to Biswas (1982) the rifting events occurred in successive stages during the migration of Indian plate after its break up from Gondwanaland in Late Triassic or Early Jurassic. The initial rifting of Gondwanaland took place along the Precambrian Dharwar trend with moderate sinistral rotation and it also resulted in the initial opening of Kachchh rift along the Precambrian Delhi trend (Biswas, 1982). After breaking from its parent mass in the Late Triassic, the Indian subcontinent moved northward with a faster pace of 16 cm / yr in Late Triassic (Biswas, 1982). The northward drift of the continent was checked during Eocene-Oligocene times, when the subduction of its oceanic crust started below the Tibetan plate. By the 45-50 Ma the collision of the Indian and Tibetan continental crust began and uplift of the Himalayan range started. In the course of its northward journey the Indian plate passed over four mantle plume heads centered at Crojet, Keruguelen, Marion and Reunion Islands. The Reunion plume induced Deccan volcanism in the subcontinent. Around 66 Ma (Maastrichtian age) the western margin of India crossed the equator and passed over the Réunion/Deccan hot spot resulting into Deccan volcanic eruption (Courtillot et al., 1986; Biswas, 1982). Extensive sub-aerial eruptions of flood basalts in the next million years covered an area of about two million square km with several basalt flows known as Deccan Traps. In response to the weakened lithosphere in the vicinity of the mantle plume the Seychelles separated from Mainland India about 63 Ma. As India moved off the hot spot, lithospheric cooling was accompanied by subsidence and the formation of Narmada-Son-Tapti Graben and its offshore extension, the Surat Depression (Biswas, 1982 and Gombos et al., 2005).

Rifting in the subcontinent along certain Precambrian structural trends started since its detachment from the mainland. In the western margin of the Indian Shield, the faulting was controlled by NE-SW Aravalli-Delhi trend, ENE-WSW Son-Narmada-Tapti trend and NNW-SSE Dharwar trend (Biswas, 1987). Thus, during the northward migration of the Indian subcontinent, Kachchh, Cambay and Son-Narmada-Tapti basins developed. Thick sedimentation of different ages along with the volcanic activities marked the depositional history of these basins (Fig.6.1). These basins are separated by the Saurashtra horst, which is established to be the extension of the Aravalli range, which got uplifted in part during the Late Cretaceous times. The sea started receding from the Kachchh Rift Basin by the Early Cretaceous times and allowed deposition of continental facies.

The onset of the collision of Indian plate with the southern margin of Eurasian plate occurred in Late Palaeocene-Eocene times. Estimates of the dates of collision range from ~ 50 Ma (Patriat and Achache, 1984; Besse et al., 1984) to ~ 66 Ma (Jaeger et al., 1989; Beck et al., 1995). After the collision of the plates, spreading motion slowed down to 4 to 6 cm/year (Biswas, 1982). Beck et al. (1995) argue, based on stratigraphic data, that suturing was complete by 49 Ma. Biswas (1982) suggest that the final welding of India and Eurasia occurred in Eocene-Oligocene times, when motion nearly halted. Slow northward movement continued with anti-clockwise rotation of 9° in Miocene-Pliocene time. An increase in the rate of subsidence in the Surat Depression in Early Miocene (20 Ma), was interpreted by Gombos et al. (1995) to represent structural response to stress reorientation associated with the Himalayan orogeny.

Thus, by Late Miocene the East-West trending Kachchh Rift Basin was formed and was being subjected to a roughly N-S compressive stress field (Biswas, 1982). The maximum horizontal stress that is responsible for current tectonic activities in the Kachchh is oriented N-S to NNE-SSW (Gowd et al., 1992). In the Kachchh basin the Mesozoic sediments were deposited in two cycles of Late Triassic- Late Jurassic marine transgression and Late Jurassic-Early Cretaceous post rift deltaic regression environment. After the deposition of the Mesozoic sediments, the Tertiary sedimentation took place in the terrestrial environment but by the Early Eocene times, there was marine transgression while the Eocene-Middle Miocene Period saw a varied environment of lagoonal, marine shelf to open marine platform type. In Plio-Pleistocene times the environment of deposition was littoral to fore shore. Most of the Quaternary Period experienced a terrestrial environment of deposition with dominance of marshy deposits in the latest part. Dry and hot spell of the environment in the early Holocene Period is responsible of the desertification of Kachchh (Biswas, 1981).

