4

TECTONIC FRAMEWORK

CHAPTER 4

TECTONIC FRAMEWORK

GENERAL

The inter-relationship between the sedimentation of alluvial architecture and tectonics is now an established fact. Though the relations between extra-basinal and intra-basinal parameters are not yet fully understood, it is very difficult to explain the sediment relation and geometry of the lithounits occurring in the field by tectonic parameter. The allocyclic (extra-basinal) parameters, include tectonic adjustments and climatic changes, whereas the autocyclic (intra-basinal) parameters, include changes in channel morphology, channel avulsion etc., (Kraus and Middleton, 1987). The two sets of parameters are inter-related with each other. The allocyclic factor controls the intra-basinal (autocyclic) changes. The change in climatic regime and tectonic activity in the basin regulates local variations in sediment discharge, changes in sediment size, valley slopes, fluvial regime, channel directions, high angle flow trends, channel avulsion or migration resulting in aggradation and the uplifts causing the degradation (Schumm, 1986; Alexander and Leeder, 1987; Gregory and Schumm, 1987; Kraus and Middleton, 1987). Even then, it is not possible to identify a single parameter as the dominant control on the geometry and the alluvial architecture (Kraus and Middleton, 1987).

In the case of Gujarat plain the role of tectonism can be highlighted at all stages of their evolution. The control exercised by the various structural lineaments was quite effective and dominant during the evolution of the Tertiary and

Quaternary rocks. The sediment accumulation in structural basins that developed at the close of Cretaceous continued throughout the Tertiary and the Quaternary periods. All along, especially during Quaternary, the factors of glacio-eustasy and palaeoclimate combined to sustain and control the deposition.

According to Biswas (1987), the tectonic activity was initiated as early as the close of Triassic when the Gondwanaland started breaking up, and sometime in the late Cretaceous the western continental margin developed a major rift, as a result of which a regional structural fault-bound depression extending from Rajasthan southward of Narmada and beyond (Fig. 4.1), came into existence. Referred to as Cambay Basin in Gujarat part, it consists of two large fault-bound depressed blocks N-S Cambay and E-W Narmada grabens.

Initially, marine deposition took place in the basin during major part of the Tertiary, but in its later evolutionary phase, mainly during the Quaternary, the filling up was by the fluvial and aeolian sediments, consequent upon the withdrawal of the Tertiary sea. Whereas in the Gujarat plains, the main bulk is a Tertiary sequence confined to the limits of the Cambay Basin, the overlying Quaternary sediments are seen to have overfilled the main basin, spilled over the Tertiary rocks, crossed the bounding fault in the east and deposited even beyond, resting directly over the basement. A large part of these younger sediments is confined to eastern flank of the basin and is dominantly fluvio-marine, fluvial and aeolian. Of course, the limits of the Quaternary deposition are also marked by a succession of parallel faults related to the bounding faults of the Cambay Basin. Post-Tertiary deposition

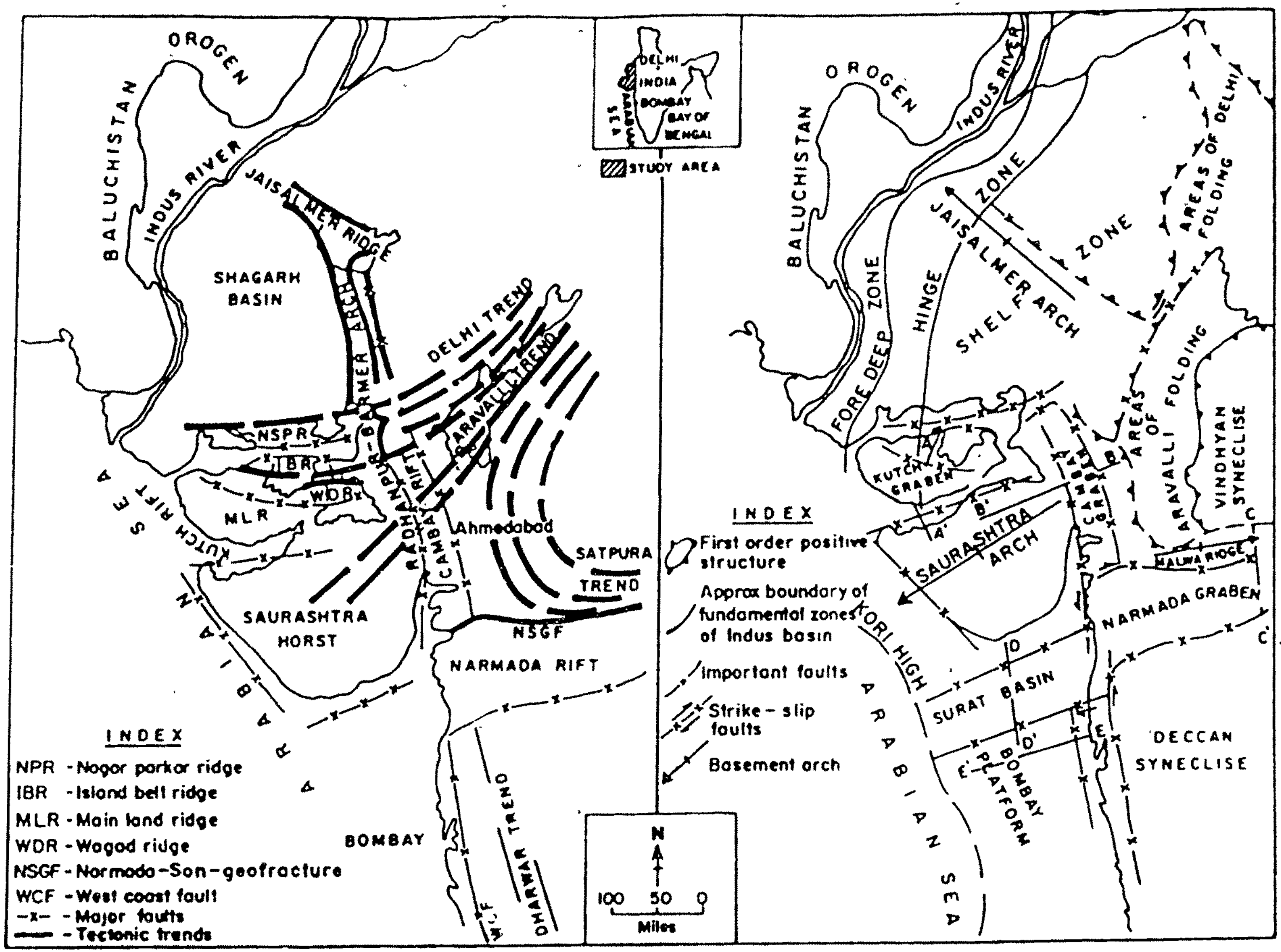


Fig. 4.1 : Map showing tectonic framework of western India (After Biswas, 1987).

also thus comprised an integral part of the geological history of the Cambay and Narmada grabens and the evolution of the Gujarat plains was also closely controlled by the Cambay Basin tectonics. The vast thickness and lateral expanse of the Quaternary sediments thus took place in a partially filled basin of phenomenal dimension, mainly because of the reactivation of pre-Quaternary faults and development of new faults.

A subsidence of the basin concomitant with the accumulation of sediments facilitated deposition of enormous quantity of sediments. This progressive deepening coincided with the uplift of the Saurashtra horst in the west, rejuvenation of the Aravalli in the NE and the uplift of the area to the south of Narmada (during Quaternary). An uplift of the order of 300 m of Aravalli during Quaternary has been postulated by Ahmad (1986).

