Chapter 5

Imprints of Neotectonics

Tectonic Instability of Saurashtra

The Quaternary carbonate deposits of the Saurashtra peninsula have attracted many workers due to their constituents being derived from the shallow marine provenance, but their occurrences at varied heights - as high as 230m amsl. Such higher occurrence of Quaternary carbonate deposits have been accounted either to the eustatic changes (Verma & Mathur, 1978) or to the tectonic uplift of the peninsula (Baskaran et al. 1989), both having unusual high magnitude. Based on the altimetric frequency analysis, Sood et al., (1982) suggested that the maximum elevation of the oldest erosional surface in Saurashtra should be around 600m; the occurrence of the Girnar complex reaching upto the heıght of 1117m has been accounted to a cymatogenic upwarping. The uplift rate of about 0 12 to 0 28 mm/year has been calculated for the southwestern coast of the Saurashtra peninsula using the geochronological data of successive coastal ridges recognized by the remote sensing (Baskaran et al , 1987). They have sited the evidence lıke dıstınct lineaments, abrupt truncatıon of the ridges, drainage disorganizatıon, etc. However, (Gupta, 1991) dıd not agree with the very high magnitude of the tectonic uplift of the Saurashtra peninsula inferred out of the radiometric dates of the Quaternary carbonate deposits due to the paucity of the field evidence. Brückner et al. (1987) could evidently demonstrate the marine transgression pertaining to the MOI Stage 5 with the help of ESR dating of megashells from the raised beach and lagoon deposits from the

Chorwad, Mangrol and Porbandar area, and ruled out any uplift at least after 125 ka. The occurrence of such deposits up to 4m amsl being slightly lower than the 'normal' glacio-eustatic sea level of the stage 5 prompted them to suggest a slight subsidence, instead Patel (1991 a&b) also favoured the tectonic stability of the region and inferred three major sea level fluctuations pertaining to the Middle Pleistocene (~+20m), Late Pleistocene (-20 to -30m) and Holocene (+6 to +10m) and accounted the deposition of all inland miliolites to the aeolian processes that lifted the carbonate sand from the exposed shelf of the Middle-Late Pleistocene regressive sea. The recent geomorphic studies aided with some radiometric dates have, however, demonstrated the influence of the neotectonics in association with the climate driven sea level changes along the Saurashtra coast (Pant & Juyal, 1993a; Kar, 1995; Juyal et al., 1995). According to Pant & Juyal (1993a), the succession of raised marine terraces and wave cut notches were found linked to the 7m high sea level pertaining to the last interglacial (120ka), but the steep vertical cliffs, distorted notches and staircase platforms found indicative of tectonic uplift, overprinting the evidence of the Holocene high sea. Pant & Juyal (1993b) further demonstrated the neotectonics in south Saurashtra also with geological field evidence in the form of folding in miliolite. Kar (1995) suggested that the neotectonics had an overriding role in shaping out the geomorphic set up of the western India, in comparison with the climate change; the drainage anomaly, stream capture and terrace formation characteristically seen along the 20m contour in the coastal plain of Saurashtra was accounted by him to the tectonic uplift. Referring to the earlier work, Juyal et al. (1995) confirmed the tectonic instability of Saurashtra coast based on the occurrence of oyster reef dated 87.2 $\pm$ 9.7 ka at +4m altitude which otherwise should be at -13m as per the global oxygen isotope sea level curve. They further calculated net uplift of about 7m near

Harshad on the basis of oyster date (126.5 $\pm$ 8.5 ka), when the global the sea-level was at +6m altitude. Chamyal et al., (2003) have demonstrated an intricate role of environmental and tectonic changes in the evolution of the fluvial systems of mainland Gujarat, Kachchh and Saurashtra, and observed that the short, straight and parallel courses of river in the direction of tectonic slope along with the incised and confined channel belts in Saurashtra peninsula are suggestive of strong component of tectonic uplift. Recently, Mathur & Pandey (2002) have suggested a mild epirogenic uplift of the Okha-Dwarka block complimentary to rifted depression of Okha Rann based on high precision AMS dates of corals, gastropods and foraminifers from a coral-algal stratigraphic sequence exposed about 2-4m amsl. This review of earlier work has prompted the author to give a special attention to the influence of the neotectonics on the geomorphic evolution of the southwestern Saurashtra coast. The present chapter enlists the imprints of neotectonism encountered in the coastal as well as fluvial sequences described earlier. A morphometric analysis of coastal fluvial system has also been carried out to appreciate its response to the neotectonics

Seismisity on Saurashtra peninsula

In order to evaluate the tectonic stability/instability of any region, seismic data provides first order information, as they are expression of stress release in the form of earthquakes (Zinoy & Yerks, 1985). Seismisity reflects the far-field stresses in the intraplate region (Sykes, 1978) and hence indicates the nature of the plate driving forces. Saurashtra is an intraplate region much away from the Carlsberg ridge and NE trending Chaman fault that lie in the western margin marking the boundaries of the Indian plate (Goud et al., 1992). The seismic swarm of the year 2000 in the Bhavnagar region and that of the Haripura-Gir Gadhda area along with the continued experience of the aftershocks pertaining to the January, 2001 earthquake of Kachchh are remarkable in this context. Table V.1 enlists the prominent earthquakes recorded in the Saurashtra region. Although no active fault has been identified yet, the recurrence of moderate intensity earthquakes has been found associated with certain lineaments like Rajula Fault, Savarkundala Fault and Shihor Fault (Karanth & Sant, 1995). The gravity anomaly map (Fig.1.8) ascertains the deep crustal nature of these faults in the form of high gravity. Figure 5.1 presents the distribution of the earthquake epicenters in this part of the region. The prominent lineaments occurring in the Saurashtra peninsula are shown in Figure 1.7 and the summary of the major trends of these lineaments is presented in the Table V.2

Table V 1 Major occurrences of earthquakes in Saurashtra region.
(Source. Marathe, 1981, Bansal & Gupta, 1998, Pande et al , 2003)

Year	Month	Lat.	Long.	Magnitude
1668	May	indus delta		8 3
1684	-	20° 07'	72° 24'	3
1705	-	21° 01'	72° 16'	8.3
1819	June	23° 00'	69° 24'	8 3
1820	January	23° 00'	69° 12'	3
1820	November	23° 00'	69° 12'	3
1821	August	22° 14'	72° 12'	3 6
1828	July	22° 09'	69° 59'	5
1842	October	22° 00'	73° 18'	3
1843	February	23° 12'	73° 23'	3
1845	April	23° 22'	68° 40'	3 6
1856	December	21° 07'	73° 00'	3 6
1864	April	23° 12'	73° 23'	5
1903	January	24° 00'	70° 00'	5 6
1909	April	24° 03'	72° 45'	3
1919	April	21° 45'	72° 45'	6.3
1922	March	22° 00'	71° 00	4 3
1927	November	21o 30'	68° 00'	5 6
1935	July	21° 09'	72o 45'	3 6
1938	June	22° 15'	71° 33'	5
1938	July	22° 15'	71° 33'	5 & 5 6
1940	October	22° 03'	70° 02'	5
1950	June	24° 00'	71° 01'	3 6
1956	July	23° 04'	70° 00'	7

Contd...

