CHAPTER 3
GEOLOGY OF KACHCHH: A REGIONAL PERSPECTIVE

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3.1 STRATIGRAPHY

Kachchh region forms an important site of Mesozoic and Cenozoic sedimentation (Fig.3.1). An unbroken richly fossiliferous Jurassic sequence is very well preserved and easily accessible in this region and hence stratigraphic and palaeontologic aspects of these rocks have received much attention in the past.

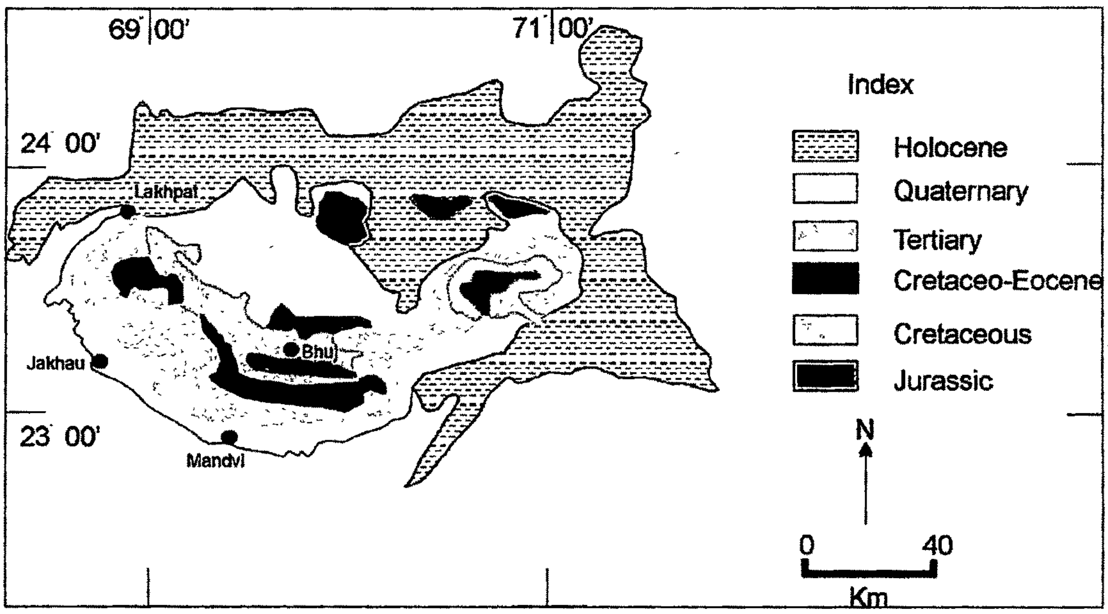

Fig 3.1 Generalised geological map of Kachchh region (Biswas and Deshpande, 1970)

The fault-related uplifts and consequent folding have affected the Mesozoic strata, and the uplifts are surrounded by strips of gently dipping Tertiary strata forming peripheral plains, which wrap round the Mesozoic structures (Biswas, 1980, 1982, 1987). The depressions between the uplifts comprise the Cenozoic sub-basins.

According to Biswas and Deshpande (1968) the base of Mesozoic strata is exposed only in Meruda Hill in the Great Rann, about 25 km north of Khadir Island. The basement syenite rocks believed to be equivalent to Erinpura Granite are exposed in this hill. A bed with some granite boulder conglomerate exposed in Cheriyabet at the northern-most point of Khadir is the oldest bed exposed, marking the beginning of Mesozoic sedimentation in Kachchh on a Precambrian basement. The Mesozoic rocks ranging in age from Middle Jurassic to Lower Cretaceous (Table 3.1) occur conspicuously in various major uplifts, and are exposed extensively in Kachchh Mainland, Wagad, the islands of Pachcham, Bela and Khadir, and Chorar hills. The mainland outcrops expose a continuous Mesozoic succession from Bathonian to Santonian.

Table 3.1: Mesozoic and Cenozoic rock succession in Kachchh region (based on Merh, 1995)

AGE	ROCK TYPE
Holocene	Coastal sands, mud flats, Rann sediments, alluvium, residual deposits
Pleistocene	Miliolite (Aeolian)
Eocene to Pliocene	Marine to fluviomarine beds
Unconfirmity	
Palaeocene	Laterite
Upper Cretaceous to Palaeocene	Basalt and associated intrusive mafic rocks
Unconfirmity	
Lower Jurassic to Middle Cretaceous	Marine to fluviomarine beds
Unconfirmity	
Precambrian	(Basement)

In Wagad is encountered the intermediate sequence, from Oxfordian to Portlandian. The Tertiaries are exposed along the coastal belt of southern and western Kachchh bordering Mesozoic rocks. These also occur in the `islands' of Pachham, Khadir, Bela and Wagad. On the mainland of Kachchh, these form two broad structural *noses,* around the crests of Mesozoic anticlines (Biswas, 1980, 1982). Tertiary rocks are best developed in southwestern Kachchh in the areas north and west of the village Waior. The Quaternary deposits occur all along the coastline and in some inland areas. These include coastal marine sand and silt and aeolian miliolite dunal accumulations within the highlands. The sediments of two Ranns constitute the youngest formation.

3.1.1 Mesozoic

Mesozoic rocks of Kachchh were first mapped by Wynne (1869) of G.S.I. who described a few important sections classifying the sequence into upper and lower Jurassic Groups; Waagen (1871) studied in detail the ammonite fossils and suggested the existing four-fold subdivision, namely, Pachham, Chari, Katrol and Umia. According to him, the Pachcham, Chari, Katrol and lower part of Umia corresponded with the "Lower Series" and the upper part of the Umia with the "Upper Series" of Wynne (1869). Rajnath (1932, 1934a,), on the basis of study of ammonites, lamellibranchs and plant fossils established a Jurassic succession somewhat different from the previous ones, restricting the term 'Umia' only to the lower Umia of the Waagen (1871); the upper Umia made up of non-marine beds was called by him as Bhuj Series of Middle Cretaceous or even slightly younger age. Spath (1924) dealt with the Jurassic cephalopods and divided the lower part of Jurassic into a number of fossiliferous zones. Subsequently, Rajnath (1942) established several unconformities in the Jurassic strata, which indicated sea level oscillations, and according to him, there existed some form of connection and a close faunal relationship between Jurassics of Kachchh and Madagascar.

Krishnan (1968) in his Text Book of 'Indian Geology' has adopted a classification of Rajnath (1942) with modifications of age (Table 3.2). The Mesozoic stratigraphy of Kachchh has been subsequently revised by Biswas (1971). He modified the earlier four-fold classification in the light of his own detailed mapping and as per the International Code of Stratigraphic Nomenclature. He recognized three main lithologic provinces within the basin and rocks of each province were classified separately.

