Chapter IV

NEOTECTONISM

4.0 INTRODUCTION

"Neotectonism" has been one of the most familiar terms amongst the geoscientists, engaged in unraveling the Neogene and Quaternary history, throughout the globe. This term was first introduced in the literature by Obruchev (1948), to describe the study of the young and recent movements taking place at the end of the Tertiary and the first half of the Quaternary periods. Stewart and Hancock (1987) have defined "Neotectonism as a branch of tectonics concerned with the understanding of earth movements that occurred in past and are continuing in the present day". Mukherjee (1980) has defined "Neotectonics as the study of structures of the earth's crust created by the latest movements, having a distinct influence on the formation of present day surface relief". According to Slemmons (1991), "Neotectonics can be broadly described as tectonic events and processes that have occurred in post-Miocene times...". Although neotectonism has been defined in various ways by several workers, however Morner (1990) is of the opinion that the neotectonic phase starts at different times in different places, depending on the tectonic regime.

The south Gujarat in general and the study area in particular, have not remained an exception as far as neotectonic activities are concerned. The studies carried out in these areas, have clearly demonstrated the influence of these activities, persisted throughout the Quaternary times. Owing to the potential nature of the study area and its surroundings in terms of the neotectonic activities, the present study is aimed to understand the role of these activities and their signatures, well imprinted on its geological and geomorphological expressions, mainly based on the field observations and sub-surface data. The following paragraphs furnish a detail account of the neotectonic signatures observed within the study area and their vital role in the Quaternary history of the terrain.

4.1 NEOTECTONIC STUDIES IN LTRB AND ITS ENVIRONS – A REVIEW

The south Gujarat alluvial plains in general and the study area (LTRB) in particular, have always remained the areas of attraction for the earlier and present workers engaged in the study of neotectonic activities. The studies on neotectonism carried out by earlier workers pertaining to the study area and its environs, although sporadic in nature, however, they are significant and clearly demonstrates the persistence of neotectonic activities during the Quaternary times.

Vrendenburg (1906) has worked on the Pleistocene movements indicated by the irregularities of the gradients of rivers in peninsular India. Based on his studies, he envisaged the role of early Pleistocene anticlinal warping responsible for thick accumulation of alluvium in central Narmada. Tapi, Purna and parts of Godavari and Krishna river basin. Auden (1949), while carrying out the studies on the dyke patterns in western Indian, has opined that the periodic movements along the Narmada- Tapi lineaments have occurred till the beginning of Pleistocene period. Sali (1973) has worked on the archaeological aspects of central Tapi basin in Maharashtra. In his opinion, this basin had experienced tectonic movements till late Pleistocene and the present courses of Tapi and Purna rivers have been influenced by these movements. Mukherjee (1980) has worked on the neotectonic aspects of south Cambay basin. According to him, neotectonic features are best exhibited in the form of Quaternary landforms that are concentrated on the eastern margin and lineaments in the south Cambay basin. He has further suggested the evidences of neotectonic activities in the region north of the study area.

Khan and Banerjee (1984), based on their studies in the central Tapi basin, have described the evidences of neotectonism, indicated by the steep inclination of Quaternary deposits, drainage reversals and other related features. According to them, the neotectonic activities have resulted on account of the rejuvenation of the basement trends. Dubey and Saxena (1988) have envisaged the role of Quaternary tectonism in the form of fracturing and warping of trappean rocks, dyke emplacements and tilting of the alluvium in central Tapi basin. Alavi (1990) has opined that the existing landforms of the south Gujarat terrain, clearly indicates the role of Quaternary tectonism in their evolution. Mallik (1995) has put forth brief idea about neotectonic activities in LTRB and has suggested that the sinuosity of the river and the channel-fills are on account of reactivation of NW – SE fractures during the late Quaternary period.

4.2 NEOTECTONIC SIGNATURES

The signatures of neotectonic activities in and around the study area have been observed in the surface outcrops as well as sub-surface data. The signatures of neotectonism includes the sub-surface tectonic features; tilting of trappean basement, river cliffs and sedimentary layers; sediment deformations; shifting of river channels; anomalous behavior of river channels and tributary streams; variable thicknesses of alluvial deposits; unpaired river planation surfaces; development of ravines; break in river profiles; geo-thermal springs; and seismicity. A systematic description of these neotectonic signatures is as follows:

