CHAPTER-4

TECTONIC GEOMORPHOLOGY OF THE NSF ZONE

The study area is confined to the narrow alluvial tract between the NSF scarp line and the Narmada River (Fig. 4.1). In the present study, this area is termed as the 'NSF zone'. Filed studies and interpretations based on remote sensing imageries suggest strong structural control over the landscape and significant change in the geomorphic setting of the NSF zone moving from east to west. Hence the emphasis was on morphotectonic characterization of the NSF zone to establish the segmented nature of NSF and the factors responsible for its segmentation and to determine pattern of neotectonic activity.

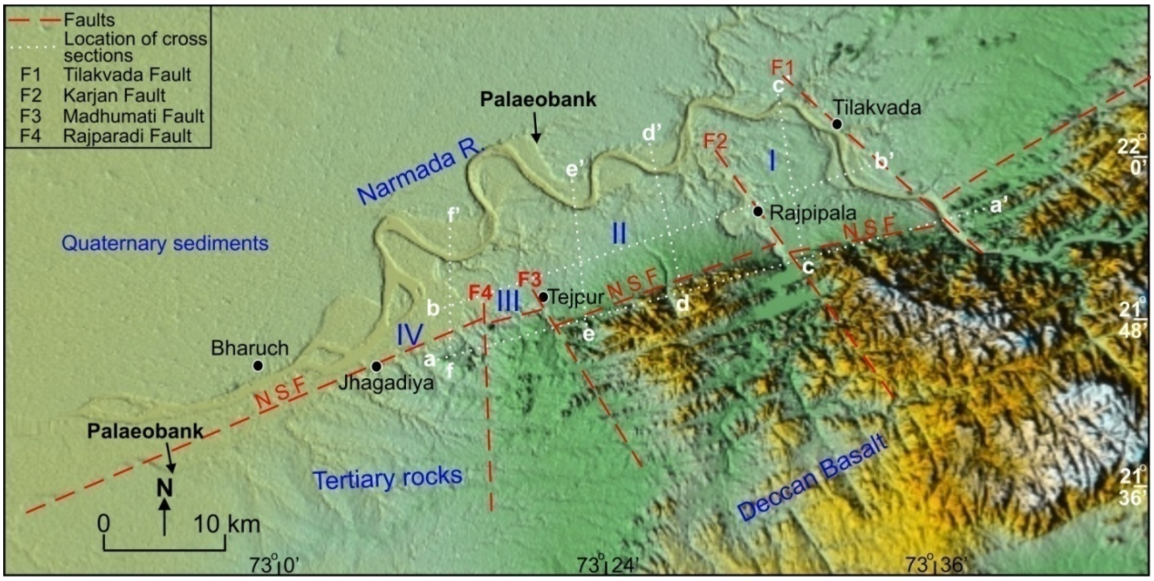

Figure 4.1 Digital Elevation Model (DEM) of the study area. I to IV are the morphotectonic segments of the study area. Alignments of topographic sections in Figures are also shown. Note ENE-WSW trending north facing scarpline delimiting the uplands. Incising drainages in the alluvial terrain to the north of the scarpline is also seen.

The landscape of the study area is mainly controlled by the active tectonics and is characterized by rugged topography, incision river cliffs, steep mountain front, entrenched meanders (Fig. 4.2A), anomalous drainage patterns, knick points, straight channel course and northward sloping alluvial plain. Geomorphologically, the area is divisible into two major domains – the upland area to the south of the NSF scarp line and the alluvial plain towards the north (Fig. 4.1). The uplands comprise mountainous landscape over the south dipping basaltic flows (Fig. 4.2B) and relatively gentler hummocky topography over the folded and faulted Tertiary rocks. The alluvial plain comprises of loose Quaternary sediments. This physiographic contrast makes the geomorphologic expression of the NSF as a linear series of ENE-WSW trending prominent north facing scarps which is morphologically traceable up to the coastal zone in the west. The scarps are developed in the different rocks from eastern to western part of the study area. In the eastern part, the scarps delimit the rugged mountainous terrain developed over south dipping basaltic flows of the Deccan Trap formation to the south and northward sloping alluvial terrain to its north. Whereas, in the western part, the scarps are formed in the northern limbs ENE-WSW trending folds in the Neogene rocks. In the extreme western part, continuous ENE-WSW trending straight scarp formed in the late Pleistocene sediments is described as the palaeobank of the Narmada River in its estuarine reach (Agarwal, 1986; Maurya et al., 2000; Chamyal et al., 2002).