Table 3.2 Rock classification and important fossils from individual formations (after Krishnan, 1968)

FORMATION	AGE	SUB-DIVISIONS	LEADING FOSSILS
UMIA (1000m)	Post-Aptian	Bhuj beds (Umia Plant beds) Sandstones and shales.	*Palmoxylon* in upper beds *Ptylophyllum* flora, similar to Jabalpur flora in lower beds.
	Aptian	Ukra beds-Marine calcareous shales	*Australiceras, Colombiceras Cheloniceras,Tropaeum*, etc.
	U.Neocomian	Umia beds: Barren sandstones and shales.	Unfossiliferous
		Trigonia beds	
	Valanginian	Barren sandstones	*Trigonia*
		Umia ammonite bed	Unfossiliferous
	U. Tithonian		*Virgatosphinctes, tychophyllo-ceras, Micracanthoceras, Hemi-lytoceras, Umiaites*, etc
KATROL (300m)	M. Tithonian	Up. Katrol Shales	*Hildoglochiceras, orsoplanites Haploceras*
	M. Tithonian	Gajansar beds	*Belemnopsis, Streblites, Phylloceras Hildoglochiceras Aulacosphinctoides, Virgatosphinctes*
	L. Tithonian	Upper Katrol (barren) Sandstone.	*Waagenia, Katroliceras, Katroliceras, Pachysphinctes, Aspidoceras.*
	M Kimeridgian	Middle Katrol (red sandstones)	*Torquatisphinctes, spidoceras, Ptychophylloceras, Taramelliceras, Streblites, Waagenia, Hybonoticeras.*
	M. Kimeridgian	Lower Katrol (Sand- stones, shales, marls)	*Epimayaites, Prograyiceras, Ataxioceras, Biplices, Prosophinctes, Torquatisphinctes, Trigonia.*
	Up. Oxfordian	Kantkote sandstone (Bimammatum zone)	
CHARI (360m)	Up to L Oxfordian	Dhosa oolite (green and brown oolites) (Transversarium zone)	*Taramelliceras, Discosphinctes, Perisphinctes, Mayaites, Epimayaites, Paracenoceras, Peltoceratoides. Peltoceras, Orionoides*
	U. Callovian	Athleta beds (marls and gypseous shales)	*Perisphinctes, Indosphinctes, Reineckeia, Kinkelniceras, Hubertoceras*
	M. Callovian	Anceps beds (limestones and shales)	*Reineckeia, Sivajiceras, Idiocycloceras, Kellawaysites*
	M. Callovian	Rehmanni beds (yellow limestone)	*Macrocephalites, Dolichocephalites,*
	M. Callovian	Macrocephalus beds (shales with calcareous bands, with golden oolite-diadematus zone-in the upper part)	*Indocephalites, amptokephalites, Pleurocephalites, Belemnites*
PACHCHAM (300m)	L. Callovian	Patcham coral bed	*Macrocephalites, Sivajiceras, Procerites, Thamnastrea, Stylina, Montlivaltia.*
	L. Callovian to Bathonian	Patcham shell limestone	*Macrocephalites, Trigonia, Corbula Corbula, Eomiodon, Trigonia*, etc
		Patcham basal beds (Kuar Bet Beds).	

A correlation was then attempted between the three sets of rock unit sequences to bring out the overall stratigraphic relationship of the total basin. More recently, several workers (Fursich et al., 1991) have advocated the retention of the older and familiar nomenclature, and have preferred to designate the various 'series' of older classification as 'Formations'. Table 3.3 shows the lithostratigraphy.

Table 3.3 Lithostratigraphy of Kachchh Mainland

Cretaceous	Albian		Bhuj Fm
	Aptian	Umia Fm	
	Neocomian		Jhuran Fm
	Tithonian		
Jurassic	Kimmeridgian	Katrol Fm	
	Oxfordian	Chari Fm	Jumara Fm
	Bathonian		

3.1.2 Deccan Trap

Deccan Trap is restricted only to Kachchh Mainland bordering the Mesozoic highlands extending from Lakhpat in the west to Anjar in the east. Lava flows are dominantly tholeiitic basalts that overlie the Jurassic sandstone, occupying the southern and southwestern slopes of the central highland. The rocks form a more or less linear outcrop extending across the mainland with a maximum width of about 10 km in the east near the town of Anjar and gradually tapering westward. In the western part they form an inlier within the Tertiaries comprising an area of about 200 sq km (Biswas, 1973, 1988).

The basalt flows show gentle southerly dips and the formation wraps around the western extremities of the Mesozoic flexures. Six major flows have been reported at the eastern extremity (Dhola hills near Anjar). A maximum thickness of about 500 m is recorded in the eastern part (Dhola hills) while it decreases to almost 150 m in the northwest. The flows gradually thin out northward and are absent further north in the Island

Belt and Wagad. The distribution and extent of traps in Kachchh appear to have been controlled by the pre-trappean topography and central part of the mainland was already elevated and the Mesozoic rocks were folded when the traps began to erupt and flow. Deccan Trap is also represented by a number of long narrow dykes that occur to the N, NW and NE of the lava flow occurrences. Most of the dykes occur along faults extending N-S, NNE-SSW and NNW-SSE (Biswas, 1973; De, 1981). The average length of dykes is about 5 km but lengths of the order of 15 km are not uncommon. The thickness of the dykes rarely exceeds 30 m (Hardas, 1969, Biswas, 1973, 1988). An interesting aspect of the Deccan volcanism in Kachchh is the occurrence of alkaline basalt and its derivatives as plugs, laccoliths and sills (Biswas, 1973). These are generally confined to the structural domes in the Mesozoic. Laccoliths are common along the northern marginal faults of Kachchh Mainland. Besides, a host of dykes, ring-dykes, cone-sheets commonly occur in the Mainland, Wagad highland and in the northern chain of fault blocks. Biswas (1982) has considered various plugs, cones and vents to comprise volcanic centres along which the basalt flowed. But according to De (1981) various plugs are of alkali olivine basalt and olivine-nephelinite are slightly younger to lava flows. Isotopic studies have established an age range of 65 to 67 M.Y. for these alkalic rocks; the tholeiitic basalt have yielded an age around 67 M.Y.; the overlap suggesting a close temporal association between these two types of magmatism. Occurrences of inter-trappean beds have been reported from the villages Kora, Dayapar and Lakhmipar in western Kachchh and Anjar in eastern Kachchh.

3.1.3 Laterites

In Kachchh, the laterites form a linear narrow Paleocene belt extending for a few hundred metres wide and several hundred kilometers long. It is exposed parallel to the Tertiary rocks and is sandwiched between the basalts of the Deccan Trap and the Tertiaries. It forms a terrain that is characterized by 10 to 15 m high elongated ridges separated by broad intermittent valleys. The laterite profiles show all the three major soil horizons (Wynne ,1872). The topmost lateritic layer contains large reserves of economically workable bauxite and are located at the contact with the Tertiaries.

