CHAPTER - 2

BACKGROUND INFORMATION

The various geomorphic facets of Kachchh landscape such as the landsurfaces, the drainage characteristics, the relief patterns and the plains and Ranns clearly reveal a complex interplay of tectonism, sea level changes, lithology and Cenozoic processes of erosion and deposition. The region of Kachchh has been greatly affected by many minor and a few major earthquakes. The earthquakes have been responsible for the upliftment of the area, development of the gullies, mountain front scarps, warpings, change in the course of the rivers. The most powerful earthquake of 1819 changed the course of Indus river, by creating a long ridge (called Allah Bund) in the Great Rann of Kachchh. It has also been responsible for the devastation of Lakhpat fort and Vigokot. The earthquake of 1956 completely demolished the old town of Anjar. It is a fact that Kachchh is an earthquake prone zone, and still there are high possibilities of deadly earthquakes in the region. Minor earthquakes of less than 2 to 3 magnitude visit every year.

PHYSIOGRAPHIC DIVISIONS

Taking into consideration the factors of altitude slope and ruggedness of relief, Kachchh can be divided into four main physiographic units (Fig.2.1):

1. The Ranns,
2. The low lying Banni plain,
3. The hilly Region and,
4. The Southern Coastal plain.

The Ranns

These unique features have no counterpart in the world. They occupy eastern and northern parts and have a total area of 22,000 Sq km. The Ranns are divided into two, the Little Rann and the Great Rann of Kachchh. It comprises a flat geomorphic terrain rising upto 4 m above mean sea level. In rainy season the Western and North-western parts of Rann are inundated by saline water. In summer and winter seasons, practically the whole region is covered with a fairly hard salt encrustation. The Ranns are geomorphologically divisible into five units (Merh and Patel, 1988):

(a) Bet Zone (BTZ),

(b) Linear Trench Zone (LTZ),

(c) Great Barren Zone (GBZ),

(d) Little Rann of Kachchh (LRK).