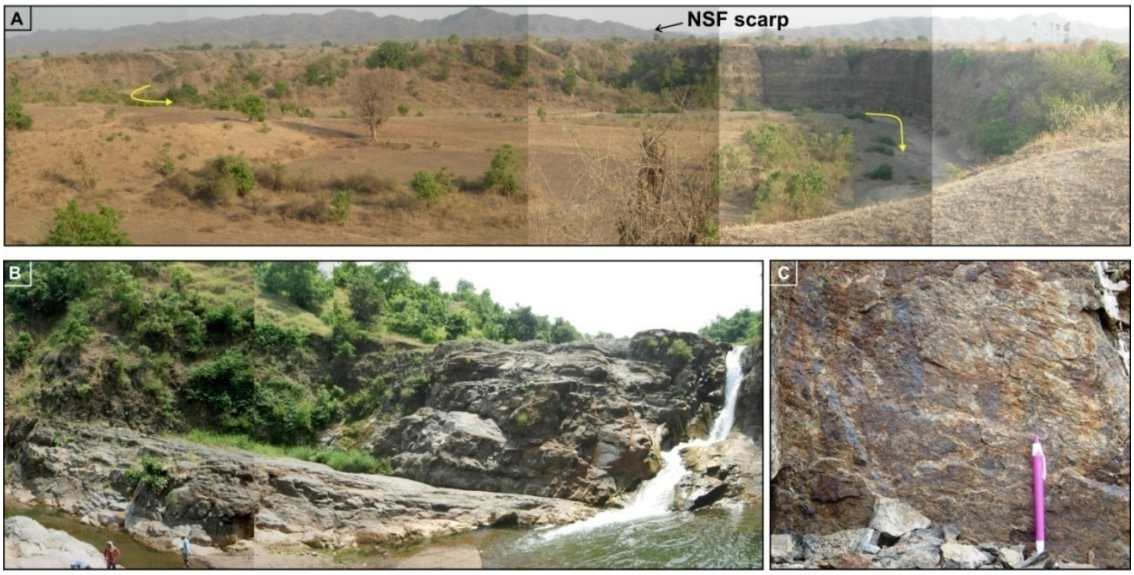

Figure 4.2 Photographs of the study area showing various characteristics of tectonically controlled landscape. **(**A) South-viewing photomosaic showing the sharp physiographic contrast along the NSF. The scarps cut basaltic flows of the Deccan Trap Formation. The foreground is the incised alluvial plain. Arrows indicate downstream direction of the Nandikhadi River. (B) View of a ~16 m high waterfall along the Nandikhadi River near the upland zone. South-dipping basaltic flows can be seen in the channel. (C) Close view of the slickensided surface of the Madhumati Fault in basaltic rocks indicating oblique slip movement.

Because of the compressive stresses related to continue northward movement of the Indian plate several transverse faults have formed and displaced the NSF scarp line. Some of the transverse faults are mapped in the upland area to the south of the mountain scarps (Agarwal, 1986; Chamyal et al., 2002) which presumably extend up to the NSF and possibly beyond. These include the NW–SE trending Tilakwada Fault along the Narmada River which appears to have displaced the scarp line by ~2.5 km. The other two comprise the NW–SE trending Karjan Fault and the Rajpardi Fault. The Karjan Fault is located at the right bank of the Karjan River and controls the path of the River mainly in the alluvial zone. The Rajpardi Fault located in the western part of the study area marks the tectonic contact between the basaltic flows and the Tertiary rocks. During field studies another NNW–SSE trending fault was mapped at Tejpur. This fault shows a right lateral offset of the NSF for about 1 km. The presence of the fault is evidenced by the straight channel of the Madhumati River and the formation of a large deeply incised and compressed meander in alluvium as it emerges from the uplands (Fig. 4.1). The slicken sides exposed in basaltic rocks on the left bank of the river, suggests oblique slip movement (Fig. 4.2C).

The geomorphic analysis and field setting indicate that there is a pronounced variation in the geomorphic setup of the area laterally along the length of the NSF in the ENE-WSW direction. This lateral discrimination in the geomorphology is because of the various transverse faults which is also supported by the other evidences discussed in the Chapter 5 and 6. Hence, based on the existence of transverse faults, geomorphic analysis and field setting, a new tectonic framework has been prepared for the study area, wherein, the NSF zone is divided into four distinct morphotectonic segments from east to west (Fig. 4.1) (Joshi et al., 2013a). Segment I is located between the Narmada and Karjan Rivers; segment II is between the Karjan and Madhumati Rivers, segment III is between the Madhumati River and the Rajpardi Fault; and beyond which lies segment IV. These four segments have different geomorphic setting. The difference in the geomorphic setting is reflected in the change of depth and pattern of river incision, topographic elevation, type of sediment deposition and drainage pattern. For example, moving from segment I to segment II the depth of incision increases. The maximum incision depth in the alluvial zone of the rivers of segment I is about 6 m, which increases to 40 m in the segment II. Along with the depth of the incision, topographic elevation also increases from segment I to segment II. Likewise, changes in geomorphic setting also varies for segment III and IV. Sedimentation pattern changes, for example, there is deposition of group of alluvial fans in segment I and II, which are absent in the segment III and IV. Overall, this type of changes indicates tectonic control over the geomorphology and also variation in the pattern or magnitude of tectonic activities. This is evidenced by detailed geomorphic studies carried out during the present work.

TECTONIC GEOMORPHOLOGY

The study area is divisible into two major geomorphological domains – the upland zone to the south of NSF comprises of Deccan traps and Tertiary sedimentary rocks, and the alluvial plain to the north comprises of loose Quaternary sediments (Fig. 4.3).

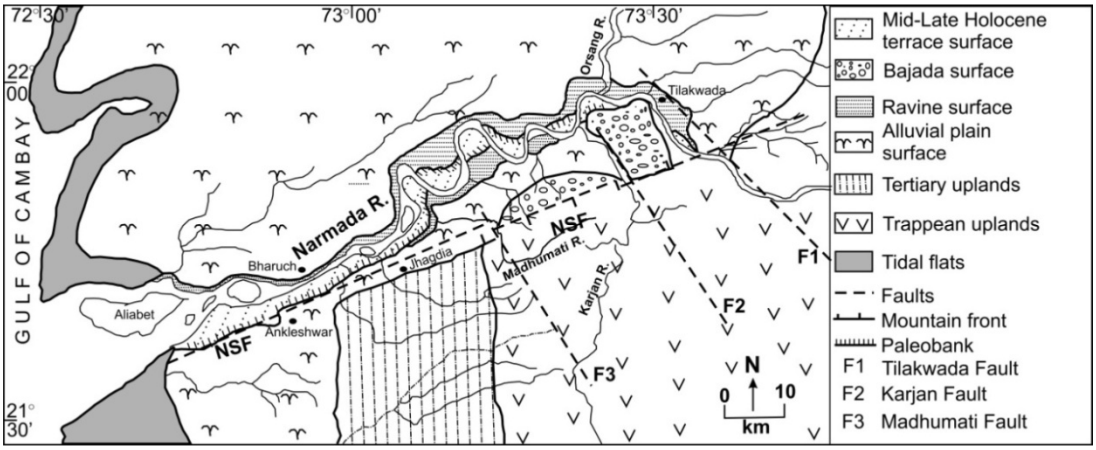

Figure 4.3 Geomorphic map of the lower Narmada basin showing various geomorphic surfaces (modified after Chamyal et al., 2002).

