CHAPTER - VI

T E C T O N I C   A S P E C T S

GENERAL

FRACTURE PATTERN

NEOTECTONISM AND SEISMICITY

T E C T O N I C   A S P E C T S

GENERAL

In this chapter, the author has described and analysed the various tectonic features, major structural lineaments, local faults, joint sets of several generations, and the control exercised by them on the overall topography and landscape evolution.

The fracturing of the study area in space and time, has to be viewed from the point of view of regional tectonics, which is a manifestation of the continuing NNEward drift of the Indian continental mass.

As has already been stated earlier, the study area reflects tectonism related to two sets of megafractures, ENE-WSW and NNE-~~the~~ SSW, that are characteristic features of the rifted western margin of the Indian subcontinent. The continental shelf in the Gujarat region is a product of uplifts and subsidences along these two major fracture systems. It has been pointed out by Biswas (1987) that the entire tectonic framework is controlled by the reactivation of Precambrian basement structural lineaments, and this fact is of great relevance to the present study. According to Nair et.al,(1988) who studied the Deccan Traps of Narmada - Tapi region in Maharashtra and Madhya Pradesh, "The Satpura region between the Narmada - Son and Tapi-Purna valleys, extending from Western Ghats to Saraguja in the east is a tectonically highly disturbed region. The region appears to be an upfaulted block with several subsequent block faults. Step faulting with throws of the order of 10-25 meters are identified both in the Narmada and Tapi - Purna valleys. The Narmada-Son and Tapi-Purna valleys represent rift valleys developed along pre-existing structural weak zones".

The basement fracture pattern is well reflected in the structural setup of South Gujarat. Rejuvenation of the basement structures during Cenozoic, generating several sets of related fractures over a protracted period is now manifested in the existing fracture pattern. The fracture pattern in turn, has substantially contributed to the development of the present landscape. The fracturing in the Trappean Highlands, at all scales (macroscopic to mesoscopic), has resulted into uplifts, subsidences or lateral shifts along fractures related to either one or both of the above mentioned two major structural lineaments. The fractures apart from forming step-faults, horsts and grabens, have also facilitated increased erosion.

In order to fully understand the tectonic control over landscape, the extents, trends, and intensities of the major faults, smaller dislocations and the various joint-sets in different parts of the study area were recorded and studied in considerable detail. A critical analysis of the data obtained from toposheets, (drainage, landforms) and satellite imagery to decipher the detailed structural pattern of the study area, was carried out. The author undertook extensive field work for on-the-spot check and to ascertain the various structural features.

Keeping in mind the regional tectonic picture as postulated by earlier workers (Kaila, et al, 1981; Biswas, 1982,1987; Rao, 1987; Power 1981, Sychanthavong, 1984), the present author has attempted to describe his own observations and explain the nature and significance of the various fracture sets encountered.

FRACTURE PATTERN

The fracture pattern of the study area, as revealed by the landscape in totality and the various faults and joints recorded, points to a strong control exercised by two basement tectonic lineament directions, (E-W to ENE-WSW and N-S to NNE-SSW). Within the limits of the study area, two major NNE-SSW and several ENE-WSW faults have been recognised. Along the major ENE-WSW faults, various rivers are flowing.

Of the two NNE-SSW faults, the western fault, marks the boundary between the Uplands and the Trappean Highlands, and is the southerly extension of the Cambay Basin Eastern Boundary Fault (Rao 1987, Biswas, 1987). The eastern fault that marks the sudden rise of the Deccan plateau (Fig.VI.1) forms the northern extremity of the regional fault that extends along the Western Ghat Escarpment (Scheidegger & Padale, 1982; Krishna & Kaila, 1986). Of the various E-W faults of regional dimensions, which broadly coincide with the river courses, the two i.e. along Tapi

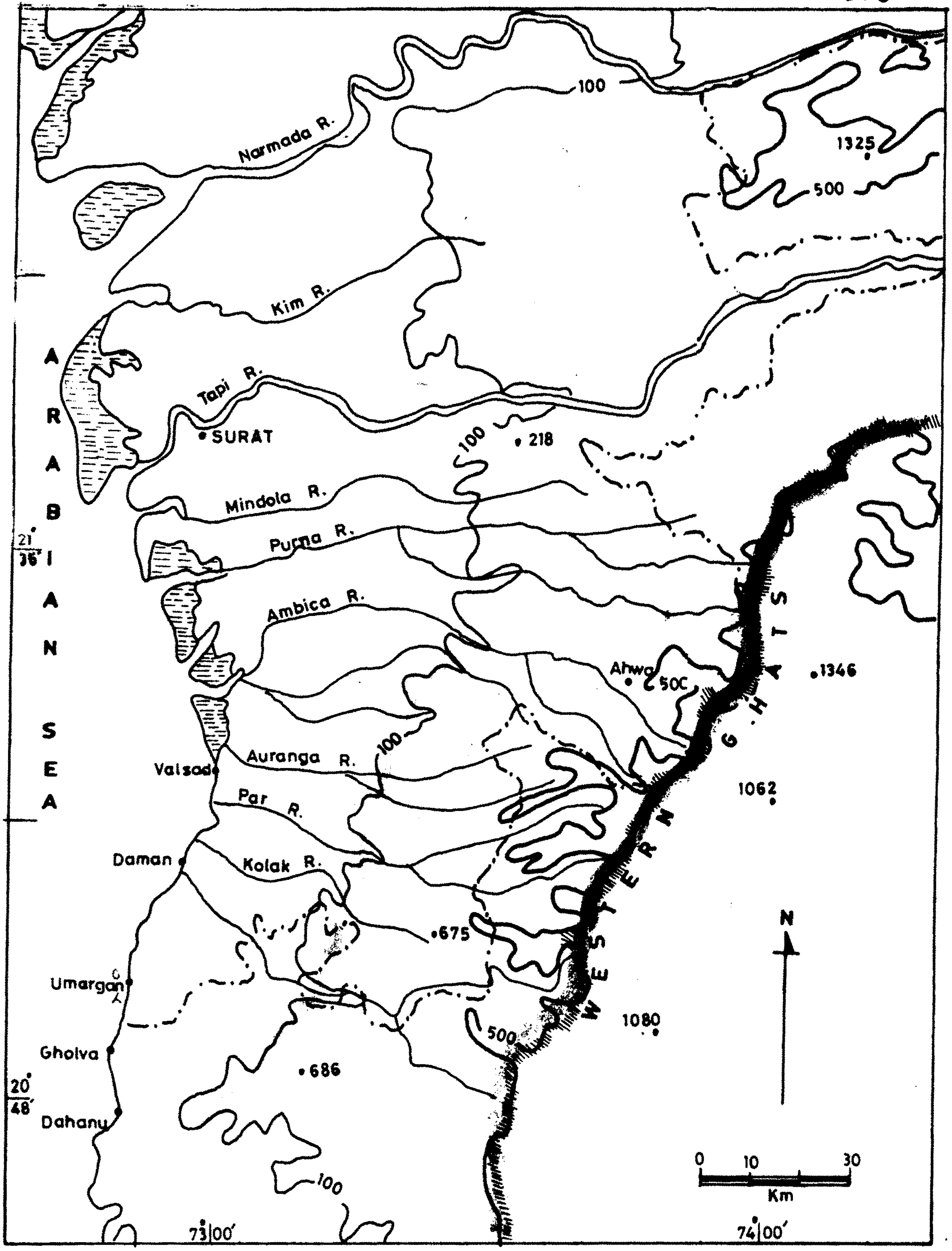


Fig: VI.1 NNE-SSW TRENDING REGIONAL FAULTS DEMARCATING GEOMORPHIC SUB-DIVISIONS and Purna have been recorded and mentioned by (Figs. VI.1 & VI.2) earlier workers (Kaila et al, 1981, Power, 1981), and the rest have been deciphered by the present author on the basis of his own observations and analyses.