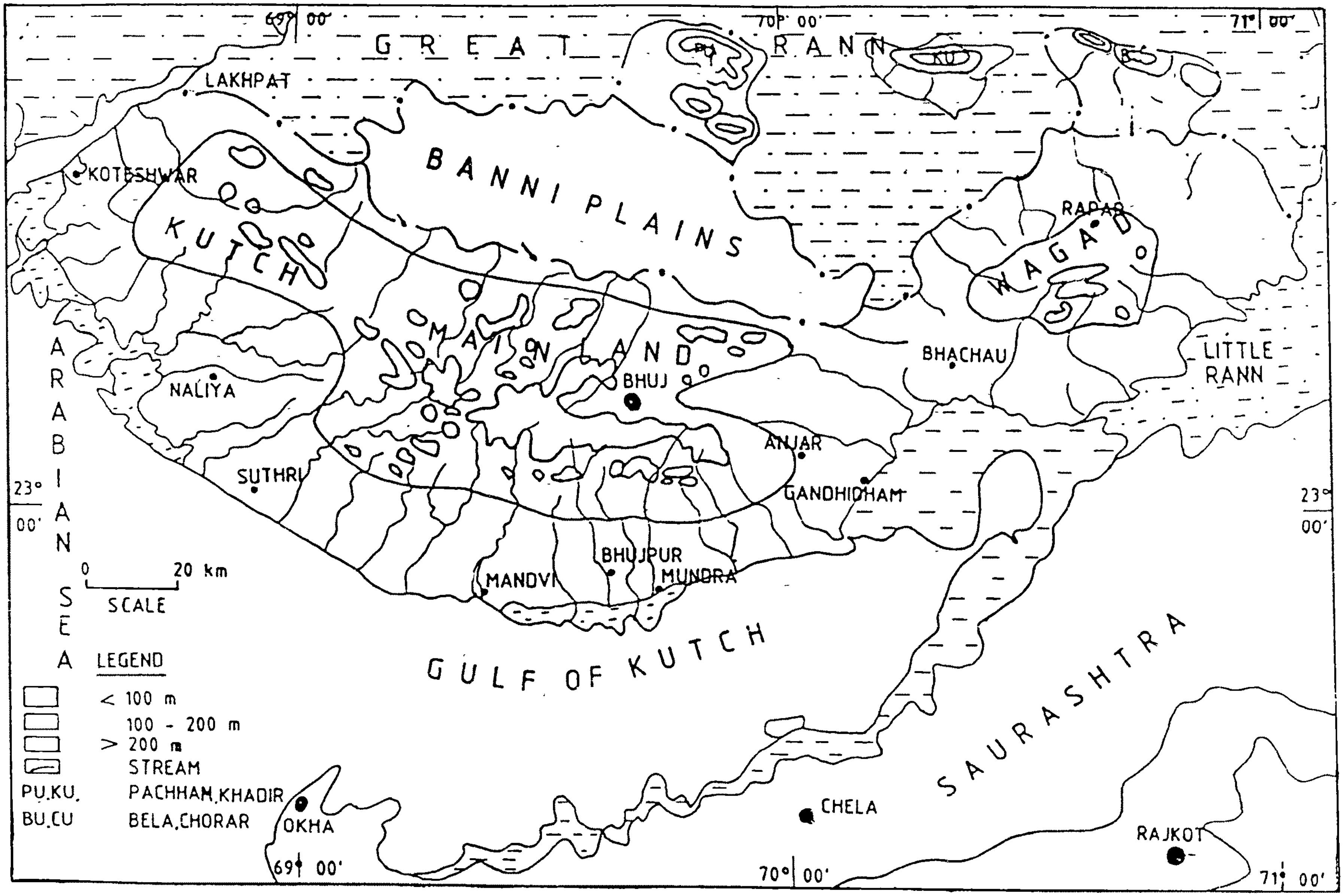

Fig. 2.1 Physiographic map of the Kachchh.

Bet zone forms a slightly uplifted area in the north of Allah Bund, and represents an old mouth of a river. The southern limit of this complex network of bets and inlet channels, is marked by the Allah Bund while to the north it merges into the sand ridges of Sindh-Pakistan. The Bet-zone landscape points to a wetter past and comprises relicts of an ancient delta.

The Linear Trench Zone is a depression extending from the Kori Creek eastward upto Kuar Bet. This depressed terrain lying between the Banni and the Allah Bund, gets inundated by tidal waters of the Arabian sea through the Kori Creek. Its western portion in the proximity of the Kori Creek is a region of regular marine inundation, the central portion comes under the influence of high tides only during monsoon months.

The Great Barren zone is a vast shallow saucer shaped depression which to the north merges into the sand dunes of Thar Desert, to the south it abuts against the mainland and to the east it rises into the alluvial plains of Banaskantha. It is separated from the LTZ by a narrow highland known as 'Punjabi Road'. The river Luni and the tributaries discharge rain water into this depression, therefore this zone generally remains under water during rainy season.

The Little Rann is an extension of the Gulf of Kachchh when the sea level was high during the Holocene transgression. This vast wasteland is about 4 meters above high water line.

The low lying Banni plain

The plain of Banni forms a low alluvial tableland between the Mainland of Kachchh and the Great Rann. It occurs 3 - 10 m above the level of the Great Rann. It is more or less flat and almost gradientless saline grassland covering an area about 3000 Sq Km. Looking to the nature of the sediments this zone is quite similar to the Bet zone.