1. Sub-Surface Tectonic Features

The role of Quaternary tectonism is very well observed in the sub-surface geological data of the study area, obtained from several organizations. In order to obtain a clear insight of the neotectonic signatures, several transverse as well as longitudinal profiles criss-crossing the study area (Fig. 4.1, 4.2A&B), have been prepared, based on the above data. The transverse profiles A – A' and B – B' do not represent any signatures of tectonism, however, in C – C', the abrupt termination of Quaternary sediments and their juxtaposition with the Tertiaries is observed. This clearly points to the displacement of Quaternary sediments which is attributed to the post Quaternary tectonism along the E – W fractures and southern extension of Eastern Cambay Basin Marginal Fault. The evidences of tectonism recorded in longitudinal profiles D – D', E – E' and F – F' also supports the above observations. The D – D' and E – E' profiles distinctly show the Eastern Cambay Basin Marginal Fault along which the Quaternary sediments are getting abutted, however the F – F' profile marks the fault contact between the Deccan Traps, Tertiary and Quaternary sediments. Owing to the curved nature of the fault surfaces, the displacement appears to be of a listric type. The observations made along the sub-surface profiles provide the evidences pointing to the active tectonism during Quaternary times in and around the study area.

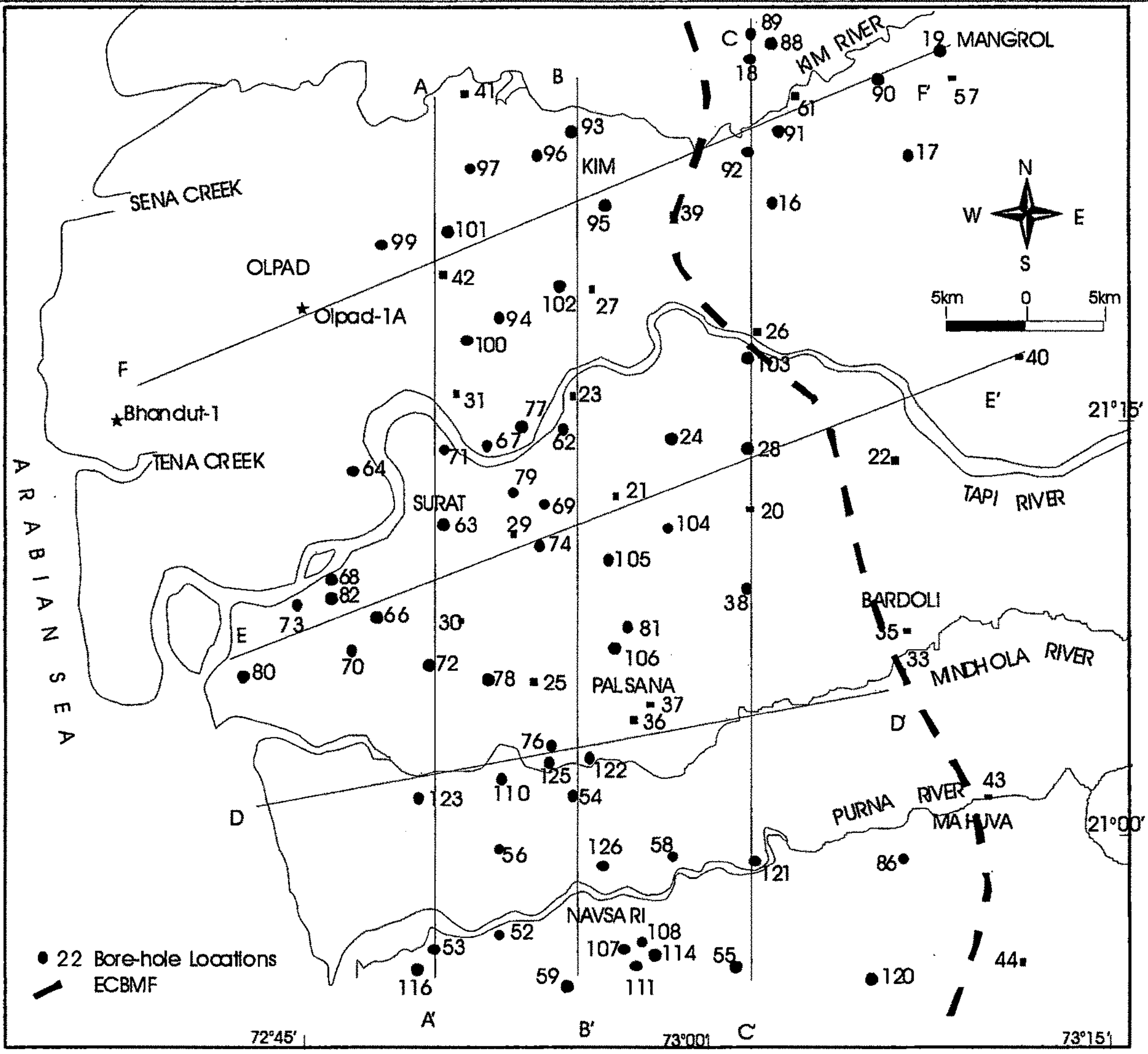

Fig. 4.1 – Figure Showing The Locations Of Transverse And Longitudinal Profiles In The Study Area.