TECTONIC SETTING

The Cambay Basin extends broadly in a NNW-SSE direction in the onshore and offshore parts of Gujarat. Northward, it swings due NE-SW merging into the Rajasthan Basin. Data generated by the ONGC, mainly on the Tertiary deposits, reveal the basement configuration and the control exercised by faults in dividing the basin into several tectonic blocks or sub-basins. Each tectonic block behaved somewhat differently during the deposition, on account of differential uplifts along the various bounding and transecting faults. The basement typically comprised fault- bound uneven surfaces made up of horsts and grabens. Movements along faults parallel as well as oblique to the main basin, controlled the thickness of sediments. Even the Quaternary deposits in the different parts of the Cambay Basin and its eastern margin show variable thicknesses. Obviously, the pre-depositional and syn-depositional tectonism played a dominant role. Variations in thickness, progressive discordance's and changes in lithofacies are quite often linked to fault scarps, or to external block-tilting of half-grabens, indicating syn-sedimentary faulting processes.

The cross-section showing thickness data (Fig. 4.2) brings out the role of tectonism prior to and during deposition. The varying thicknesses, thus are obviously due to the fact that the sediment accumulation took place in various fault-bound depressions (Maurya *et al.*, 1995). The depositional sites continued to be unstable during the filling up of the basin, as the limiting faults, of the main basin as well as of the sub-basins, have affected the Quaternary sediments. Their reactivation even after the deposition, has been well established. From the deep sounding seismic surveys (DSS) of Mainland Gujarat (Fig. 4.3), it has been established that the various major bounding faults, extend upto the Moho discontinuity (Kaila *et al.*, 1981a).

The Cambay Basin is bound by two en-echelon faults (Raju, 1968). These two sub-parallel faults, Eastern Margin Cambay Basin Fault (EMCBF) and Western Margin Cambay Basin Fault (WMCBF) trending in NNW-SSE direction. These faults exhibit NE-SW, NNE-SSW and E-W faults that have segmented the basin into four major blocks (Chandra and Chowdhary, 1969). These faults are

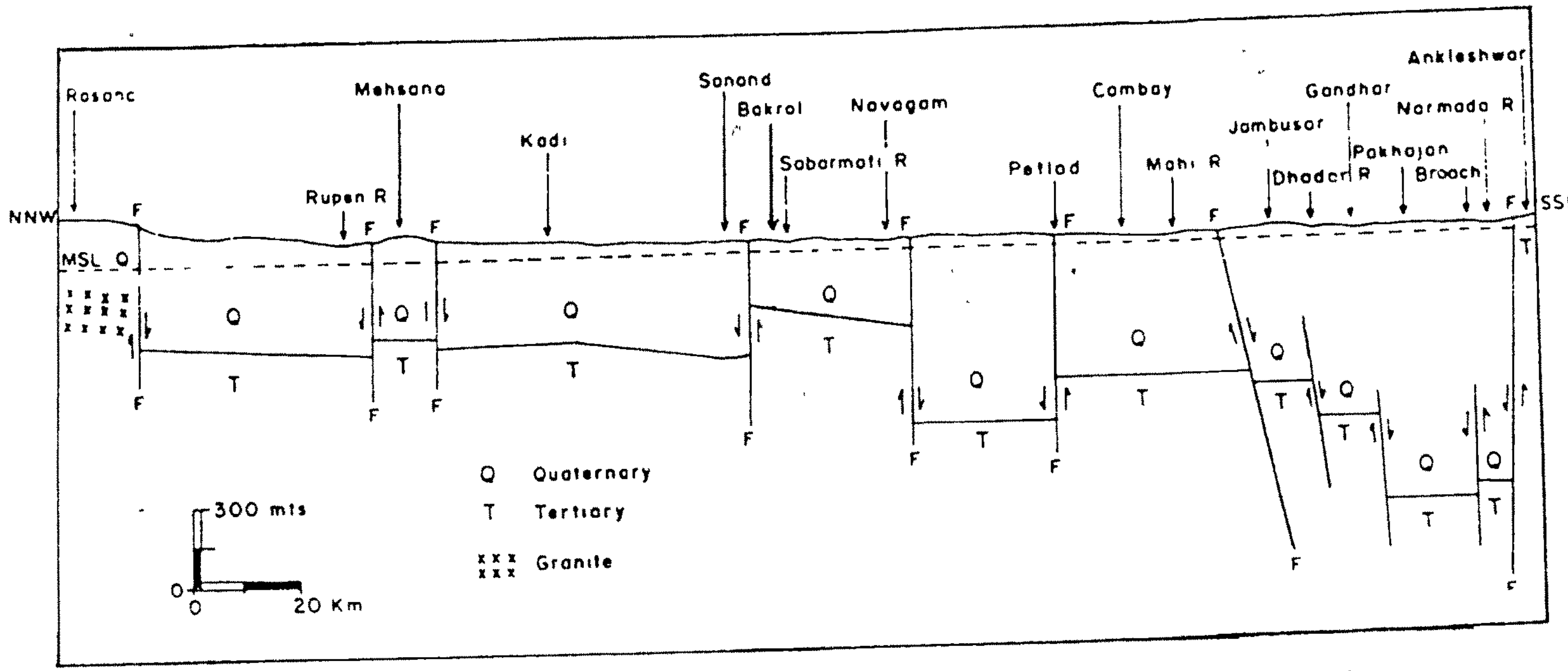
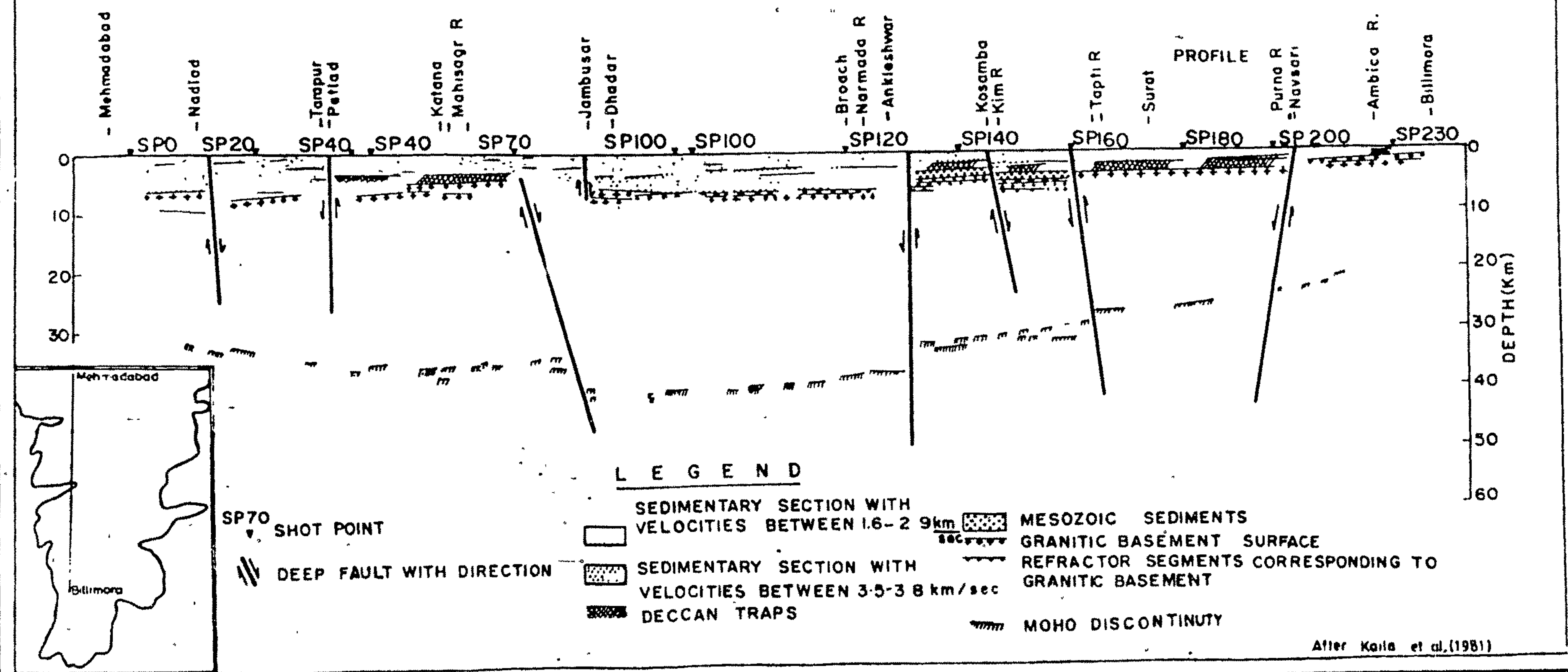


Fig. 4.2 : Schematic NNW-SSE cross section of the Quaternary basin, based on thickness data obtained from ONGC. (After Maurya, *et al.*, 1995).