The Hilly Region

The uplifted hilly region of Kachchh consists of three parts viz. Island Belt, Mainland, and Wagad. The northern "island belt" comprises four "islands' viz Pachchham, Khadir, Bela and Chorar. These highlands are commonly described as "islands" as they stand out amidst the plains which are submerged during the monsoon. These four islands occur in east-west line to the south of the Great Rann. Northern boundaries of all the islands are steeper while the gradient is very low towards south. A large upland region towards northeast of the Mainland, and south of Khadir, Bela and Chorar islands is known as Wagad Highland. This table like region has very low dip due south or south west. The Mainland of Kachchh constitutes a rocky terrain having broadly two sub-parallel E-W trending hill ranges; the Katrol hill range and northern dome dominated hill range with intervening low grounds known as Central Highland. The Mainland also comprises a coastal plain in the south.

The northern hill range is bordered by the plain of Banni and the Great Rann of Kachchh in the north and by the high upland areas in the south. This hill range forms a chain of domes of Jurassic and Cretaceous rocks. The major domal hills are the manifestations of the half-anticlines, anticlines and other structural features. Jura, Jumara, Panjal, Kera, Lyari, Chari, Dhar Dungar, Jhurio, Habo, Kas etc. are the major structurally controlled hills. The Kachchh Mainland Fault which marks the northern boundary of the Mainland 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 that coincide with the dip of the strata are gentler. The basaltic hills show moderately steep slopes on the northern side.