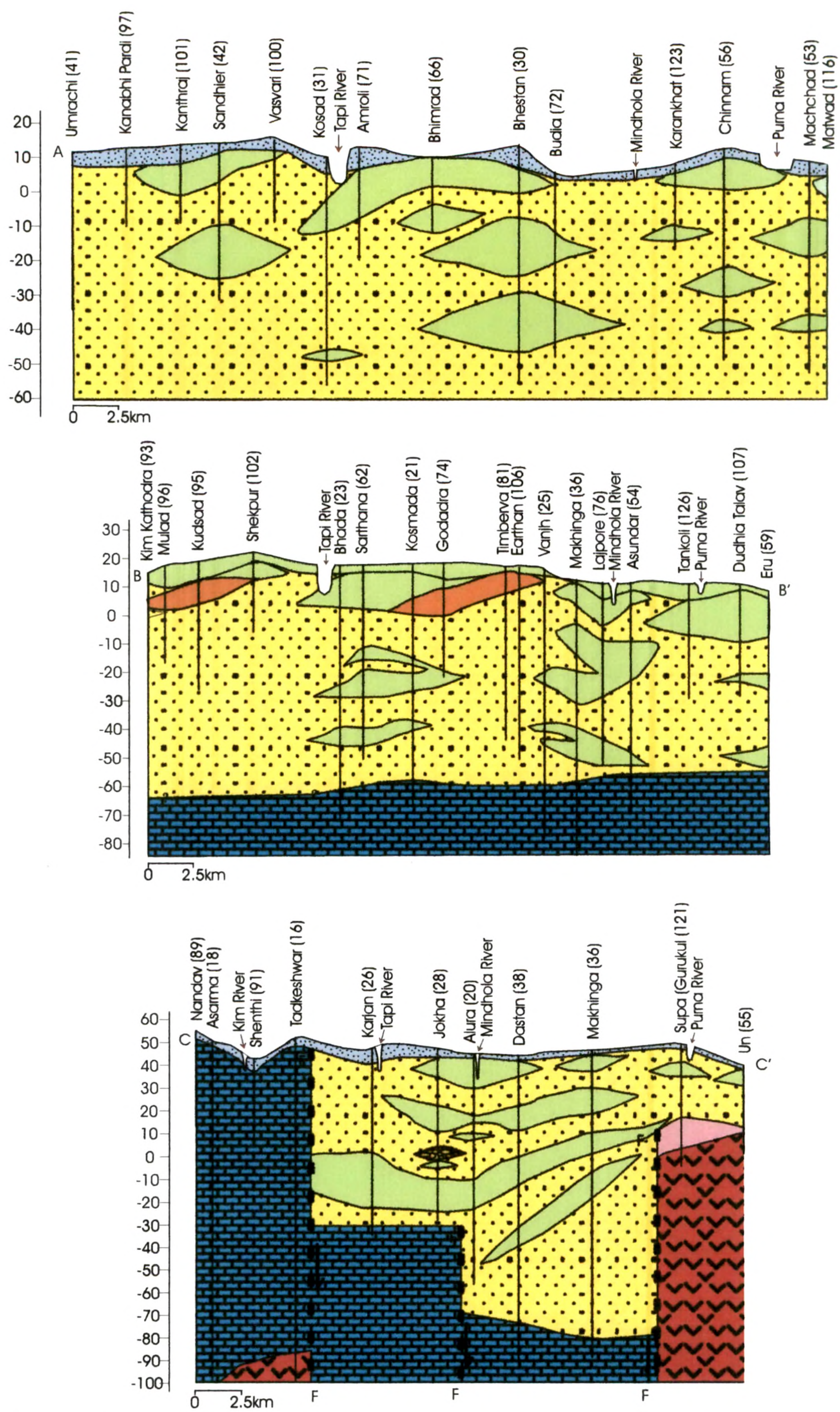

Fig. 4.2A - Figure Showing The Sub-Surface Transverse Profiles Along A - A', B - B' And C - C' Of The Study Area.

