CHAPTER - VIII

QUATERNARY BASIN EVOLUTION

Chorley (1967) has called the drainage basin as the 'fundamental geomorphic unit'. In the same way, Leeder (1993) argues that the sedimentary basin is the fundamental geological unit. However both are complementary to each other as the erosion and transport processes going on in the drainage basin ultimately control the magnitude of sediment flux that issues into the drainage basin (Leeder, 1993). Basin type is established by tectonics and provides macroarchitectural framework for the deposition of sediments. However the interaction between sedimentation and tectonics though known for a long time is still poorly understood.

Role of tectonics in sedimentation is implicit on two counts,

1. Formation of a basin i.e. providing a site for the deposition of sediments.
2. Provide an uplifted area from where sediments are derived.

The evolution of a sedimentary basin is a complex phenomena and is based on interaction of several geological factors over a period of time. The Quaternary basin of Mainland Gujarat is unique in several respects and has evolved to the present alluvial plain as a result of interaction between several factors during Quaternary, most important among them being tectonics. An attempt has been made here to understand the role of tectonics in the evolution of Gujarat plains during Quaternary.

THE QUATERNARY BASIN

The Gujarat alluvial plains extend as a linear belt from the borders of Rajasthan and Gujarat in the north and terminate at the Narmada river in the south. The fact that the plains do not extend south of the Narmada river points to the important role played by the Narmada geofracture. The eastern fringe of the plains is marked by the Aravalli orogenic mountains and the trappean highlands. On the west, the plains abruptly terminate against the Ranns of Kachchh and the Saurashtra horst. The Narmada geofracture, the Aravalli belt, the Ranns of Kachchh and the Saurashtra peninsula are all known tectonic units of western India where tectonic movements during Quaternary are well established (Fig. 8.1). Thus the control of tectonism in the evolution of the Gujarat alluvial plains is clear, the accumulation of the sediments having taken place in a structural depression.