The complex interaction of the climate, geology and the tectonism, especially in the active areas like Kachchh, has resulted into the current configuration of the landscape of the peninsula. The differences in the lithology give rise to differential erosion of the different litho-units; resulting into a particular landscape whereas the climatic parameters degrade the landscapes through the chemical and physical erosive action of various agents like wind, water etc. The geological structures can influence the large scale pattern or grain of a landscape. These variables have direct influence on 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 influence on landscape evolution. In the foregoing chapters of 'Morphometric Analysis' and 'Neotectonism' the interaction of geology, structure and tectonism on the geomorphic processes of fluvial systems have been described in detail.

The five river basins, which have been described in detail, form a crucial and major area of the Kachchh, whose evolution is closely associated with evolutionary history of Mainland Kachchh. The evolutionary history of the area dates back to Mesozoic, as has been described earlier. Majority of the litho-units exposed in the area belong to Mesozoic with localized occurrences of Tertiary and Quaternary patches. In general the strata show a gentle southerly dip but near the KMF they are northerly dipping with steep to moderate dips. This is due to the effect of faulting and warping in the KMF zone.

Evolutionary history of Kachchh basin starts with the marine transgression during the Middle Jurassic Period subsequent to the formation of the basin. During this transgression the Pachchham and Chari Formation of the rocks were deposited. The Mainland was the main centre of deposition during this transgressive phase (Biswas, 1981). Subsequently, the sea started to regress while the Katrol and Bhuj Formation of rocks were deposited during the regressive phase. These two phases are separated by an unconformity (Biswas, 1977, 1981). The Bhuj Formation of rocks shows fluvial nature in the east with increasing marine influence in the west. This unit was deposited in the final phase of the marine regression resulting into delta complex (Biswas, 1981). During this period the basin subsided at a faster rate resulting into thick sedimentation and came into influence of the median high (Biswas, 1982), which is responsible for the poorly developed upper and middle parts of the Bhuj Formation in the area. This phase of Mesozoic sedimentation was truncated by a phase of orogenic movement.

Mesozoic rocks in Kachchh Peninsula are intruded by basic dykes at various places which have been found in the vicinity of faults or along the faults, suggesting syntectonic nature of the intrusive rocks (Biswas and Deshpande, 1973; Maurya et al., 2003). These activities took place after the deposition of Bhuj Formation (Late Cretaceous), but before the onset of Deccan Trap volcanic activity. This was followed by a major diastrophic cycle, which accompanied the main volcanic activity of Deccan trap, around 65 Ma (Guha et al., 2005). The Matanomadh Formation (Madh Series) of Paleocene age is exposed north of Kukma village extending further north-eastward up to Paddhhar and is of continental origin (Biswas et al., 1973). Upper Miocene units occur in the form of scattered patches deposited in tidal flat to littoral environment of a transgressive sea (Biswas et al., 1973).

The Quaternary sediments are confined along the fault lines and in the river valleys of the area, but the most extensive Quaternary deposits comprise the Banni plain in the north of the KMF, hosting the alluvial fans of all the channels debouching into the Rann. The Quaternary deposits of the area comprise alluvial and colluvial fans and valley fill miliolitic limestone of fluvio-aeolian environment. Numbers of conspicuous alluvial and colluvial fans are found associated with the Kachchh Mainland Fault which is suggestive of degradation of the fault scarps. The colluvial fans are incised by various streams and are overlain by miliolitic limestone suggesting that these deposits are of Pleistocene age. The miliolitic deposits occurring on the hill slopes are aeolian in origin whereas in valleys they seem to be fluvial or fluvio-aeolian as they contain cobbles, pebbles and some boulders in the fine grained calcareous sand.