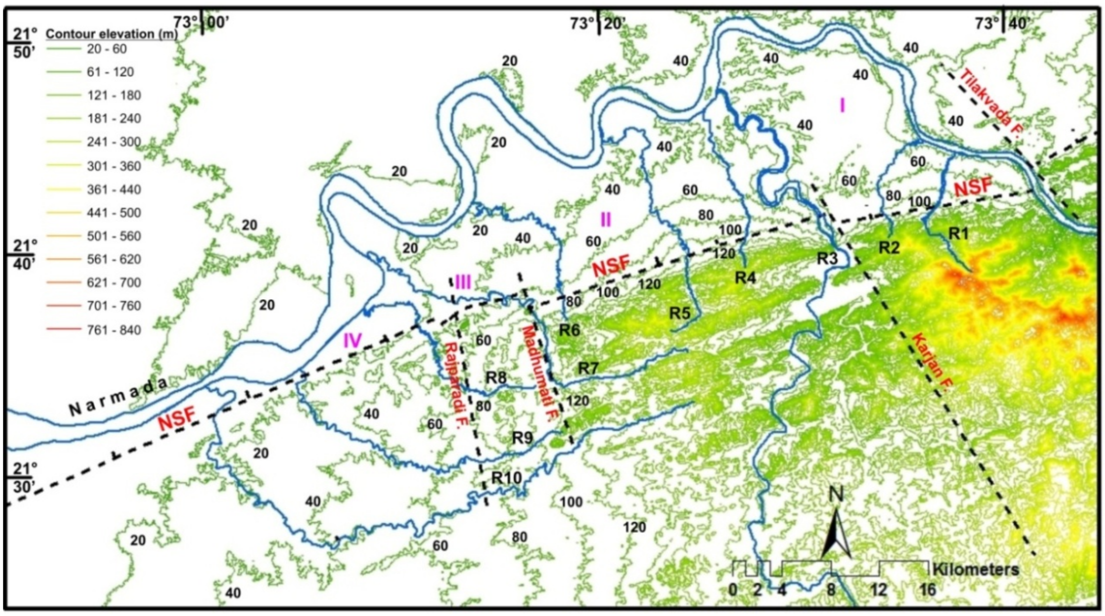

Figure 4.4 Contour map of the study area with drainage and fault lines. Note the ENE–WSW trending north-facing scarps of the NSF and the gentle northward slope of the alluvial plain.

Upland zone

In the study area, the upland zone comprises of the Deccan volcanic upland and Tertiary highlands. In the segment I, the upland zone consists dominantly of basaltic flows and patches of Cretaceous sandstones of Bagh Formation. In the segment II and III, uplands consist of various basaltic flows. In the segment IV, upland comprise of a low highland of Tertiary rocks. In all the segments, the upland zone is densely forested and hence good exposures are not easily available. The exposures can be seen along the incised channel sections. In the area, the uplands show several evidences of rejuvenation in the form of youthful topography, presence of narrow and deep gorge like river channels, various knick points and waterfalls.

Deccan volcanic upland

The exposed basaltic trappean rocks form a part of the Deccan volcanic province of Penninsular India and are example of continental flood basalt provinces associated with passive continental margins. The trappean area shows a highly rugged topography with E-W trending linear rows of hills that rise 200-300 m amsl. The Deccan basalts overlie the Mesozoic sediments made up of fluvio-deltaic sandstones and shallow sea sediments, which, in turn, rest uncomfortably on the Archaean Aravalli craton (Biswas, 1982, 1987). The Mesozoic rocks are highly folded and faulted exposed as inliers in the segment I of study area.

Lithologically, the trappean rocks consist of amygdaloidal, non-amygdaloidal and massive basalts, and are frequently associated with andesite, trachyte and picrite (Power, 1980; Agarwal, 1984). They are traversed by numerous dolerite dykes trending N 70° (Auden, 1949; Krishnamacharlu, 1972; Power, 1980). These dykes vary in width from a few meters to hundred meters or more and some can be traced for many kilometers (Krishnamacharlu, 1972). The study of lineament fabric shows a concentration of lineaments in the azimuth range of N 60°- 69° and a subordinate concentration about the N 320° and N 350° (Choubey, 1971; Power, 1980). The lineament patterns obtained are characteristic of regional uplift and there is strong correspondence between dyke orientation and fracture pattern. Auden (1949) has drawn attention to the fact that the dykes are not distributed in haphazard manner but are concentrated in a few areas and have definite orientation. The dykes are almost exclusively oriented in the N 70° direction, paralleling the NSF and the fractures concentrated in the azimuth range N 60°- 69° (Auden, 1940; Power, 1980). Also the drainage pattern shows structural control with the streams flowing almost exclusively along N 70° and N 30° oriented structural lines.