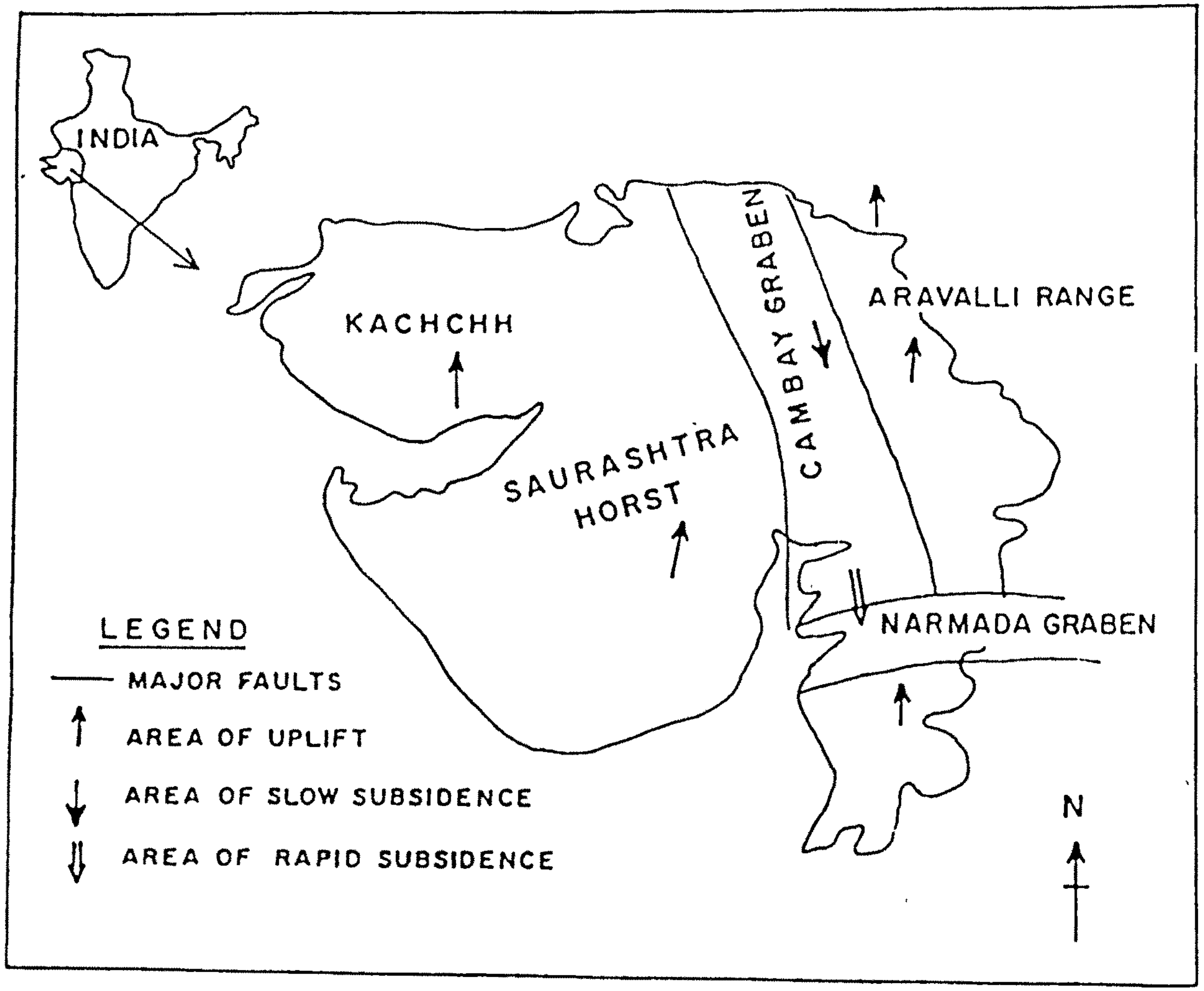


Fig. 8.1 Schematic map of Gujarat showing major tectonic movements during Quaternary.

The geographical limits of the Quaternary deposits shows remarkable correlation with the basinal boundaries of the Cambay and Narmada grabens. The deposition of sediments during Quaternary is thus closely connected with the Cambay basin tectonics. The Quaternary sedimentation forms an integral part of the geological evolution of Cambay and Narmada grabens. White et al (1986) have shown that the pattern of deformation in the sedimentary fill of an active graben is partly dependent on the nature of the major basin bounding faults.

The bounding faults of the Cambay basin viz. ECBMF (Eastern Cambay Basin Margin Fault) and WCBMF (West Cambay Basin Margin Fault) have played a significant role in controlling the Quaternary deposition within the Cambay basin. However the extension of the Quaternary sediments beyond the ECBMF in the east is the case of basin overfill during the later stages of sedimentation leading to the formation of a shallow wide pediment. The subsurface data confirms the presence of basement rocks at shallow depths outside the ECBMF, representing the pediment. This is also well evidenced by the frequent occurrence of rocky outcrops within the various channels. However, this does not in anyway limit the significance of the ECBMF in Quaternary sedimentation because the ultimate boundary of the Quaternary basin is marked by the faults related to the ECBMF.

Thus it is clear that the site for Quaternary sedimentation was provided essentially by the Tertiary Cambay graben. Initially, marine deposition took place in the Cambay basin during the Tertiary, but in its later evolutionary phase, it was filled up by fluvial sediments during Quaternary consequent upon the withdrawal of the

Tertiary sea. According to Merh (1993), the withdrawal of the Tertiary sea from the west coast perhaps marked the advent of Quaternary period. Within the Cambay basin, the Tertiary sediments form the basement of the Quaternary sediments while outside the Cambay basin, they directly overlie the Mesozoics or Precambrian rocks.

The subsurface characteristics of the Quaternary basin presented here is based on critical evaluation of the subsurface data generated by various agencies engaged in subsurface exploration including ONGC. However the data is either too fragmentary or too meagre or confined to the Tertiary rocks lying beneath the Quaternary sediments. The lithologic data on the unexposed Quaternary sediments have been found to be grossly inadequate to be able to indulge in any type of lithologic correlations or related geologic interpretations. In the absence of any substantive data on the subsurface Quaternary deposits, it is not possible to say anything with certainty except making a few relevant generalizations based more on reasoning and logic. However, the scanty borehole data by and large indicates the more or less consistent prevalence of continental conditions during the Quaternary.

STAGES IN BASIN EVOLUTION

The evolution of the Quaternary basin took place in phases (Fig. 8.2). Phase-I includes the Quaternary basin evolution from Lower Pleistocene to Middle Pleistocene, Phase-II includes the evolutionary period from Middle Pleistocene to Terminal Pleistocene and Phase-III includes the period from Terminal Pleistocene to Recent.