The two major NNE-SSW faults that cut across the study area comprise, a set of step faults progressively downfaulted to the west, and are located on the eastern flank of the Cambay Graben. These two faults are typically reflected in the geomorphic sub-divisions, the eastern fault marks the Trappean escarpment, whereas the junction between the Coastal plains and the Uplands, forms the other fault. From south to north, the various ENE-WSW faults, have again given rise to a progressive downfaulting; these belong to the Narmada - Tapi Graben System. The decrease in the heights from south to north, and from east to west has been observed to indicate original step-like topography, comprising progressively downfaulted blocks from south to north and east to west respectively. The various fracture systems consisting of smaller faults, fractures and joint sets, are related to the megafractures.

The fracture pattern of the study area as revealed by drainage (Fig. VI.4) and landforms is characterised by two distinct sets, viz. NNE-SSW and ENE-WSW. Obviously, these two trends follow the regional structural lineaments. An overview of rose diagrams of the fracture trends revealed by patterns of streams of various orders in different basins (Fig. VI.5; Table

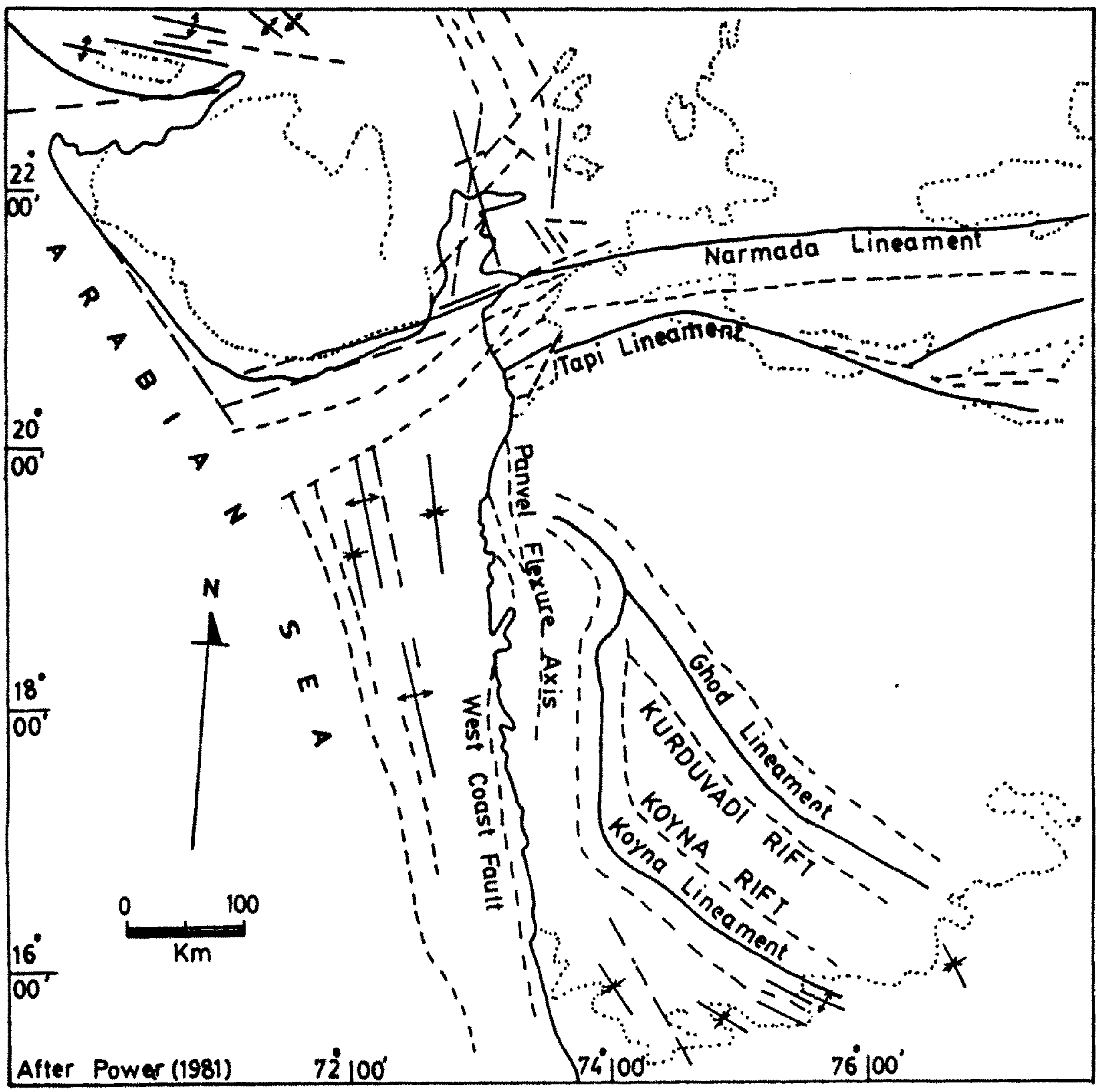
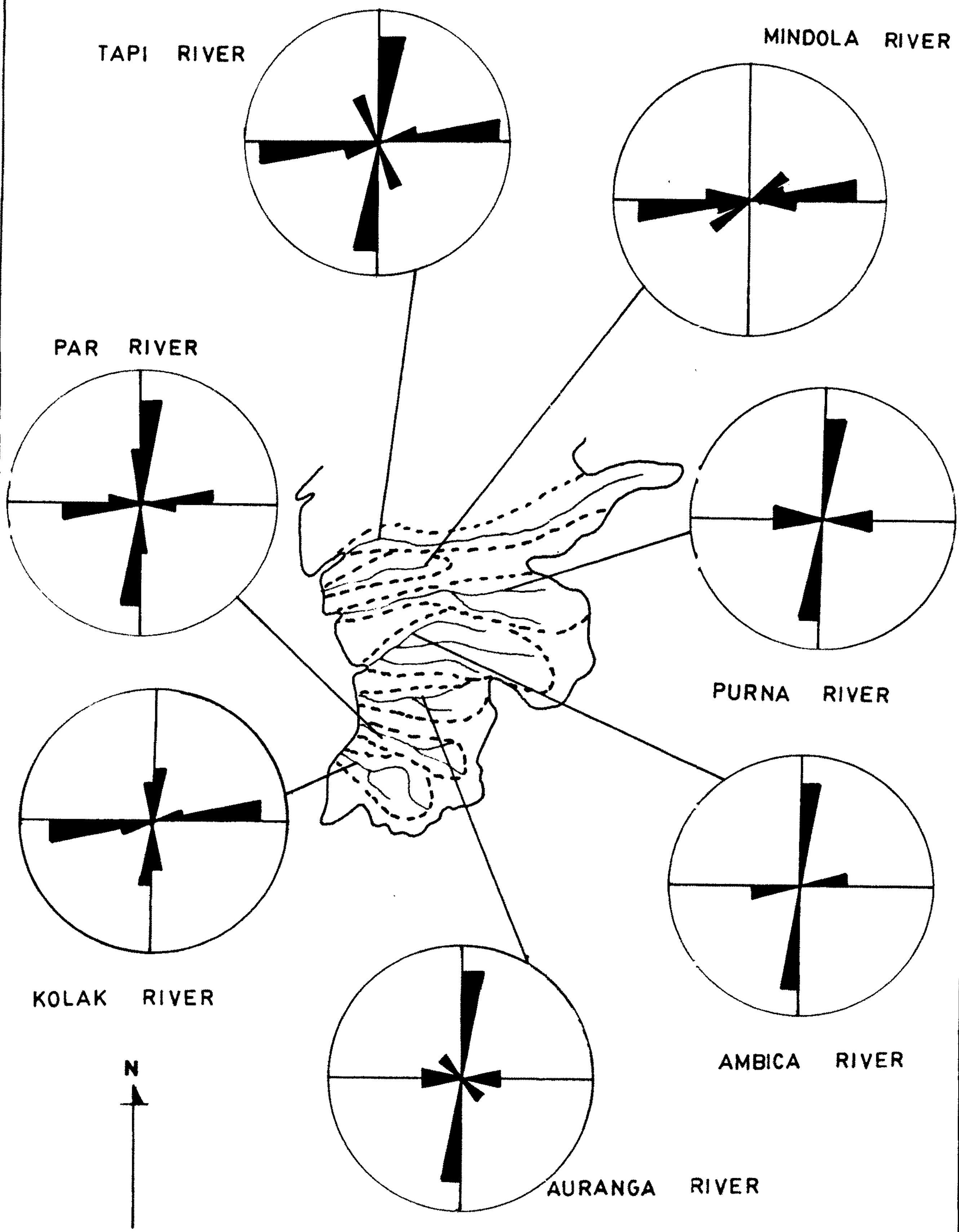


Fig:VI.2 TECTONIC FRAMEWORK OF THE WESTERN PART OF DECCAN VOLCANISM

Fig:VI.5 SYNOPTIC VIEW OF ROSE DIAGRAMS OF FRACTURE PATTERNS OF VARIOUS RIVER BASINS



V.1.) provide valuable information on the trends and intersections of the various fracture sets.