Fig. 4.3 : N-S DSS profile across Mainland Gujarat (After Kaila, *et al.*, 1981).



believed to have been reactivated during the Quaternary (Bedi, 1978; Pant and Chamyal, 1990). These structural lineaments were responsible for the formation of grabens and half-grabens that are well evidenced by the variable Quaternary sediment thickness.

STRUCTURAL PATTERN

The present Mahi basin is bounded by Cambay Graben in the south and the Aravalli orogenic belt in the NE (Fig. 4.1). The lineament map of the study area was prepared using satellite imageries, topographic sheets and incorporating published work (Bakliwal and Ramasamy, 1987) (Fig. 4.4). The Precambrian Aravalli orogenic belt comprises major lineaments trending NNE-SSW, NW-SE and ENE-WSW. The Mahi basin in its upper reaches comprises three major structures, viz. (i) Rakhabdev lineament trending NNW-SSE, (ii) Udaipur-Sardarpur lineament trending NNW-SSE and (iii) Jaisalmer-Barwani lineament trending WNW-ESE have controlled the drainage and were responsible for shaping the basinal landforms (Bakliwal and Ramasamy, 1987; Ramasamy, *et al.*, 1991). A fracture parallel to Jaisalmer-Barwani lineament marks the geomorphic divide between the rocky uplands and alluvial plain. Some of these lineaments run for long distances 300 to even 1000 km cutting across Precambrian metamorphics of the Aravalli Supergroup and Cretaceous Deccan basalts. These appear to have been active during the Proterozoic to Cenozoic (Bakliwal and Ramasamy, 1987). The major Cambay basin lineaments trending NNW-SSE, NE-SW, E-W and NNE-

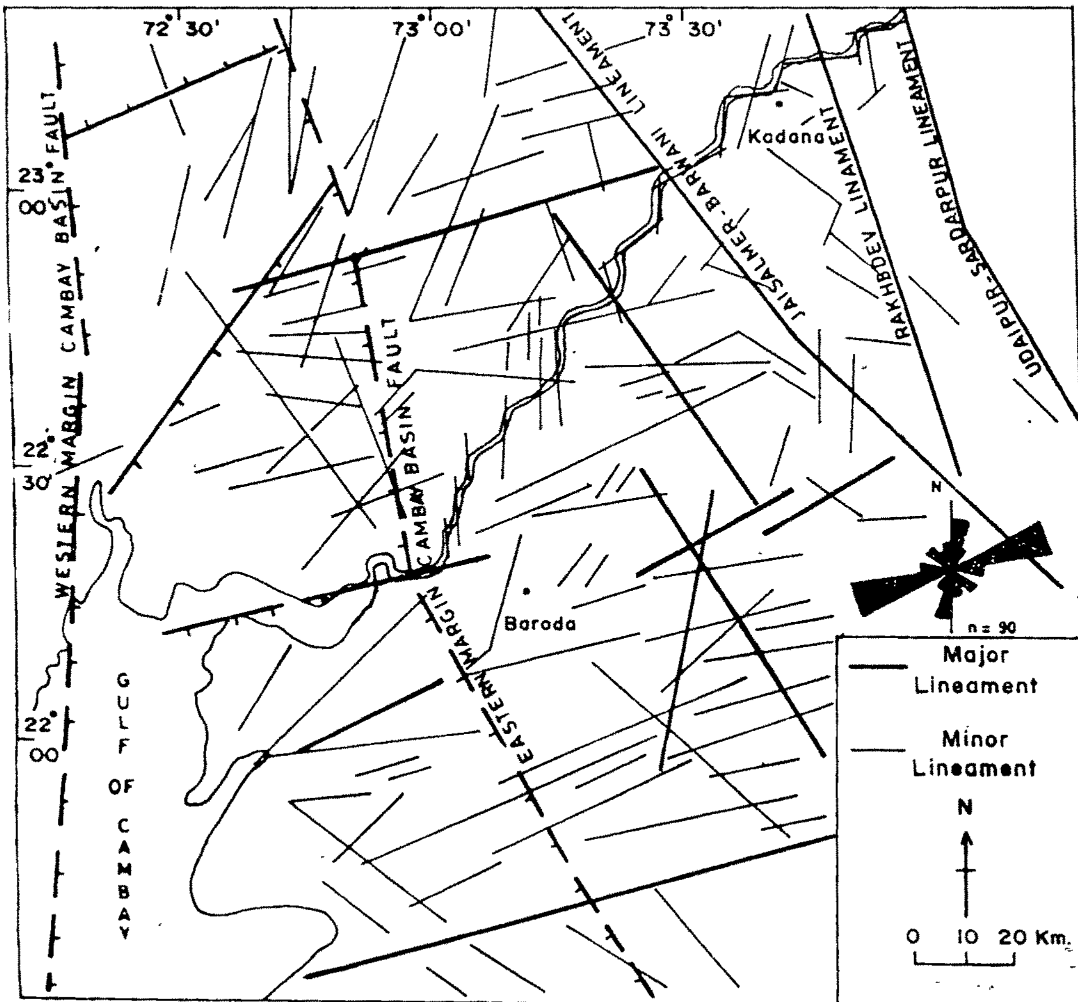


Fig. 4.4 : Lineament map of the study area (Based on Bakliwal and Ramasamy, 1987; Chandra and Chowdhary, 1969).

SSW have influenced the Mahi basin in its lower reaches, that have resulted into the formation of graben and half-graben structures evidenced by variable sub-surface thickness in various blocks, controlled the drainage pattern, and ravine development along the valley side due to subsequent upliftment of the fault bounded horst blocks (Bedi, 1978; Pant and Chamyal, 1990; Maurya *et al.*, 1995). The subsidences and uplifts along various pre-existing fractures during Quaternary created the variable alluvial architecture marked by different high energy sedimentary structures as well as the manifestation of the present day landforms and channel characteristics.

NEOTECTONISM

The tectonic adjustment in the Mahi basin is complex. Not much evidence related to tectonic controls are observed in the field. The field manifestation of the changes in the various landforms and the discordance in the sediments influenced by the tectonic activities are obliterated by various aggradational and degradational events, so the exposed sediment columns have not preserved much evidences of the late Quaternary tectonic events. The alluvial channels are sensitive indicators of changes caused by active tectonics (Schumm, 1986; Gregory and Schumm, 1987). The river channel often show change in its morphology characterised by local development of entrenched meanders, local development of braided pattern, local widening or narrowing of the channel, straightening of channel, deep incision by channel in the alluvium as well as in the rocky upland, sudden change in flow trends, distorted meanders, cut-off channels etc. (Schumm, 1986; Alexander and Leeder, 1987; Singh *et al.*, 1996).