3.1.4 Cenozoic

Kachchh is considered as the 'type area' for the marine *Tertiary rocks* of India where a more or less complete sequence has developed. These show almost complete sequence from Paleocene to Pliocene. Wynne and Fedden (1872) studied these rocks for the first time over a century ago. Biswas (1965) has given a detailed account on Tertiary of Kachchh. He has summarised the finding of his and his associates of the Oil and Natural Gas Corporation Ltd who subsequently remapped the Tertiaries and found the earlier classification to be a mix up of lithostratigraphic and biostratigraphic nomenclatures. They therefore proposed a revised stratigraphy, and taking into account various factors, suggested a time-stratigraphic classification.

Studies by O.N.G.C. have also established that the Tertiaries of Kachchh were not connected directly with those of Sindh-Baluchistan and that the sedimentary basin of Kachchh included the whole of Kachchh and western part of Banaskantha (Santalpur) district of North Gujarat. The Tertiary sediments in Kachchh were deposited on the eroded surface of the Deccan Trap and the Mesozoic sedimentaries, and the deposition started with a marine transgression during Lower Eocene and ended in Pliocene.

3.1.5 Quaternary Deposits

Miliolite deposits occurring as outliers within the rocky mainland mostly comprising wind-blown accumulations represent an only undoubted Pleistocene rock type. Miliolites occur as obstacle dunes and as sheet deposits and occupy low grounds at the base of the hills and in the topographic depressions within the hilly areas and hollows on the slopes of big hills and ridges. The constituent rock is quite identical to that of Saurashtra except that it has got a somewhat higher lithic content. Baskaran (1989) radiometrically dated the miliolite occurrences by Th-230/U-234 method and found them to belong to three age groups, namely 170 $\pm$ 30, 95 $\pm$ 15 and 60 $\pm$ 10 K.Y. May be, they lie submerged on account of tectonic subsidence. The conglomerate and grit of the Kankawati Series that represent fluvial sediments were probably deposited during this period of low strandline. This series is yet to be dated. On the whole, Quaternary record in Kachchh is rather fragmentary. *Pleistocene* marine rocks are nowhere encountered in the Mainland and the related marine sediments are represented by aeolian accumulations of miliolites far inland from the coastline. The Quaternary sequential stratigraphy has been given in Table 3.4.

Table 3.4: Table showing the Quaternary stratigraphy of Kachchh region (based on Merh, 1995)

Sediments of the Little and Great Ranns; Raised mud flats along the Kachchh coast.	Holocene
Dunal accumulations of miliolite	Upper to Middle Pleistocene
Conglomerate and grit of the upper part of Kankawati Series	(?) Lower Pleistocene

Holocene deposits (including Sub-Recent to Recent) of Kachchh belong to two categories, namely, (1) the sediments of the Ranns and (2) coastal mud-flats and sandy beaches.

3.1.5.1 *Unconsolidated Rann Sediments*

The Great Rann and the Little Rann comprise unique examples of Holocene sedimentation. The two Ranns represent accrued gulfs and mark the site of accumulation in an estuarine delta environment that was marked by a fluctuating strandline since the advent of Holocene. During the last 10,000 yrs, the area came under the influence of glacio-eustasy and seismicity-related tectonism, the two factors influencing the strandlines and fluvial sedimentation (Roy, 1973, Shrivastava, 1971). Even today, during the annual southwest monsoon, the western and central portions of the Great Rann and part of the Little Rann at the head of the Gulf of Kachchh are flooded not only by surface run-off from the surrounding highland but also by waters driven up the creeks from the Arabian Sea by storm tides. The tidal waters carry with them a lot of sediments brought from the Indus delta region. The coarser sediments deposit in the inlet channels at their heads while the finer sediments are carried further and spread over the flooded areas and get deposited as mud-flats. Thus, mud banks have gradually built up year after year.

The low parts of the Rann surface are salt encrusted, and form salt playas during rains. The deeper portion of the playa lakes are made up of unlayered, bluish grey and yellowish brown oxidized, silty gypseous clay with traces of mica. Towards the margins of the playas, the sand percentage increases. The Banni plains are made up of fluvial deposits and in all probability, consist of a portion of an ancient delta, now tecctonically disrupted.

Very scanty sub-surface data on the Holocenes of the Rann are available and only a conjectural stratigraphic picture has been constructed on the basis of the descriptions given by earlier workers. Perhaps, the oldest Holocene merges downward into terminal Pleistocene comprising fluvio-marine to fluvial sediments which in turn rest over a marine sequence correlatable with the Miliolite Formation of Saurashtra.

3.1.5.2 *Coastal Mud-flats and Beaches*

The Kachchh coastline has remained practically uninvestigated and only recently Sharma (1990) has described raised mud-flats and raised beaches deposited during the high Holocene strandline. The outer segment from Koteshwar in the north to Suthri in the south is chiefly made up of extensive tidal mud-flats and a series of off-shore sandbars. The middle portion of the coast between Suthri and Bhujpur overlooking partly the Arabian sea and partly the Gulf of Kachchh is dominantly made up of sandy beaches with coastal dune ridges, and a rocky platform. The innermost segment extending from Bhujpur to Cherai in the east falls within the Gulf, and is marked by a featureless vast terrain most of which comprises either tidal mud deposits or saline wasteland merging further east into the Little Rann. It has been concluded by Sharma (1990) that the three coastal segments have reacted differently to the successive sea-level changes because of differential movements of fault-blocks along the old lines of weaknesses. On the basis of heavy mineral studies, he has established affinity of the coastal terrigenous material with the Indus river sediments.

3.2 STRUCTURE

Tectonically, Kachchh is situated at the area where northwestern margin of the Indian continental shield meets the geosynclinal belt of Sindh-Baluchistan (Fig 3.2). Thus, this marginal portion of the Indian shield is characterised by block faulting and consequent folding. According to Biswas (1987) block faults typically involve the basement made up of Precambrian rocks.