Lineament map prepared from Satellite Imagery (1:250,000) is also quite revealing (Fig.VI.6 and Table VI.1). On the imagery the various drainage basins and the important streams of higher orders can be delineated very clearly. The linear shapes of the different basins also conforms with the development of E-W lineaments. The map not only confirms the existence of the fractures and joints related to the two major tectonic directions, but also shows the areal variation in the number and intensity of the two fracture sets. It ideally shows how both the sets of fractures have mutually affected each other and shifted one set by the other.

The author personally visited most parts of the area and recorded the joint pattern shown by the basalts. The localities where the readings were taken are shown in (Fig.VI.7) and, the values of the actual readings are given in (Table VI.2). The rose diagram based on these readings, is consistent with the overall pattern revealed by the drainage and the satellite imagery. The actual spot readings have established one very important feature, i.e. most of the fractures and joints are near vertical.

The fracture pattern as seen to-day establishes following facts :

TABLE : VI.1 DATA FOR LINEAMENT ORIENTATION, NUMBER AND LENGTH BASED ON SATELLITE IMAGERY

Azimuth Class 0	Total No.	Total length (km)	Number %	Length %
0-10 NE	175	900.25	17.54	16.4
10-20	64	378.7	6.41	6.92
20-30	52	280.75	5.21	5.13
30-40	34	175.75	3.41	3.21
40-50	14	75.00	1.40	1.37
50-60	61	322.75	6.11	5.90
60-70	140	755.56	14.03	13.81
70-80	161	923.50	16.13	16.88
80-90	32	142.00	3.21	2.60
360-350 NW	56	395.00	5.61	7.22
350-340	38	243.50	3.81	4.45
340-330	34	193.50	3.41	3.54
330-320	28	170.25	2.81	3.11
320-310	24	142.75	2.40	2.61
310-300	22	117.50	2.20	2.15
300-290	3	17.25	0.30	0.32
290-280	12	64.50	1.20	1.18
280-270	48	172.50	4.81	3.15

MAP SHOWING LOCALITIES VISITED FOR JOINT READINGS

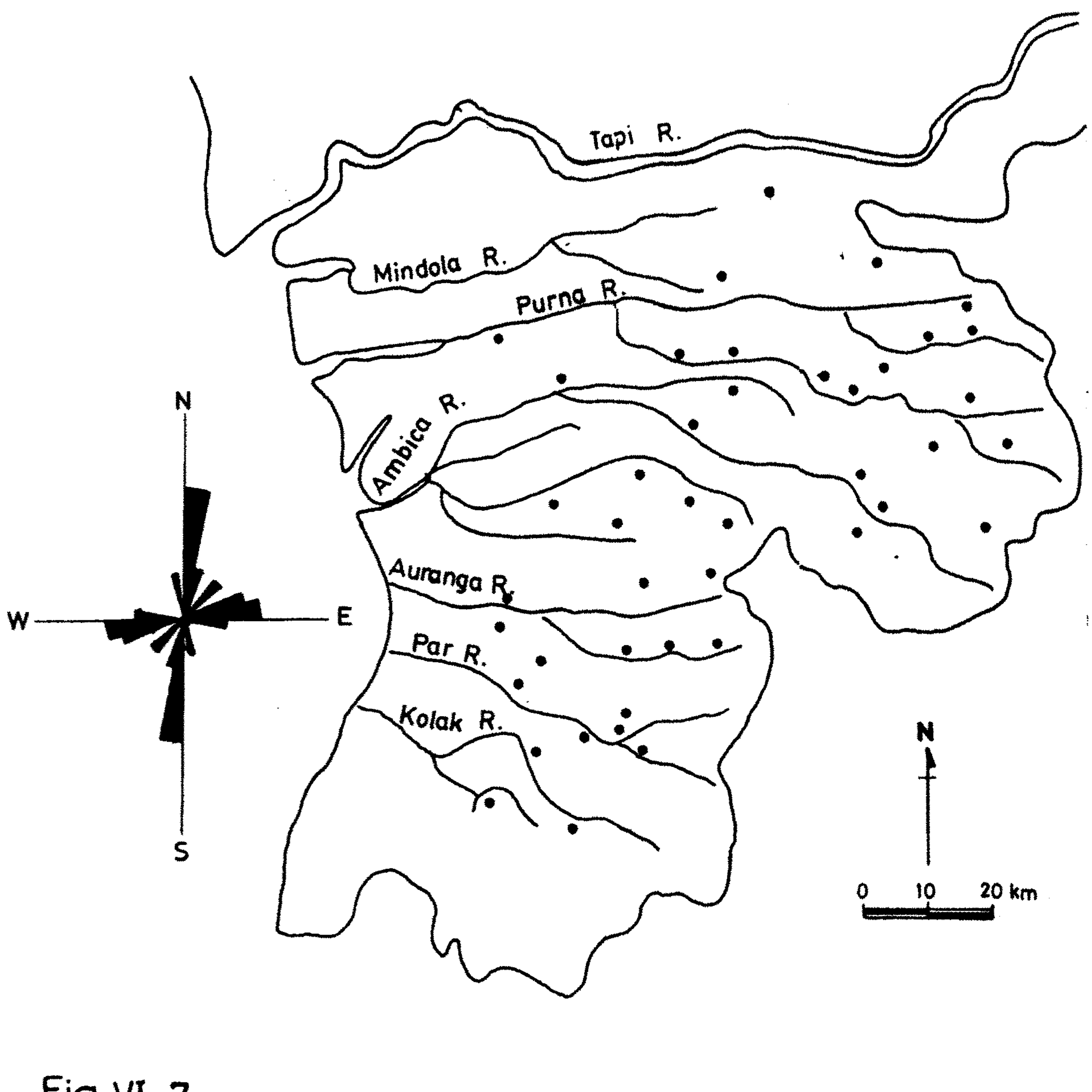


Fig: VI. 7

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TABLE : VI.2 ACTUAL READINGS OF JOINT FROM DIFFERENT LOCALITIES OF THE STUDY AREA

Azimuth Class	No. of Joints	Number %
0-10 NE	34	21.52
10-20	10	6.33
20-30	5	3.16
30-40	1	0.63
40-50	10	6.33
50-60	3	1.90
60-70	8	5.06
70-80	15	9.49
80-90	19	12.02
360-350 NW	5	3.16
350-340	9	5.70
340-330	7	4.43
330-320	7	4.43
320-310	4	2.53
310-300	4	2.53
300-290	4	2.53
290-280	6	3.80
280-270	7	4.43

(1) Step-faulting from E to W and S to N forms an integral part of the phenomenon of the graben development (N-S Cambay Graben and E-W Narmada-Tapi Graben).

(2) Fractures (faults, joints etc.) are genetically related to the two megafracture directions.

(3) The two dominant fracture directions point to a conjugate relationship.

(4) Fracturing initiated at the close of Cretaceous continued to take place all-throughout the Tertiary and Quaternary periods, essentially being related to the northeastward drift of the Indian landmass.