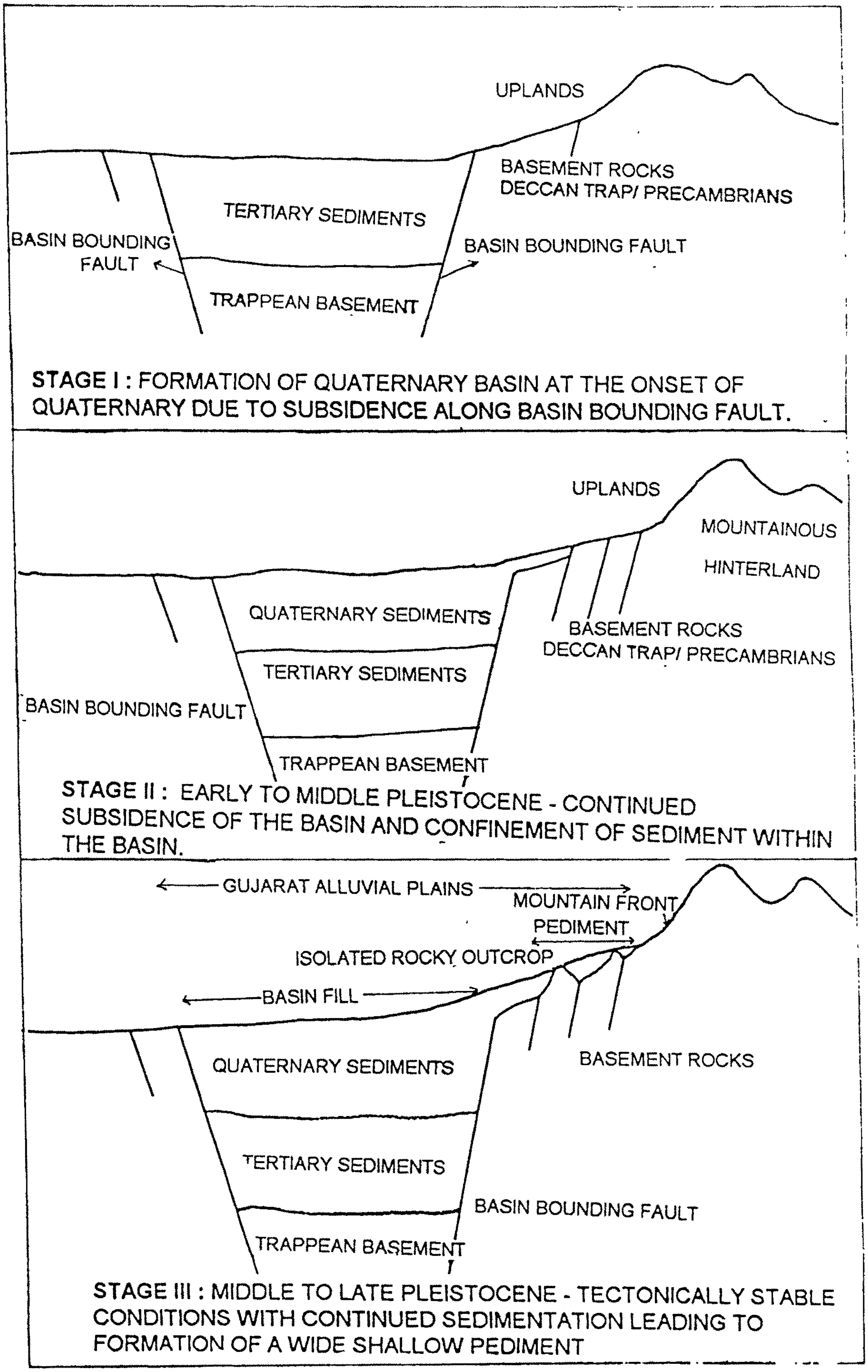


Fig. 8.2 Idealised E-W cross-sections across Gujarat alluvial plains showing stages in Quaternary basin evolution.

PHASE-I

This evolutionary phase includes the period from Lower Pleistocene to Middle Pleistocene. The sediments deposited during this phase are nowhere exposed in the area. The exposed sediment column is of the order of 40 to 50 m dating back to Middle Pleistocene which is less than one tenth of the total Quaternary sediment thickness. Thus a large chunk of the Quaternary sediments was deposited before Middle Pleistocene which occurs in the subsurface.

The huge thickness (Fig. 7.1) and the vast lateral expanse of the Quaternary sediments indicate that the sedimentation took place in a basin of regional dimension. The basin was formed at the beginning of the Quaternary period because of the reactivation of the pre-Quaternary basement faults. These faults were essentially the same which led to the formation of the Cambay rift. The thickness data of the Quaternary sediments in the Cambay basin provides clear and unequivocal evidence of the huge thickness of the sediments. The N-S basinal cross-section across the alluvial plains within the Cambay basin is particularly revealing (Fig. 7.1). It can be seen that the thicknesses of the Quaternary sediments greatly varies from north to south. The average thickness is around 300 m in the north whereas it is found to be abnormally thick in the southern part of the basin, being around 800 m. The sediment thickness suddenly decreases to almost 50 m south of the Narmada. This suggests the effective role played by the Narmada geofracture in confining the Quaternary sedimentation with the Cambay basin.