Year	Month	Lat.	Long.	Magnitude
1962	September	24° 12'	73° 00'	5
1965	March	24° 02'	70° 00'	4 6
1968	October	21° 08'	71° 08'	3 6
1968	October	21° 07'	71° 06'	3 6
1993	August	20° 64'	71° 36'	5
2000	August	21° 09'	72° 02	4 3

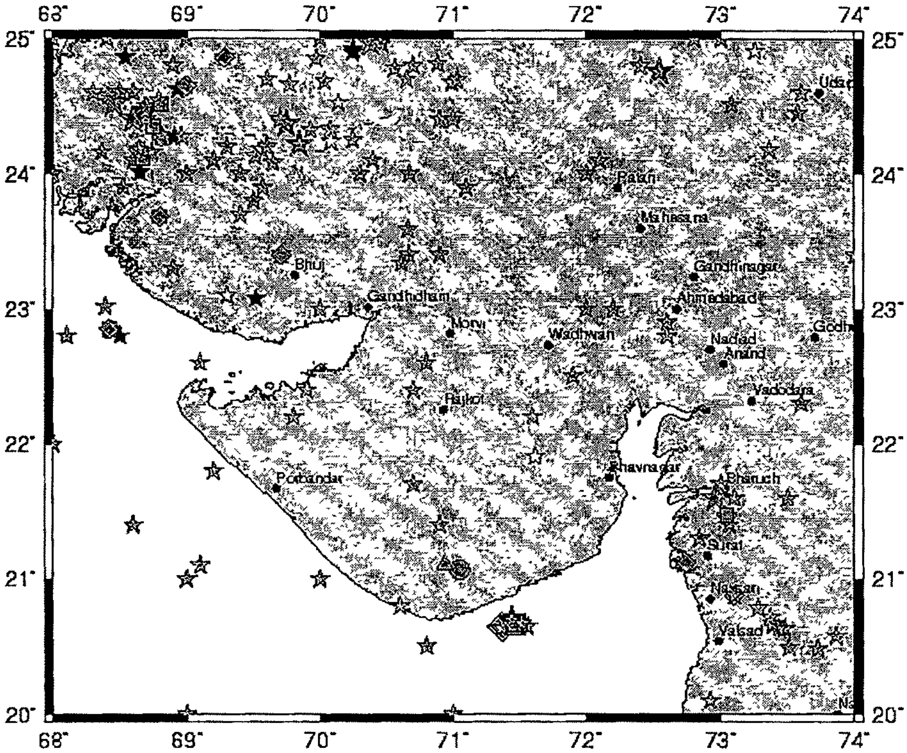


Figure 5 1 Map showing the distribution of the major earthquake epicenters in Gujarat
(Source www ams com)

Table V 2 Summary of major faults and lineaments of Saurashtra peninsula.

Tend	Description
NE-SW	Aravalli trend and dominant in SE part of Saurashtra
ENE-WSW	Pre-Cambrian trend of Narmada-Son geofracture and dominant in South Saurashtra
NW-SE	Parallel to West coast of Saurashtra representing coastal tectonics which might have evolved during late Jurassic due to break up of Gondwana from Africa
N-S/NNE-SSW	East central part of Saurashtra parallel to Cambay rift basin evolved during late Cretaceous.
Saurashtra Arch	Trending NE-SW, palaeogene high.

Field Observations

The Quaternary carbonate sequences of the coastal Saurashtra exhibits prominent deformational structures in the form of joints, open flexures, warping and contorted beddings. Although, the majority of them do not occur very commonly the joints are much peculiar and therefore, are studied in detail.

The ephemeral stream of Rupen river that flows almost along N-S after originating from the Gir highland for about 18km and then abruptly takes westward turn to debouch its water into the mud flats at Chikhli where a presence of open fold in miliolite limestone along with prominent orthogonal joints (Fig. 5.2 & 5.3) between the Lerka5. and Chikhli (N 20° 47' 49.48" & E 70° 51' 48.40"). The similar structure from the nearby area has also been reported earlier by Pant & Juyal (1993b).

Figure 5.2 Orthogonal joints in the miliolite limestone in Rupen river bed near Chikhali. (Diameter of compass 8cm)

Figure 5.3 An open antiformal structure in miliolite near Chikhali in Rupen river. (Height of bag 20cm)

Of similar nature, but more prominent deformed beddings in miliolite have been encountered in the Noli river about 2.5km south of Mangrol (N21° 06' 03.12" & E 70° 09' 23.46") on the upstream side of the bridge (Fig. 5.4, a) The outcrop extends for about 30m in length and 4m in height. The structure is shown by about 0.75m thick unit that has a sharp top over which thinly bedded horizontal miliolite unit can be seen. The upper unit doesn't show such kind of deformation. The pattern is characterized by wave like elliptical form that range in size from 0.25m to 1m. This has been interpreted as ball &

pillow structure by Gharia (1993). However, the geometry of structure, pattern of deformation in beddings and non-occurrence of alternate sand-clay layers doesn't satisfy the definition of ball and pillow structure given by Reinick & Singh (1980). Alternatively, it is more appropriate to call this structure as convolute bedding indicative of syn-sedimentary deformation. The contorted stratifications (Fig. 5.4, b,c) have been very commonly seen in the litho unit-4 that occurs sharply resting over the pinkish coloured miliolite belonging to the unit-2 forming the coastal cliffs along the south Saurashtra coast.