Overall, the fabric of the Deccan volcanic province is largely the result of vertical movements accompanied by arching (Power, 1980) which is reflected through the southward dipping basaltic flows (Fig. 4.5). In the present study, the field studies suggests that the southward dip of basaltic flows ranges between 12° to 25°. The other significant character of basaltic flows noticed during the field work is the northward dip of basaltic flows (Fig. 4.5). They are well exposed in the upstream area of the Nandikhadi River. The northward dip is steeper than the southward dip which varies between 35° to 40°. Also it has been noticed that the dip increases as one moves from north to south i.e. towards the master fault location where it becomes almost vertical. To the south of the master fault the dip of the basaltic flow changes towards south. This indicates existence of fold like structure with steep northern limb.

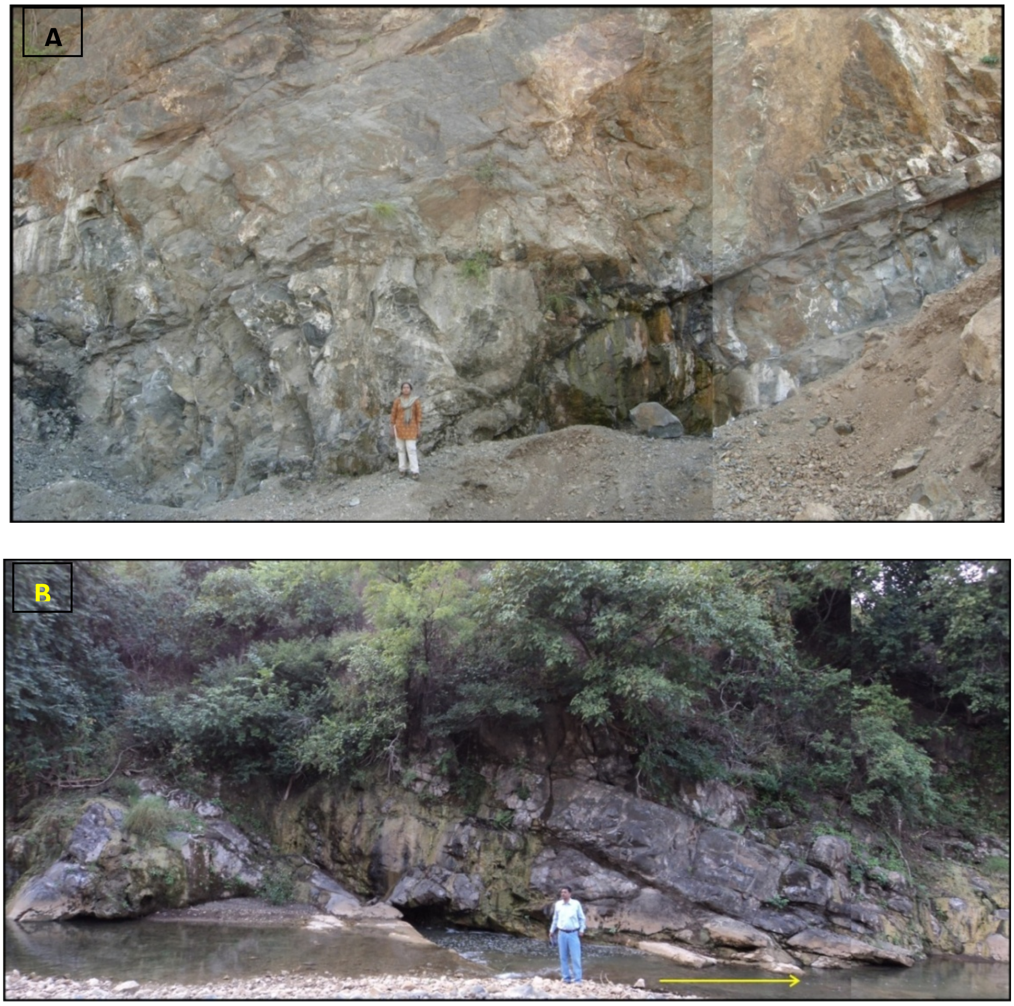

Figure 4.5 Photographs of dipping basaltic flows. **(A)** Photograph showing southward dipping basaltic flows exposed in the upstream area of the Madhumati River near the Tejpur. (B) Photograph showing northward dipping basaltic flows exposed in the incised cliff section of the Nandikhadi River in the upstream area near Jhuna Ghanta. Arrow indicates downstream direction of the river.

Tertiary highland

Tertiary highland located in the segment IV of the study area are represented by a full sequence from Eocene to Pliocene sedimentary rocks overlying the Deccan Trap. These rocks consists of conglomerates, sandstones and limestones. The rocks are folded into several narrow anticlinal structures separated by gentle synclinal lows. The linear anticlinal structures trending NE to ENE direction and invariably flanked by reverse faults along southeastern limbs. These anticlines also show SW to WSW plunges, and occasionally towards NE (Agarwal, 1984).

However, the folds in the northeast are tight comparatively and faulted, the beds showing steep dips, whereas in the central and southwestern parts, the folds are gentler

(Agarwal, 1984). This could be related to the Rajparadi Fault located at the eastern fringe of segment IV. The integrated tectonic activities of the NSF and transverse Rajparadi fault could have formed the tight folding and faulting of anticlinal structures in the eastern part. Quaternary sediments overlying the Tertiary rocks also show evidence of neotectonic activities in a form of geomorphic highs (Agarwal, 1984). The drainages emerging from the Tertiary highlands show strong control of structures over the drainage pattern. Overall, the geomorphology of segment IV shows strong control of tectonic activities.