The Katrol Hill range trending E-W in the Mainland is gently sloping towards south having steep fault scarps in the northern side. The southern coastal plains border, the Mainland, overlooking the Gulf of Kachchh in the south and the Arabian sea in the west.

DRAINAGE CHARACTERISTICS

The drainage of Kachchh provides an interesting example of combination of lithologic and tectonic controls along with the influence of sea level fluctuations during Quaternary period in its evolution. The Central Highland forms the main water shed with numerous consequent streams draining the slopes with a radial pattern, 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.2.2). The Southward flowing streams include Naira, Kankawati, Chok, Sai, Vengdi, Kharod, Rukmawati Khari (of Mundra) Nagawanti, Phot, Bhukhi, Mitti, Sakra and Larekh emptying their waters into the Gulf of Kachchh and the Arabian sea.

The streams originating from the northern slopes of the Central Highland, pour their water into the Chhari, Bhukhi, Trambo, Khari (of Bhuj), Pat, Pur, and Kaswali rivers which in turn, drain themselves into the Rann of Kachchh. Eastward flowing river systems such as Sakra and Song in eastern Mainland and westward flowing river systems such as Mitti and Kali in western part of the Mainland, clearly show relative movement of three blocks of the Mainland during the later part of the upliftment.

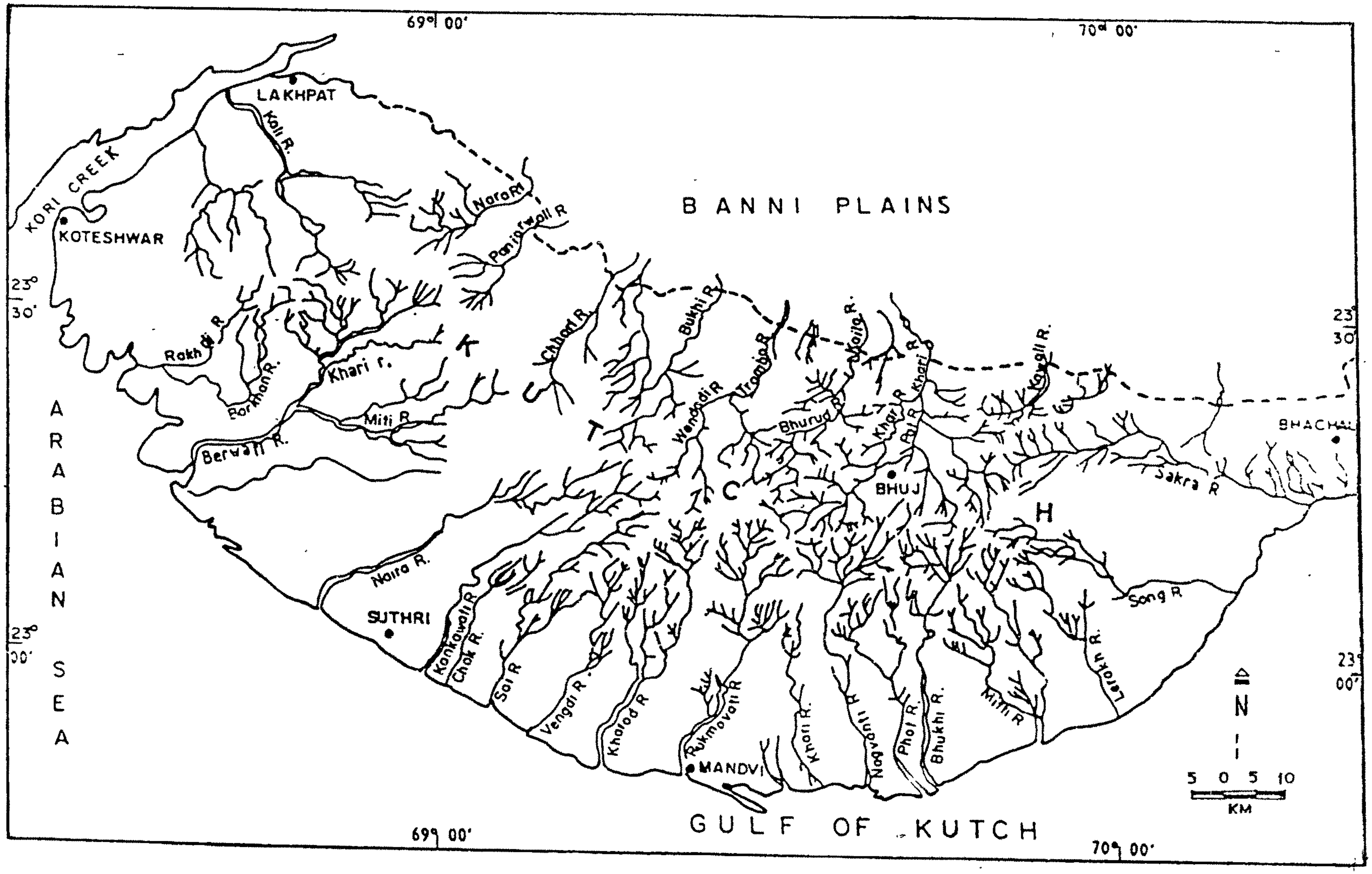

Fig. 2.2 Drainage map of Mainland Kachchh.

REGIONAL GEOLOGICAL SET UP

The Kachchh region forms an important site of Mesozoic and Cenozoic sedimentation (Fig.2.3). The Mesozoic rocks ranging in age from Middle Jurassic to Lower Cretaceous occur conspicuously in the various major uplifts, and are exposed extensively in the Kachchh Mainland, Wagad, the islands of Pachchham, Bela and Khadir, and the Chorar hills . The Mainland outcrops expose a continuous succession from Bathonian to Santonian. The oldest sequence from Bathonian to Callovian is recorded in the Island Belt. In Pachchham, Bathonian to Callovian rocks are exposed, while in Khadir, Bela and Chorar, Bathonian to Oxfordian sequences are present. The intermediate sequences, from Oxfordian to Portlandian are encountered in Wagad (Agrawal,1982).

The Tertiary rocks are exposed along the coastal belt of southern and western Kachchh bordering the Mesozoic rocks. These rocks also occur in the 'islands' of Pachchham, Khadir, Bela and Wagad. On the Mainland of Kachchh, these form two broad structural noses - Narayan Sarovar Nose and Vinjan Nose, around the crests of the Mesozoic anticlines. Tertiary rocks are best developed in the 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.