(5) Tensional fractures were generated during the earlier stage (rifting) and they were subsequently subjected to compressional stresses during the later stages of the drift.

Although it is somewhat difficult to visualise the precise stress-fields during the two stages of deformation; but an approximate conjecture can still be made. During the rifting stage, the tensional stress-field was so oriented that the two pre-existing major fractures opened up and resulted into Cambay and Narmada-Tapi Graben Systems. This was probably related to the transform or lateral displacement during late Cretaceous, as visualized by Mckenzie & Sclator (1971), and Biswas (1987).

The compressional stage is better understood. It was during this stage that the major bulk of reactivation of older fractures and formation of new sympathetic fractures and block uplifts etc. took place.

The effects of compressional stress field are observed to be different from one part to the other and this phenomenon is reflected in the variable intensities of NNE-SSW and ENE-WSW fracturing and jointing. This could be due to the variations in the amounts of the stresses acting on different blocks and the presence or absence of major fractures of either trends. This is very well seen in the fracture controlled drainage of the study area (Fig.VI.4).

The numbers, lengths and spacings of the two fracture sets, have primarily been the most vital factors for imparting diversity of the shapes, sizes and extents of the various landforms. Closely spaced fractures are responsible for the development of numerous narrow linear ridges. The ridge formation is due to two reasons. Either the two flanks of a ridge have eroded faster along major fracture zones, or they indicate horsts and grabens (Figs. VI. 8,9 & 10). Erosion of horizontally bedded basalts along the two fracture directions in a variety of combinations appears to be the main cause of the formation of the flat-topped ridges and hills (Fig. VI.11). Two categories of horst and graben structure have been recognised, in the altitude of the ridges. Some ridges point to a certain amount of stepping down, while others show equal elevations (Fig. VI.12). The nature of dissection of landscape is very well

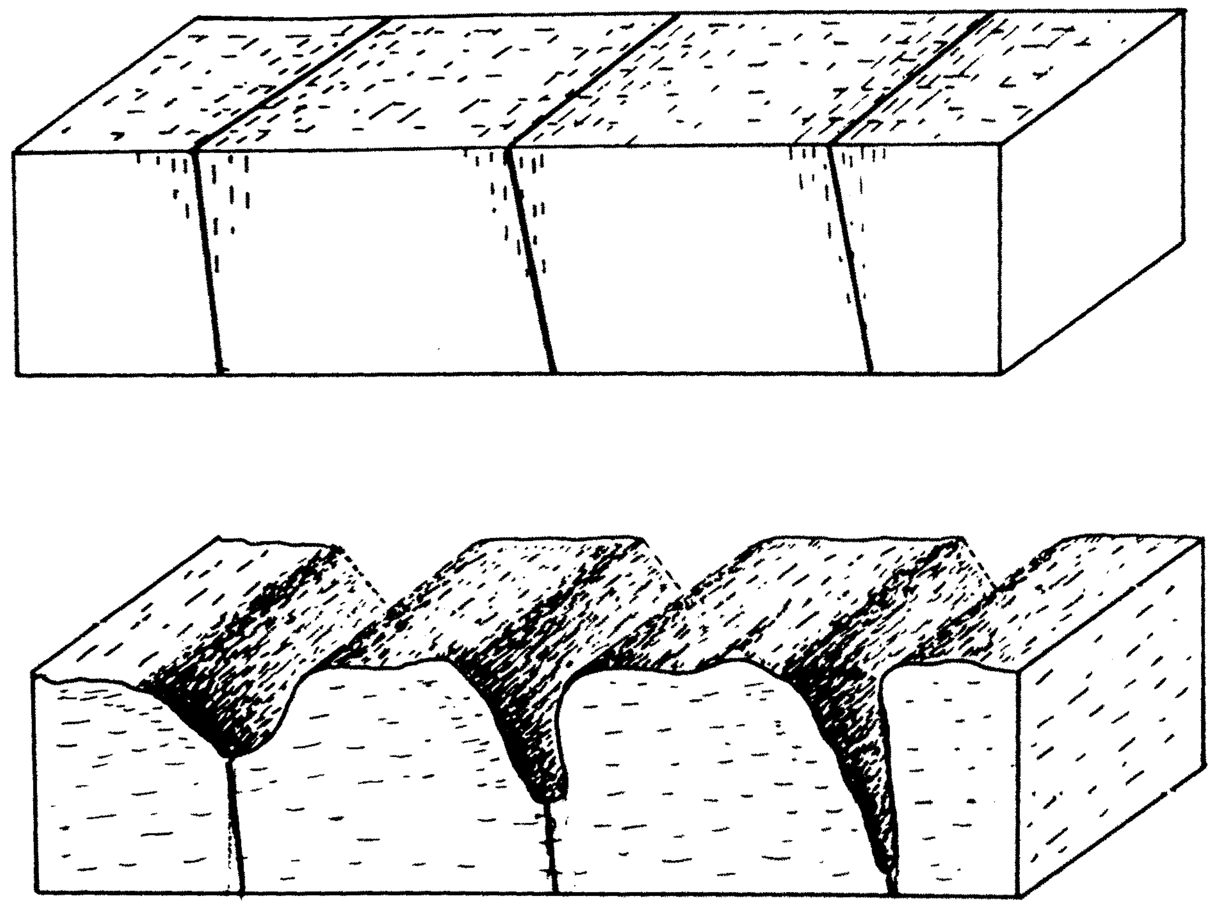


Fig: VI.9 BLOCK DIAGRAM SHOWING EROSIONAL TOPOGRAPHY DUE TO MAJOR FRACTURES(JOINTS)