Alluvial plain

The vast alluvial plain occurs to the north of the uplands and comprise of unconsolidated fluvial sands, silts, gravels and mud flats. The coarser and finer sediments correspond with the basin part and narrow coastal zone respectively. It is geomorphologically classified into the four geomorphic surfaces - the alluvial plain, the extremely dissected ravine surface, a gravelly fan surface and the flat-topped valley fill terrace (Fig. 4.3) (Chamyal et al., 2002). The almost flat but gently sloping alluvial plain is extremely dissected in the vicinity of the river valley and exhibits gullies as deep as 20-30 m (Fig. 4.6, 4.7). An extensively gullied ravine surface distinguishes it from the un-dissected alluvial plain and the fundamental importance of the extensive dissection in the geomorphic evolution of the area. The terraces show no evidence of ravine erosion and abut against the abandoned cliffs (palaeobank). The gravelly surface comprising a series of alluvial fans deposited along the mountain front scarps of the NSF near Rajpipla. This fan surface is bounded by a NW-SE trending fault passing through the Narmada River on its eastern side and by a NNW-SSE trending fault passing through the Karjan Rivera on its western side. The wide flat topped terrace surface of 5-12 m height, occupies a deeply incised fluvial valley.

The alluvial plain shows strong control of tectonic activities in its geomorphic evolution. It is highly dissected by the alluvial rivers emerging from the uplands and flowing towards north to meet the Narmada River. Specially, in the vicinity of the NSF scarp alluvial plain is deeply incised by rivers (Fig. 4.6). It shows steep gradient towards north which is evidenced by the incision pattern of the rivers. For example, in the Nandikhadi River basin the depth of incision in the upstream area is 40 m which decreases to 6 m in a distance of about 2.25 km. However, the depth of incision varies in all the segments which could be because of the different magnitude of tectonic activities related to the NSF as well as transverse faults.

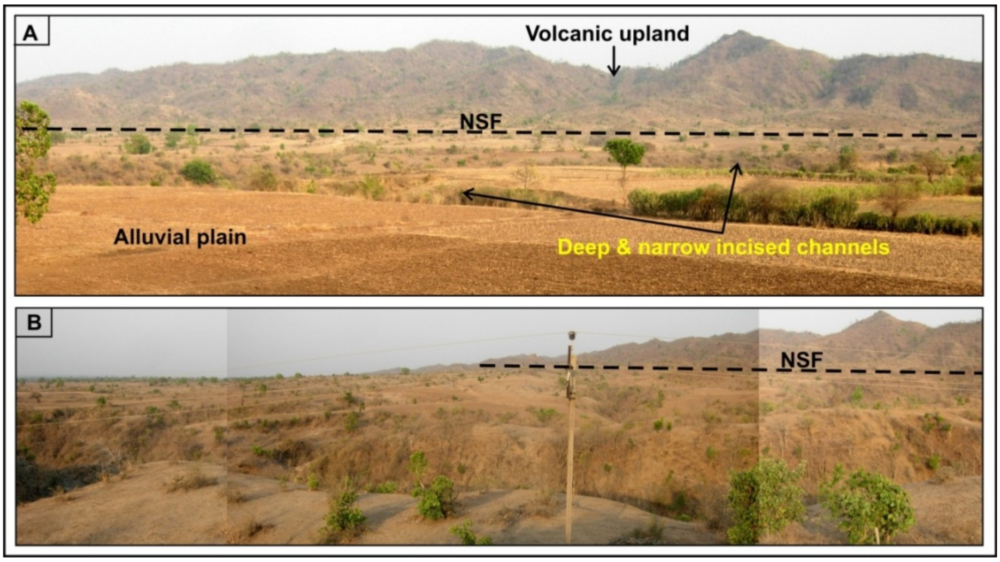

Figure 4.6 (A) Photograph showing field setting of the alluvial plain. (B) Side view of the terrain shown in the (A).

The segmented nature of the NSF influences the geomorphology of the alluvial plain which is significantly visible in the topographic profile drawn along the trend of NSF (Fig. 4.7). The profiles show significant difference in the elevation of segments in a definitive manner. The elevation of the alluvial plain is maximum in the segment II which is between Madhumati and Karjan Rivers (Fig. 4.7). The variation in relief of the alluvial plain is found to correlate well with the transverse fault bounded segments of the NSF discussed in the previous section. This can be explained by a close linkage between the geomorphic evolution of the alluvial plain and the variable pattern or magnitude of neotectonic activity along the NSF.

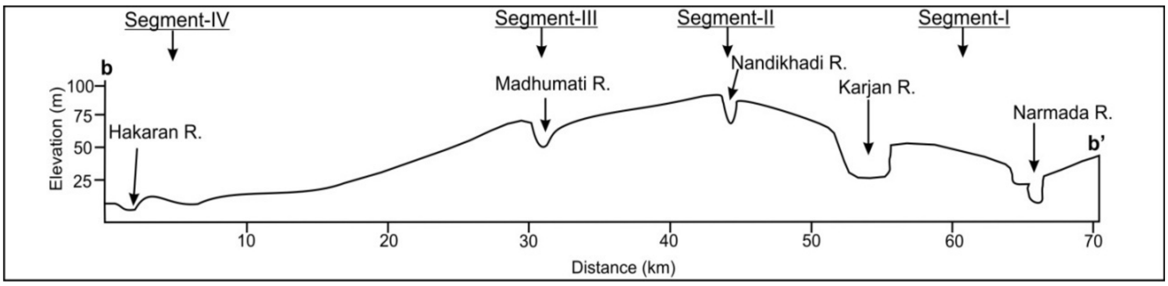

Figure 4.7 Topographic profiles drawn along the trend of NSF (trend shown in Fig.4.1) over the alluvial terrain to the north of the scarps. Note the prominent variation in the elevation of the alluvial surface in different segments.