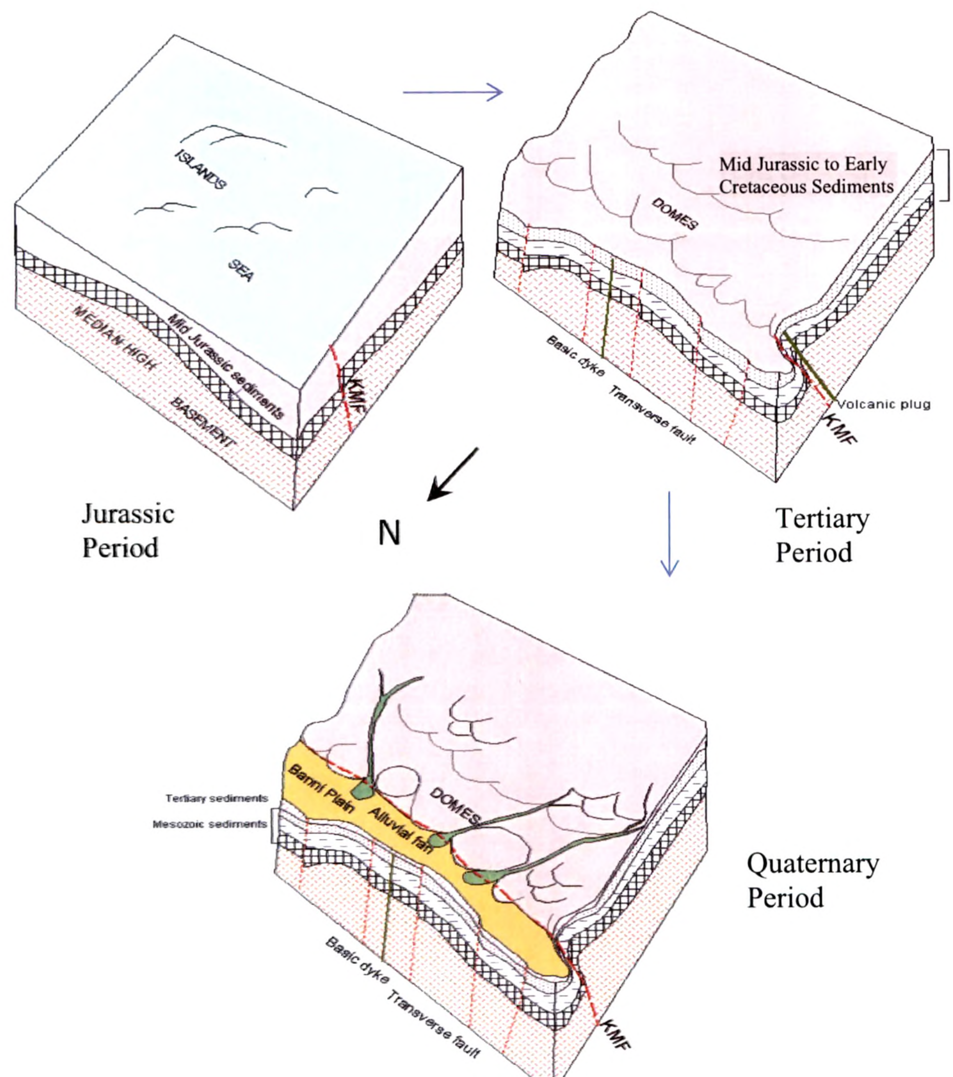

Fig.6.1: Evolution of Kachchh Mainland in relation to the KMF.

The Kachchh Mainland Fault is marked by the straight fault scarps which is typical of a fault generated mount front (Mayer, 1986; Bull and McFadden, 1977). The formation of domes along the KMF has influenced the geomorphology of the area in a large extent. The series of domes like Devisar, Khirsara, Habo, Jhura, Keera, Nara, Jumara and Jara domes, from east to west, flank the Kachchh Mainland Fault. The northern sides of these domes are steeply dipping, at places vertical, while they show gentle slopes (10-22°) in the south. Some of the domes show basic rocks in their core, several N-S trending dykes, plugs and sills. Many of these domes are cut through or bounded by transverse faults in the east and west sides. The tectonic upheaval after the termination of the Mesozoic sedimentation is responsible for the complication in the structural set up of the area which is manifested in the present landscape. Various transverse faults were developed during this period. The general trends of these transverse faults are NNW-SSE, NW-SE, NE-SW and N-S.

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 of activity gave rise to several domes and flexures described earlier. The presences 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. According to Biswas and Deshpande (1973) the intrusives with the exception of plugs belong to a pre-Deccan trap phase. As discussed earlier, the Indian plate was passing over the Reunion hot spot during the Cretaceous Period which resulted into massive effusion of Deccan lava in India (Raval, 1995). The age of the traps is 65 Ma and the oldest sea floor spreading magnetic anomalies in the Arabian Sea is 59.0 to 63.3 Ma (Condie et al., 1989). This indicates that Deccan trap volcanism is synrift event. The trappean lavas are erupted from Hawaiian type shield volcanoes and most of the domes were evolved during that time (Biswas and Deshpande, 1973). This phase of tectonic upheaval ceased before the on set of Tertiary Period as evidenced by the very gently dipping Tertiary sequences overlying the Mesozoic rocks. But these Tertiary sequences are tilted near the KMF due to post Tertiary neotectonic activities in the area under compression. Near Amardi village the conglomerate beds overlying the Bhuj sequence are tilted northerly at about 30° (Fig.6.2).