Figure 5.4 a A general view of an outcrop showing convolute bedding in miliolite limestone unit overlain by a horizontally bedded unit in Noli river south of Mangrol. (Height of bag 20cm)

Figure 5.4 b A part of the above outcrop exhibiting a complex pattern of bedding deformation. (Height of bag 20cm)

Figure 5.4 c A closer view of deformation in the miliolite beddings as shown in a window of Fig. 5.4b. (Length of pen 10cm)

Apart from these, abrupt lithological change in the form of an abutment of the miliolite limestone (litho unit-1) against the fossiliferous clays of the Gaj Formation has been encountered in the Singwado river near Chhachar that evident a presence of fault. The southerly flowing river also takes northwestward turn here against an east-west trending 6m high cliff (Fig. 5.5) and after half a kilometer regains in southward direction. A distinct broadening of the river bed depicting the effect of such a gradient reversal to create river ponding can be seen here. A presence of about 8m high waterfall about a kilometer downstream of Ghantwad in Sigwado river is also a very characteristic feature in view of the neotectonics. It is worth mentioning here that the miliolite deposits of typical marine characters (current beddings, ripple marks, mud cracks, biogenic structures, etc.) have been encountered as 60 to 80m amsl in the Hiran and Singwado rivers.

Figure 5.5 River bank cliff near Chhachar outcropping the fossiliferous clay unit of the Gaj Formation. (Height of the person 165cm)

In comparison with the all other features, the frequent occurrences of joint in the coastal carbonate sequences were found very peculiar. The usefulness of the joints in sandstone for neotectonics and to infer regional stress pattern has also been discussed by many (Engelder, 1982; Hancock & Engelder, 1989; Scheiddegar, 2001, Bai, 2002). The carbonate sequences of the Saurashtra are mainly (carbonate) sand dominating one and behave as a brittle rock mass under compressive stress regime; better developing the orthogonal joints in them. Recently, Khadkikar (2001) have reported neotectonic joints from the miliolite deposits of the Gopnath area of the SE Saurashtra and attributed them to the NE-SW oriented horizontal maximum compressive stress (S_{Hmax}) after Gowd et al.

(1992). In general, the frequency of joints is higher in the older sequences, especially the litho unit-1, 2 and 3 described in detail in the earlier chapters. The joints in the study area have been observed commonly on the shore platforms and coastal cliffs along the south Saurashtra coastline.

In the coastal cliffs of Dwarka near the Bhadkeshwar Mahadev E-W oriented joints cutting through the cliffs have been observed. At some place the continuation these joints in the shore platforms can also be traced out. At Gorinja, of Segment-1 south of Dwarka, recrystallized limestones making the shore platforms having width of about 80m shows presence of joints oriented in two directions i.e. NW-SE and E-W (Fig. 5.6). Above this lies the coarse grained shell limestone which is devoid of joints. But, towards south of this near Okhamadhi (N 22° 06' 35.82" & E 69° 04' 41.76") the NW-SE oriented joints in the coarse grained, shell rich and recrystallized limestone can be seen.

Figure 5 6 Prominent two sets of joints in a relatively finer grained shell limestone unit near Gorinja. (Length of the pen 12cm)

Significant joints have been observed in the Veraval-Jafrabad area. Here also, their presence is recorded in the shore platforms. At Adri 6km north of Veraval the raised shore platform about 4-5m amsl and made up of the recrystallized limestone with bedding attitude 100°/10° due SW shows the joints oriented in the NE-SW direction (Fig. 5.7).

Near the light house at Veraval the shore platforms which

Figure 5.7 Orthogonal joints in the slightly recrystallized In miliolite limestone unit as seen near Adri (scale 15cm)

gets exposed during the low tides shows the heavy concentration of joints. The orthogonal joints have been observed in the recrystallized limestone belonging to litho unit-3. These joints are prominently oriented in the NW-SE direction. However, another joint set shows the NE-SW orientation which is less frequent. The fracture opening range from 3 to 10cm. The joints are also traversing through the above lying coarse grained shell limestone unit.

On the Diu Island the joints have been noticed in the recrystallized limestone unit. These joints are prominently exposed in the high cliffs in south of the Diu near Nagwa where they area mainly oriented in the N-S direction. In the Jafrabad – Babarkot area the NE-SW oriented joints have been observed (Fig. 5.8). The occurrences of joints continue eastward right up to the Gopnath point. At Chaanch Island also, NW-SE oriented joints have been recorded in the recrystallized limestone unit. In places on Chaanch Island the rocks have collapsed along these joint planes.

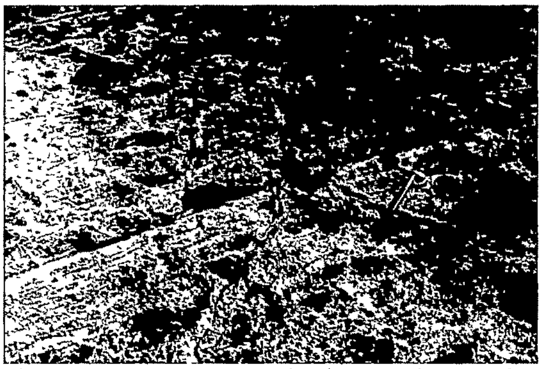


Figure 5 8 NE-SW oriented joints on the Bararkot shore platform. (Length of the hammer 30cm)

Figure5. 9 shows the composite rose diagram prepared for the joints observed in various segments of the southern Saurashtra coastline. The vector magnitude shifts from prominent NE-SW to N-S and then NW-SE along the southeastern (Gopnath) to southern (Jafrabad) and southwestern (Veraval) coast of Saurashtra. The frequency of joints

reduces in the Porbandar area but, increases towards Dwarka-Harshad area where the prominent orientation changes in E-W direction. This clearly indicates the influence of the prominent lineaments occurring nearby. These joints are interpreted to be linked with the tectonic activities along the Narmada-Son Fault that runs parallel to the southern coast of the Saurashtra and shifts in the trends from NE-SW to NW-SE may be due to the local influence of the Cambay Basin Faults and the West Coast Fault respectively. The E-W trending joints may be in this regard thought to be effected by the Okha Rann Fault and Gulf of Kachchh Fault.