To understand the tectonic complexities in the area various geomorphic landforms and changes in the present day channel morphology including main trunk stream (Mahi channel) and its major tributaries were considered. Evidences of active tectonic and the neotectonic activities are described below :

1) The trunk stream as well as its major tributaries shows a horse-shoe shaped drainage in the upper reaches (Fig. 4.5). The main channel (Mahi) and its major tributaries like Anas and Panam rivers flow almost parallel and show a similar trend. These flow from SSE to NNW direction and show a sudden deviation to ENE-WSW and NNE-SSW direction. This deflection in flow is controlled mainly by the NNW-SSE, ENE-WSW and NNE-SSW trending fractures, such deflections in the streams are strong indicators of neotectonism (Schumm, 1986; Centamore *et al.*, 1996; Singh *et al.*, 1996). The NNE-SSW trend conforms the new trend of Mahi channel in the alluvial plain. The regional slope of the basin is towards WSW to W (Fig. 4.6), but the present day Mahi channel appears as slope deviatory and flows in SSW direction. This suggests that the channel is controlled by the reactivated older fractures in the alluvial plain.

2) The rocky uplands in the northeast comprise various denudational landforms and the channel morphology reveals strong tectonic control (Fig. 4.7). The area between Lunavada and Kadana in the uplands was considered for this study. The area comprises numerous tightly folded hog-back ridges of quartzites, which at

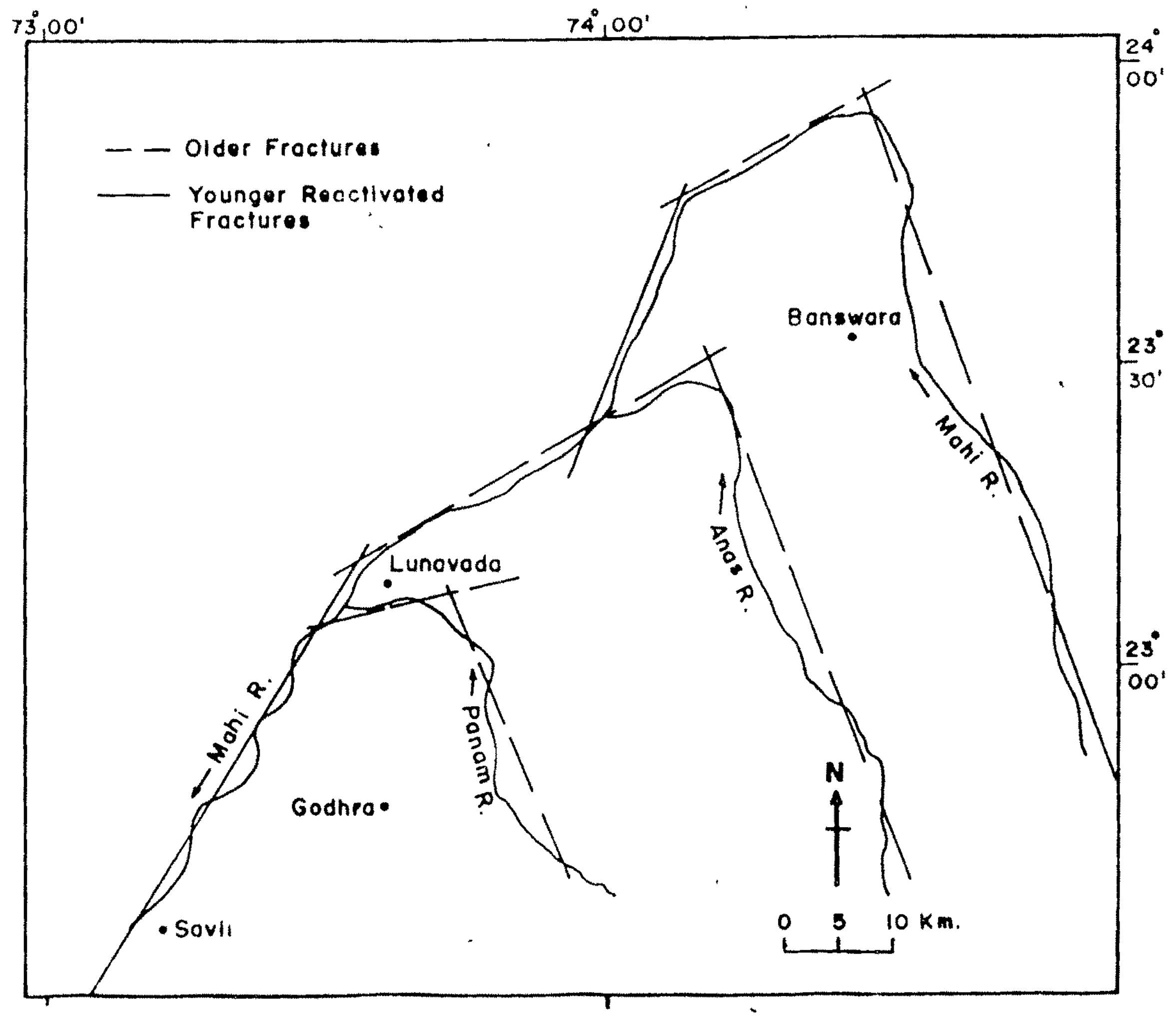


Fig. 4.5 : Schematic map explaining U-Shape of Mahi and its tributaries.

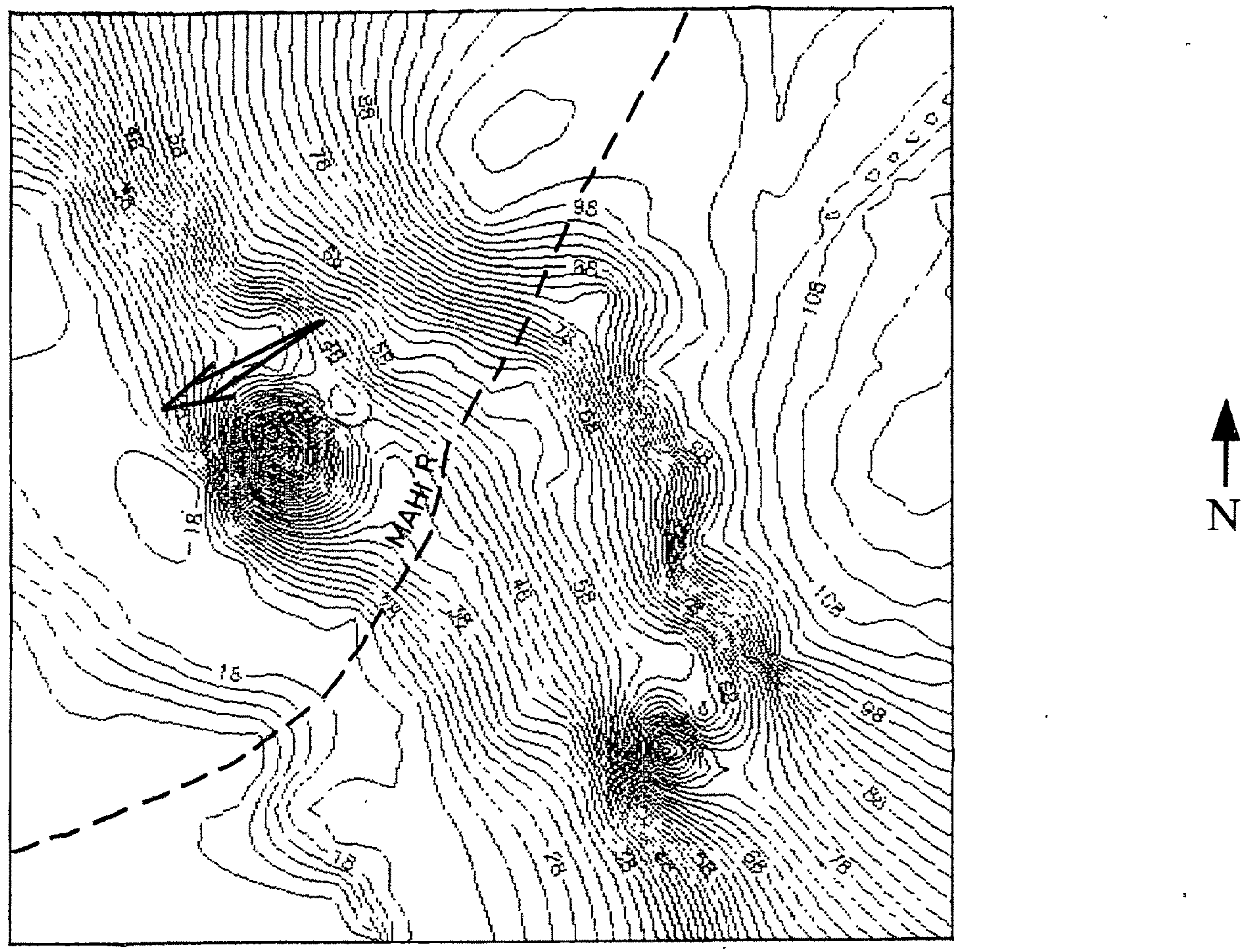


Fig. 4.6 : Contour map of the study area showing WSW regional slope.