Fig.6.2: Tertiary polymictic conglomerate overlying the Bhuj sandstone, Amardi village.

Role of Transverse faults in the evolution of the Kachchh Mainland:

The KMF and KHF are the major faults which control the present geomorphic configuration of Mainland Kachchh. These faults are not continuous but laterally displaced by various transverse faults. These transverse faults have great role in shaping the Kachchh Mainland. The possible implication of these transverse faults has been explained which seems to be intricately linked with the evolutionary history of Kachchh in the pre-Quaternary and Quaternary times. It has been pointed by Maurya et al. (2003) that some part of the stress being accumulated on the E-W trending faults is being possibly transmitted to the NW-SE to NE-SW transverse faults, which may account for the present seismic phenomenon in Kachchh.

Though the eastern termination point of the KMF is not known exactly but it is supposed that it truncates along a NNW-SSE trending transverse fault. Though this transverse fault does not have a spectacular geomorphic expression but the straight western margin of the Wagad Highland, abrupt termination of the west flowing streams along the fault indicate the existence of a transverse fault. The most evident feature to corroborate the existence of the transverse fault is the Manfara Fault in the close vicinity of the supposed major fault.

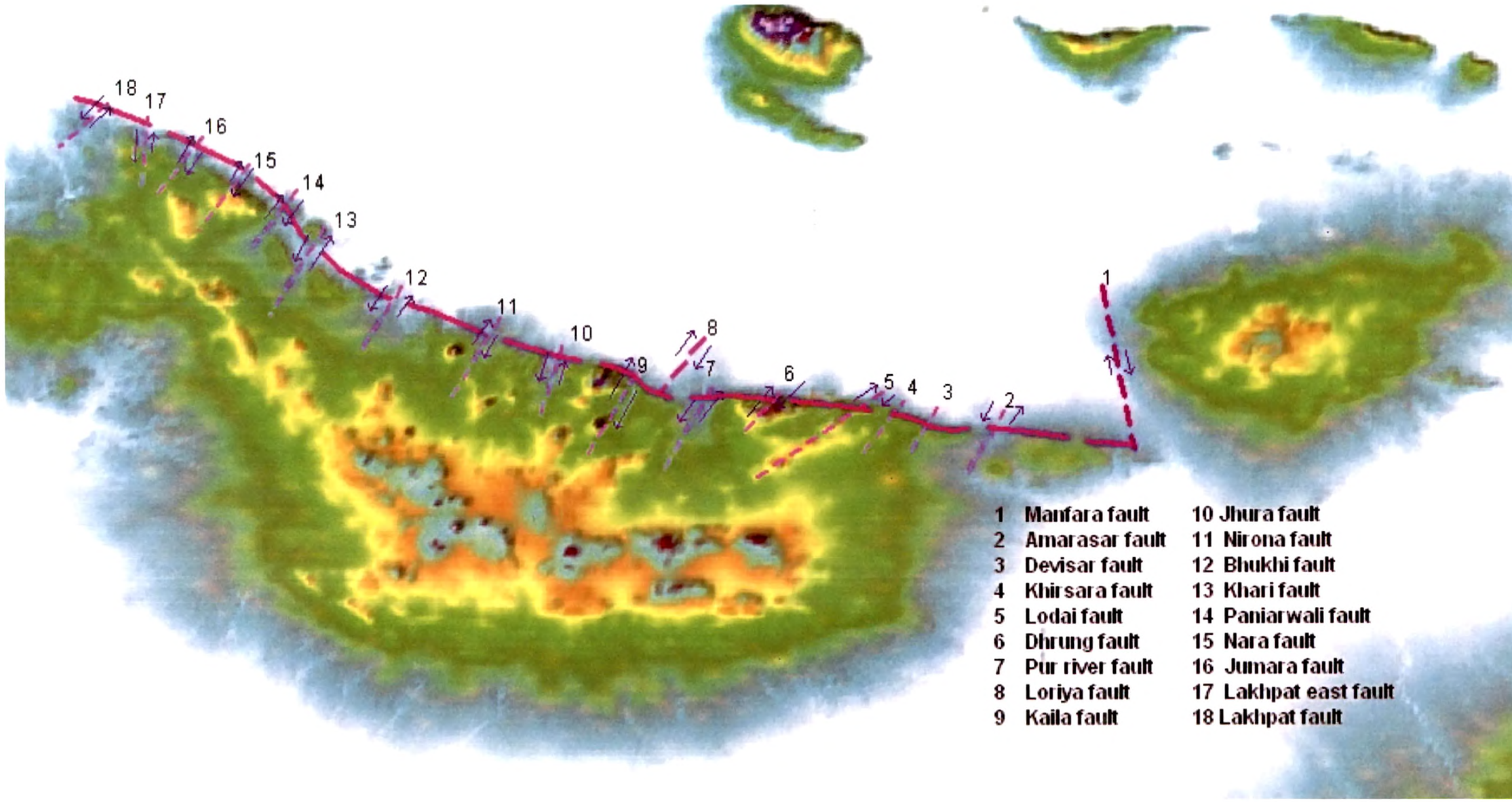

Fig. 6.3: Digital Elevation Model of the Kachchh s showing the transverse faults to the KMF and their inferred strike slip movement.