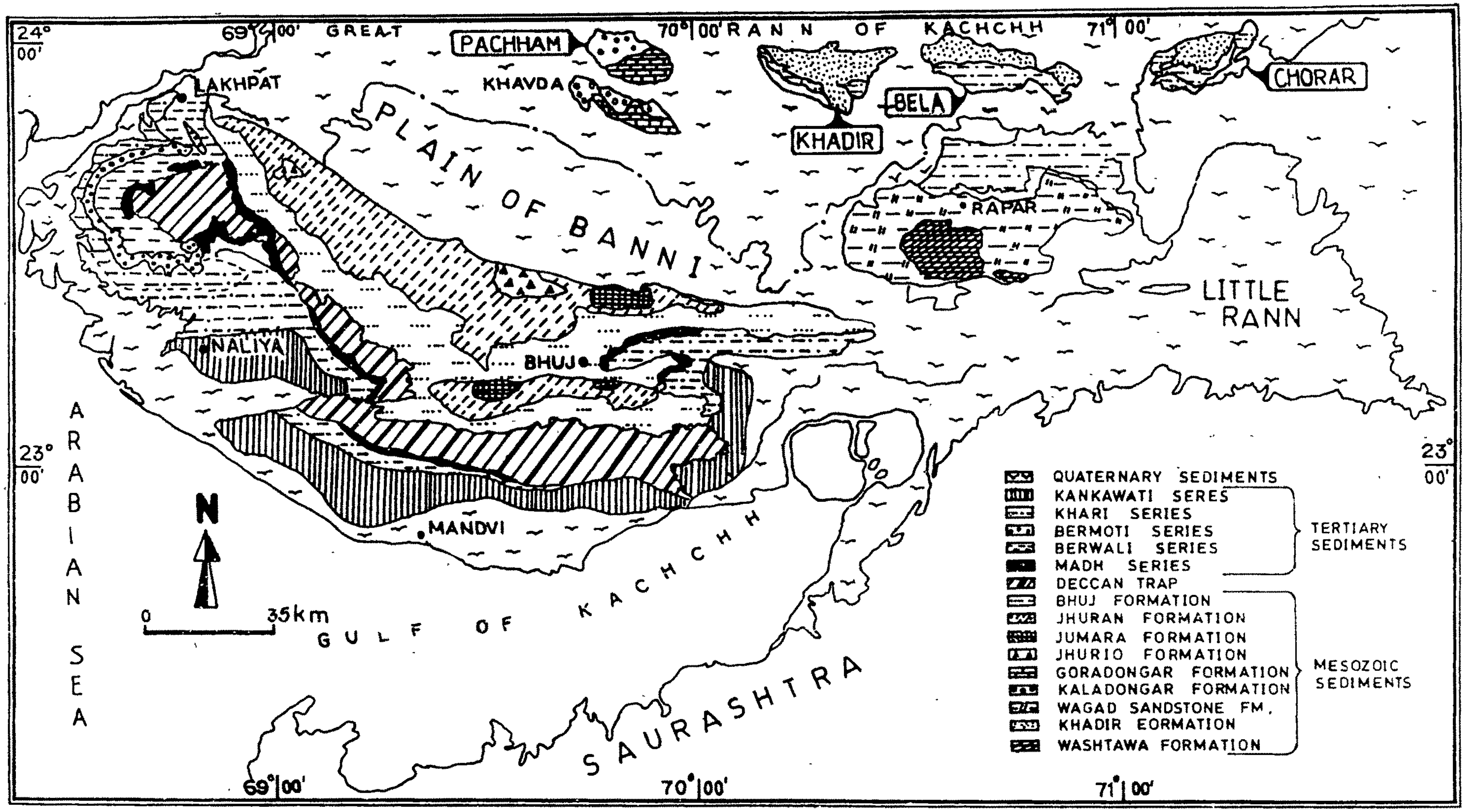

Fig. 2.3 Geological map of Kachchh (after Biswas et al., 1970).

MESOZOIC ROCKS

An unbroken richly fossiliferous sequence of rocks Jurassic upward is very well preserved in Kachchh (Table 2.1), and these rocks have received much attention in the past. The site of deposition comprised a peri-continental basin filled up with 2000 to 3000 m of Mesozoic and 1000 m of Cenozoic sediments (Biswas, 1977, 1981).

Mesozoic rocks of Kachchh were first mapped by Wynne (1872) who described a few important sections classifying the sequence into upper and lower Jurassic Groups; his "Upper Series" comprised plant bearing rocks "Palaeozamia beds" and "Lower Series" was characterized by marine fossils. Waagen (1875) studied in detail the fossil ammonites and investigated the stratigraphical relations of the rocks in the field. He also suggested the existing four-fold subdivisions, namely, Pachchham, Chari, Katrol and Umia. The Pachchham, 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. A significant contribution to the Jurassic rocks was made by Rajnath (1932) who on the basis of the study of ammonites, lamellibranchs and plant fossils established a succession somewhat different from the previous ones. Rajnath (1942) restricted the term 'Umia' only to the lower Umia of the Waggen; the upper Umia made up of non-marine beds with plant fossils was called by him as Bhuj Series of Middle Cretaceous or even slightly younger age.

The Mesozoic stratigraphy of Kachchh has been subsequently revised by Biswas (1977). He has modified the earlier four-fold classification in the light of his own detailed mapping and following the International Code of

Table 2.1 : Chronostratigraphic Classification of MESOZOIC ROCKS OF Kachchh

(Based on Krishnan, 1968)