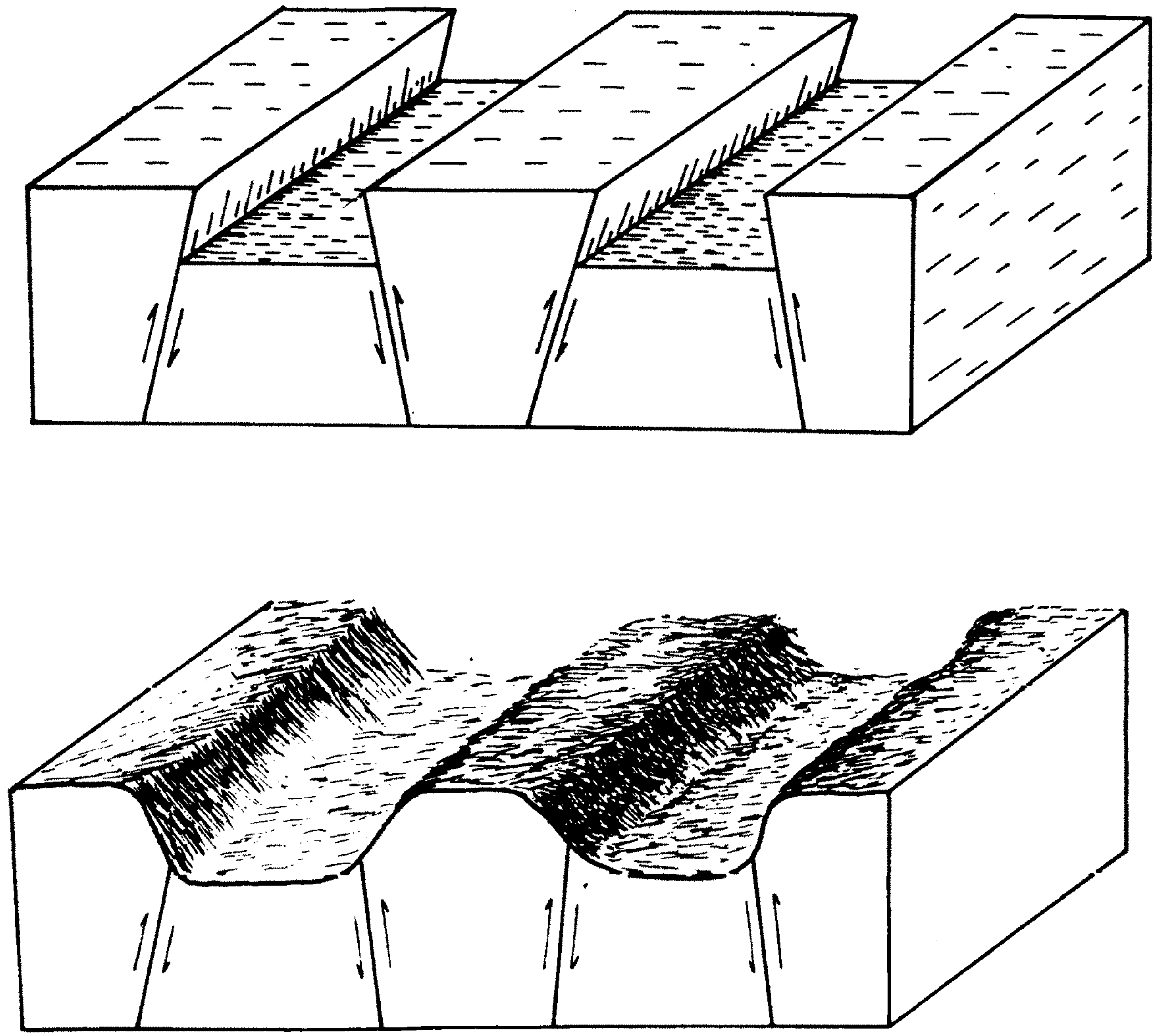


Fig: VI.10 BLOCK DIAGRAM SHOWING EROSIONAL TOPOGRAPHY DUE TO HORSTS AND GRABENS

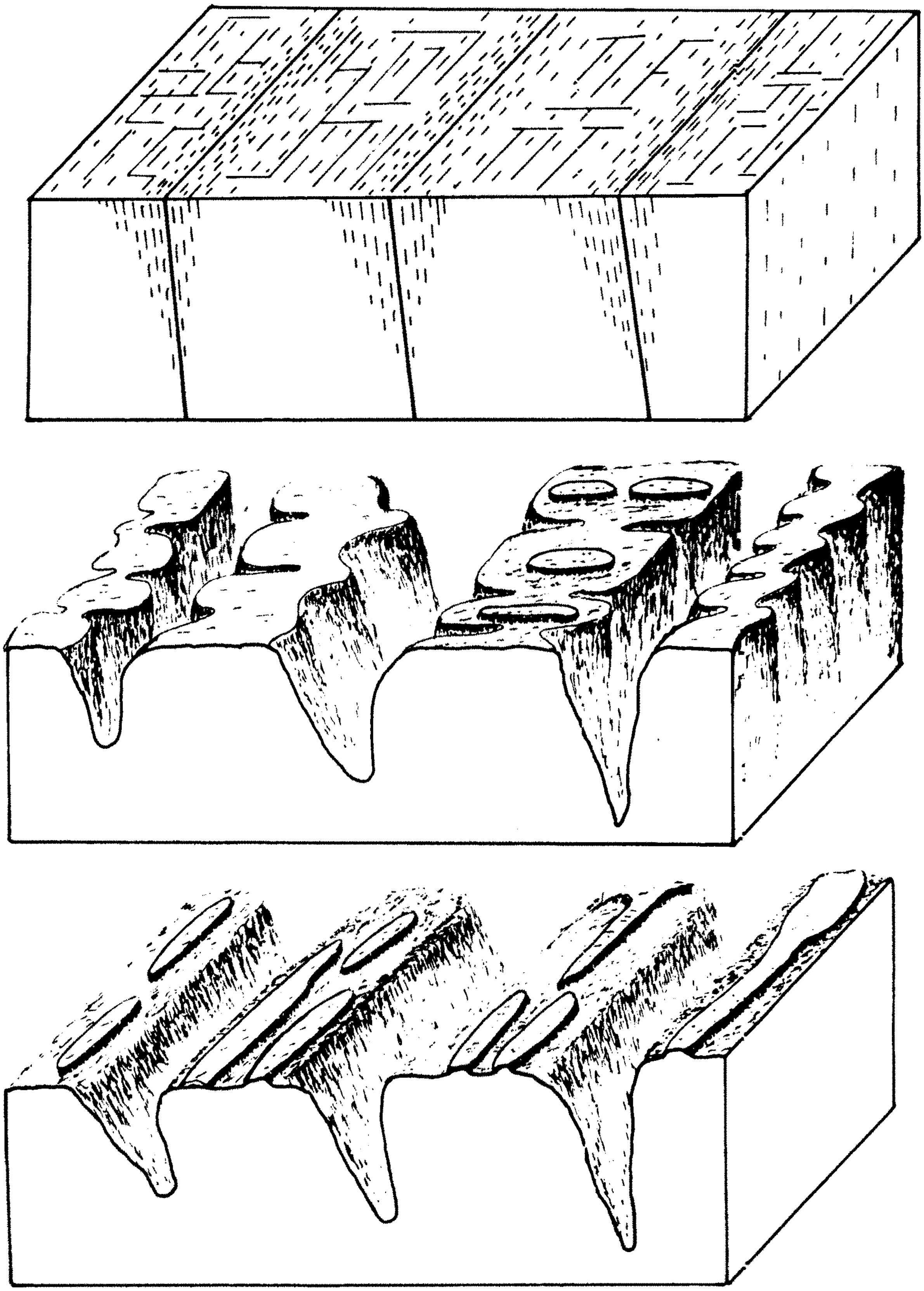
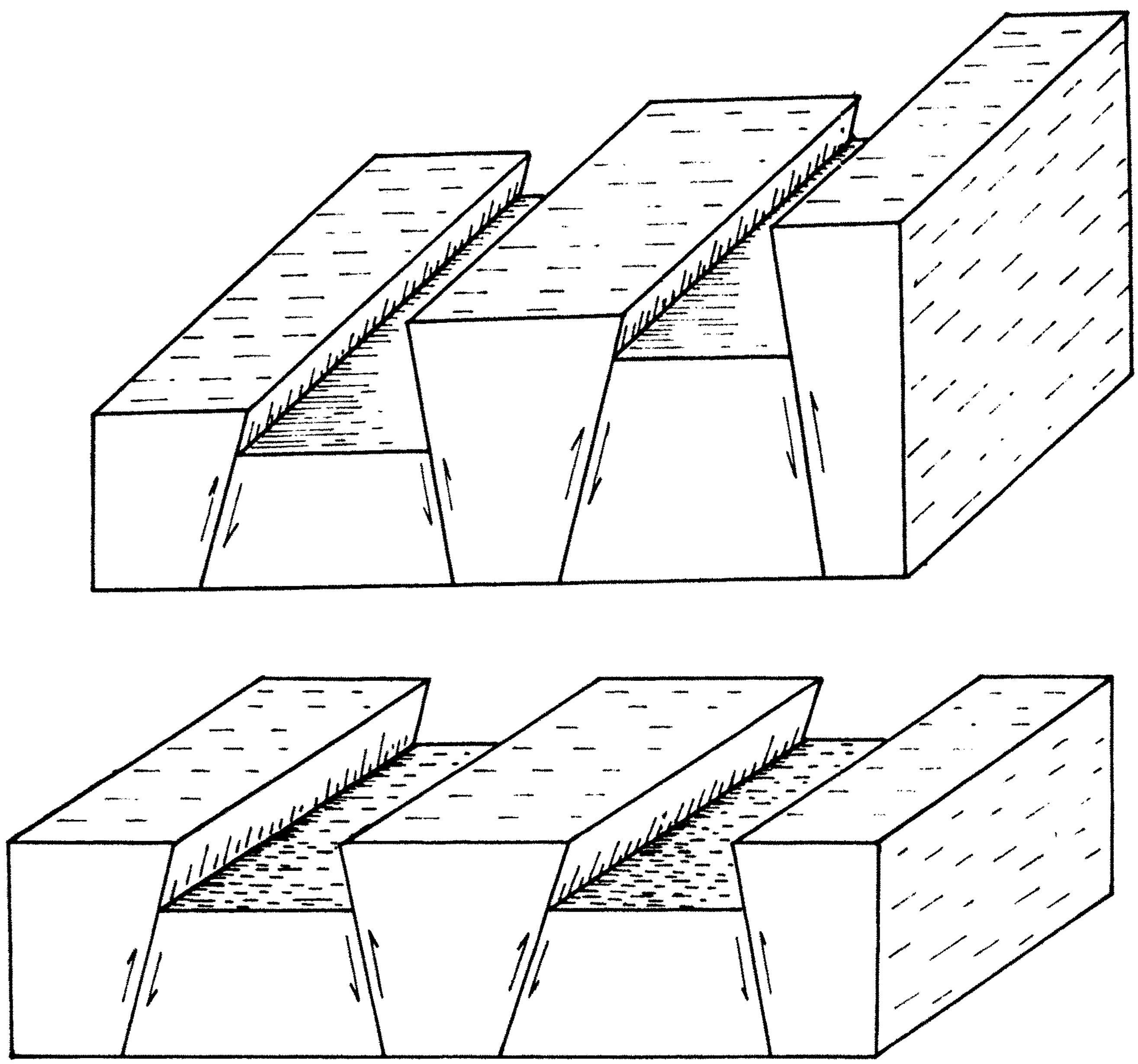