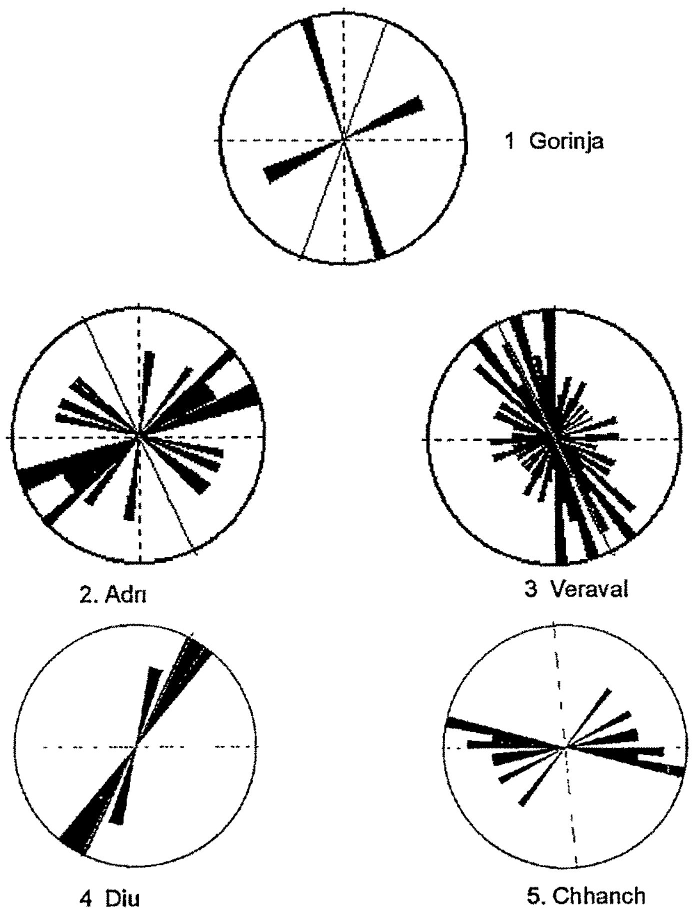


Figure 5 9 Rose diagram exhibiting the prominent frequencies of joints encountered in the Quaternary sequences of the study area.

Imprints on the Coastal Rivers

Drainage Lineaments

As described in the introductory chapter that the Saurashtra forms part of the semi-arid region of the western India. It is drained by several coastal streams like, Noli, Mgeal, Hiran, Saraswati, Singwado, etc. which originates from the Gir highlands and flows through the coastal plains of the southwest Saurashtra. Significance of the coastal streams in understanding the role of neotectonics has been dealt by Merritcs & Vincent (1989).The drainage lineament map of the southwestern Saurashtra coast was prepared based on the satellite imagery and SOI topographic sheets to understand the structural set up of this part of the study area (Fig. 5.10). Orientation of the significantly linear tributaries of the trunk stream was noted down for each individual basin of the study area. The first order streams which originate in vicinity of the coast were also considered. The rose diagram prepared based on the drainage lineaments (Fig. 5.11) shows prominent NNE-SSW and NE-SW oriented trends for the Hiran, Saraswati, Singwado, Sangwadi, Rupen and newly born coastal streams whereas, the streams like Noli and Somat have shown the trends in NW-SE.

The composite rose diagram including all the drainage lineaments characteristically shows the vector magnitude in direction N24°E. This is in accordance with the maximum horizontal compressive stress (S_{HMAX}) of the mid-continent Indian peninsula obtained through the borehole break out, hydraulic fractures and focal plane mechanism that is in N23°E direction (Goud et al., 1992).

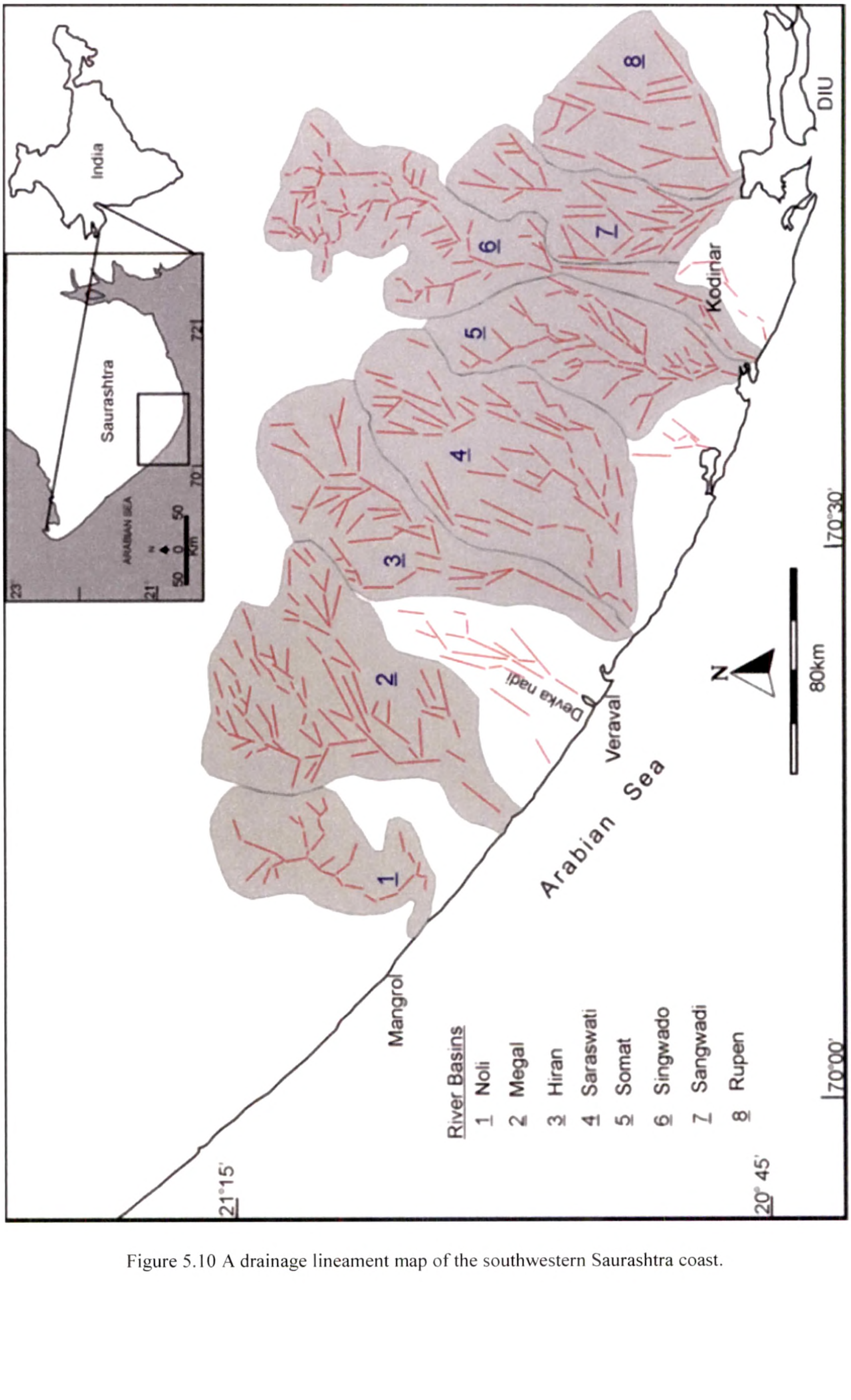


Figure 5.10 A drainage lineament map of the southwestern Saurashtra coast.