The difference in the elevation has lead to the development of different physiographic setup. This has resulted into the formation of coalesced alluvial fans in Segment I and Segment II (Bhandari et al., 2001; Joshi et al., 2013b). In Segment III and Segment IV there is an absence of the fan sediments. This is because of the presence of favorable physiographic setup for the formation of alluvial fans in the Segment I and II.

Detailed sedimentological and stratigraphical study of the fan sediments of segment II suggest that the deposition took place in bajada fan environment during the late Pleistocene (Joshi et al. 2013b). Detailed sedimentological and stratigraphical study of the fan sediments of the Segment I and II suggest that the deposition took place in bajada fan environment during the Early Holocene and late Pleistocene respectively (Bhandari et al., 2001; Joshi et al. 2013b). Discussion about the importance of occurrence of bajada surfaces is included in the Chapter 5. Absence of fan environment in the Segment III and Segment IV could be because of the small alluvial track between NSF scarp and Narmada River or because of low magnitude of tectonic activity. Overall, the geomorphic characters suggest rejuvenated surface of the alluvial plain.

NSF scarp

In the study area NSF scarp is represented by steep north facing scarps developed in the Deccan volcanic rocks, Tertiary rocks and Quaternary sediments. The scarp demarcates the northern limit of the Deccan uplands and Tertiary highlands, and southern limit of vast alluvial plain. In the eastern part of the study area (in segment I, II and III), NSF scarp expressed by a steep north facing and ENE-WSW trending mountain front developed in the basaltic rocks. In the western part (Segment IV), the NSF scarp is manifested by steep northern limbs of folded Tertiary sedimentary rocks. The anticlines occur in a linear pattern and trend in NE to ENE direction which is the trend of NSF. The northern limbs of the folds are faulted and exposed over the surface. The fault exposure shows reverse movement along the north dipping fault plane.

In the westernmost part (segment IV), the scarp is represented by steep north facing and ENE-WSW trending palaeobank of Narmada River. Palaeobank of Narmada River is an about 55 km long straight wall like scarp and comprises of loose Quaternary sediments. This is formed because of the northward shifting of the Narmada Rivers due to the uplift of the Jhagadia - Ankleswar area. The linearity suggests the presence of a fault along the palaeobank with down throw side to the NW. A seismic profile which passes across this lineament verifies the presence of fault with reverse nature (Agarwal, 1984).

The profiles were drawn across the trend of NSF in all the segments from the point of maximum height of the scarp in south to the Narmada River in north (Fig. 4.8). They provide further evidence of neotectonic activity in a form of rugged mountainous terrain and steep gradient of alluvial plain which correspond to the youthful nature of uplands and rejuvenated surface of alluvial plain. The steepness of the alluvial plain varies in all the segments but the steepest slope of alluvial plain is seen in the profile of Segment II. A steep gradient of the alluvial plain is because of the decrease in the elevation in a very short distance from south to north i.e. from upland to lowland. For example, the surface elevation of the alluvial plain is ~40 m near the Narmada River, which, rapidly increases to ~80 m near the NSF scarp. This framework can be explained with the morphology of northward tilted fault block.

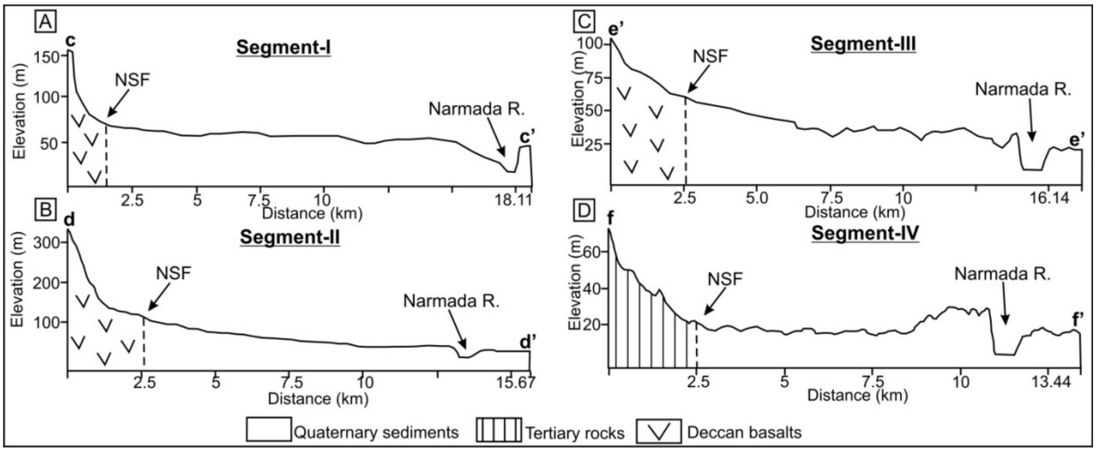

Figure 4.8 N-S oriented topographic profiles across the study area (trends shown in Fig. 4.1). Note the steep north facing scarps marking the NSF and the distinct but variable northward slope of the alluvial plain.

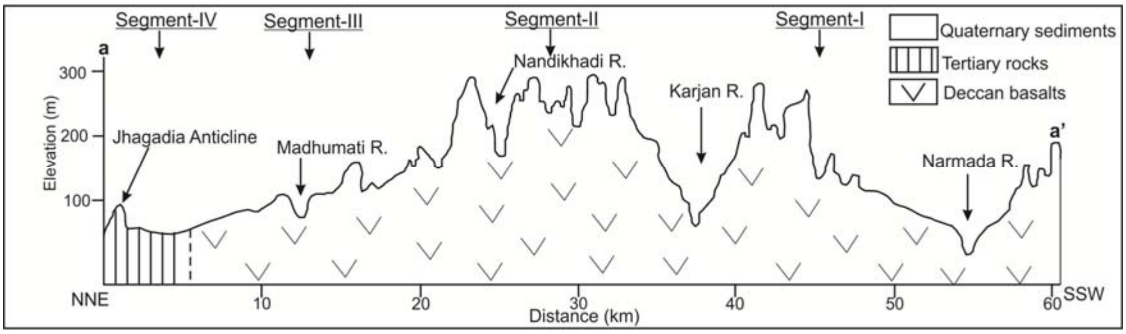

Figure 4.9 Topographic profile drawn along the trend of NSF (trend shown in Fig.4.1) over the scarpline marking the NSF. Note the prominent variation in the elevation of the crest line in different segments.