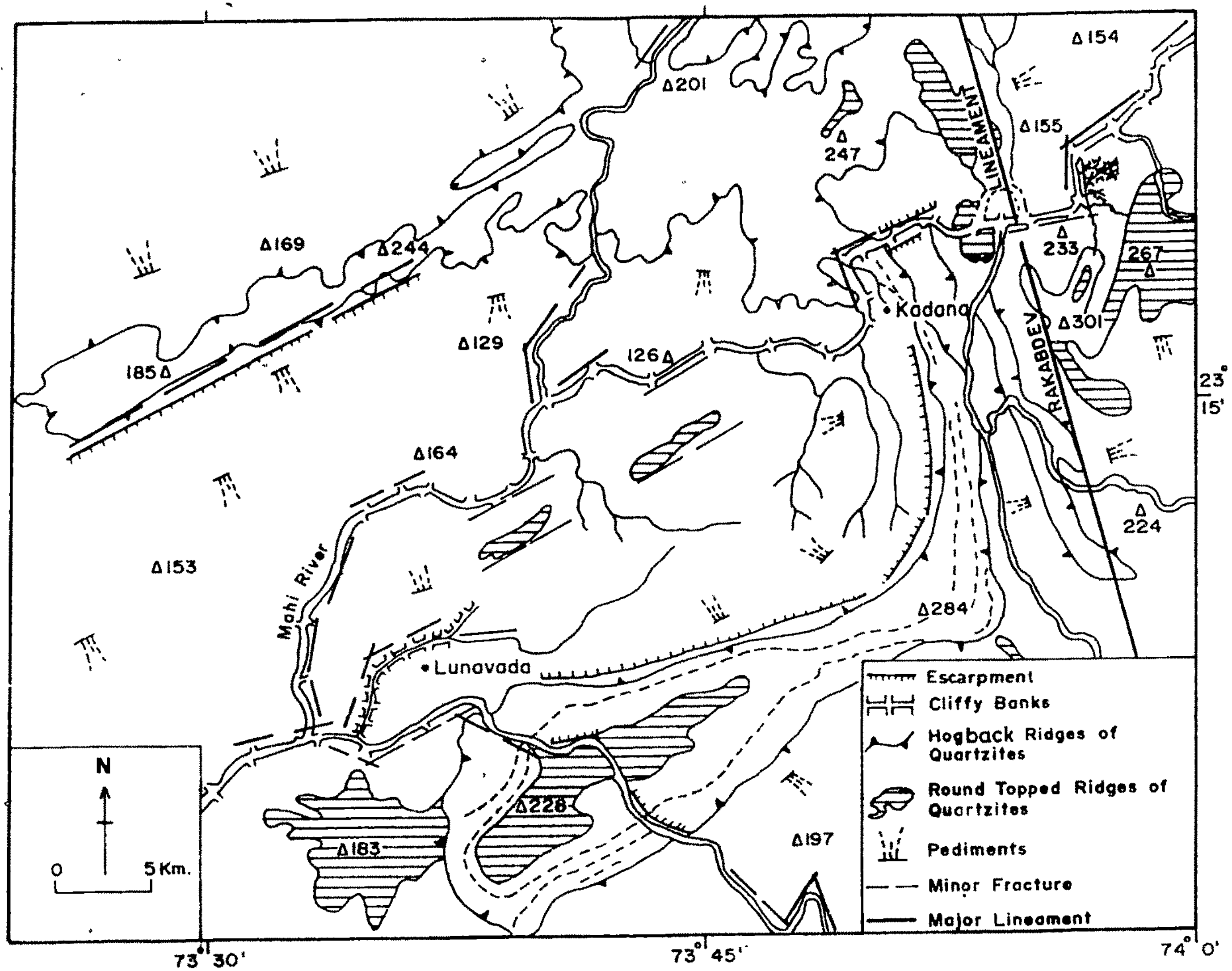


Fig. 4.7 : Morphotectonic map of the upland area around Kadana and Lunavada.

places shows almost flat to rounded top surfaces (Plate 4.1). These flat to rounded topped surfaces mark the palaeo-erosional surfaces and are indicative of upliftment in the area during Quaternary period. The asymmetrical nature of the hog-back ridges is characterized by gentle slope on one side and steeper on the other, forming well-developed escarpments are suggestive of tectonic control. The tectonic activity in the area has also influenced the flow trends and morphology of the channels (Fig. 4.7). The drainage in the area shows cut-off channel near Kadana, right angle turns or sudden deflection in the trend, straightening and narrowing of the valley, deep entrenchment creating vertical rocky cliffs etc. All these features suggest strong structural control (Schumm, 1986; Alexander and Leeder, 1987; Gregory and Schumm, 1987; Centamore, *et al.*, 1996; Peulvast *et al.*, 1996). The major tectonic orientations that have influenced the area are NNW-SSE, NNE-SSW and ENE-WSW, conforming the regional structural pattern of the Mahi basin.

3) In the rocky uplands, the Quaternary sediments are found deposited in pockets bounded by the quartzitic hills on either sides. The major tectonic orientation that influenced the area is NNE-SSW (Fig. 4.8a) as shown by the maximum azimuth of the rosette. Near Kadana, on the face of silty-clay pedogenised lithounit slickenside striations have developed (Plate. 4.1 and Fig 4.8b). These suggest strike-slip movement along NNE-SSW trending fractures. The slickensides are also suggestive of post-depositional movements that probably deflected the flow trend of channel from NNW-SSE.

Plate 4.1 : Close-up view of slickensides on the exposed face of the silty-sand unit at Kadana.

Plate 4.2 : Folded calcrete layers in stratified sand at Rayka.