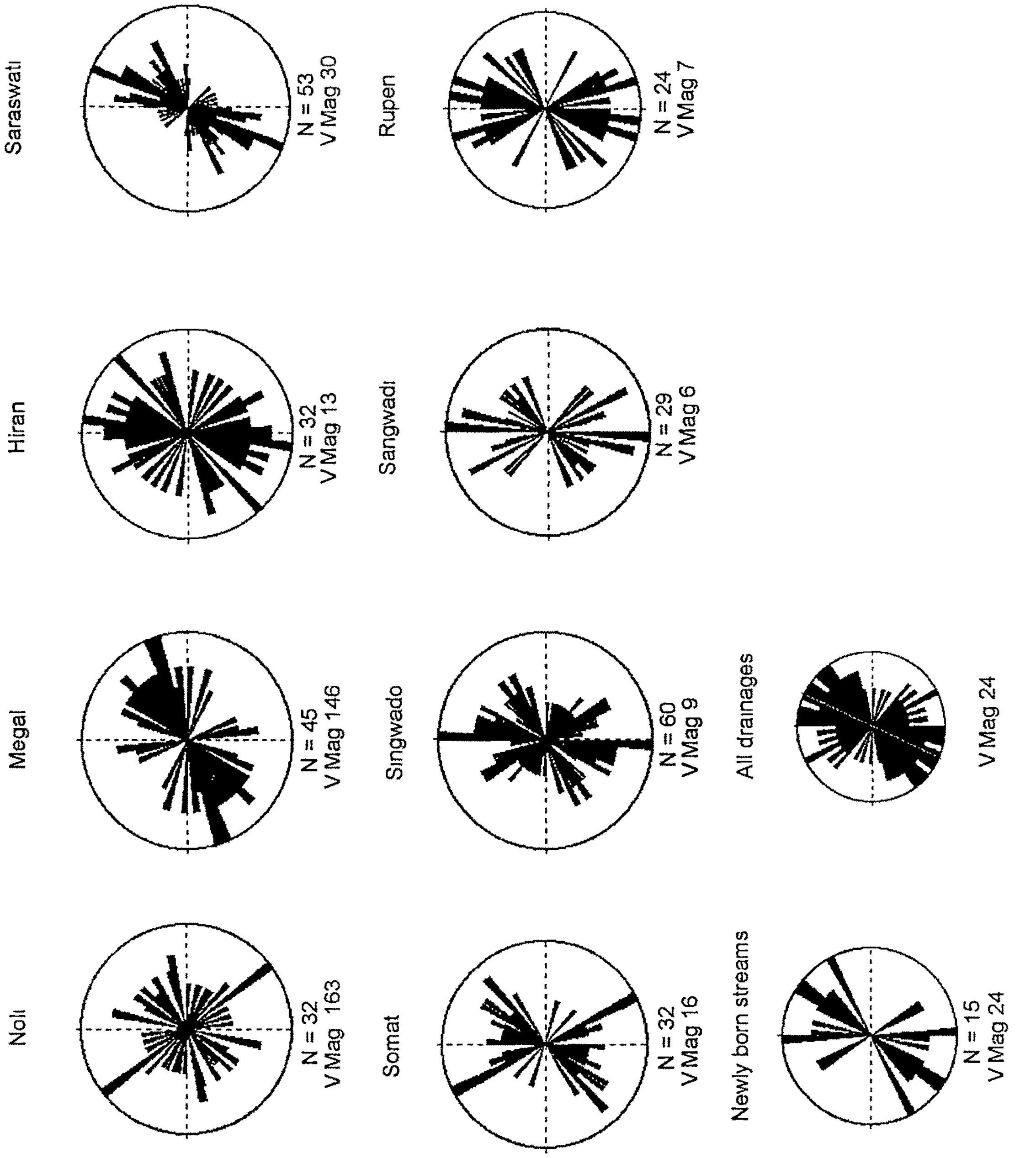


Figure 5 11 Rose diagram prepared using the drainage lineaments studied in the southwest Saurashtra.

River Morphometry

Regional analysis of drainage basin and river valley morphology using longitudinal profile, gradient index (GI) and pseudo-hypsometric integral (PHI) has been utilized to infer about differential uplift in many tectonically active regions like the Oregon Coast of western USA (Rhea 1993). Common practice to identify river response to change in the base level due to either sea level change or tectonics is the analysis of longitudinal profile which is a graph of the relationship between the river bed elevation and the river length. The importance of the longitudinal profiles has been discussed by many in detail (Demoulin, 1998; Sinha Roy, 2001). Seeber and Gorintz (1987) have shown that the longitudinal profiles are sensitive to ongoing tectonism and are useful to determine structures of any region. Further, the longitudinal profiles help in calculating gradient value (G) as well as GI and PHI. The gradient or slope is an elevation change over a distance and is useful for comparing slope changes over similar nearby lengths. Whereas, the gradient index is the ratio of elevation change over a logarithmically normalized distance and is useful for comparing slopes over greater distance and on different rivers (Rhea, 1993) Figure 5.12 represents a standard longitudinal profile and its variables for the calculation of G, GI and PHI values using Rhea (1993).