Likewise the change in structural setting of NSF scarp from east to west, the topographic variation in terms of elevation can also be explained by the topographic profile drawn along the trend of NSF (Fig. 4.9). The profile shows sharp contrast in the elevation. The scarp achieves heights of about 150m, 300m, 100m, and 60m in the Segment I, II, III and IV, with the maximum elevation in the segment II between Madhumati and Karjan Rivers. The scarp height is relatively subdued in the segments between Karjan and Narmada rivers (segment I) and between Madhumati River and Rajpardi Fault (segment III and IV). The variation in relief of the scarps closely corresponds to the fault segments delimited by transverse faults described above.

FLUVIAL GEOMORPHOLOGY OF THE NSF ZONE

Drainage pattern

The NSF zone shows dominantly transverse north flowing parallel drainage lines (Figs. 4.1, 4.4). Majority of the rivers arise in the trappean uplands and flow incising through alluvial plain before meeting the Narmada River. Few lower order streams arise from the Tertiary uplands to meet the major rivers coming from the trappean hills. The major drainage basins from east to west include Shamlayakhadi, Karjan, Nandikhadi, Madhumati, Kaveri and Amravati basins. All rivers are characterized by accelerated river incision, asymmetrical catchments and anomalous diversions. The drainage pattern is controlled by the NSF as well as transverse faults. However, the control of transverse fault on the drainage pattern is prominent which is manifested by the straight course of the channels in the direction of the transverse fault trend (Fig. 4.1).

Upland zone

The rivers in the upland zone are characterized by the occurrence of narrow deep channels, knick points and waterfalls in all the segments (Fig. 4.10). In this zone, lower order drainages show dendritic pattern, however, at places drainages are controlled by the lineaments and active faults. The structurally controlled river courses are visible in the upland zone of the major drainage basins in all four segments. For example, the path of the Karjan River in the segment I is strongly controlled by NSF and transverse Karjan Fault. Almost throughout the path, the course of the Karjan River is in N-S direction which is showing the control of Karjan Fault (Fig. 4.1). As the Karjan River enters in the alluvial plain, it makes a left turn, which is the trend of NSF and then again achieves the N-S flow direction (Fig. 4.1).

The Madhumati River in the segment III flows along a N-S trending transverse Madhumati Fault in the upland zone, and flows westward after entering into the alluvial plain along the trend of NSF before turning north and northwest to meet the Narmada River (Fig. 4.1). The Kaveri and Amravati rivers in the segment IV originate in the western fringe of the trappean uplands and flow westward along structurally controlled courses within Tertiary rocks before entering into the alluvial plain where they flow northward to meet the Narmada River (Fig. 4.1).

Alluvial zone

In the alluvial plain, higher order drainages flow almost parallel to each other in N-S direction. Also the lower order drainages flow parallel to the higher order drainages. In the upland zone the rivers flow in almost straight path, however, as the rivers enter in the alluvial plain, they become more sinuous displaying compressed meander. They show definitive pattern in form of repetition of sinuous and straight course. This phenomenon could be related to the change in a gradient. The straight courses are related to steep gradient, so gradually river meanders in order to maintain the equilibrium between discharge and slope. The other significant character is the depth and pattern of incision in the alluvial plain. The depth of incision is maximum in the vicinity of the NSF and transverse faults in all the segments. However, the rivers of segment II and III show maximum incision in alluvial plains (up to ~40 m) near the scarps which significantly decreases within a very short distance towards north indicating the tectonically generated steep slope. These characteristics indicate that the alluvial zone corresponds to northward tilted fault block related to neotectonic activity along the NSF and transverse faults.

Figure 4.10 Photographs showing drainage characteristics in NSF zone. (A) Knick point of about 2 m formed in a trappean channel bed of a small stream. (B) Zone of knick points and waterfalls. (C) Tilted gravel deposited in the upstream area. (D) Strath terrace showing Quaternary sediments resting over Deccan traps.

Basic morphometric parameters

Along with major drainage basins, there are also several smaller unnamed drainage basins and hence, therefore, the drainage basins in the study area are numbered as R1 to R10 from east to west (Fig.4.4). The basic morphometric parameters of the ten drainage basins are summarized in the Table 4.1.

Table 4.1. Basic properties of the drainage basins in the study area.

Drainage basin	Basin area (km^2)	Basin length (km)	Maximum elevation (m)	Mean elevation (m)	Minimum elevation (m)	Length of trunk stream (km)	Highest stream order
R1	7.50	9.99	783	341	29	14	V
R2	30.80	8.51	406	180	17	13	IV
R3	1525.91	64.02	849	396	13	100	VII
R4	43.37	13.90	348	166	15	18	V
R5	113.93	18.57	425	209	13	31	VI
R6	141.06	18.48	433	189	3	25	V
R7	121.46	28.09	397	188	6	42	VI
R8	95.41	16.40	158	77	3	27	V
R9	109.20	23.01	220	93	3	36	V
R10	322.02	41.10	311	129	1	75	V

Segment I

The segment I includes three drainage basins R1 (Shamlayakhadi), R2 river and R3 (Karjan). R1 is the smallest drainage basin of the study area of the V order and occupies an area of 7.50 km^2 (Table 4.1). The maximum and minimum elevations of the basin are 783 m and 29 m respectively.