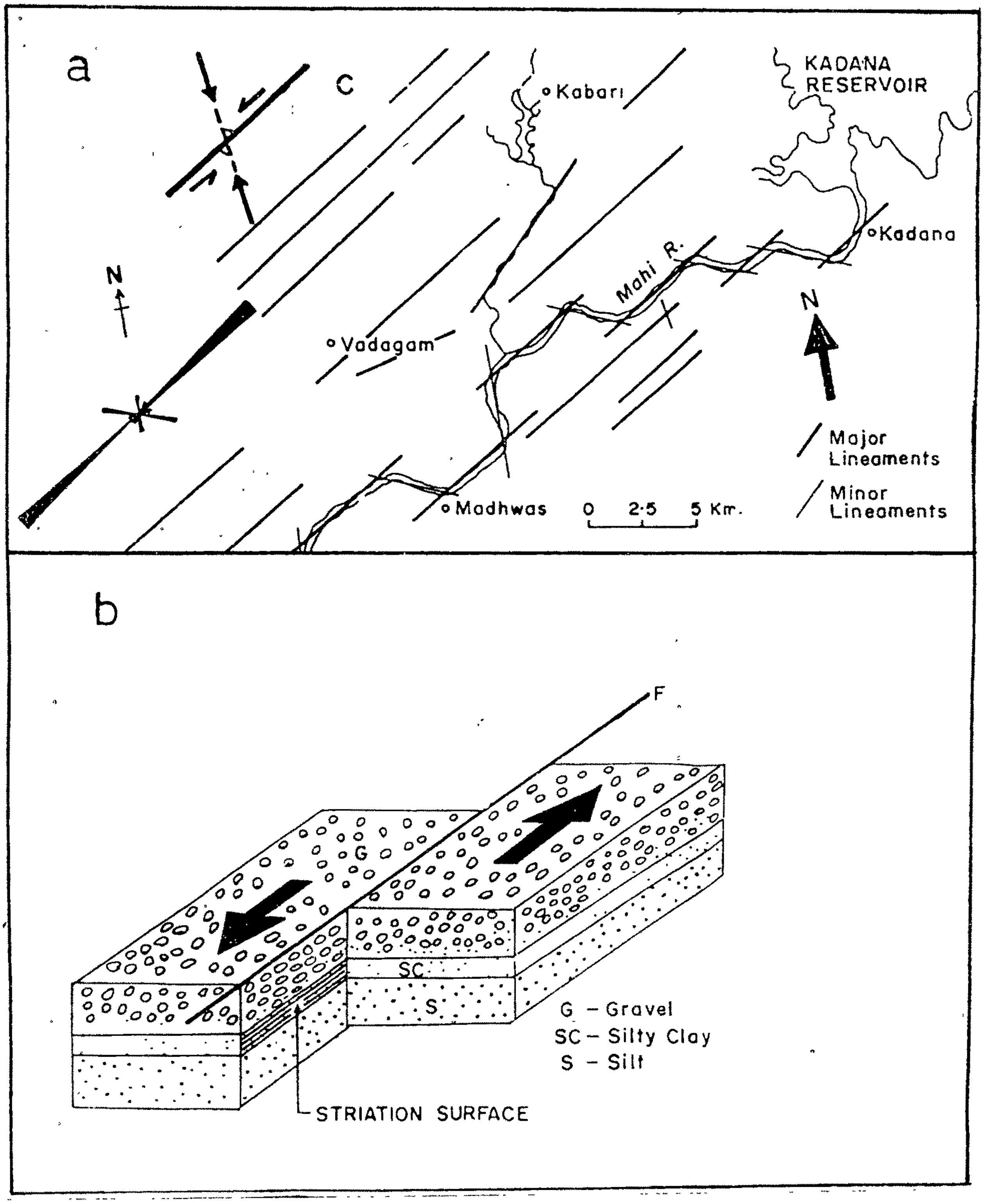


Fig. 4.8 : a) lineament map of the area around Kadana
b) Schematic block diagram showing the development of slickensides.

4) The tectonic activity has played an important role in controlling sedimentation pattern in the area. The post-depositional as well as syn-depositional tectonic features are clearly observed at some places in the basin. These features are evidenced by well-developed folds in the horizontally stratified sand lithounit (Maurya *et al.*, 1997). In the lower reaches near Rayka the exposed sediment succession shows folded calcrete layers within the horizontally stratified sand lithounit (Plate. 4.2). The folding appears to have resulted due to tilting of the block towards NNE caused by the upwarping along the minor normal faults trending ENE-WSW. From the occurrence of the fold pattern it can be deduced that the seismic event was not of large magnitude, and the lithounit was folded before the formation of the hard pan calcrete layers. Because the brecciation is not at all seen along the folded layers, and the deformation was during the plastic state of the sediments. Further downstream minor normal fractures have given rise to slump structures (Plate 4.3), evidenced by tilting of horizontally stratified sand layers showing sudden dip of around 18°-19°, as well as change in foresets dip angle of planar cross-stratified gravel of around 31°-32°. This suggests of slope instability and the bank failures caused by the seismic events (Alexander, 1987). The post-depositional fractures are well evidenced by the set of conjugate fracture pattern preserved in the trough cross-stratified conglomerate unit. The sets of conjugate fractures trending NNW-SSE and ENE-WSW are observed at Singrot (Plate 4.4). These reactivated fractures have

Plate 4.3 : Slump structures in the calcretised sandy silts at Rayka.

Plate 4.4 : Conjugate fractures trending NNW-SSE and ENE-WSW in trough cross-stratified calcrete conglomerate near Singrot.

controlled the path of the present day channel in the lower reaches (Pant and Chamyal, 1990).

5) The deformation in the valley is also reflected in the longitudinal profile (Schumm, 1986). The longitudinal profile of the Mahi channel from Saranpur (in rocky uplands) and Dhuvaran (near its mouth) reveals four concave and three convex segments (Fig. 4.9). These concavities and convexity are ideal manifestation of downwarping and upwarping in the basin or the valley floor (Schumm, 1986; Gregory and Schumm, 1987). The channel profile reveals that the gradient between Saranpur upto Juna Shihora is steeper, while in lower reaches it marks gentler slope between Poicha to Dhuvaran (Fig. 4.9).

The warping in the Mahi valley has created various geomorphic landforms and has also influenced the morphology of the channel. Numerous features like gully erosion, local meander, straightening of the valley, local braidation, almost right angle deviation of channel suggestive of the role of active tectonism have been observed (Schumm, 1986; Gregory and Schumm, 1987). Few such examples are described below :

a) In alluvial plain between Kabariya (located on the left bank of Mahi) and Waghpura (also located on the left bank), the channel shows sudden widening and development of local braid pattern (Fig. 4.10). In the upstream of Kabariya the channel is narrow (0.5 km) and downstream the channel shows width of about 1.5 km (Fig. 4.10). This type of channel morphology indicates sudden change in gradient and marks the area below the axis of uplift (Reading, 1986;

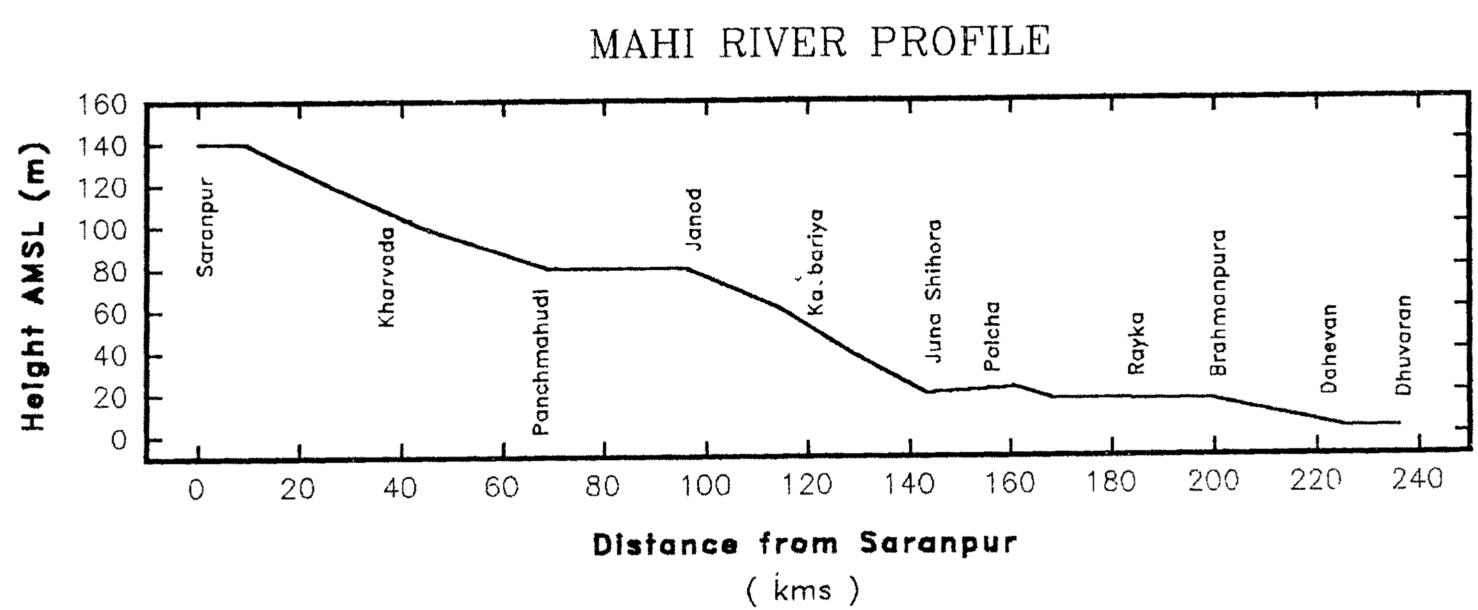


Fig. 4.9 : Longitudinal profile of the Mahi river between Saranpur and Dhuvaran.