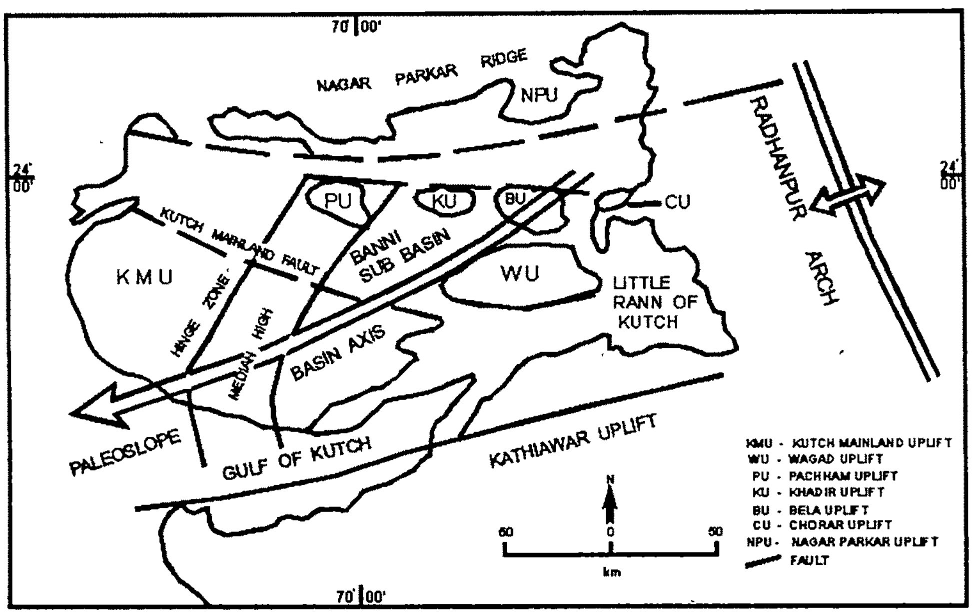

Fig 3.2 Tectonic map of Kachchh region (after Biswas and Deshpande, 1977)

This marginal belt of the Indian shield extends along the shelf zone with its coastal counterpart of the west coast from Bombay to Kachchh through Surat and Broach coasts and Saurashtra peninsula, reaching its maximum intensity near Kachchh where it borders the geosyncline of Sindh-Baluchistan.

Regionally, the structure of Kachchh is characterised by a series of uplifts along master faults (upthrusts) (Fig 3.3) and along the Delhi tectonic trend these were reactivated (Biswas, 1982, 1987). Narrow linear zones of folding mark the faulted margins of the uplifts; a string of asymmetric domes and brachy anticlines occurs along these tectonised zones. Igneous intrusions such as laccoliths, plugs, sills and dyke swarms are localized in these zones.

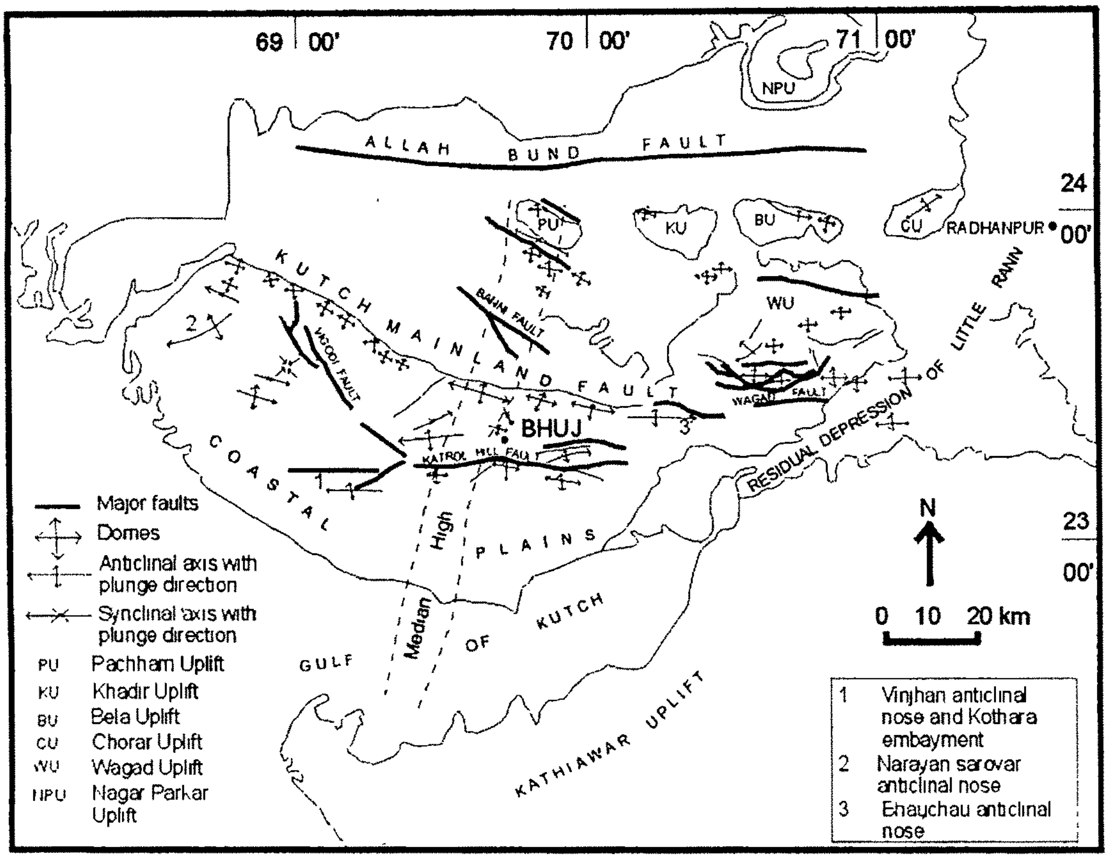

Fig 3.3 Structural Map of Kachchh region (after Biswas, 1987)

The Mesozoic strata are considerably folded, highly faulted and intruded by igneous rocks. The Tertiary strata which warp around the Mesozoic highs in contrast, show very gentle dips and lie over the eroded Mesozoic folds in some places, bearing testimony of a major pre-Tertiary tectonic movement. Biswas (1980, 1982) has invoked a unique feature in Kachchh, a meridional (median) high across the basin occurring along the hinge zone (Fig. 3.3). Evidence of sediment thickness and the facies present indicate that this high came into existence in late Oxfordian time.

The Kachchh Mainland is bound by following major regional faults, which are responsible for its existing configuration. These bounding faults are (1) Kachchh Mainland Fault striking WNW-ESE to W-E forming the northern limit of the Mainland. This fault has also caused southward tilting of the Mainland and thereby has greatly influenced the deposition of Mesozoic and Tertiary sequences, (2) Offshore West Coast Fault striking NW-SE and marking the western limit. It is probably the extension of the fault which is believed to have caused almost straight west coastline of India, and (3) Gulf of Kachchh Fault and the Little Rann of Kachchh Fault System bounding the southern and eastern limits of Kachchh Mainland respectively (Biswas, 1980, 1982).

In addition, a number of faults related to one or the other of the major faults are encountered within Kachchh Mainland which developed during various stages of the repeated reactivation of major bounding faults at later dates (Fig 3.4). These faults have significantly influenced the Cenozoic landscape of Kachchh.