Fig:VI.11 BLOCK DIAGRAM SHOWING FLAT TOPPED HILLS AND RIDGES OF VARYING SHAFES CONTROLLED BY FRACTURES

Fig:VI.12 BLOCK DIAGRAM SHOWING HORSTS AND GRABENS AT SAME ELEVATIONS AS WELL AS A STEPPING DOWN



reflected in the two Altimetric Variation Diagrams, (Heights of Summits plotted against Distance) drawn by the author along N-S and E-W directions. The diagrams give a good overall picture. The N-S Altimetric Variation Diagram illustrates a progressively step-like downfaulting from S to N along a number of faults, which are now the sites of river Par, Auranga, Ambica, Purna and Tapi (Fig.VI.13). A similar diagram drawn in E-W direction ideally brings out the effect of the two major N-S lineaments i.e. the Western Ghat Escarpment Fault and the Eastern Cambay Basin Boundary Fault (Fig.VI.14).

Considerable information has been obtained from the various topographical profiles. The author has drawn E-W profiles for the middle portions of the study area, extending from the Great Escarpment in the east and to the fringe of the Coastal plains in the west (Fig.VI.14). In all 5 profiles have been drawn to highlight the topographic expressions of the two major faults. Imagery studies, aided by a critical appraisal of the profiles, indicate that the two major N-S tectonic lineaments are not just clear cut dislocation planes but comprise narrow zones of numerous parallel and sometimes en-echelon, smaller faults. The N-S profiles provide information on the behaviour of E-W (ENE-WSW) faults within the major fault blocks. The horst and graben structures on a lesser scale have imparted the ruggedness to the terrain. In order to highlight this aspect, the N-S, profiles were drawn in the most rugged southeastern part of the area. The profiles (Fig.VI.15), throw light on the role played by E-W faults on the evolution of the hilly landscape. The detailed picture of this phenomenon is exhibited in Fig.VI.15B.

In a general way, the ENE-WSW fractures have given rise to similarly oriented flat-topped linear ridges that mostly comprise horsts and grabens. There is an overall decrease in the altitude of the ridges from south to north pointing to an increasing downfaulting, in that direction. On the other hand, most of the NNE-SSW trending ridges, do not show any significant differential vertical movement, and typically comprise erosional remnants, the intervening steep valleys having originated due to greater erosion along fracture zones.

NEOTECTONISM AND SEISMICITY

The tectonic history of the area, as revealed by the various structural features seen today points to a protracted sequence of fracture events, controlled by the two fundamental lineament directions, ENE-WSW and NNE-SSW. Faults and joints are related to these structural trends, generated since the beginning of the Cenozoic over an extended time span comprising both Tertiary and Quaternary periods. Whereas the Tertiary tectonism is very well exhibited in the Cambay basin (Cambay Graben and Narmada-Tapi Graben) configuration, structure and sedimentation, the Quaternary events are reflected in the existing (surface) landscape. Steep cliffy slopes in low order stream channels, entrenchment of channels within hilly terrains and locally developed non-cyclic unpaired river terraces or paired terraces showing height variations, are diagnostic indications of differential uplifts subsequent to their formation. Convincing evidences of continuing tectonism, are provided by the frequent earth tremors recorded in various parts of South Gujarat. The seismicity record points to the fact that neotectonic movement have continued to take place even during recent times and the seismicity data for the area compiled from different published and unpublished reports, (Table VI.3), adequately establish that from time to time, earth tremors have occurred and they are aligned with megafracture directions. Most of the earth tremors have their foci at shallow depths, never exceeding beyond 8 km. These focal depths point to crustal adjustments beneath the basaltic layer, and according to Rao et.al (1986), "The depths of a few shocks close to one kilometer suggests adjustment to be taking place apparently between the traps and the granitic layer. However, the occurrence of the tremors up to a depth of 7 km points out that many of events could be of tectonic origin, possibly associated with some fault in the region. This is also brought out by the fact that energy corresponding to an event of magnitude 4.5 could not be stored in the surficial layer i.e. traps."

Broach earthquake of 1970 is a good and convincing evidence of neotectonic movement along Narmada geofracture. Gupta (1972) has attributed this earthquake "to the movements along some pre-existing fault in the Eocene sediments of the deepest part of the Cambay Basin. In 1966, several earth tremors of slight intensity