The highly variable thickness of the Quaternary sediments indicates that the deposition took place in a number of sub basins bounded by faults related to the Cambay basin. Thus the basin which was a major site of accumulation of fluvial sediments during Quaternary comprised a large linear depression marked by several horst and grabens. The abrupt variations in the sediment thickness are indicative of synsedimentary faulting (Laville and Petit, 1984). This suggests that the fault bound sub basins continued to be tectonically active during the filling up of the basin. As the various limiting faults of Cambay basin have affected the lower Pleistocene sediments also, a reactivation of the Tertiary faults is implied. The vertical extent of the sediments is directly related to the nature, degree and rates of relative uplifts and subsidence of the various blocks of the Cambay basin.

The lack of adequate lithologic data on the subsurface Quaternary sediments is a major handicap in deciphering the exact nature of the Lower to Middle Pleistocene tectonism in the area. However the unusually high thickness of the lower to Middle Pleistocene sediments indicate overall subsidence of the basin as a whole even as the differential movements of the various subbasins continued. The subsidence of the basin as a whole concomitant with the accumulation of the sediments facilitated the deposition of enormous quantity of sediments.

The maximum subsidence took place in the southern part of the Quaternary basin which corresponds to the Broach block of the Cambay basin. The subsurface data suggests a large synclinal folding of the strata termed as the Broach syncline. Both the Tertiary as well as the Quaternary sediments are affected by this synclinal folding. Corresponding anticlinal structures are recorded in the exposed Upper Tertiary rocks south of the Narmada geofracture and north of Mahi river. Sudhakar et al. (1970) identified Quaternary deformation in the south Cambay basin which produced markedly asymmetric, well defined folds with sharp axis trending ENE-WSW or E-W (Fig. 8.3). They have noted a few minor tear faults in the stepper limb which were produced due to differential advancement of the fold. They have also envisaged some tear movement along the basin edge during Quaternary as the E-W folds terminate against the fault.

The trend of the Quaternary folds are almost at right angles to the NNW-SSE structural trend of the Cambay basin. The Quaternary deformation of Sudhakar et al. (1970) is of Lower Pleistocene age as the younger sediments exposed in the river valleys do not show any effect of the deformation observed in the subsurface. The tear faults and folds indicate existence of compresssive stresses during this period. The Narmada geofracture has played a significant role in the Lower Pleistocene deformation in this part. DSS studies (Kaila et al., 1981) have marked the existence of Narmada geofracture a few kilometeres south of the present day Narmada river. Immediately to the south of Narmada geofracture, the Tertiary sediments are exposed at the surface due to displacement along the geofracture during Quaternary. The exposed Tertiary rocks exhibit several anticlinal structures. Subsurface studies have established the continuation of the geofracture into the Cambay basin (Roy, 1991).

The subsurface studies of Roy (1991) show no evidence of wrench movement along the Narmada geofracture as envisaged by Das and Patel (1983) and Talukdar

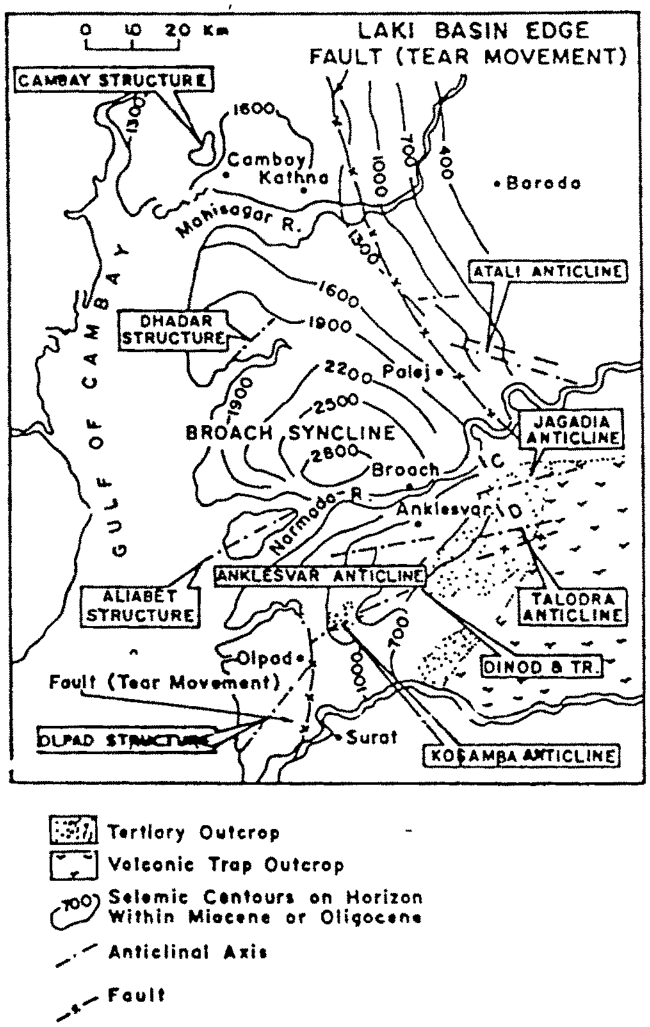


Fig. 8.3 Quaternary subsurface folds and faults in southern Cambay basin (after Sudhakar et al., 1970).