Along Kachchh coast, Cenozoic sediments typically show evidences of differential movements of faulted blocks. The folding of strata is essentially a reflection of the fault movements of various blocks under the sediment cover. The fault uplifts and subsidences occurred more or less along the old lines of weaknesses. There are ample evidences to suggest that various parts of the Kachchh Mainland have undergone differential movements even during Quaternary period, and even the coastline's geological and geomorphological evolution is controlled by the periodic movements along tectonic lineaments. The sea level changes of the Quaternary period together with various faults have contributed to the evolution of coastal landforms and sediment diversity.

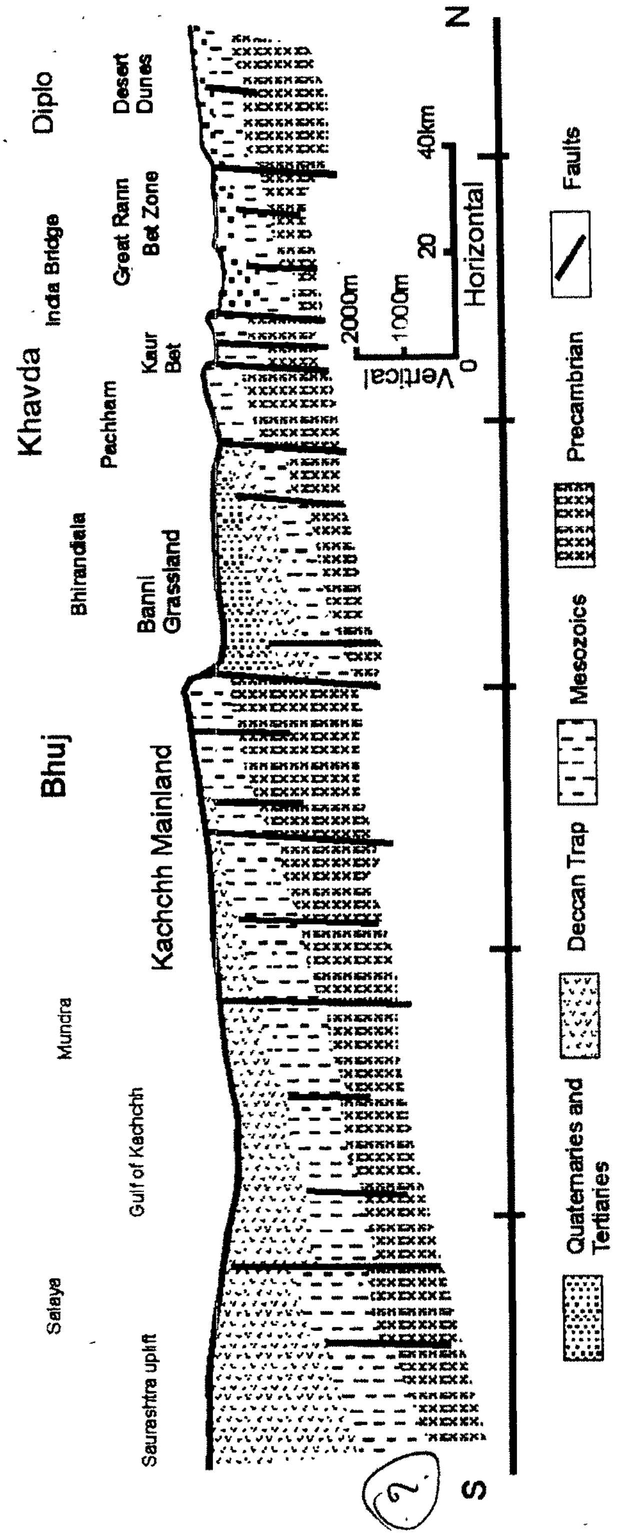

Fig 3.4 Geological cross-section across Kachchh Mainland (after Biswas, 1987)

The main structural features recorded by various workers (Biswas, 1980, 1982 and Biswas and Deshpande, 1970; Sharma, 1990), which played significant role in the post-Mesozoic geological and geomorphological evolution of Kachchh Mainland are,1. Katrol Hill Fault, 2. Vigodi Fault, 3. Little Rann of Kachchh Fault system, 4. Naira River Fault, 5. Bhujpur Fault, 6. Vinjhan Fault, Vinjhan Anticlinal Nose and Kothara Embayment, 7. Gulf of Kachchh Embayment, 8. Narayan Sarovar Anticlinal Nose, 9. Bhachau Anticlinal Nose (Fig 3.3 & Fig 3.5).

Katrol hill and Vigodi faults striking E-W and NW-SE respectively are confined to the central part of Kachchh Mainland. The alignment of these faults is more or less parallel to two marginal faults (Kachchh Mainland Fault and West Coast Fault) and originated subsequent to the main uplifting. These faults are also as important as the two marginal or master faults, since they are responsible for subsidiary upliftments and belong to the same system of faults which have not only given rise to a series of uplifts and depressions such as Charwar and Chaduva flexure zones but have also given rise to southward tilting of the southern portion of the Mainland (Biswas, 1980).

The eastern part of Kachchh is flanked by the *Little Rann of Kachchh Fault System* consisting of a set of three faults, trending NW-SE, NE-SW and E-W. These faults have imparted a triangular shape to the Little Rann, being responsible for its existing configuration. Prior to faulting the little Rann of Kachchh appears to have been a portion of the Gulf, into which many streams from the Gujarat Mainland dumped terrestrial detritus from NE during Early to Middle Quaternary. Upliftment of the land along various lines of weaknesses during the late Quaternary period coupled with withdrawal of the sea led to the formation of Little Rann separating it from the Gulf of Kachchh. Ghosh, (1981) who carried out a detailed study of the Quaternary morphostratigraphy and neotectonic activities in

Little Rann came across numerous evidences to support several phases of tectonic movements from post-Tertiary to the Recent times.

These NE-SW and NW-SE trending transverse faults or structural lineaments, named as *Naira River Fault* (NRF) and *Bhujpur faults* (BF) respectively could be taken as manifestations of reactivation of basement faults during Quaternary period. On the basis of these faults the Kachchh coast can be divided into three well defined segments having their own sets of distinctive landforms.