The lengths of the basin and trunk stream are 9.99 km and 14 km respectively. R2 is the IV order drainage basin and occupies an area of 30.80 km^2. The maximum and minimum elevations of the basin are 406 m and 17 m respectively. The lengths of the basin and trunk stream are 8.51 km and 13 km respectively. R3 is the largest drainage basin of the study area (Table 4.1). R3 is the VII order basin and occupies the largest basin area of 1525.91 km^2. The maximum and minimum elevations of the basin are 849 m and 13 m respectively. The lengths of the basin and trunk stream are 64.02 km and 100 km respectively. The maximum incision depth noted is about 6 m in the cliff section of the Shamlayakhadi River near the Phulwadi (Fig. 4.11).

Figure 4.11 Incised cliff section near Phulwadi.

Segment II

The segment II also comprises three river basins R4, R5 (Nandikhadi) and R6. R4 is the V order drainage basin and occupies an area of 43.37 km^2. The lengths of the basin and trunk stream are 13.90 km and 18 km respectively. The maximum and minimum elevations of the basin are 348 m and 15 m respectively. R5 is the VI order drainage basin occupying the an area of 113.93 km^2. The lengths of the basin and trunk stream are 18.57 km and 31 km respectively. The maximum and minimum elevations of the basin are 425 m and 13 m respectively. R6 is the V order drainage basin and occupies the an area of 141.06 km^2. The lengths of the basin and trunk stream are 18.48 km and 28 km respectively. The maximum and minimum elevations of the basin are 433 m and 3 m respectively. The maximum incision depth noted is 40 m in the Nandikhadi near Ghanta (Fig. 4.12).

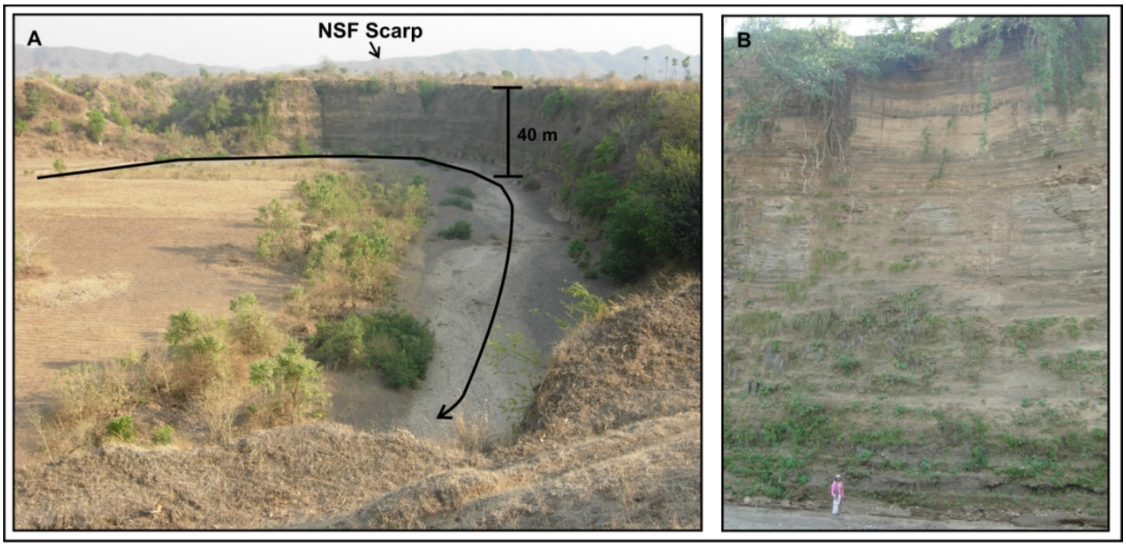

Figure 4.12 (A) Photograph showing incised Quaternary sections in the Nandikhadi River. (B) Close view of the cliff section. Arrow indicates downstream direction of the river.

Segment III

The segment III, being smallest, includes the Madhumati basin (R7) which flows along the N-S trending transverse fault described earlier. The basin is of the VI order and occupies an area of 121.46 km^2. The maximum and minimum elevations of the basin are 397 m and 6 m respectively. The lengths of the basin and trunk stream are 28.09 km and 6 km respectively. The maximum incision depth noted is 20 m in the Madhumati River near the Tejpur (Fig. 4.13A).

Segment IV

The river basins of the segment IV, R8, R9 (Kaveri) and R10 (Amravati) are for the most part, controlled by structural features of the deformed Tertiary rocks. The highest stream order for R8 is V and occupies an area of 95.41 km^2. The lengths of the basin and trunk stream are 16.40 km and 27 km respectively. The maximum and minimum elevations of the basin are 158 m and 3 m respectively. R9 is the V order drainage basin occupying an area of 106.20 km^2. The lengths of the basin and trunk stream are 23.01 km and 36 km respectively. The maximum and minimum elevations of the basin are 220 m and 3 m respectively. R10 is the V order drainage basin and occupies an area of 322.02 km^2. The lengths of the basin and trunk stream are 41.10 km and 75 km respectively. The maximum and minimum elevations of the basin are 311 m and 1 m respectively. The maximum incision depth noted is about 3 to 4 m in the Ratanpurni nadi River section near the Karad (Fig. 4.13B, C).

Figure 4.13 (A) Photograph showing incised cliff section in the Madhumati River. Arrow indicates downstream direction of the river. (B) and (C) Photograph showing incised cliff section of the Ratanpurni nadi River near Karad.