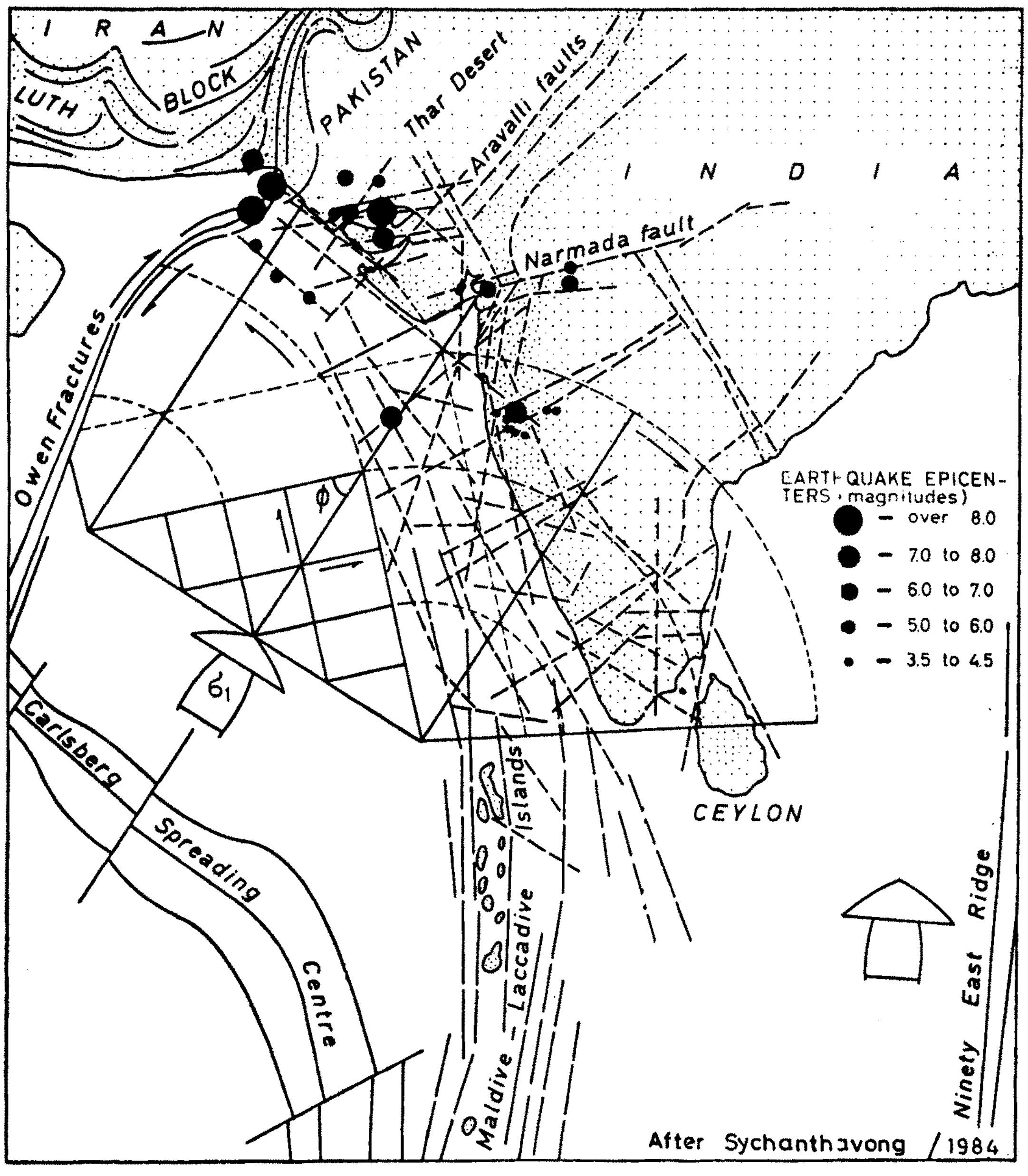
TABLE : VI.3 SEISMICITY DATA FROM DIFFERENT PARTS OF SOUTH GUJARAT

S.No.	Date	Time	Location		Depth in cm
			Lati.	Long.	
1.	14.2.79	01:52:03	21.10	72.92	30
2.	06.5.81	18:50	20.72	72.96	3.7
3.	14.9.82	20:31	20.58	73.56	-
4.	-	-	21.20	72.80	-
5.	18.11.27	-	21.00	72.80	-
6.	3.5.86	-	20.26	73.12	-

were reported from Dharampur, Bansda, Chickali talukas of Valsad districts; and according to Rao, et.al (1986), the epicentres of the tremors show a N-S alignment.

Sychanthavong (1984), while discussing the mechanism and pattern of crustal fracturing and neotectonism of the Gujarat region, has postulated several generations of faults, the first generation faults comprise the major structural lineaments, and according to him, the "periodic slicing of such crustal edges by the reactivation of the adjacent major fault planes forms a seismically active zone and is responsible for the earthquake shocks". He has also referred to the work of Gelfand, et.al, (1972) who have postulated that major earthquakes develop at the places where major fractures or faults interesect and such intersection points are termed as "Knots". Sychanthavong (1984) has shown several "knots" in the eastern region of the Cambay Basin (Fig.VI.16). Significantly Gelfand et.al (1972) have stated that "the intersection of the major active faults (faults under stresses) show peculiar geomorphic characteristics as fault scarps, straight and parallel valleys, parallel ridges with alternate valleys transversed by the other sets of parallel ridges, valleys and other types of fault scarps." The morphotectonic landscape of the study area ideally conforms to the above model.

Fig:VI.16. *STRESSES AFFECTING THE WESTERN INDIAN SUBCONTINENT, CREATING FRACTURING AND UPLIFTING OF CRUSTAL ROCKS*



(SCALE 1: 10 000 000)

Km 200 0 200 Km

REGIONAL TECTONIC FRAMEWORK

A perusal and critical evaluation of the structural data as described in the foregoing pages of this chapter, throws much light on the relationship that exists between the fracture pattern and the tectonic framework of this part of West Coast of India. The various faults and joint sets, point to two main directions ENE-WSW and NNE-SSW that show a conjugate relationship, making an angle of about 70. The entire fracture pattern, and post-Mesozoic tectonism is related to rifting along pre-existing lineaments and to the stresses generated during the north-eastward drift of the Indian plate. Sub-surface basement configuration of the Cambay Basin, is very much identical to the surface topography of the study area. It is observed that Trappean basement of the basin is extensively faulted and points to numerous horsts and grabens, comparable to those recorded by the present author in his study area. A striking similarity can be observed in the sub-surface trappean basement and on-surface topographic expression of numerous parallel faults either in NNE-SSW or NNE-SSW directions (Figs.VI.15A & 17). Obviously, all the faulting and jointing took place during different stages of the drift. Tensional stresses during the earlier (rifting) stage resulted into the development of Cambay and Narmada - Tapi Grabens. The step faulting related to this event are well reflected in the study area. The later stage of plate movement when (India collided with Asia) was marked by a compressional phase, developed due to the slowing down of speed of the Indian plate while the driving force, i.e., the underflow mantle

FRACTURE CONTROLLED TRAPPEAN TOPOGRAPHY (EAST-WEST SECTION)