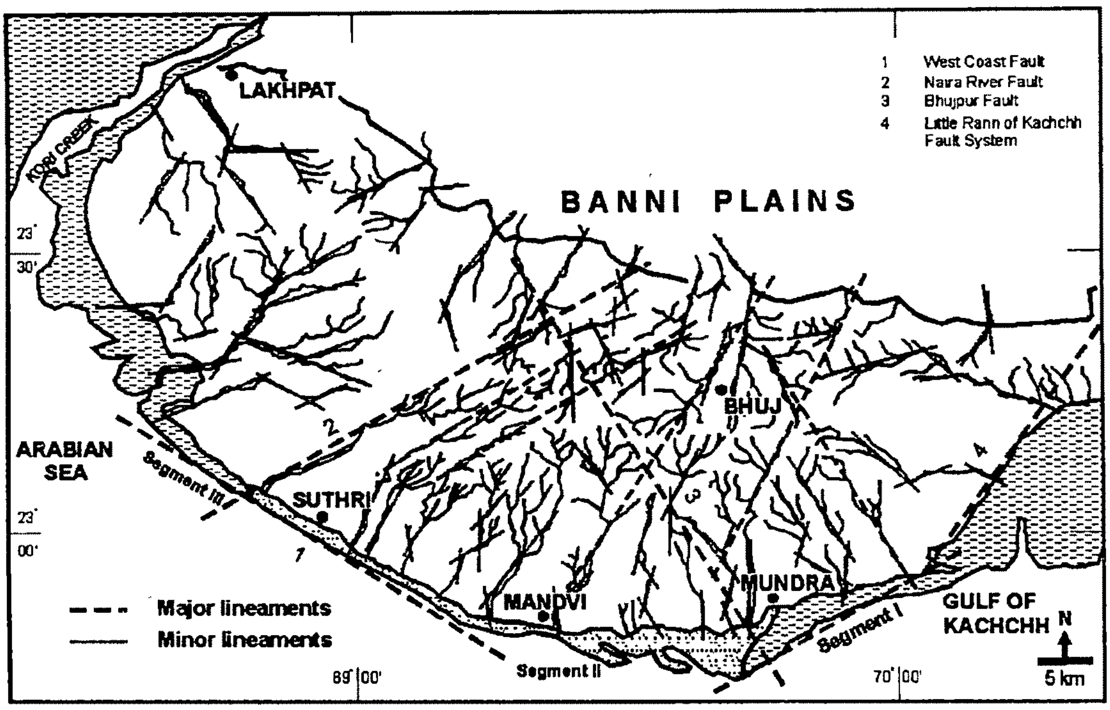

Fig 3.5 Map showing major and Minor lineaments and faults

Based on the differential movements of western and eastern blocks of the Kachchh coast along two planes of weaknesses during Quaternary (? Late Quaternary) period which have resulted in the submergence of Koteshwar-Suthri Segment (III) and Bhujpur-Chirai Segment (I) dominantly made up of finer clastics (silt and mud) due to emergence of Suthri-Bhujpur (middle) Segment (II) is composed of coarser sediments (beach sands). Both the faults have been observed to extend offshore into the Gulf and have affected even the topography of Gulf bottom (Sharma, 1990). Width of the offshore zone between 5m isobath and the shoreline is more towards west of Naira river fault and the contour comes closer to the shoreline towards east supporting the submergence of the western block. Bhujpur fault has greatly influenced the drainage patterns of the Segments I and II. Because of downward movement towards east, the streams of Segment III have adopted SE courses in their lower reaches in contrast to the almost southward lower courses in Segment II.

Various E-W trending structures, namely Vinjhan Fault, Vinjhan Anticlinal Nose (Fig. 3.3) and Kothara Syncline appear to be mutually related. The Vinjhan fault is vertical to slightly overturned outward. Further west towards Naliya, the fault goes below the cover of Tertiary sediments and its effect is reflected in the folded outcrop pattern in the overlying Tertiary sediments. According to Srivastava et al., (1964), a half graben (Kothara embayment) was formed due to gravity faulting along the Vinjhan Fault before the initiation of the Tertiary sedimentation; this graben gradually sank northward due to increasing thicknesses of Tertiary sediments. The Kothara Syncline and Vinjhan anticlinal nose represent the drag features developed in the overlying Tertiary blanket. The dips of the beds here are very low, upto 4°-5° in the south away from the fault. The axis of Vinjhan structural nose swings gradually from a southwesterly direction in the southern half to west in the central portion and finally merges into the Quaternary sediments towards west. The northern flank of the anticlinal nose is bounded by Vinjhan Fault. The Gulf of Kachchh is a fault embayment somewhat comparable with the Kothara embayment; as its structural pattern is similar to that of the Kothara embayment- Vinjhan fault and Vinjhan anticline. Biswas (1980 and 1982) has invoked a ENE-WSW trending deep seated fault extending from Onshore into the gulf, passing at some distance to the north of the present day Saurashtra shoreline. Seismic reflection studies of the Gulf of Kachchh by Gopala Rao (1988) have revealed two parallel ENE-WSW to E-W trending faults in the central part of the Gulf forming a graben structure.

A broad gentle swing of the Tertiary rocks forms the Narayan Sarovar anticlinal (Biswas, 1980; 1982) nose feature (Fig 3.3), about 15 km long and 30 km wide. Its westerly plunging axis finally dips beneath the coastal sands and tidal flats. The dip of the beds are very low, upto about 5°, and from a southwesterly direction in the southern half of the region. It gradually swings to west in the central portion and finally from northwest to north in the area to the NE of the Narayan Sarovar. There are several minor anticlinal flexures and synclinal depressions superimposed on this regional structure, seen wrapping around the Trap ridges and as humps and in the embayments between the Trap highs. Very gentle dip and almost undisturbed Tertiary rocks developing noses around older and comparatively steeper folds, and the thinning of sediments nearer the anticlinal crest primarily show that the structure developed within Tertiary rocks is a drape fold over the pre-existing folded Mesozoics (Biswas, 1980). That some folding associated with this structure continued in the Quaternary is evidenced by the occurrence of an asymmetrical fold plunging towards NE in a nala southwest of Pipar. This feature evidently points to the reactivation of the tectonic block movements during Quaternary period.

Bhachau anticlinal nose (Fig 3.3) constitutes the eastern half of the middle anticline of Kachchh whose western half (towards the western Kachchh) is known as Lakhpat anticlinal nose. General trend of the structure is ESE-WNW but it becomes E-W in the middle portion. Broadening of the middle region is due to subsidiary folding of the northern limb. The nose plunges into the alluvial plains towards east, and is flanked in north and south by gently dipping Tertiary rocks. The northern limb has steeper dips ranging between 55° and 70° and is cut off by the Kachchh Mainland fault. The anticlinal nose is 35 km long and 3 km wide with a broad middle region, giving rise to a spindle shaped form to the anticline (Biswas, 1980; 1982).