and Rao (1979). North-south seismic profiles across the geofracture indicate that the fault dies out before it reaches the coast of Gulf of Cambay (Roy, 1991). Behaviour of the Narmada fault as it traverses the Cambay basin is shown in the block diagram (Fig. 8.4). The Narmada fault is near vertical normal fault at depth but becomes markedly reverse near the surface (Fig. 8.5). The evidences of the fold structures on both sides of the Narmada fault suggests that the reverse movement along Narmada fault occurred during Lower Pleistocene due to compressive stresses.

The Lower Pleistocene deformation thus appears to be more intensive in the southern part of the Cambay basin as compared to the northern part. However a general tendency to subside is uniformly seen all over the basin which accommodated huge volume of Lower Pleistocene sediments. The progressive deepening of the basin, seem to coincide with the uplift of Saurashtra horst in the west and rejuvenation of the Aravallis in the NE (Sen and Sen, 1983) and the uplift of the area to the south of Narmada during Quaternary. An uplift of the order of 300 m of the Aravallis has been postulated by Ahmad (1986) during Quaternary.

PHASE II

The phase I came to an end in Middle Pleistocene which coincided with the marine transgression. The bluish mottled clays which forms the base of exposed sediments in the three major river valleys got deposited in the beginning of this phase. The phase II includes the period from Middle Pleistocene to Terminal Pleistocene. This period was largely a period of tectonic quiescence in contrast to the