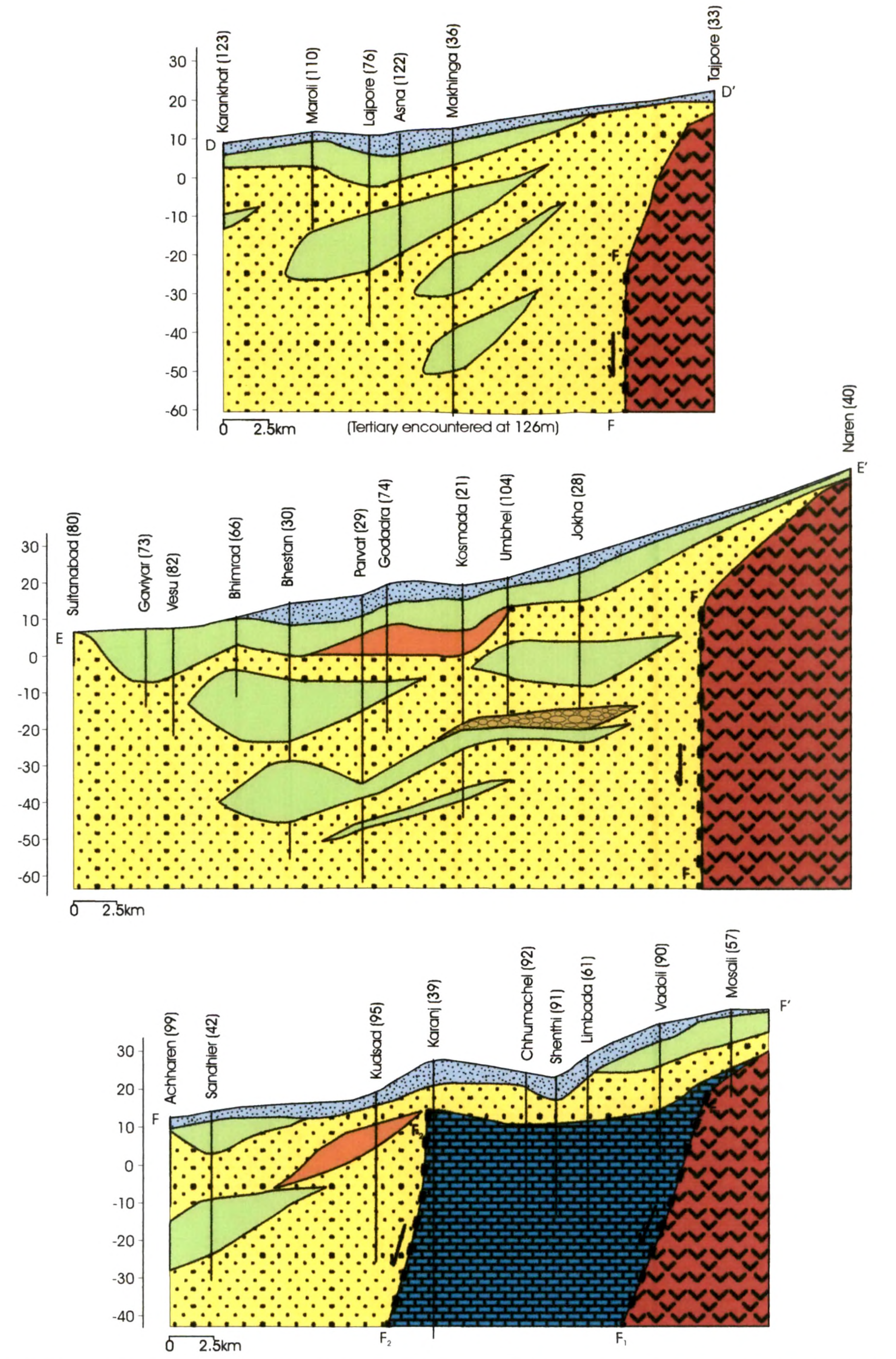

Fig. 4.2B - Figure Showing The Sub-Surface Longitudinal Profiles Along D - D', E - E' And F - F' In The Study Area.

2. **Differential Tilting of Trappean Basement, River Cliffs and Sedimentary Layers**

One of the striking and important evidences reflecting neotectonism includes the differential tilting of beds. Within the study area, such features have been observed. These features include the outcrops of Deccan Traps showing appreciable tilting and inclined nature of river cliffs and sedimentary layers. Illustrative examples of these features observed at several locations with in the study area are described as follows. Along the Tapi river, the trappean outcrops show an inclination of 20^0 to 25^0 due SW near Mandvi, $13^0 - 15^0$ due west near Kadod (Plate 4.1), on the left bank of Tapi river and further downstream, on the right bank, the trappean outcrops are inclined by 20^0 due west.

Plate 4.1 – Field Photograph Showing Inclined Deccan Trap Outcrops (Loc: Haripura – Kadod).

Similarly near Gavachhi village, in Vare Khadi (a tributary of Tapi river), the trappean outcrops show dips of 25^0 to 30^0 due west (Plate 4.2). The evidences of tilting of traps is uniformly observed along the middle reaches of Tapi river also wherein they show an inclination of 35^0 to 40^0 due west, near Piloda and Thalner localities.

Plate 4.2 – Field Photograph Showing Inclined Deccan Trap Outcrops (Loc: Gavachhi, Vare Khadi).