The Manfara fault shows right lateral strike slip. The various transverse faults to the KMF have been reported by various workers (Fig. 6.3). The most recent among them are the Manfara and the Loriya transverse faults (Singh et al., 2011). The fault planes of these transverse faults are either vertical or steeply dipping (Maurya et al., 2003). In general these faults dip towards the domes. Significant shifting of the east-west trending KMF has been recorded due to the lateral movement along these transverse faults, which has given the current slightly curved shape to the KMF and thus the configuration to the Kachchh Mainland.

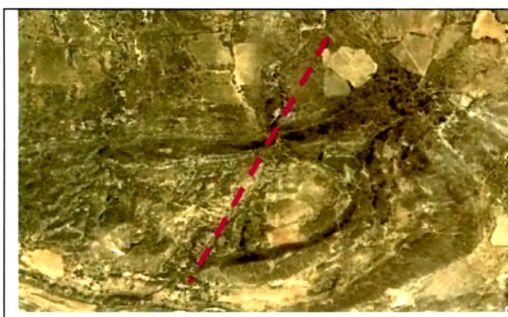

Fig. 6.4: Devisar Transverse Fault.

Fig.6.5: Amrapar (Dudhai) Transverse Fault.

Fig 6.6: Transverse fault to the east of Lakhpat.

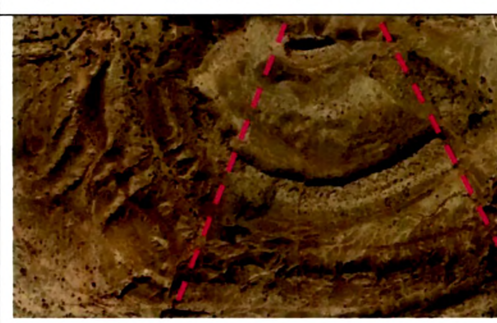

Fig.6.7: Transverse fault across the Jara dome.

Various landforms are developed due to the effect of these transverse faults along the KMF which includes offset fault scarps of KMF, deflected or beheaded drainage, sags, shutter and pressure ridges (Maurya et al., 2003). A significant feature observed in the mainland is that all major transverse faults have been occupied by stream channels debouching into the Banni plain, making conspicuous alluvial fans. The faults have been named on the basis of the channels occupying them or nearest villages (Fig.6.3). These rivers are characterized by the deeply incised channels and other features like entrenched meanders, drainage offsets, small sags, knick points as seen in their long profiles, which all suggest lateral movement along the transverse faults. The faults show dextral as well as sinistral slips, as indicated by fault scarp offsets and by direct observation during coseismic activities. Exceptionally fresh nature of fault scarps has also been recorded in the KMF zone (Thakkar et al., 1999). Observed amount of offset of KMF segments, along the transverse faults, range from a few hundred meters to kilometres (Maurya, et al., 2003).