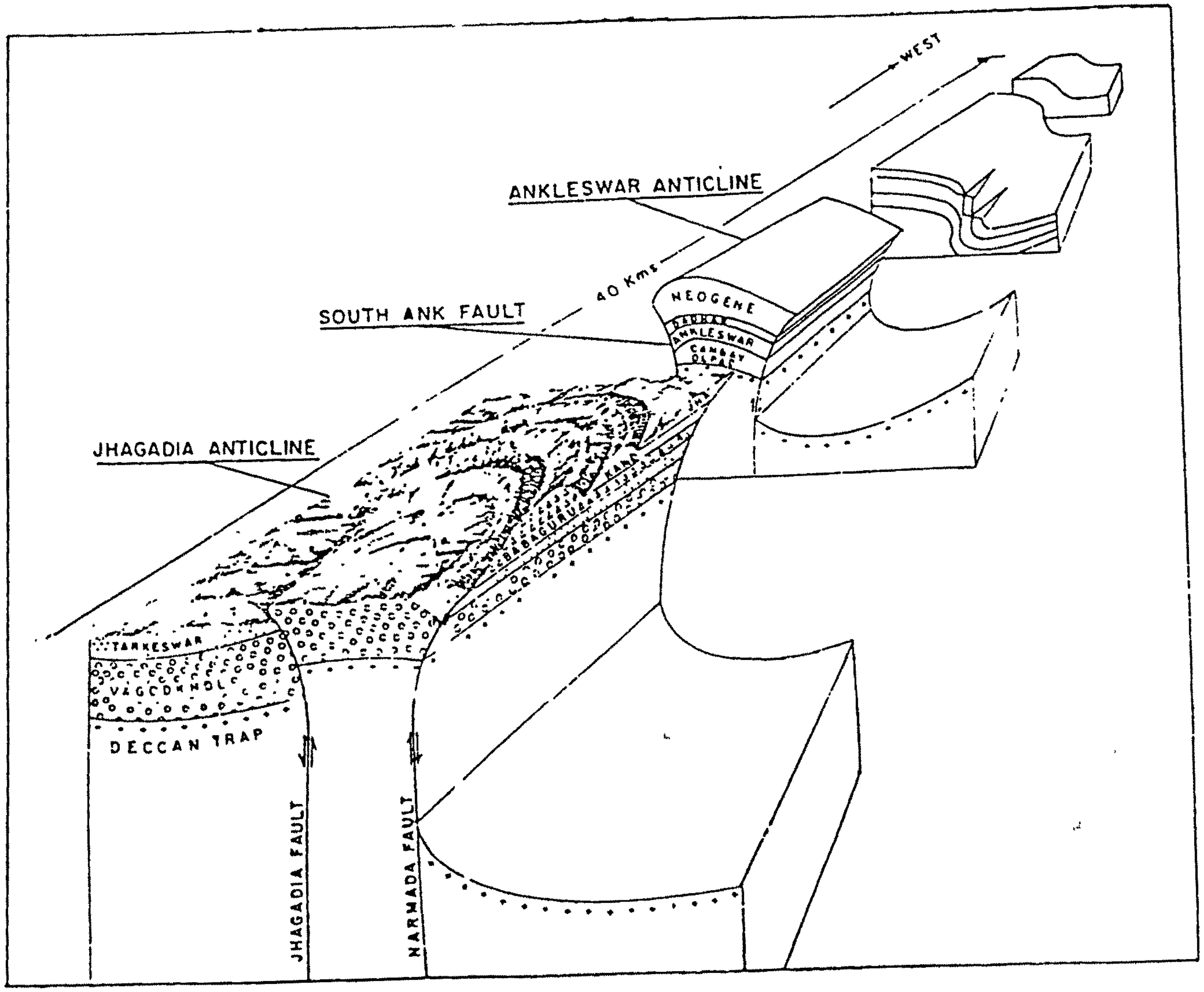
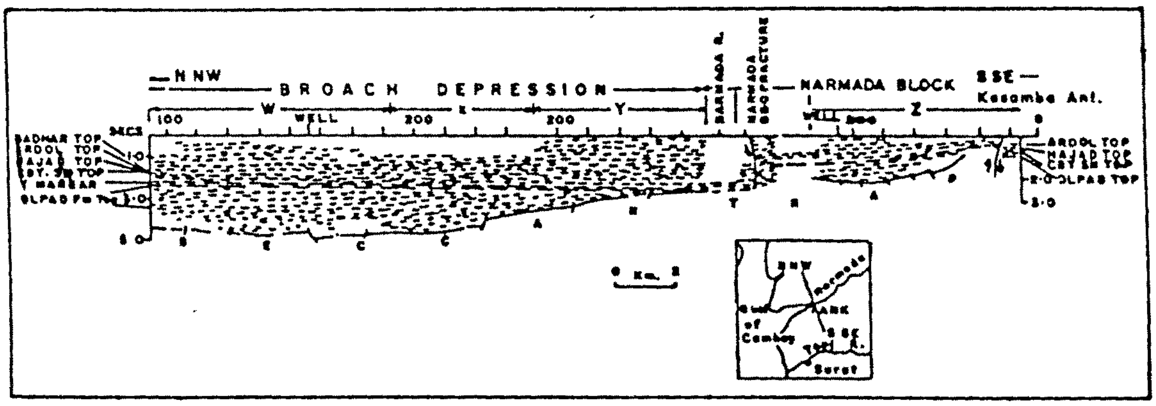
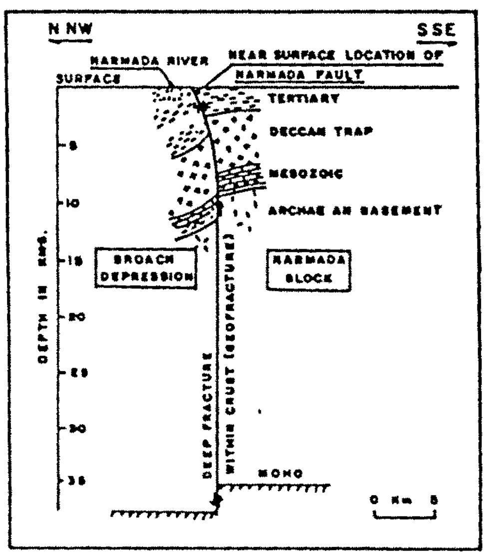


Fig. 8.4 Block diagram showing the nature of Narmada fault (after Roy, 1991).



A



B

Fig. 8.5 A - Seismic section of southern Cambay basin and B - Cross section across Narmada geofracture showing nature of Narmada fault (after Roy, 1991).

Lower Pleistocene. The sediments deposited during this period are exposed along the cliffy banks of the various rivers.

Lithostratigraphic studies on these sediments have established correlatability of the exposed sediment columns in the various rivers which suggest identical paleoclimatic conditions over a wide area. Frequent occurrence of palaeosols in the upper part of the exposed sequence provide testimony to the tectonic stability of the area. However, presence of soft sediment deformation structures between gravel-I and gravel-II indicate a tectonic episode of slow synsedimentary subsidence of the basin.

The bluish mottled clay forming the base of the exposed sediment column, were deposited during the Middle Pleistocene high sea level (Merh, 1992). These clays have yielded shallow marine microfauna (Rachna and Chamyal, 1997). Based on the occurrence of the bluish clays Merh (1992) suggested that the Middle Pleistocene high sea was of the order of +25 m above the present mean sea level. Overlying these clays is a thick sequence of fluvial deposits which are capped by a thin aeolian cover in the entire area.