Along with the trappean outcrops, the Quaternary sediments in the study area, also represents a marked inclination. Illustrative sections depicting such features are seen near Mandvi on the right bank of Tapi river, where the Quaternary sediment layers show an inclination of about 15^0 – 20^0 due WSW, however, near Puna they show 15^0 due WSW (Plate 4.3) and 20^0 due west (Plate 4.4) near Umarsadi.

Plate 4.3 – Field Photograph Showing Inclined Siltstone Beds (Loc: Puna).

Plate 4.4 – Field Photograph Showing Inclined Deccan Traps And Quaternary Sediment Layers (Loc: Umarsadi).

The evidences of tectonism are also represented in the form of tilting of the river cliffs at several locations in the study area. Some of the important locations exhibiting these features are listed below.

(i) In the lower reaches of Tapi river, near Kamrej, the cliff sections show an inclination of 30^0 due east, whereas near Mandvi, an inclination of 10^0 due west in observed.

(ii) In the middle reaches of Tapi river, near Tekwade and Jhaloda localities, the cliffs are inclined by 30^0 to 40^0 due W and 25^0 to 30^0 E respectively.

(iii) The cliff-sections exposed near Utara, in the Mindhola river, displays an inclination of 15^0 to 20^0 tilt due NNW.

3. Deformation of Sedimentary Layers

Within the study area, the Quaternary sediments show occasional presence of deformational structures. These structures include the open warping, pinching and swelling of sedimentary layers, particularly observed around Haripura village (Plate 4.5), along the left bank and near Mandvi, on the right bank of Tapi river.

Plate 4.5 – Field Photograph Depicting Open Warping In Quaternary Sediments (Loc: Haripura).

Evidences of deformation of the sedimentary layers have also been observed in the middle reaches of the Tapi river. The deformation structures include the dislocation of calcretic layers and gravelly horizons (Plate 4.6), along with open warping of sedimentary layers (Plate 4.7), near Piloda, Jhaloda and Tekwade locations.

Plate 4.6 – Field Photograph Showing The Dislocation Of Calcretic Layers And Thrusting Of Quaternary Sediments (Loc: Jhaloda).

Although the deformational structures are occasionally noticed, there presence aptly indicates the effect of local slumping and thrusting. The overall orientation and geometry of the deformational features probably points to the compression as well as extension type of stress regimes along E – W direction.

Plate 4.7 – Field Photograph Showing Open Warping In The Sedimentary Layers (Loc: Piloda).

4. Abandoned River Channels

The evidences of neotectonism have been observed in the satellite data (IRS 1C LISS III, 1998) in terms of abandoned channels linearly oriented in ENE – WSW and NW – SE directions within the interfluve region of the present-day Tapi and Mindhola rivers (Fig. 3.1). These channels seem to represent the remnants of earlier drainage network, which have been later occupied by the younger sediments. Along with the abandoned channels, the satellite data also reveals the presence of linearly oriented sand-bodies. The presence of abandoned channels as well as the sand-bodies in the area bounded by the present-day Tapi and Mindhola rivers represents the shifting of these rivers, attributed to the active tectonism prevailing during the Quaternary times.

5. Anomalous Behavior of River Channels and Tributary Streams

The role of active tectonism within the study area has been profoundly revealed by the anomalous behaviors of the present day river channels and their tributary streams. Overall, the major trunk streams and their tributaries represent a westerly flowing more or less parallel to the Narmada – Son geo-fracture. However, a detailed observation indicates a strong control of the regional fractures oriented in ENE – WSW, NW – SE, NE – SW and N – S directions on the flow patterns of these streams. These criss-crossing fracture systems appear to have influenced and controlled the overall drainage network. The presence of linear drainage segments, abrupt right angle swings by the streams, tight windings, deep entrenchments and river capturing phenomena aptly points to the role of active tectonism in the study area. Some of the location specific illustrative examples depicting these evidences in the study area have been cited below.

(i) The Tapi river, which almost follows an ENE – WSW trend throughout its course, abruptly plunges in the SW direction, near Kamrej, almost making an angle of 45^{0} with respect to the main course.

(ii) The presence of the river pools near Kadod, along the Tapi river and near Gavachhi along the Vyara Khadi (a tributary of Tapi river); the rectangular pattern shown by Tapi river near Surat and the dynamic N – S oriented hook-shaped Tapi river mouth, near Bhada, is attributed to the active tectonism.

(iii) The present-day Mindhola river, which cuts the floodplains of proto-Tapi river, distinctly shows tight windings thought out its course and deep entrenchments. One of the classical examples of deep entrenchment is seen near Amalsadi, wherein a subsequent stream meeting the main Mindhola river channel at almost right angle, is characterized by more than 20m entrenchment probably representing local uplift of the crustal block.