3.3 GEOMORPHOLOGY

The variety of geomorphic facets (Fig. 3.6) of Kachchh peninsula such as the present surface configuration, its landforms, drainage characteristics and relief pattern reveal a complex interplay of tectonism, sea level changes, lithology and the Cenozoic processes of erosion and deposition. Interestingly, within limits of the Kachchh peninsula, one comes across conspicuously high hills and extensive low plains. The uplands comprise rugged hilly terrains exposing folded Mesozoic rocks (Middle Jurassic-Lower Cretaceous) bordered by thin strips of gently dipping Cenozoic rocks (Paleocene to Pleistocene) which form the coastal plains. The highlands are the areas of uplift whereas the plains of low lands represent structural basins between the uplifts and are made up of alluvium, mud and salt flats (Ranns). Topographically, Kachchh region is made up of east-west trending hill ranges i.e. Island belt, Kachchh Mainland and Wagad hill ranges. The hill ranges in each of these areas are separated by large tracts of low ground. All hill ranges and the intervening low ground run almost parallel, a characteristic feature indicating that the topography has been controlled to a large extent by the geological factors of folding, faulting and lithology. The highest peak in Kachchh is that of Kaladungar (Δ 465 m) in the Pachcham island and in the Kachchh Mainland there are several peaks, the Nanadungar showing the maximum altitude of 430 m.

The landscape comprises rocky highlands standing out like "islands" amidst the vast plains of the Great and Little Ranns of Kachchh. Whereas the Ranns and Banni are the depositional plains of Recent times, the highland areas bear evidences of multiple erosional cycles Biswas (1987). According to Biswas (1974) the five denudational cycles are correlatable with major periods of tectonic movements in the region. This aspect is discussed further in a later section.

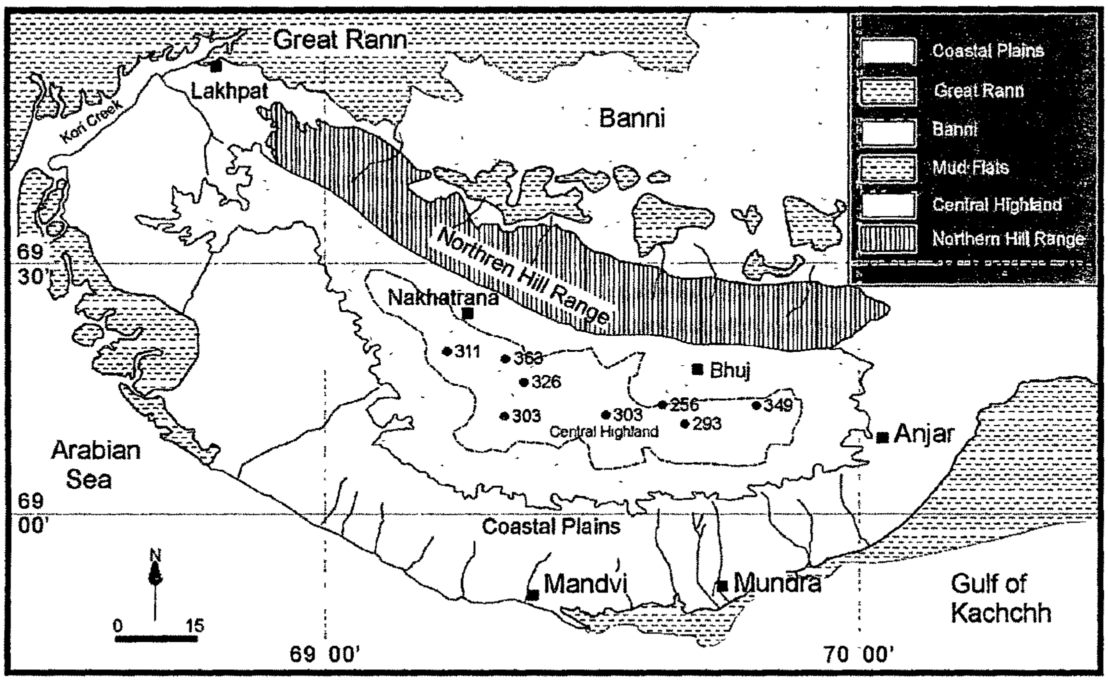

Fig 3.6 Generalised Geomorphic map of Kachchh Showing different geomorphic zones

3.3.1 Physiographic Divisions

Taking into consideration the factors of altitude, slope and ruggedness of relief, Kachchh can be divided into four main physiographic units from north to south (Fig.3.6), viz; (1) The Ranns, (2) The Low Lying Banni Plain, (3) The Hilly Region, and (4) The Southern Coastal Plains.

The above four units show considerable diversity within each of them, depending on the rock types, their mode of occurrences and fault patterns. The *Rann* is the most remarkable and unique feature of Kachchh region occupying its northern and eastern parts, forming more than half of the areal extent of Kachchh. It comprises a flat geomorphic terrain rising just upto 3 to 4 m above M.S.L, and is divisible into two parts, viz. the Great Rann occupying the northern part and the Little Rann forming the eastern and southeastern parts of Kachchh. Within the Great Rann occur a chain of islands comprising Pachham, Khadir, Bela and Chorar, rising above the saline wasteland. The Rann area mostly remains dry except for the rainy season when it is covered by saline water. During summer and winter seasons, practically the whole region is covered with a fairly hard salt encrustation. Different aspects of the Rann have been described by a number of workers (Frere, 1879; Ghosh, 1981; Glennie and Evan, 1976 ; Roy and Merh, 1977 and Gupta, 1975).

The *Plains of Banni* represent an embayment between the Kachchh Mainland in the south, the uplifts of Pachham in the north, and the Wagad and the Bela uplifts in the east, and cover a wide area. These rise a little higher than the surrounding Rann and are covered with green grass and other shrubs. No outcrop is seen within these featureless plains. These receive water from the Mainland and the islands from the north and east respectively during rainy seasons. The *Hilly Region* of Kachchh consists of following three components:
1) Island Belt: It consists of four island, viz. Pachham, Khadir, Bela and Chorar from west to east, 2) Mainland: The area lying to the south of Banni plains and extending upto the Gulf of Kachchh in south is called Mainland and 3) Wagad: This region lies to the NE of the Mainland and forms an isolated landmass.

The *Mainland* comprises a rocky terrain and broadly consists of two subparallel E-W trending hill ranges; viz the Katrol Hill Range (KHR) situated in central highland and Northern Hill Range (NHR) with an intervening low ground, and a southern coastal plain. Lithologically, the central highland is made up of Mesozoic rocks which southward have been separated from the Tertiary rocks and southern coastal plains by the Deccan basalts. Lithology and tectonics have played a very important role in the formation of present geomorphic features of Kachchh Mainland. The northern hill range is bordered by the Banni plains and the Rann in north and by 80-140 m high upland areas in the south (Fig.3.6). This hill range forms a chain of domes of Jurassic and Cretaceous rocks, and is flanked to the north by E-W trending Kachchh Mainland Fault (KMF). From west to east, it is marked by a series of domes like Jura, Jumara, Panjal, Keera, Lyari, Chari and Dhar Dongar and anticlines like Jhurio, Habo and Kas. The KMF has significantly controlled the physiography of this part of the terrain. On account of this fault, the northern slopes are steeper whereas the southern slopes coinciding with the dip of strata are gentler. The *southern coastal plains* that border the Mainland and overlook the Gulf of Kachchh in the south and the Arabian sea in the west are made up of Tertiary and Quaternary sediments and form a 25-30 km wide belt showing very low gradient. These plains rise gradually from the high waterline to altitude of 80 m beyond which the ground tends to show a rather more conspicuous rise, merging into the central highland with a steeper gradient.