The occurrence of soft sediment deformation structures between the two gravel units in the lower part of the sequence point to a significant tectonic episode of slow active synsedimentary subsidence. These structures include synsedimentary folds, faults, slump structures, pseudonodules etc. All these structures indicate slow synsedimentary subsidence of the basin along the various step faults related to ECBMF. The gravel horizons suggest rejuvenation of the source area. These tectonic episode perhaps mark the last dying pulses of the major subsidence phase of Lower Pleistocene. This phase of slow synsedimentary subsidence is not observed in the northern part of the basin as inferred by the absence of soft sediment deformation structures in the exposed sediment succession of Sabarmati valley.

The development of three to four palaeosols in the upper part of the sequence indicate tectonic stability of the basin after the deposition of gravel-II. Such multiple palaeosols are characteristic of a long tectonically stable period (Bull, 1990). The wide pediment zone along the eastern margin of the basin is also indicative of tectonically stable conditions (Mayer, 1986) during this period. The tectonically stable conditions prevailed upto the end of Pleistocene

The deposition of aeolian sediments during the last glacial maximum marks the end of phase II of the evolution of the Quaternary basin. Radiocarbon dates of pedogenic carbonate nodules from the red soil exposed at Dabka have given an age of around 23 ky (Hegde and Switsur, 1973) suggesting that the overlying aeolian sediments have been deposited during the period of Terminal Pleistocene aridity. The gently rolling topography of Gujarat plains at various places is due to the stabilised dunes deposited during this period.

PHASE III

The present landscape of the Gujarat alluvial plains is the result of this phase. This phase includes the period from Terminal Pleistocene to Recent. This period witnessed a complex interplay of tectonism, climate and sea level changes. The deposition of the aeolian deposits over the fluvial sediments marked the end of Pleistocene aggradational phase. This was followed by a major erosional phase during early Holocene which resulted in the formation of deep gullies, ravines and cliffy banks and incised entrenched meanders along the various rivers (Fig. 8.6).

The ravine erosion affects the youngest sediments exposed suggesting that this erosional phase post-dates the aeolian deposition. Fluvial incision within the channel accompanied the phase of ravine erosion. The occurrence of Mid-Late Holocene terraces which do not show any sign of ravine erosion indicates that this erosional phase took place in a short period of time i.e. during Early Holocene. This suggests that this erosional phase was aided by tectonic uplift of the area and is not related to the fall in sea level. The Early Holocene was a period of rapid rise of sea level on the west coast of India (Hashimi et al., 1995). This suggests uplift of the area during Early Holocene. This uplift gave rise to 45 to 50 m cliffs of Pleistocene sediments and deep ravines along various rivers. Ahmed (1973) has related extensive ravine erosion to tectonic uplift. The phase of ravine erosion and river incision ceased as the sea reached the post-glacial maximum.

The Middle Holocene high sea resulted in aggradation within the incised river valleys due to the formation of a depositional wedge which extended far into the upstream parts of the rivers. This aggradation phase led to the deposition of sediments ranging from fluvial, estuarine/ tidal and open marine. The landward migrating tide limit and its associated grain size barrier effect (Allen and Posamentier, 1993) obstructed the transport of fluvial material downstream of the upward migrating