(iv) The southern most watershed boundary of Mindhola river is found to be in the proximity of the main trunk stream. This has resulted in an asymmetrical drainage basin with few tributary streams contributing the southern bank (Fig. 3.13). The asymmetrical nature of the Mindhola drainage basin is attributed to the upliftment of the southern block of Tapi river basin (Kaila et al., 1981), which has resulted in the southern shift of Mindhola river.

The asymmetry in the drainage basin is also observed in the Tapi river basin, wherein the southern watershed boundary shows proximity to the trunk stream with few tributaries contributing to the southern bank.

6. Variable Thicknesses of Alluvial Deposits

The variation in the thickness of alluvial deposits, across and along the river channel, is attributed to active subsidence that limits the differential aggradation of the fluvial belt with respect to the surrounding flood plains (Dumont, 1998). Interestingly, within the study area, the variation in the thickness of alluvial deposits across and along the Tapi river channel is observed at several locations. At Kakrapar, in the upstream areas, the thickness is about 12 – 13m, which gradually decreases to 7 – 8m near Mandvi in the downstream and further shows an increase with a maximum of 16m near Puna village. Near Wareth-Petia, the alluvial deposits attain a thickness of 15m on the right bank of Tapi river whereas on the opposite bank, it displays a thickness of 5m only. Similarly in case of Mindhola river the thickness of the alluvial deposits near Karchaka, Wadhawa and Utara villages in the upstream areas, is found to be around 13m, however there is a gradual decrease in the thickness of these deposits and is found to be 2m near Tajpura village in the downstream side. Further downstream of this location, again the thickness of these deposits gradually increases and is found to be around 19m, near Amalsadi village. The variation in the thicknesses of alluvial deposits observed along the Tapi and Mindhola river channels could be the result of differential movements of crustal blocks during Quaternary times.

7. Unpaired Planation Surfaces and River Cliffs

Riverine features such as unpaired planation surfaces and river cliffs with distinct altitudinal variation, have been recorded at several locations within the study area, which are described as follows.

(i) In the upstream side of Tapi river near Wareth, the left bank exhibits three distinct planation surfaces as compared to the right bank, which shows one planation surface.

(ii) In the lower reaches of Tapi river, between Puna and Gaypagla the right bank is characterized by two distinct planation surfaces, however the left bank is devoid of the same.

(iii) All along the Tapi river, the cliffs are found exhibiting distinct variation in their altitudes and represents exceptional heights at several locations. Particularly near Jhaloda, Piloda and Tekwade in the middle reaches of Tapi river, they attain height of 30 – 40m, whereas, near Kamrej in the lower reaches show height of 15m. The presence of unpaired terraces as well as the exceptional heights of the river cliffs is attributed to the local uplift of crustal blocks reflecting the role of neotectonism.

8. Development of Ravines

The study area has been bestowed with the presence of extensive developments of ravine lands. The formation of ravine lands in any area is attributed to the differential upliftment of crustal blocks. Within the study area, extensive development of ravines are observed near Kamrej and Mandvi (Plate 4.8) on the right bank of Tapi river and between Karchaka and Palsana localities (Fig. 3.3 C) on the right bank of Mindhola river. These ravines are associated with the sudden increase in cliff heights, deep entrenchments, inclination of cliffs, deformation of sedimentary layers and appearance and disappearance of Deccan trap outcrops within the riverbed.

Plate 4.8 – Field photograph showing a ravine, presently occupied with monsoonal water (Loc: Mandvi).

Although, these features have been observed locally, however their presence is significant, indicating the differential upliftment of crustal blocks, on account of tectonism.

9. Break in River Profiles

The field observations of Tapi and Mindhola river courses have pointed out the presence of features such as rapids, cascades and knick points, particularly near

Kakrapar, Mandvi, Pipariya, Bodhin, Gavachhi and Munjhlav (Plate 4.9) localities along the Tapi river and near Tajpura along the Mindhola river showing parallelism with N – S oriented fractures. The presence of these features has caused discontinuity in the normal flow of the river. Since these features have specific orientations, parallel to the existing fracture systems, they have been attributed to be the result of tectonism in the study area.

Plate 4.9 – Field photograph showing the presence of a knick point within the river channel (Loc: Munjhlav).

10. Geo-Thermal Springs

The presence of geo-thermal springs in an area indicates high heat flow, steep geo-thermal gradients and a very fragile and sensitive nature of the crust (Tandon and Chaudhary, 1968; Lee and Rayleigh, 1969; Singh et al., 1975: Ravishankar and Dubey, 1984; Ravishankar, 1987). Although the study area is devoid of these features, however their presence is reported from the adjoining areas. Chandrasekharam (2000) has identified seven geo-thermal provinces of India, three of which are located in and around the study area. These provinces comprise the Cambay zone, Son-Narmada-Tapi Rift zone (SONATA) and West Coast zone. The detailed studies of these provinces by several earlier workers (Gubin, 1969; Chandra, 1977; Rao and Rao, 1984; Rao et al., 1986; Dubey and Saxena, 1988; Kaila, 1988; Verma and Banerjee, 1992; Mahadevan, 1995; Bansal and Gupta, 1998; Mishra et al. 1999) have pointed out the presence of numerous deep seated faults, also referred as palaeo-suture zones. According to Jain et al (1995), these deep seated faults appear to have formed during the collision of Deccan proto-continent with the Bundelkhand proto-continent. An illustrative example of the geo-thermal springs is seen south of study area at Unai, near Vansda, comprising of 60 geo-thermals, showing their proximity to the deep crustal Purna fault and Eastern Cambay Basin Marginal Fault.