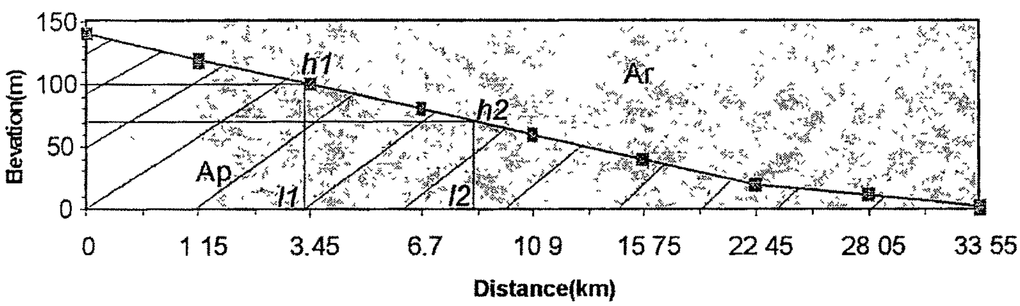
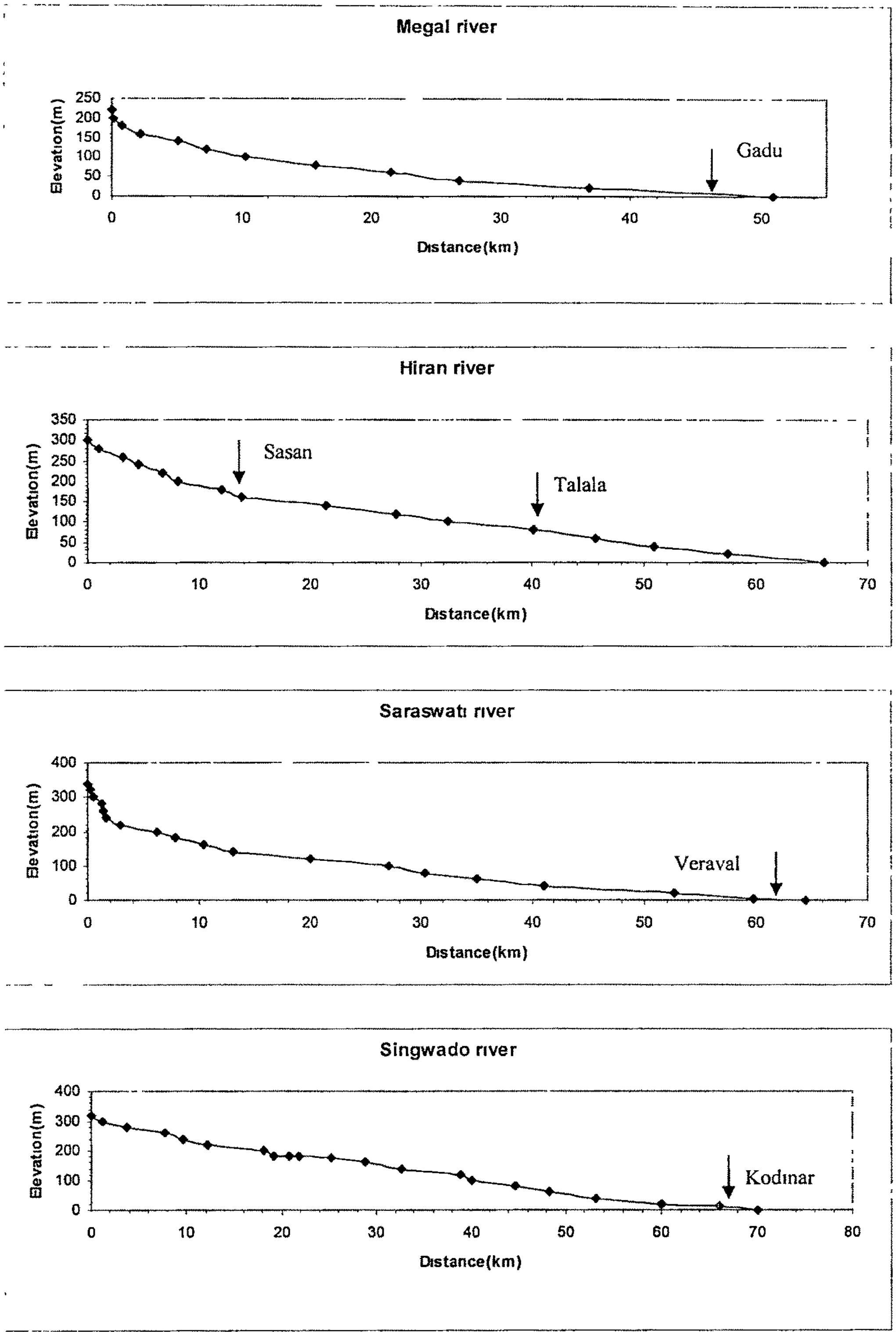


Figure5 12 A generalized longitudinal profile of a river, where h1 and h2 are two elevation points and l1 and l2 are corresponding distances from the origin. Ap is the area under profile and Ar is the area of rectangle (After Rhea, 1993)

Longitudinal Profiles:

Longitudinal profiles have been prepared for the major and minor rivers of the southwestern part of the study area as shown in the Figure 4.1. The longitudinal profiles of all these river basins were prepared using the SOI topographic sheets on 1:50,000 scale with 20m contour interval (Fig. 5.13). The Megal river has about 50km long profile showing a prominent knick-point at 140m height, and another knick-point at 60m. From 140m up to about 20m elevation the longitudinal profile shows a distinct convex upward profile of about 20km length. The other rivers like Hiran and Saraswati also exhibit convex upward nature of a part of their longitudinal profiles. The most interesting longitudinal profile found in the study area is of the Singwado river. The river originates in the Gir High land at about 320m and runs for 70km before meeting to an Arabian Sea near Mul Dwarka. The basin area covered by this river is 456.2 km^2 with one tributary named Adkan river. There are two prominent knick-points in this profile, one at 200m elevation and the other at 120m. Between 260 and 200m elevations, the river shows two prominent riverbank cliffs attaining height of 18m and 15m. This stretch is also characterized by the moderate to deep cut ravines. This significant incision is found in the volcanic rocks of the Deccan Trap Formation that forms the Gir Highland. At 200m elevation the river enters in to the piedmont zone of the Gir Highland. The knick-point at this elevation thus, may be related to the lithological change. The knick-point at 120m elevation is significant in a way the river has incised here onwards the compact and a bit recrystallized limestone of the Miliolite Formation. About 8 to 10m cliffs have been encountered in this part. The valley width has markedly reduced to about 7km from 25km just in a few kilometer distance south of Ghantwad. The course has also become straight along N-S direction for about 25km length between Ghantwad and Chhachar