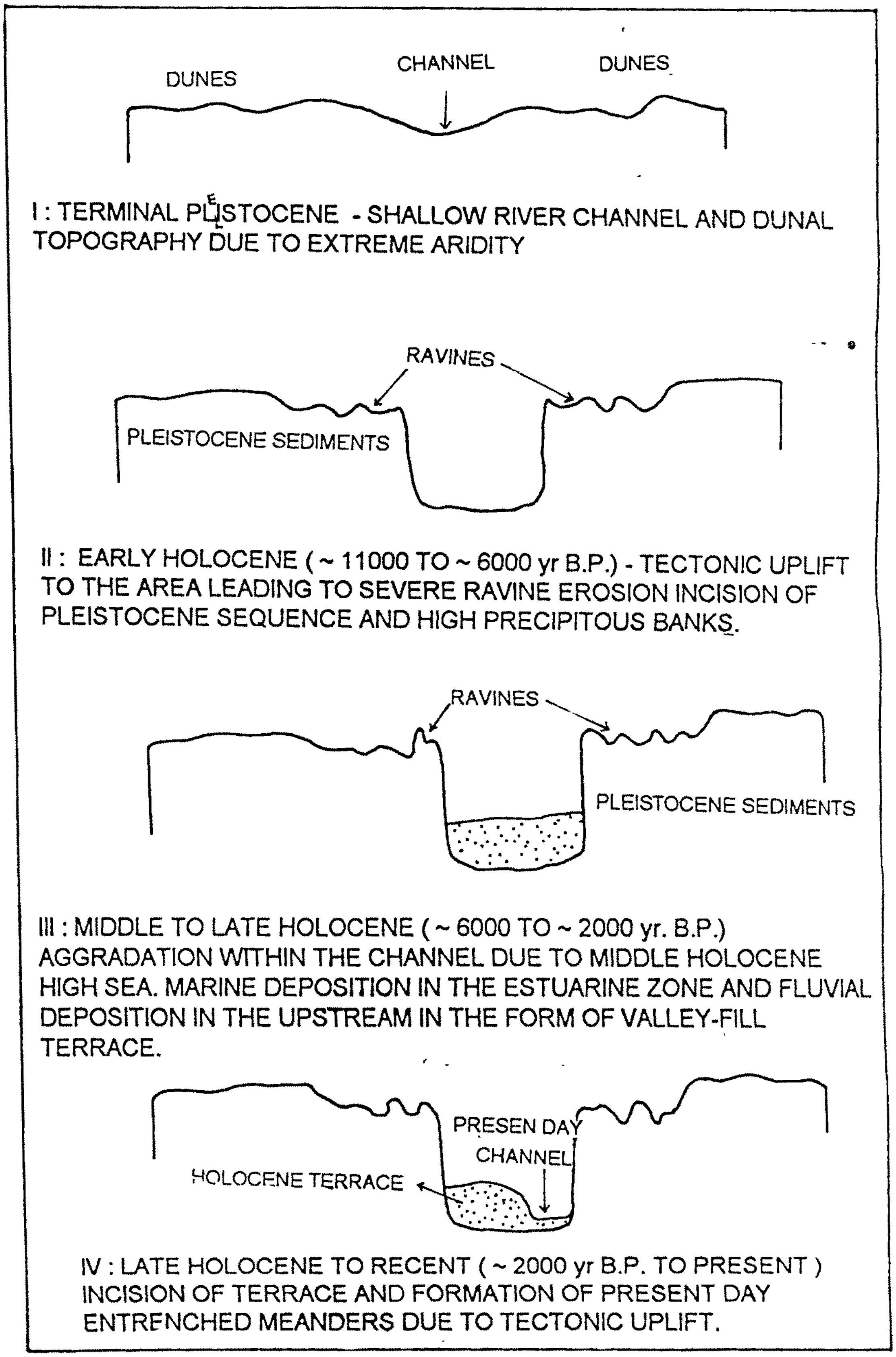


Fig. 8.6 Idealised cross-sections showing Terminal Pleistocene-Recent evolution of landscape around the rivers of Gujarat alluvial plains.

bayline. This led to the deposition of tidal estuarine facies within the lower reaches and fluvial facies within the upper reaches of the river channels. It should be mentioned here that the sea ingress was within the fluvial incised valleys only formed during Early Holocene. The lower reaches of the various rivers were transformed from a fluvial incised valleys into estuaries during this period. A large part of the lower reaches of the Sabarmati river was submerged under the Holocene sea. Tidal to shallow marine deposition took place in the lower reaches and fluvial deposition in the upper parts of the various rivers.

The sea level is presumed to have remained at the same level with minor fluctuations (Kale and Rajaguru, 1985; Chapell and Shackleton, 1986). Absence of regressive facies in the marine terraces in the estuarine zones of the Mahi and Narmada rivers, indicates that the upliftment of the terraces is related to yet another phase of tectonic uplift of the area during Late Holocene to Recent. The seismically induced soft sediment deformation structures in the Holocene terraces of Mahi and Orsang valleys also suggest tectonic instability during this period. Siesmicity of the area specially in the southern part indicates that the tectonic instability of the area continues even today.

The Quaternary tectonic history of the Gujarat alluvial plains worked in this study shows good correlations with the neotectonic studies carried out in adjacent areas. Sen and Sen (1983) have shown Late Quaternary uplift in the Aravallis to the east and north east of Gujarat alluvial plains. Sen and Sen (1983) attributed this to the continued northward movement of the Indian subcontinent. Similar observations of neotectonic activity have been made by Khan and Banerjee (1989) from the trappean highlands to the SE of the study area. Ahmed (1973) attributed ravine erosion to peripheral uplift of the Peninsular shield against the Himalayas. Pant and Juyal (1993) and Juyal et al. (1995) have shown that the evidences of sea level rise on the Saurashtra coast are masked by the emergence of the landmass during Holocene.

Rao et al. (1996) have documented several evidences from the western continental shelf in favour of neotectonic activity during Late Quaternary. They have shown subsidence by atleast 40 m on the north western margin during Holocene. Whiting et al. (1994) attributed the subsidence of the western Indian margin to the loading of the Indus fan. According to them the areas closer to the loading are depressed and the areas to the far are uplifted. This perhaps explains the Holocene uplift of Mainland Gujarat and Saurashtra.