11. Seismicity

The presence of seismic activities in an area, testifies the prevalence of active tectonism. According to Guha et al. (1974), the marginal areas of the peninsular India that includes the Kutch graben, Cambay graben, Narmada-Son-Tapi graben and the West Coast regions, have been considered seismically active, having a potential to generate earthquakes of moderate intensities. The studies carried out by Bansal and Gupta (1998), very well indicates that the study area in particular and the adjoining areas in general, have experienced earthquakes of low to moderate intensities (Table 4.1). From these studies, it can be very well understood that the study area and the adjoining regions had remain seismically active since historical times and had experienced earthquakes of various magnitudes (Fig. 4.3), with a maximum of 5.6M. The historical data also reveals that since 1684, the area around Surat has experienced seismicity and that the earthquake of 20th July 1935, having epicenter at Dumas, has been so far the highest magnitude earthquake with an intensity of 5M.

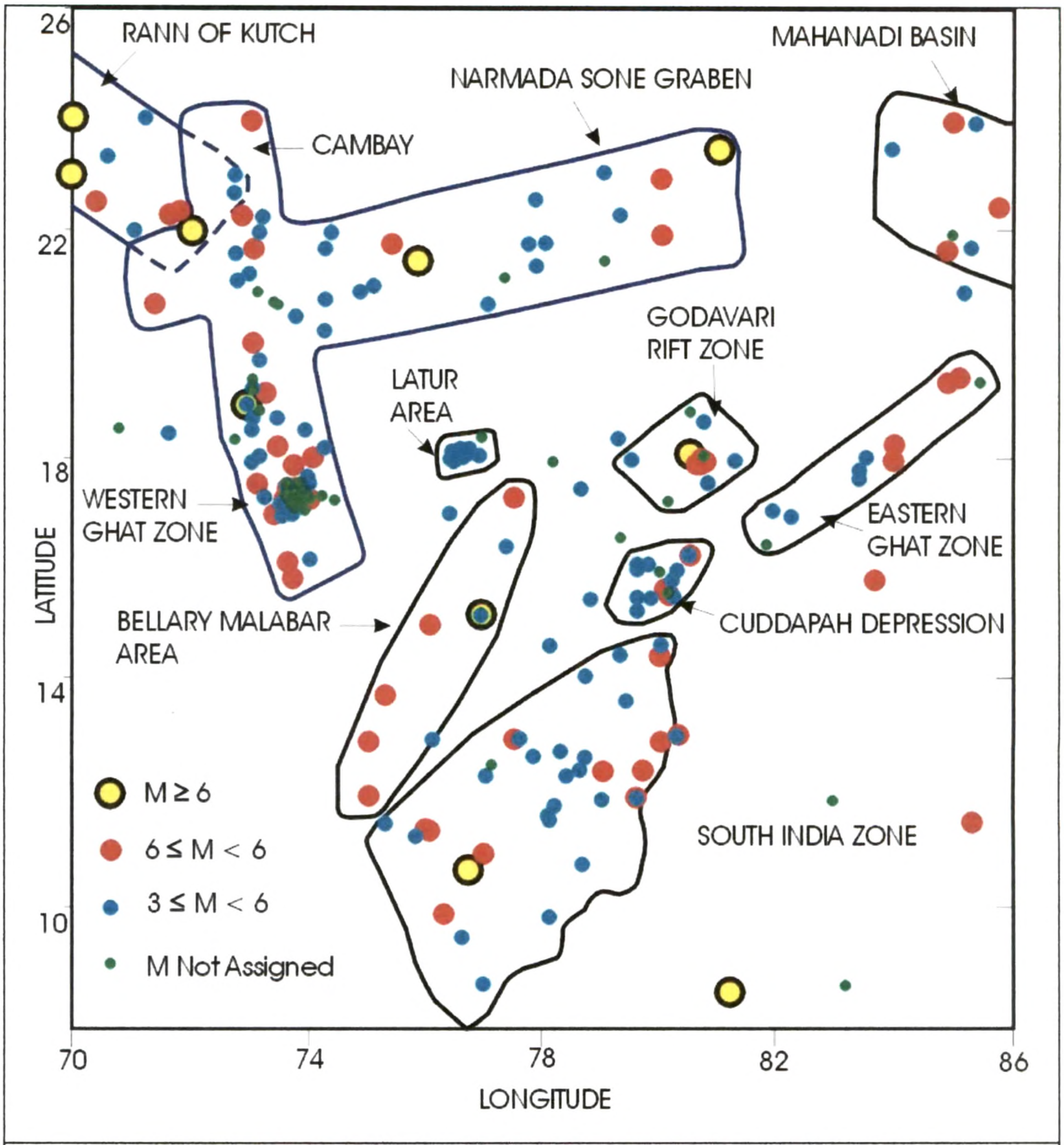

Fig. 4.3 – Distribution Of Epicenters In Seismic Provinces Of Peninsular Shield Area (After Bansal And Gupta, 1998).