Figuure 5.13 Longitudinal profiles of the major drainages of southwestern Saurashtra coast

where a distinct meander turns the otherwise southward flowing river channel towards the west for 2km; the river flows again southward then onwards. Abrupt lithological change in the form of the miliolite limestone abutting against the 6m high left bank cliff made up of fossiliferous clay of the Gaj Formation along this NW-SE lineament substantiates its tectonic origin. Longitudinal profiles of the other coastal streams like Somat, Sangwadi and Rupen were also prepared (Fig. 5.14). The streams are comparatively very small and their longitudinal profiles have shown initially steeper nature but, almost horizontal in the vicinity of the coast. About half a kilometer away from the present shore, the stream beds become very flat and merge in to the palaeo-tidal flats The course of certain rivers like Noli and Megal distinctly shows control of the coastal ridges, especially in the near shore regions. Comparatively, the rivers of the southern part of the Saurashtra depict the tectonic control over their basin shape and the longitudinal profiles.

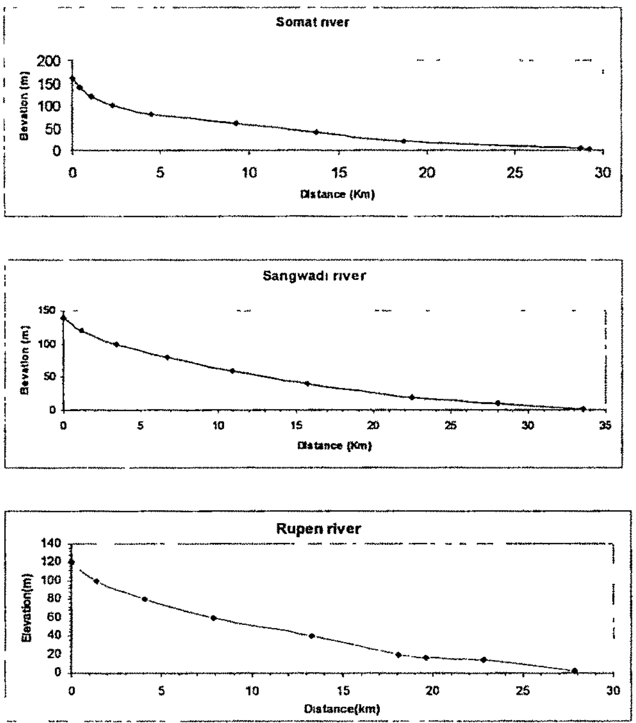


Figure 5.14 Longitudinal profiles of the minor coastal streams of the southwestern Saurashtra

Gradient and Gradient Indices (GI):

The values of gradient and GI have been calculated for each river using its longitudinal profile after Rhea (1993). Accordingly, gradient can be calculated as ..

$$\textbf{Gradient} = h1 - h2 / l2\text{-}l1$$

Whereas, Gradient Indices (GI) were calculated based on the formula

$$\textbf{Gradient Index} = h1\text{-}h2 / \ln l2 - \ln l1$$

Where, $h1$ & $h2$ are elevation in meter for individual data point and $l1$ & $l2$ are corresponding distances in kilometer for individual data point (Fig. 5.12).

Table V.3 summarizes thus calculated G and GI values of individual rivers. Figure 5 15 represents plots of gradient indices and distance on long profile for the major and minor rivers of the south Saurashtra. A longitudinal profile for any trunk stream can be quantified by using this index (Hack, 1973). This variable has been identified as the morphological element most sensitive to the tectonics; being highly variable in the area experiencing an intermediate rate of uplift near Cape Mendocino, California (Merrits & Vincent, 1989). However, the lithological contrasts can also influence the GI value (Beaulieu, 1973; Neim & Neim, 1985).

Table V 3 Summary of Gradient and Gradient Indices of the rivers of the SW Saurashtra

River	Basin Geometry			Gradient ($m.km^{-1}$)			Gradient Index
	Max. Elev. (m)	Length (km)	Area (km^2)	Max	Min	Mean	Mean
Megal	220	50.9	417	200	0.83	25.42	46.665
Hiran	300	66.1	512	19.04	2.32	7.22	105.67
Saraswati	340	64.5	365.6	133.33	0.61	25.69	87.98
Somat	160	29.25	268.8	50	1.59	13.78	57.4
Singwado	320	70.05	456.2	190.4	1.42	6.99	169.08
Sangwadi	140	33.55	225.4	17.39	1.54	5.91	42.31
Rupen	120	27.85	210	14.81	0.625	5.1	39.67