SYSTEM	FORMATION	AGE	SUB-DIVISION	LEADING FOSSILS
CRETACEOUS	UMIA (1000M)	Post-Aptian	Bhuj beds (Umia Plant beds) Sandstones and shales	Palmoxylon in upper beds Ptylophyllum flora in lower beds
		Aptian	Ukra beds - Marine calcareous shales	Australiceras, Colombiceras, Cheloniceras, Tropaeum, etc.
		U.Neocomian	Umia beds:- Barren Sandstone and shales	Unfossiliferous
		Valanginian	Trigonia beds, Barren sandstones	Trigonia Unfossiliferous
JURASSIC		U. Tithonian	Umia ammonite bed	Virgatosphinctes, Ptychophylloceras, Micracanthoceras, Hemilytoceras, Umiaites, etc.
	KATROL (300m)	M. Tithonian	Up. Katrol shales	Hildoglochiceras, Dorsoplanites, Haploceras
			Gajensar beds	Belemnopsis, Streblites, Phylloceras, Hildoglochiceras
		L. Tithonian	Up. Katrol sandstone (Barren)	Aulacosphinctoides, Virgatosphinctes
		M. Kimmeridgian	Mid. Katrol (red sandstone)	Waagenia, Katroliceras, Patchysphinctes, Aspidoceras
			Lr. Katrol (sandstones, shales, marls)	Torquatisphinctes, Aspidoceras, Ptycophylloceras, Waagenia, Hybonoticeras, etc.
	CHARI (360M)	Up. Oxfordian	Kanthkot sandstone	Epimayaites, Prograyceras, Ataxiceras, Trigonia Biplices, etc.
		Up. To Lr. Oxfordian	Dhosa oolites (green and brown oolites)	Taramelliceras, Discosphinctes, Perisphinctes, Mayaites, Epimayaites
		Up. Callovian	Athleta beds (marls and gypseous shales)	Peltoceras, Orionoides.
		Mid. Callovian	Anceps beds (limestones and shales)	Perisphinctes, Indosphinctes, Reineickia, Kinkeliniceras, Hubertoceras.
			Rehmani beds (yellow limestons)	Reineickia, Sivajiceras, Idiocycloceras, Kellawaysites
			Macrocephalites beds (shales with calcareous bands, with golden oolite-diadematus zone in the upper part)	Macrocephalites, Dolichocephalites, indocephalites, Belemnites, etc.
	PACHCHAM (300M)	L. Callovian	Pachcham coral bed	Macrocephalites, Sivajiceras, Procerites, Stylina, Montlivaltia
			Pachcham shell limestone	Macrocephalites, Trigonia, Corbula.
			Pachcham basal beds (Kuar Bet Bets).	Corbula, Bomiodon, Trigonia, etc

Stratigraphic Nomenclature (Table 2.2). He found that the earlier classification did not fit in the modern stratigraphic concept. Status and rank of units were not fixed such that various rank term suffixes have been used differently by different workers. Stratigraphic evidences collected by him indicated many discrepancies and ambiguities in the designation of stratigraphic units on the basis of ammonite zones, plant beds, etc. by the earlier workers. Another major weakness pointed out by him was that of the difficulties of correlatability of the scattered outcropping areas.

The variation in lithofacies from one part of the basin to the other and the detached fault-bounded outcrop areas separated by covered plains made it difficult to trace a set of rock units recognized in one area strikewise to the other areas. This prevented the use of a uniform rock unit sequence throughout the basin and created intrabasin correlation problem. He therefore recognized three main lithologic provinces within the basin and rocks of each province were classified separately (Table 2.2). A correlation was then attempted between the three sets of rock unit sequences to bring out the overall stratigraphic relationship of the total basin. The units were named according to the carefully chosen stratotype (Biswas, 1977,). His rock stratigraphic classification is fairly comprehensive and when examined together with the earlier four fold classification provided a wealth of data on the Mesozoic of Kachchh in general and Jurassic rocks in particular.

The base of the Mesozoic strata is exposed only in the Meruda Hill (Biswas, 1971, 1977) in the Great Rann, about 25 Km north of Khadir island. The syenite rocks believed to be equivalent to Erinpura Granite are exposed in this hill. A granite boulder conglomerate exposed in Cheriyabet at the northern-most point of Khadir is the oldest bed exposed, marking the

MESOZOIC ROCKS OF

Table 2.2 : Lithostratigraphic Classification of Kachchh

(after Biswas, 1971, 1977)