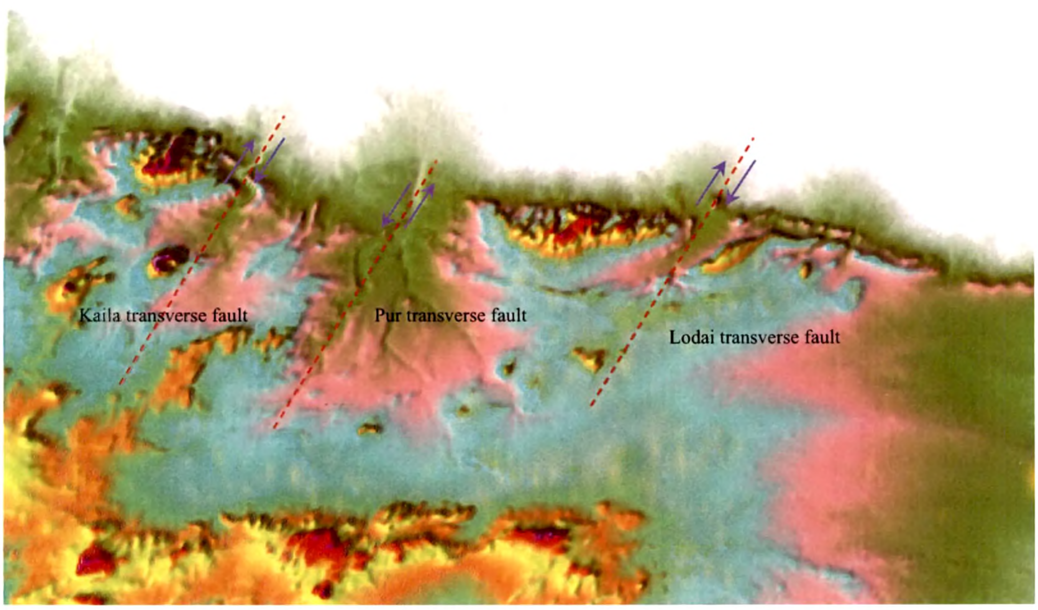

Fig.6.8: Strike-slip movement along the Lodai, Pur and Kaila transverse faults visible on the DEM of the area along KMF.

The lateral displacements of the strata in various domes along transverse faults (Fig. 6.4 to 6.8) suggest that the last phase is dominated by strike-slip movement, as evidenced by horizontally displaced fault scarps of the KMF. This event is related with the final drift history of the Indian plate which resulted into complete welding of Indian and Eurasian plate during Eocene-Oligocene Period (Biswas, 1974, 1982). These transverse faults have been accommodating part of the stress generated during the northward movement of the Indian plate.

Quaternary Tectonic Evolution

Quaternary tectonic activities have been affecting the present landscape of the area. The first order topography and the seismic activities provide ample evidences of tectonic instability in the area during Quaternary (Kar, 1993). Neotectonic uplifts along various faults have been responsible for the present landscape of the Kachchh Mainland. Recent studies have indicated that the Quaternary uplift took place in two major phases (Thakkar et al., 1999, 2001). These two phases are separated by a phase of miliolitic deposition. The pre-miliolite uplift phase took place during the Early Quaternary and the post-miliolite uplift phase took during the Late Pleistocene and Holocene which is still continuing. The Early Quaternary tectonic activity took place mainly along the E-W trending master faults i.e. KHF and KMF whereas the Late Pleistocene-Holocene phase of tectonic activity took along the transverse faults (Thakkar et al., 1999; Maurya et al., 2003). The miliolite deposits found overlapping the colluvial deposits along KHF indicate that E-W faults were more active during Early Quaternary (Thakkar et al., 1999) but the master-fault (KMF) can not remain isolated with any type of neotectonic activity in the area in recent times. The compressive stress accumulates along these faults and then is accommodated by movements along the transverse faults. During the Bhuj (2001) earthquake, ground fissures and upheaval of land was also associated with the KMF, though the causative fault was a hidden transverse fault. Tectonic activities along the transverse faults have been modifying the physiography of the Early Quaternary times. The Loriya Transverse Fault has cut the alluvial fan of the Pur River in the Recent times (Singh et al., 2011). Tilting of miliolitic limestone sheets near the transverse faults also indicate that most recent activity is more concentrated along the transverse faults.