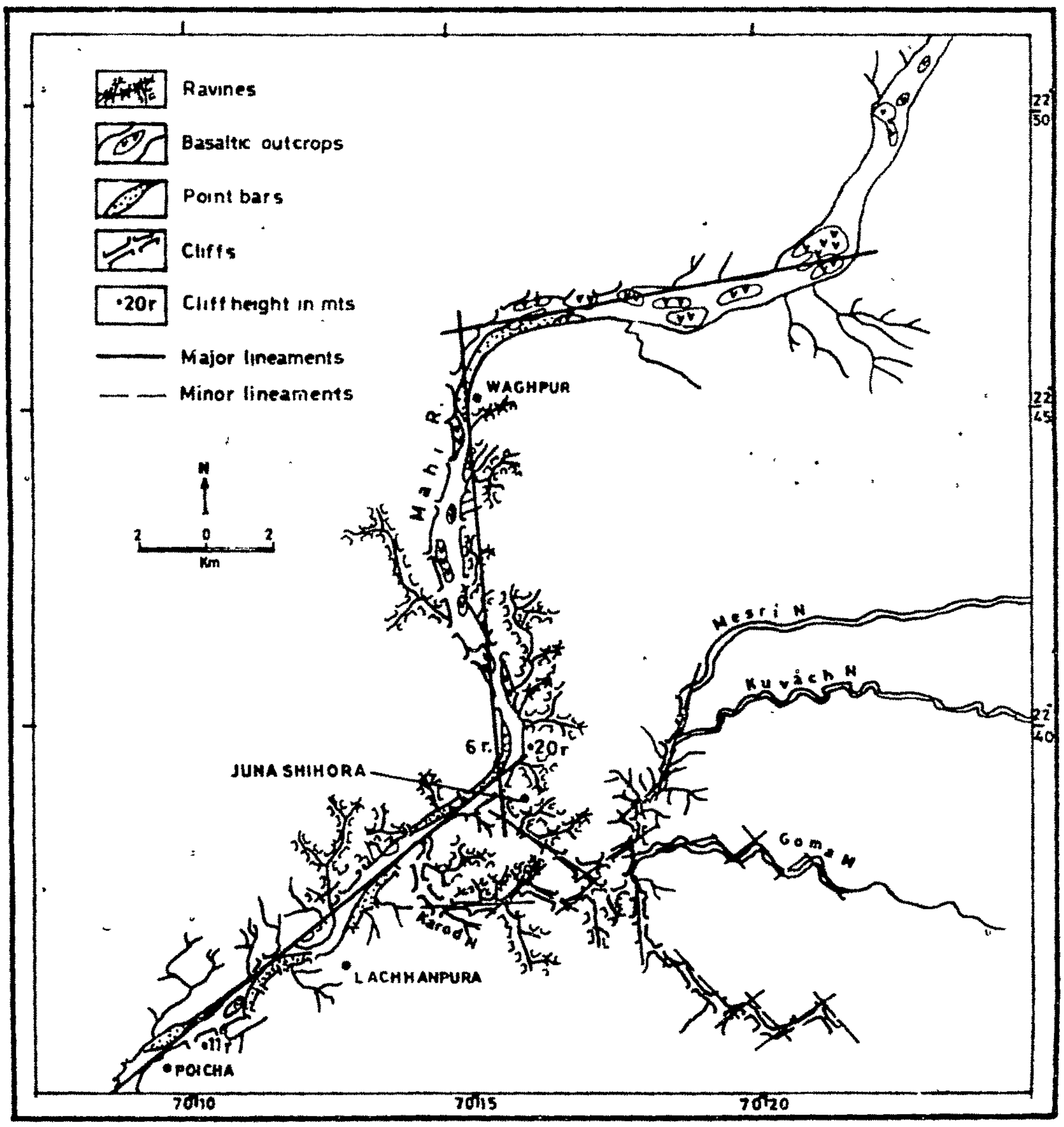


Fig. 4.10 : Morphotectonic map of the area around Juna Shihora.

Schumm, 1986; 1993), the channel further downstream of Waghpur narrows down and shows incision giving rise to 20 m high cliffs indicating uplift. The uplift in the area is also evidenced by highly dissected surface (marked by ravines) on the left bank. The change in right angle flow trend from almost E-W to N-S near Waghpur suggests fracture control (Centamore *et al.*, 1996).

b) Farther downstream of Poicha (Fig. 4.10) the profile shows a zone of convexity. The gradient of the valley floor is very gentle. The upwarping has led to slight increase in slope, due to which the channel has incised the alluvial sediment succession as 28-34 m high cliffs. This is a clear indication of upliftment in the area and the moderately meandering pattern of the stream also suggests the upwarping and fracture control (Bedi, 1978; Schumm, 1986; Pant and Chamyal, 1990; Schumm, 1993; Malik, 1995).

6) To understand the overall tectonic scenario, the lineament map of the Mahi basin was prepared using Survey of India topographic sheet on 1:250,000 and 1:50,000 scales. The basin area was divided into two zones i.e., A and B. B- the rocky uplands and A - the alluvial and coastal zones. The lineament trends were drawn considering variation in the channel characteristics like straightening of the channel, sudden deflection in the flow trends, cut-off channels, distorted meanders, change in channel morphology like local widening and narrowing of the channel, local braidation. On the basis of the lineament map individual trends were measured and individual rosettes were prepared (Fig. 4.11), and are tabulated. The lineaments in the rocky uplands (segment-B) show dominant