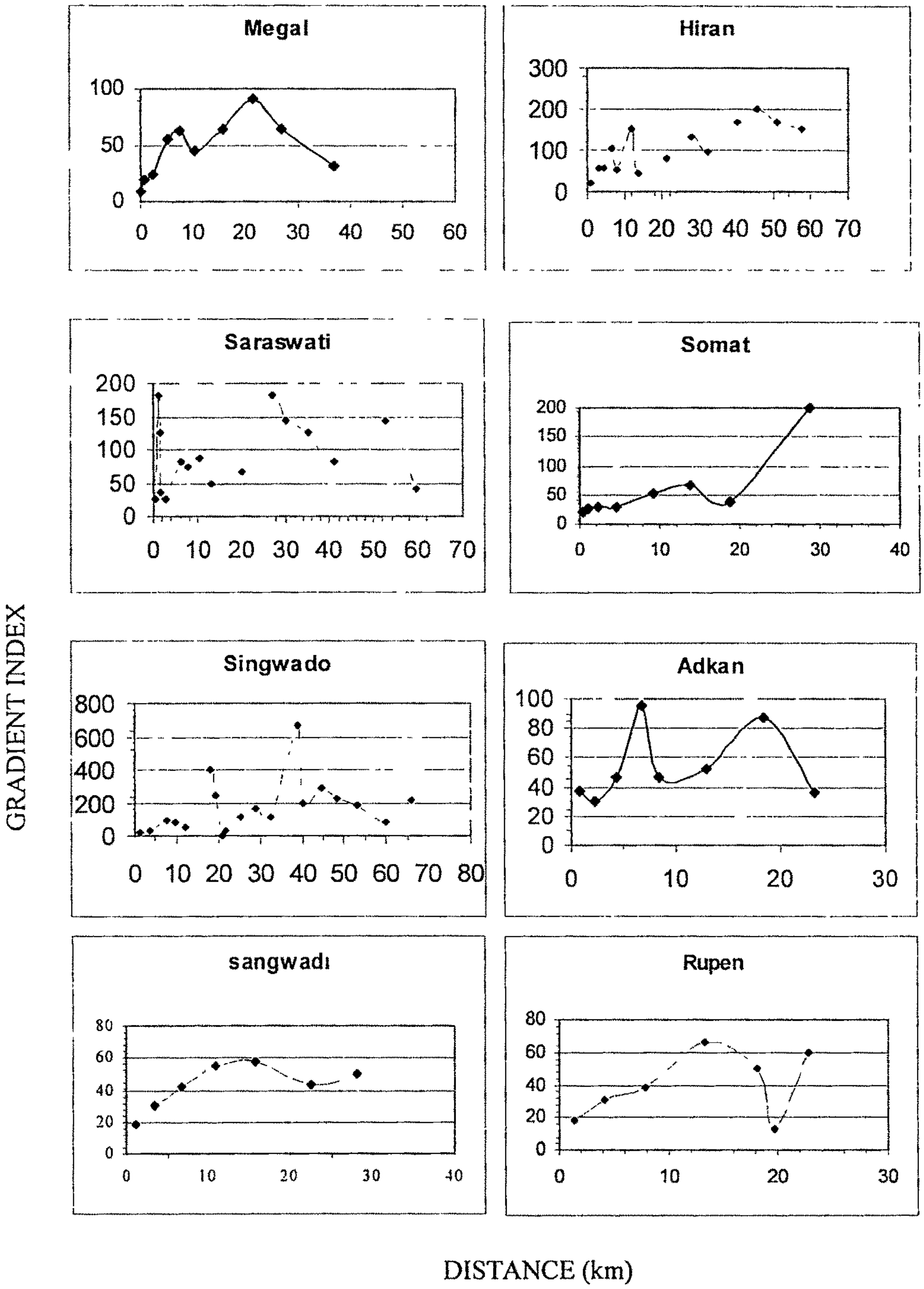


Figure 5.15 Plot of Gradient Indıces against distance on longitudinal profile of various rivers studıed.

For Megal river, maximum gradient value found in the longitudinal profile is between 220 and 200m elevation with a mean of 25.42 whereas, GI varies between 10 and 90 with an average of 46.66. Two higher values of GI have been observed in the profile of the Megal at 120m and 60m elevations (Fig. 5.15).

The Hiran river runs for about 66km, and shows the average gradient value of 7.22. The GI values are ranging between 18 & 166 with an average of 105. The GI values of Hiran river when plotted against the distance, show three peaks at 12, 27 and 45km in the profile (Fig. 5.15). The sedimentary rocks belonging to the Gaj Formation encountered at an elevation of 85m near Semarvav 28 km inlandwards from the coast. An abrupt increase in the GI from this point onwards reflects the higher erodability of these sedimentary rocks in comparison to volcanics. The GI again decreases from 45km distance on the long profile upto the coast. The lithology being softer miliolite limestone does not suit to such decrease. Hence, this can be accounted either to the tectonic uplift of the coastal plain or to the decreased stream energy. The Saraswati river which originates at about 340m in the Gir highlands and runs for about 65km before meeting an Arabian Sea near Prabhas Patan has also shown fluctuations in the GI value. This river basin is adjacent to the Hiran river basin mentioned above. It has also reflected three peaks in the GI value on its profile, i.e. at 2, 27 and 53km distances

The longitudinal profile of Singwado river basin has shown prominent knick-points as described earlier. The G and GI values for this river have shown two distinct peaks in the GI plot, which correlates well with the longitudinal profile (at 19 & 38 km distances). The plot (Fig. 5.15) shows sharp peaks in GI value representing sudden increase in the gradient. Apart from the lithological control, the gradient behaviour of this river has a clear influence of tectonism About 6-8m incision in the sub-horizontal compact miliolite limestone and presence of a waterfall of 4m height between Ghantwad and Chhachar support this inference regarding the erratic behaviour of GI in this part of the river basin. When other rivers show common decrease in the GI value near to the coast, the Singwado river shows slight increase in it (Fig. 5.15).

PHI (Pseudo Hypsometric Integral):

This variable is determined as a ratio of the area covered under the longitudinal profile to the total area of rectangle defined by the profile. This particular index is useful to describe the overall shape of the longitudinal profile, and is a numerical expression. It helps in comparing various drainage longitudinal profiles as it removes the bias of scale and vertical exaggeration in the longitudinal profile (Rhea, 1993). This is calculated from the longitudinal profile based on the formula (Fig. 5.12).

$$\mathbf{PHI} = Ap / Ar$$

Table V.4 gives the PHI values calculated from the long. Profiles of the rivers discussed earlier The PHI values for the rivers studied range from 0.23 to 0.45. It is interesting to

Table V 4 PHI values calculated for the longitudinal Profiles of the SW Saurashtra rivers

River profile	PHI value	River profile	PHI value
Megal	0.26	Somat	0.43
Hiran	0.33	Singwado	0.41
Saraswati	0.23	Sangwadi	0.45
		Rupen	0.42

note that the PHI values are increasing from west to east. This may be due to the relative uplift of the southern Saurashtra coast drained by the streams of higher PHI as the higher value of PHI suggest more coverage of the graph area under the longitudinal profile. These can also be accounted to the resistive lithology or fluvial aggradation (Neim & Neim, 1985; Rhea, 1993). However, in the study area no distinct lithological change is seen that may influence the PHI values due to its varied erodability. The structural controls on the streams showing higher PHI can also be obviously seen in the field as well as other morphometric parameters.

The morphometric attributes of the coastal rivers are found significant in understanding the river response to the change in sea-level overprinted by the tectonic uplift during the Late Quaternary time in south Saurashtra coast. The increasing values of gradient indices and PHI from the Megal river in west to the Singwado river in east demonstrate the dominant role of the tectonic uplift along the NE-SW tectonic trend which is in conformity with the Narmada-Son Fault that runs off shore parallel to the southern coast of the Saurashtra. The post Miliolite 6m uplift of the southern bank of Singwado river provides an onland field evidence of the neotectonic activities in the region The occurrence of flexuring and warping along with the profound occurrences of joints substantiate this inference. Thus, the evidence exists in favour of the neotectonics in Saurashtra peninsula, but of amiable magnitude that too varying in different parts of the study area