The asymmetry factor clearly indicates that the river basins have experienced tilting during the Quaternary times. Since all the river basins are showing westward tilting, it is concluded that the Kachchh Mainland has undergone westward tilting, in general, during Quaternary Period. Biswas (1974) opined that there is differential uplift along various faults of the Mainland during Early Quaternary due to which the entire Kachchh region including Rann and Banni plains have been elevated. Sharma (1990) also postulated that middle block of the Kachchh Mainland is elevated in comparison to the other two blocks.

Late Pleistocene tectonic activity along transverse faults is evidenced in the Late Pleistocene alluvial deposits in the form of tilting of miliolite sheets near these faults and youthful fault scarps. The present tectonic instability of the Kachchh region is evidenced by the seismic activities in the area due to tectonic movements along these transverse faults (Johnston, 1996). In the Himalayan region the neotectonic movements along thrust planes are transmitted to various transverse faults which account for the present day seismicity (Valdiya, 1973). The tectonic rejuvenation of peninsular India during Quaternary (Radhakrishna, 1993) is also attributed to repeated tectonic movements along the various transcurrent faults (Valdiya, 1998). The compressive stresses accumulating on the E-W trending master faults like KMF and KHF due to locking up of the Indian plate with Eurasian plate is responsible for the movements along the transverse faults resulting into seismic activities in the area and shaping the basin.

As it is evident from the above discussion that transverse faults are playing crucial role in Quaternary evolution of the Kachchh Mainland and more importantly, the current tectonic activities are concentrated along these transverse faults. These transverse faults were originated during a phase of pre-Deccan trap dyke emplacement and the compressive stresses generated on the KMF, due to collision of the Indian plate with Eurasian plate during Eocene-Oligocene. On the basis of evidences in the field and published data, a tectonic map of Kachchh showing the KMF and its transverse faults has been attempted, which gives the nature of movement along the transverse faults. Segmental effect of the seismic activities can be addressed demarcated by the transverse faults. The coseismic features recorded from the Bhuj earthquake indicate that a segment of the KMF bounded by the Manfara fault in the east and the Loriya fault in the west was affected most (Singh et al., 2011). Thus, it seems pertinent to mention that the transverse faults are of prime concern for understanding the recurrent seismic activities in the Kachchh region and for their mitigation measures.

The studies of the basin morphometric analysis suggest strong proof of episodic upliftment of the landmass. The parameters like longitudinal profile, valley height and width ratio and mountain front analysis of the five river basins corroborate the concept of Quaternary upliftment of the Mainland. The Pur and Nirona Rivers are 7th order channels while Chhari and Kaila Rivers are 6th order streams. The total channel lengths of all the stream orders indicate stream richness, especially in the Pur, Nirona and Chhari basins. The length and the number of the lower order streams in all the basins suggest moderate to high relief head water area in general. The circularity ratio values range from 0.307 for Chhari basin to 0.437 for Kaila basin. Highest elongation ratio is for the Kaila basin while for all other basins it is near 0.6 which indicates that all these basins are elongated in shape due to neotectonic activity. Texture ratios of basins vary from 6.01 in Kaswali basin to as high as 23.087 for Nirona basin which is extremely high. This high texture ratio is indicative of recent upliftment. The ruggedness for the Kaila and Nirona basins is more than 1 while it is about 0.5 to 0.7 for the Kaswali, Pur and Chhari basins. These values suggest high drainage density and comparatively low relief, definitely indicating neotectonic activity in the area.

All the streams have very low Vf ratio near their source in the hilly terrain while away from the source near KMF, it is quite high due to broad valley morphology. The results of the sinuosity parameters of the Pur and Nirona Rivers suggest that they are controlled dominantly by tectonism. The evolution of these river basins in the later phase of tectonism is indicated by the sinuosity indices. The analysis of the Mountain front sinuosity index of the east-west trending mountain fronts associated with the KMF are very near to 1, which falls in the tectonic activity class-I of Bull and McFadden (1977) indicating that the area has experienced active tectonism.

Many interesting features are formed due to latest tectonic episodes in Quaternary Period like boulder and gravel beds in the river valley terraces at levels higher than valley floor. Deep gorges are formed around Dhrung, Jawaharnagar and Lodai villages. The reactivation along the transverse faults during Bhuj earthquake, like Loriya and Manfara faults; development of the new streams as a result of tectonic tilting and coseismic features like ground fissures indicate that the area is tectonically very active.