TIME SCALE	ROCK UNIT	LITHOLOGY	ENVIRONMENT
Cretaceous (Neocomian to Santonian ?)	BHUJ FORMATION 400-900m (+) Thickning to the west	Upper part: Coarse grained felspathic sandstone, pale brown to dirty white, friable , current bedded Lower part: Brown and reddish felspathic sandstone with rhythmic alternation of gray kaolinitic shale, sandy shale and thin hard ironstone bands. Shale occasionally carbonaceous, and contain plant fossils. In western kachchh tongues of marine rocks occur (Ukra beds) Disconformity	Fluvial to Deltaic
Argovian to Neocomian	JHURAN FORMATION 375-850m (Thickening to the west)	Katesar member: Greenish sandstone with occasional Trigonia bands (exposed only in Ghuneri Mundhan area, W Kachchh) Upper Member: Mainly pink and yellow sandstone with minor shale. Middle Member:(Rudramata shales) Gray shale with thin sandstone bands. Lower Member: shale and sandstone with thick calcareous sandstone bands.	Infralittoral
Callovian to Oxfordian	JUMARA FORMATION 300m	Mainly Khaki and grey gypseous shale with thin marl bands. Highly fossiliferous formation. Upper part characterized by shale with thin fossiliferous oolitic marl bands (Dhosa oolites bands)	Sub-Littoral
Upper Bathonian to Callovian	JHURIO FORMATION 325m (+)	Upper part: Bedded white limestone mainly pelmicrite and pelsparite. Golden oolitic bands occur in lower half Middle part: Golden oolitic limestone and shale. Lower part: Thinly bedded limestone, shale and golden oolitic limestone.	Sub-Littoral

beginning of the Mesozoic sedimentation in Kachchh on a Precambrian basement.

MAINLAND

The lithostratigraphic sequence of Mainland is divided into four formations named as the Jhurio (Jhura), Jumara, Jhuran and Bhuj formations in ascending order (Biswas, 1977, 1981). The Bhuj formation is disconformably overlain by the basic flows of the Deccan Trap Formation on the south while the base of the Jhurio Formation is not exposed (Table 2.2).

JHURIO FORMATION

A thick sequence of limestone and shales with bands of 'golden oolites' in the lower part of the Mainland stratigraphy, has been named as the Jhurio formation after the type section in Jhurio hill, in North-Central Mainland. The formation is exposed as small inliers in three hills which are large domal structures, along the northern margin of the Mainland-Habo, Jhurio, and Jumara from east to west. The upper part of the formation is made up of thinly bedded white to cream coloured limestones (pelmicrite and biomicrite) with thin bands of 'golden oolite' (Balgopal,1973). The middle part is composed of thick beds of grey yellow weathered shales alternated with thick beds of golden oolitic limestones and the lower part comprises thin beds of yellow and grey limestones (Agarwal, 1957 and Balgopal, 1973). The maximum thickness estimated in the type section is 300 m. The base of this formation is not seen anywhere. Its boundary with the overlying formation is conformable and well marked by the contrast of its white limestones and the green shales of Jumara Formation. The physical and biological aspects of the formation indicates littoral to infra-littoral environment. The formation ranges from Bathonian to lower Callovian.

JUMARA FORMATION

A thick argillaceous formation overlying the Jhurio Formation has been named after its type section in Jumara hill near the Rann, north of Jumara village. The formation is exposed as inliers at the centre of the domal and anticlinal hills along the northern edge of the Mainland and the Katrol-Charwar range in circular and elliptical outcrops. The formation is characterized by monotonous olive-grey gypseous laminated shales with thin red ferruginous bands.

The Jhurio and Habo dome sections to the east of the type section are important reference sections (Biswas, 1977). The thickness of the formation is uniform throughout the area and is around 300 m. Its upper boundary with Jhuran Formation is conformable excepting local disconformity observed at places where the Jhuran shales are seen resting over the eroded Dhosa oolite member. The Jumara formation ranges between Callovian to Oxfordian.

JHURAN FORMATION

It comprises a thick sequence of alternating beds of sandstones and shales. The formation is defined by the Dhosa oolite member below and non-marine sandstone of Bhuj Formation above. The formation is divided into four members-lower, middle (Rudramata shale), upper and Katesar member (Biswas, 1977). The type section is exposed along the stream by the ruined Jhuran village between Lotia dam and Roha hill. The formation is extensively exposed along the southern flanks of the northern and central hill ranges in two wide east-west strips. In the central and western parts of the Mainland, the lower, middle and the lower part of the upper members are exposed. The middle member is very well exposed in Khari river valley around Rudramata temple, 14 km north of Bhuj, which is a good reference section for the member. The lower member consists of alternating red and yellow sandstone and shale. The middle member is mostly shaly comprising dark grey to black laminated gypseous shales. The upper member is predominantly arenaceous and composed of red and yellow massive current bedded sandstones with intercalations of shale, siltstone and calcareous sandstone. The formation is thickest in Jara-Mundhan area of northwest Mainland where it is 900 m but thins down eastward to 350 m in the Central Mainland (Biswas, 1977). The upper limit of this formation is defined by the contact between marine and non-marine rocks. Kimmeridgian to Valanginian age is fixed for this formation.