According to Rao et al. (1986), the frequency of the occurrence of earthquake tremors recorded at Ukai observatory (Fig. 4.4) indicates that the region around Ukai and adjoining areas have been experiencing earthquake tremors, classified to be of swarm type and attributed to the local crustal adjustments.

Sl. No.	Year	Latitude	Longitude	Magnitude	Location
1	1684	21.200N	72.900E	-	Surat
2	1871	21.200N	72.900E	3.7MB	Surat
3	1935	20.000N	73.000E	5.0MS	Near Dumas
4	1970	21.700N	73.000E	5.4MB	Broach
5	1970	21.700N	73.000E	3.8MS	Broach
6	1970	21.700N	73.000E	3.5MS	Broach
7	1970	21.600N	72.700E	4.1MS	Broach
8	1970	21.600N	72.700E	3.4MS	Broach
9	1971	21.700N	73.000E	3.4MS	Broach
10	1986	20.482N	73.722E	4.3MB	Near Surat
11	1986	20.636N	73.430E	-	Near Surat
12	1986	20.712N	73.367E	-	Near Surat
13	1991	20.879N	73.099E	-	Near Surat
14	1993	21.117N	72.740E	3.8MB	Bharuch

Table 4.1 Historical Records Of Earthquakes In The Study Area And Its Environs (After Bansal And Gupta, 1998).

Based on the observations made by the earlier workers related to the seismicity in and around the study area, it broadly confirms that the LTRB in particular and south Gujarat in general, have remained tectonically active owing to their proximity with the major tectonic domain such as Narmada – Son, Cambay and West Coast Fault.

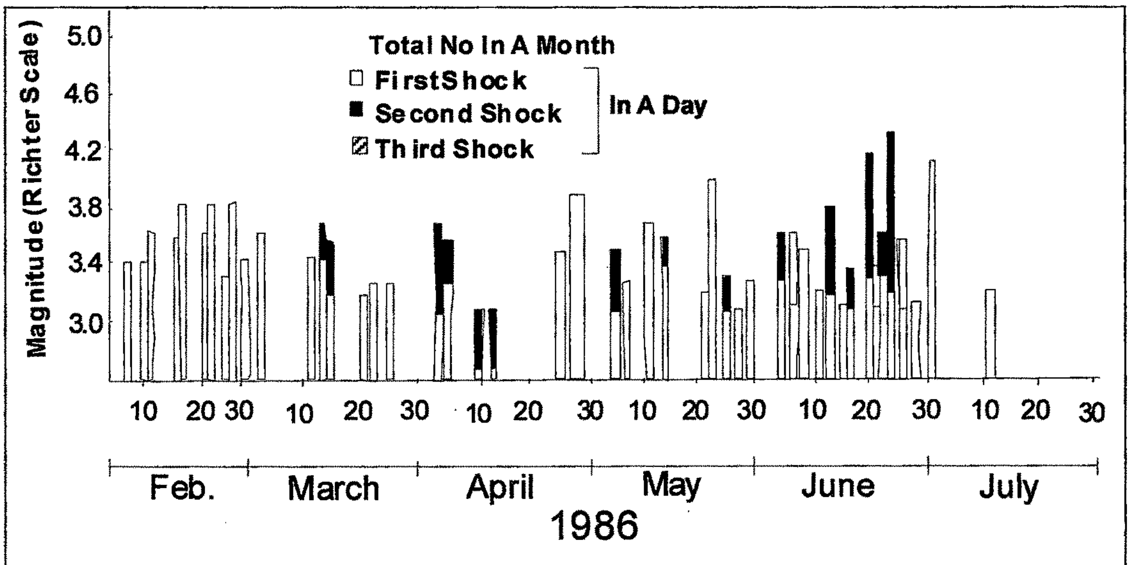

Fig. 4.4 – Seismograms Of 1986 Earthquake Event Recorded At Ukai Observatories (After Rao et al., 1986).