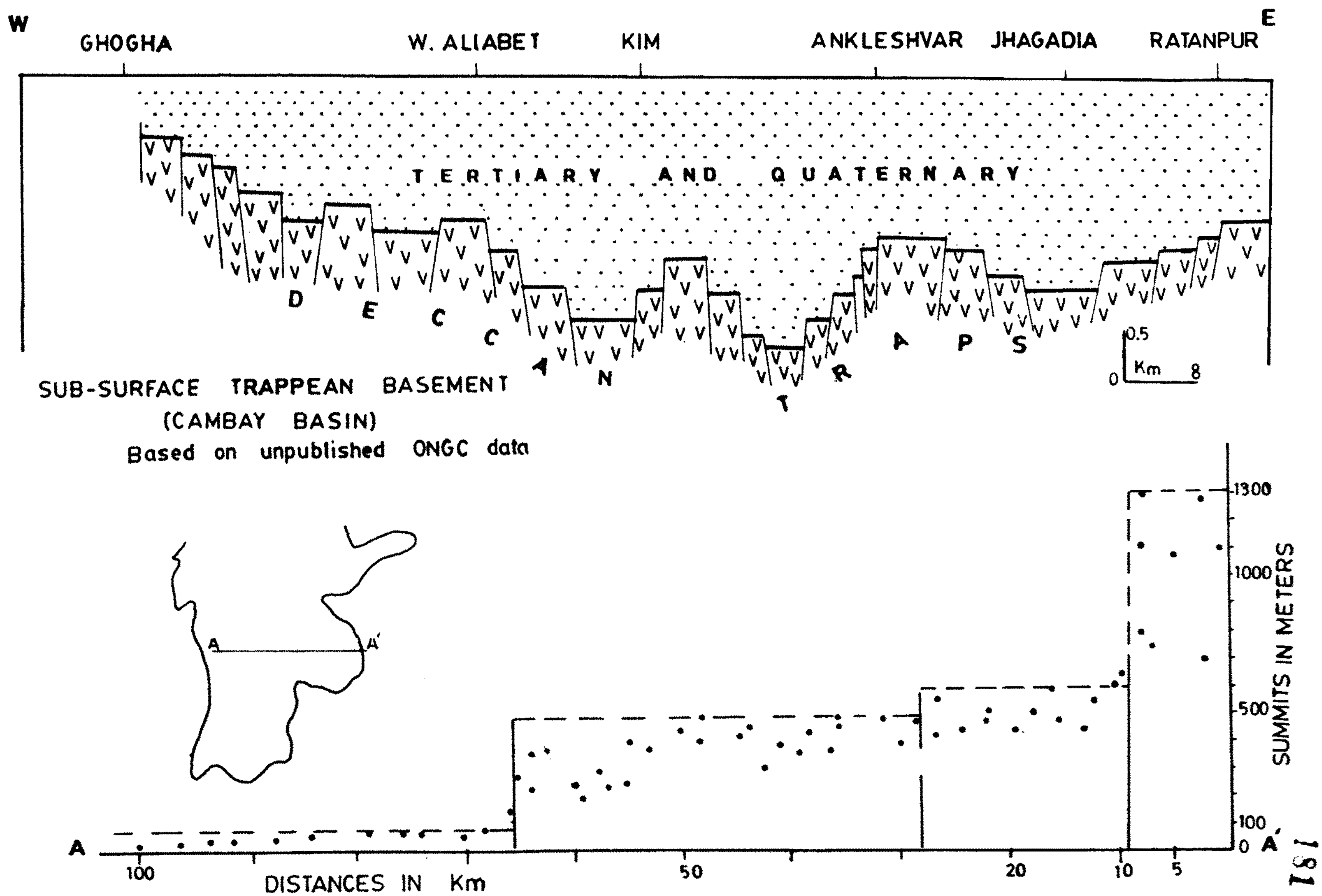
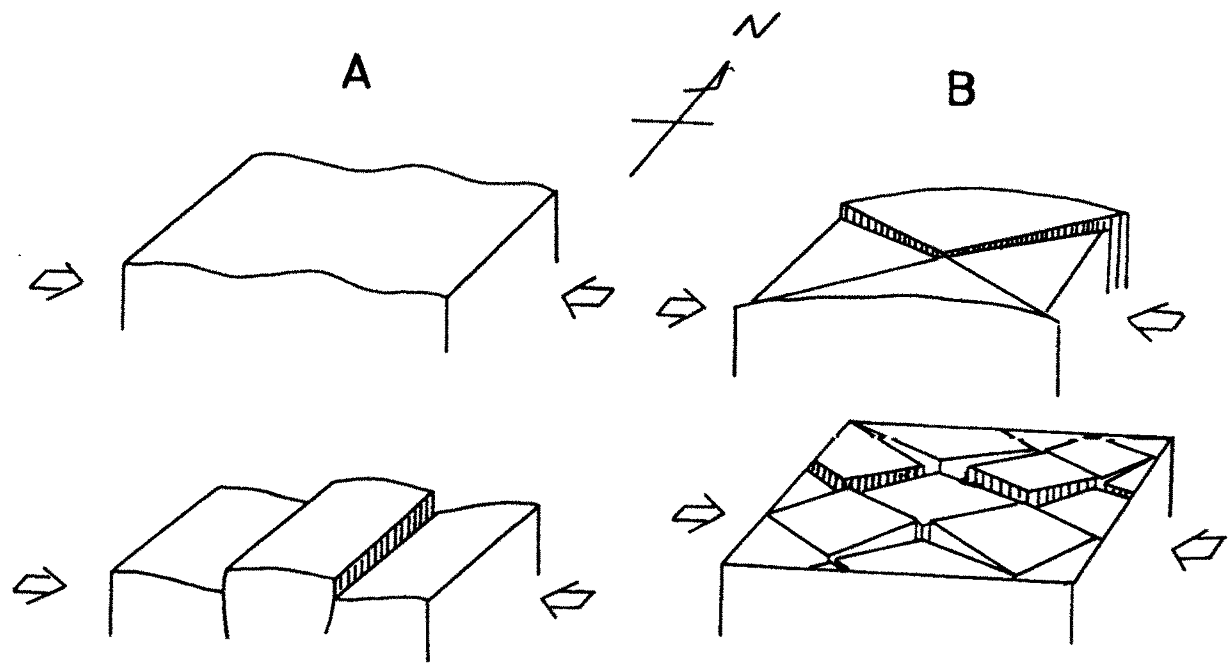


Fig:VI.17

convection remained more or less the same (Sclator and Fisher, 1974). During this phase, considerable reactivation took place along pre-existing fractures, and also new sets of related fractures were generated, and various fracture-bound uplifted blocks developed. According to the present author, the application of the concept of stress analysis and rock fracturing as designed by Ramsay (1967) and Mogi (1972) is adequate to explain the various stress phenomenon related to plate movement.

According to Biswas (1982) who has described the various stages of the break up of the Indian landmass from the Gondwanaland, the Mesozoics of Kutch, the Tertiaries of Cambay basin and the exisiting South Gujarat landscape, all comprise a genetically related tectonic sequence, forming an integral part of the NNE drift during Mesozoic and Cenozoic times. This author has visualized the West Coast Fault and the Narmada Geofracture as comprising pre-existing Precambrian structural trends, which controlled the tectonic evolution of the western margin of India. The rifting along the continental margin and subsequent drifting of the Indian landmass during Tertiary and Quaternary periods, generated stress conditions that gave rise to the existing conjugate fracture system. Differential movements have taken place along some of these fractures throughout the Cenozoic times. Lateral compressional stresses could give rise to vertical uplifts along linear fractures. Also, they could generate uplifted fault-blocks bounded by conjugate fractures. An uplift mechanism, very much identical to the present area, has been described by Huzita et al (1973) to explain the geological structures of the Kinki area in Japan (Fig.VI.18). According to Yokota (1974) the Kiniki area provides an ideal example of neotectonic landforms that reflect fracturing in horizontal tectonic compression. These phenomena, to a certain extent, are could be valid in the study area. During the compressional stage, the NEward dragging generated the maximum compressional stresses in that direction, that affected the crustal rocks to have eventually uplifted differentially. The conjugate sets of fractures which bounded the blocks were activated a number of times. Such an uplift of fault bounded blocks have been observed in experimental modelling deformation studies carried out by the present author (Plate VI.1). The present author is inclined to attribute this structural evolution to a stress field which exerted varying amount of stresses (shear and tensional, finally deviating into compressional) on the crustal rocks ultimately manifestating into various types of crustal movements, horizontal and vertical.

Fig:VI.18. SCHEMATIC MODELS OF THE STRUCTURES OF THE BASEMENT SURFACE DUE TO LATERAL COMPRESSION

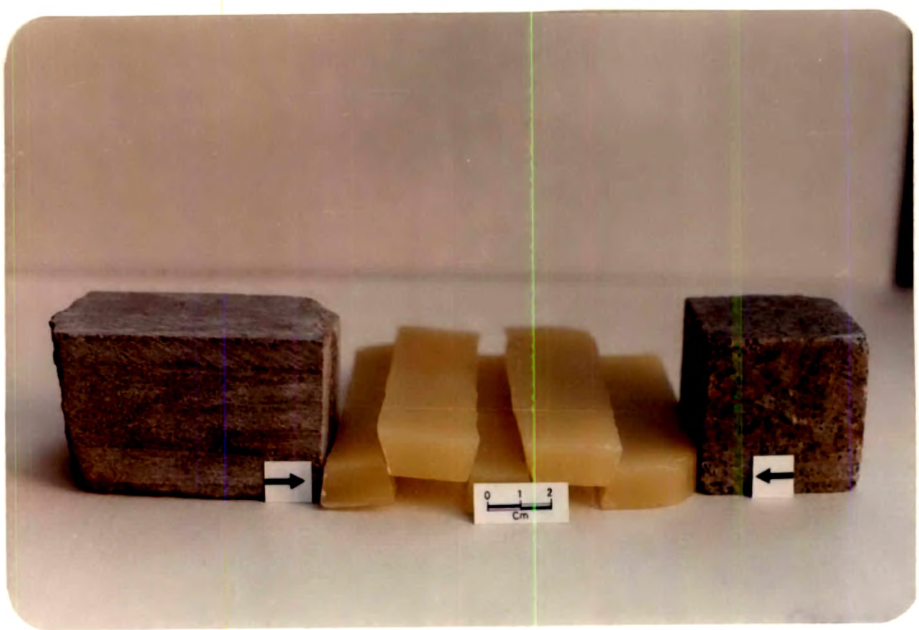


A. DEVELOPMENT OF THE UNDULATORY DEFORMATION TO FAULT BLOCKS SEPARATED BY THRUSTS.

B. MOSAIC MOVEMENTS OF THE RHOMBIC FAULT BLOCKS BOUNDED BY THE CONJUGATE STRIKE - SLIP FAULTS.

After Huzita et al.,(1973)

STAGE - I



STAGE - II

PLATE VI.1 Experimental model showing upliftment of wax blocks under compressional stress (Simulating Horst and Graben Formation)