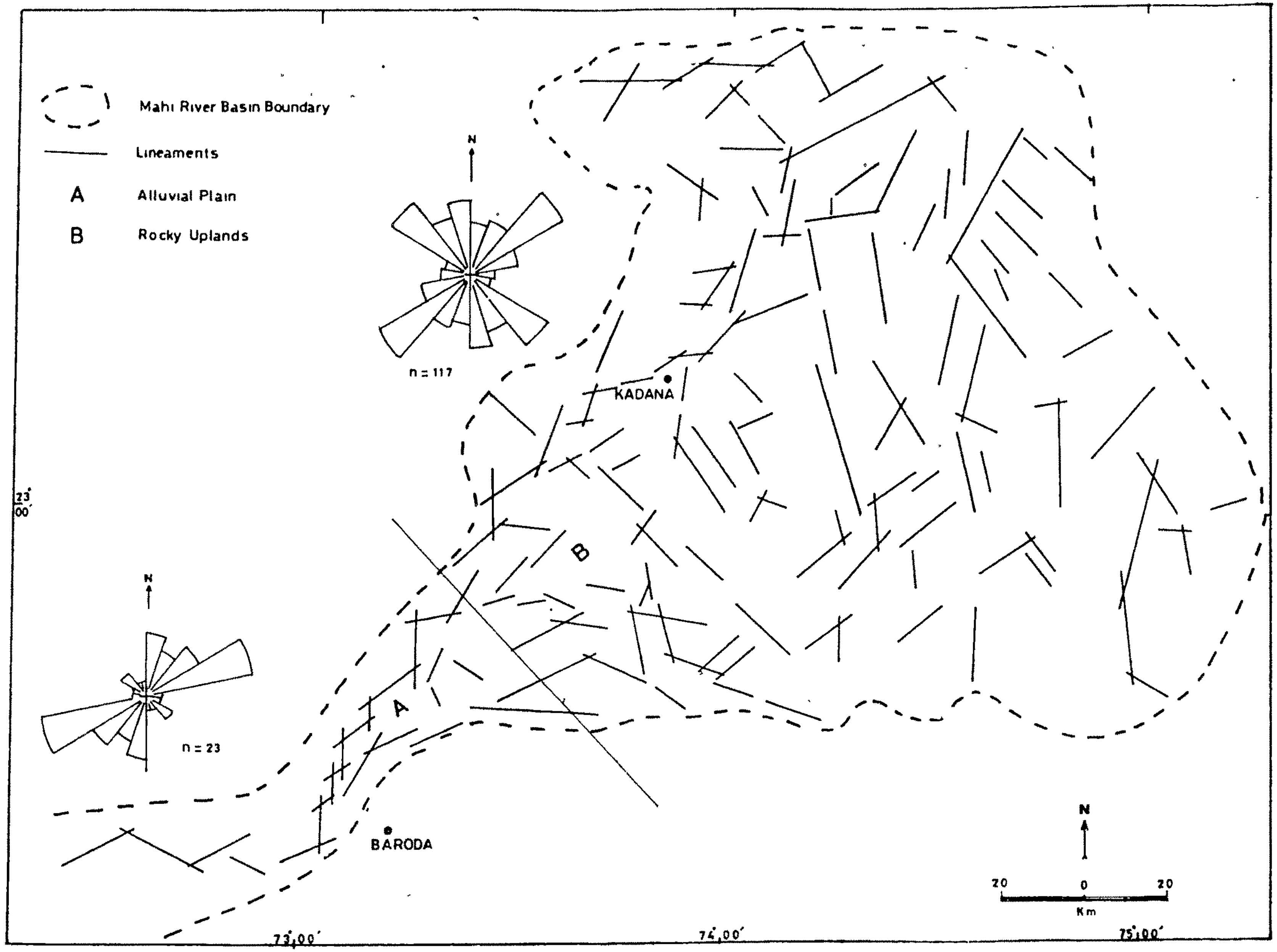


Fig. 4.11 : Map showing lineament trends of the Mahi basin.

NNE-SSW, ENE-WSW and NW-SE trends, the major direction being ENE-WSW. This trend conforms with the principal tectonic orientation of the area that represent the major Precambrian Aravalli trend (Fig. 4.4). The lineaments (in segment - A) show dominant ENE-WSW and NNE-SSW trends, ENE-WSW as major direction. This suggests that the ENE-WSW trending lineaments have played important role in controlling the channel. From the lineament analysis, it is clear that the ENE-WSW, NNE-SSW and NNW-SSE are the fractures related to the regional Precambrian and Cambay basin tectonic trends and reactivated during the Quaternary period which played important role in controlling the channel trends.

Area in the basin	Major lineament trends
Alluvial Plain Segment - A	ENE-WSW and NNE-SSW, composite rosette show ENE-WSW as major direction.
Rocky Upland Segment - B	ENE-WSW, NNW-SSE and WNW-ESE, composite rosette show ENE-WSW as major direction.

TECTONIC HISTORY

The structural history of the lower Mahi basin since its inception right upto almost Sub- Recent, can be chronologically arranged as under:

i) ***Post Mesozoic reactivation of N-S and NNW-SSE Precambrian faults as also of Narmada geofracture:*** This event gave rise to Cambay Basin a structural depression. This happened at the advent of the Cenozoic. Two regional faults that limited the downfaulted block, have been delineated by the ONGC, and referred to as Western Margin Cambay Basin Fault (WMCBF) and Eastern Margin Cambay Basin Faults (EMCBF) (Figs. 4.1 and 4.4). Varying trend of these two bounding faults from south to north and even those of the Rajasthan Basin, is a manifestation of the combination of faults with different trends, following one or other directions of fracturing. Whereas smaller faults were responsible for the horst and graben topography of the Cambay Basin basement over which Tertiary sediments were deposited, somewhat larger faults trending NE-SW appears to have dissected the main basin into 4 sub-basins. Probably, several step faults east of and parallel to EMCBF, also simultaneously developed, thereby providing a wide expanse of low ground, which later on became the site of Quaternary deposition.

ii) ***Differential movement along the various faults all - throughout the Tertiary and Quaternary deposition:*** Variable thicknesses especially in the Tertiary sequences are attributed to this syn-depositional tectonism. Variable thickness of Quaternary deposits in the various structural blocks, indicate continued vertical movement during their accumulation. However, it appears that the intensity of this tectonic activity progressively decreased so much that during upper Pleistocene and Holocene, it practically died down, or at least considerably reduced.

iii) ***During Quaternary E-W to ENE-WSW fracture trends continued to be effective in the manner that they provided preferred directions for the various rivers of the older drainage system:*** It is so obvious that numerous streams flowing SW to W from the eastern rocky highland impinged into the basin, crossing successively the various step faults depositing finally transected the EMCBF over Tertiary succession. The older fluvial system (which now stands disrupted) relicts of which are well preserved, point to a control exercised by the regional southwestward slope and the E-W to ENE-WSW fractures. Almost entire part of the sediment thickness (mostly fluvial) was the result of this ancient river system, which is clearly indicated by the different palaeocurrent direction of the older sediment succession. The process of fluvial aggradation came almost to a close with the onset of the Terminal Pleistocene aridity. This last fluvial aggradation was followed by the aeolian aggradation, that marked by the dunal activity.

iv) ***Last major phase of tectonic activity took place sometime in early Holocene, after the aridity:*** During this tectonic event, numerous lineaments trending NNE-SSW, ENE-WSW (conforming to that of the Mahi) dissected the earlier deposited Quaternary continental succession, disrupted the older rivers, deflected their courses, such that Sabarmati (Sridhar, *et al.* 1994) and Mahi started flowing along new channels. Cliffy channels of Mahi flow in a zig-zag manner, simulating entrenched meanders, straight valley formation infact reflects the influence of (?) intersecting or en-echelon fractures that developed in soft sediments during this late tectonism. The rivers flowing along these fractures, in due course have given rise to loops and curves which resemble and behave and to a certain extent simulate true meanders, making it difficult to recognize the tectonic control. This phenomenon is very well reflected in the development of vertical cliffs and deeply cut ravines of about 20-35 m deep gullies, sinuous channels of trunk stream as well as those of major tributaries. This late fracturing was responsible for the drainage disruption and development of new channel for Mahi. This tectonic episode is recorded all over the Gujarat plains and its effect is seen in most rivers, right from Luni river in the extreme north upto Narmada in the south (Sridhar *et al.*, 1994; 1997a, 1997b). This tectonic event is attributed to the Sabarmati river as it flows to-day, new course of Mahi and the capturing of Orsang by Narmada.

An important and striking feature of this tectonism and fracturing seen in Sabarmati and Mahi, is a gentle northwesterly and southwesterly tilt of the newly faulted blocks respectively, as a result of which there occur no tributaries on the respective right banks in each case and smaller streams meet the main rivers only along the left banks. Also, the areas to the west of the middle segment of Sabarmati and lower reaches of Mahi, are totally devoid of any drainage and represent uplifted areas with a slight tilt; subsurface information also indicates uplifts (Maurya *et al.*, 1995). Obviously these NNE-SSW and ENE-WSW reactivated fractures resulted in the uplifts and the tilting, these were part and parcel of the same late Holocene tectonic event.