3.3.2 Drainage

Drainage of Kachchh provides an interesting example of a combination of lithologic and tectonic controls along with the influence of sea level fluctuations during Quaternary period. Central highland forms the main watershed with numerous consequent streams draining the slopes with a radial pattern and pouring their water and sediment load into the Arabian sea, the Gulf of Kachchh and the plains of Banni and the Rann in west, south and north respectively (Fig. 3.7). The southward flowing streams include Naira, Kankawati, Chok, Sai, Vengdi, Kharod, Rukmawati, Khari, Nagavanti, Phot, Bhuki, Mitti, Sakra and Larekh streams which empty their water into the Gulf of Kachchh and the Arabian sea.

The streams originating from the northern slopes of the Central highland, join the streams originated from the Northern hill range and pour their water into the Chhari, Bhukhi, Trambo, Kaila, Pur and Kaswali streams which, in turn, debouch into the Rann. In general, the streams are ephemeral (seasonal) and carry water only during good monsoon. Many streams like Kankawati, Kaswali, Kharod, Rukmawati and Bhukhi. show very broad channels and vertical cliffy banks in their lower reaches. Drainage characteristics of the Kachchh Mainland and the relatively well carved valleys which now carry only very little water clearly point to the fact that the area had experienced a more wet climatic phase in the past during which the streams carried more water and sediment load and the stream dissection was more effective.

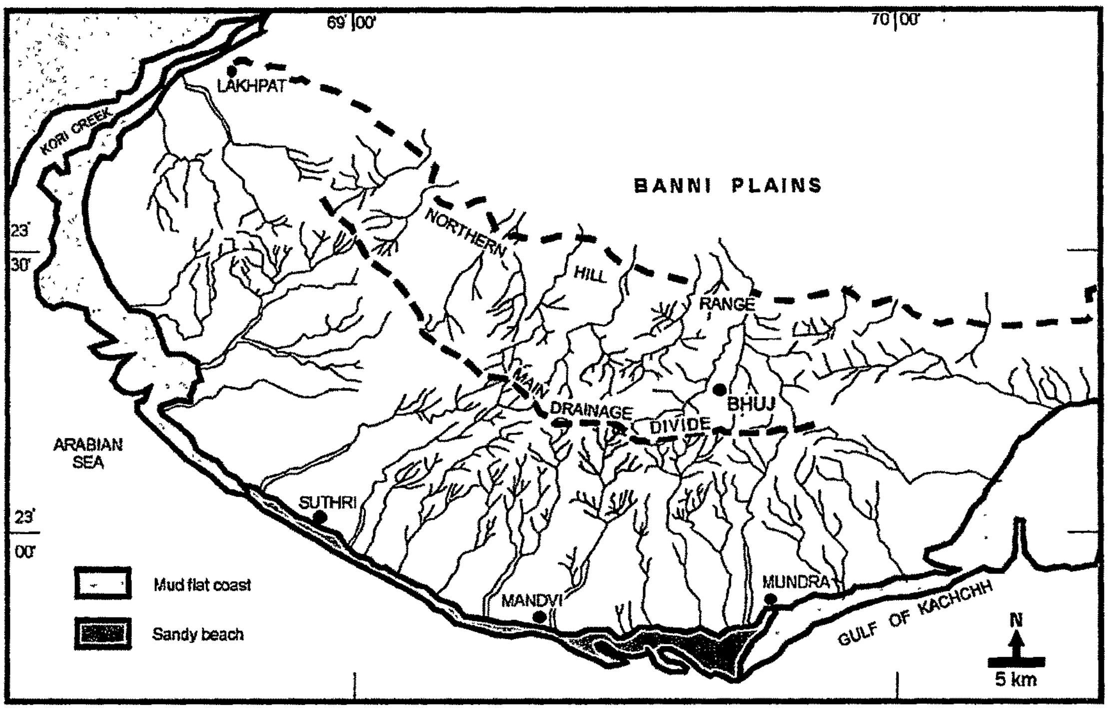

Fig 3.7 Generalised drainage map of Kachchh

3.4 THE RANNS OF KACHCHH

Vast saline wastelands of the Great and little Ranns of Kachchh comprise a rather unusual Quaternary terrain of Western India. Rising barely above the sea level, the Great Rann (about 16,000 sq. km) and the Little Rann (about 6,000 sq. km) are separated from each other by highlands. Their monotonous flatness, salinity and annual inundation have rendered them a geomorphically mysterious ground. Year after year, during the rainy season vast areas of the two Ranns get flooded by waist-deep waters and this phenomenon of innundation, its causes and pattern, have baffled the scientists. The Ranns represent filled up gulfs of a Holocene sea, marking sites of ancient river mouths.

A significant feature of Rann is that of frequent tectonic movement during the late Quaternary times, so much so that the pattern and course of sedimentation during Neogene, Pleistocene and Holocene were influenced by periodic vertical movements. The Great Rann has been tectonically unstable even during historical times. The existing relict channels of the Bet zone represents a palaeo-delta complex formed by a number of major rivers and there are strong evidences to suggest that River Sutlej (Shatadru), Sarasvati and Drishadvati which now flow into the Indus once used to flow into the site of Great Rann (Malik et al, 1999). This could have happened during the last 10,000 years. Tectonism was effective as late as 1819 when a major earthquake finally destroyed the delta complex. An uplift in the Great Rann gave rise to a 10 m high E-W barrier (Allah Bund) and this truncated the flow of Nara into the Arabian sea through the Kori Creek.

The sediments of the Bet zone and the Banni plains are rather identical. They mostly comprise sandy silts of fluvial origin; the heavy mineral present in order of abundance are biotite, muscovite, hornblende, tourmaline, zircon and rutile. These reflect a provenance that was purely gneissic and schistose, and only rivers originating in the Himalayan crystalline terrain could have provided the Great Rann with such an assemblage of heavy minerals. Roy (1973) attributed the Bet Zone and Banni Plain sediments to the Indus river. Malik et.al (1999) have recently suggested that these sediments comprise a delta complex representing several Himalayan rivers like Sarasvati, Shatadru (Sutlej) and Drishadvati. It is interesting to observe that the Banni plains, though quite close to Kachchh mainland show a strong affinity to Indus river sediments, making it obvious that there is no genetic relationship between the Banni sediments and Mainland source rocks.