BHUJ FORMATION

A huge thickness of non-marine sandstones of uniform character constitutes the youngest formation of the Mesozoic stratigraphy of Kachchh. Named after its type locality around Bhuj, this formation is defined by the marine beds of the Jhuran Formation below and the Deccan trap flows above. The Bhuj rocks are exposed extensively in the Mainland occupying about $3/4^{th}$ of the total area of the Mesozoic outcrop. It crops out in two wide belts stretching from Bhachau on the east to Guneri on the west occupying low lands between the hill ranges. The lower member is characterised by cyclic repetition of ferrugenous or lateritic bands, shales and sandstones. The upper member consists of wheatish to pale brown, massive, current bedded, coarse grained, well sorted sandstones. The formation is bounded by the plains of disconformity. In the south, Deccan trap flows rest on the eroded undulating surface of this formation. The sediments represent deltaic deposits with distal part (delta front) towards the west and the proximal part (fluvial) to the east in the direction of the land. Lower Cretaceous (Valenginian) to Santonian time range is fixed for this formation.

DECCAN TRAP

The Deccan Trap is restricted only to the 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 basaltic terrain could be categorized as rocky upland with a moderately rugged topography. 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 it forms an inlier within the Tertiaries comprising an area of about 200 sq km On the whole, the flows show good exposures and have been observed to be of pahoe-hoe type (Biswas and Deshpande, 1973).

The trap flows show gentle southerly dips and the formation wraps round the western extremities of the Mesozoic flexures. Six major flows have been reported at the eastern extremity (Dhola hills near Anjar) where they show alternations of columnar and amygdaloidal basalts, occasionally separated by inter-trappean beds.

The distribution and extent of trap flows in Kachchh appears to have been controlled by the pre-trappean topography and the central part of the

Mainland was already elevated and the Mesozoic rocks got folded when the trap began to erupt and flow.

Intrusives

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. The dykes are generally of basalt. Most of the dykes occur along transverse faults extending N-S, NNE-SSW and NNW-SSE. The average length of dykes is about 5 km but length of the order of 15 km are not uncommon. The thickness of the dykes does not exceed 30 m.

An interesting aspect of the Deccan volcanism in Kachchh is the occurrence of alkaline basalt and its derivatives as plugs, laccoliths and sills. 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. Isotopic studies have established an age range of 65 to 67 M.Y. for these alkali rocks , indicating a span of 2 M.Y. for alkaline magmatism. The tholeiitic basalt yield an age around 67 M.Y., the overlap suggests a close temporal association between these two types of magmatism, most identical to that prevailing in the Lower Narmada Valley.

Inter-Trappean Beds

Good sections of inter-trappean beds have been reported from a number of localities, and occurrences from the villages Kora, Dayapar and Lakhmipar in western Kachchh and Anjar in eastern Kachchh (Sahni, 1956).

The inter-trappeans were obviously deposited in shallow basins and depressions over trappean surfaces, fed by simultaneously formed rivulets. The basins were in the form of small pools, lakes and marshes as shown by the lithology and faunal assemblage. The constituent rocks are variegated shale (black carbonaceous, green, grey, brown), gritty sandstone, grey bentonitic mudstone and cherty limestone; the total thickness varies between 4m (at Anjar) and 7m (at Lakhmipar). The fossils comprise mega and micro-vertebrates (fish, frogs, snakes, turtles, lizards, crocodiles and dinosaurs), invertebrates (gastropods, ostracods) and plant remains (charophytes). Egg-shell fragments collected by these workers have been tentatively considered to be of dinosaurs similar to those of Kheda in Mainland Gujarat. An uppermost Cretaceous (Maastrichian age) is inferred for these inter-trappeans.

Laterites

In Kachchh, the laterites show good development and form a narrow elongate Paleocene belt, a few hundred meters wide and several hundred kilometers long running parallel to the Tertiary rocks. The laterite belt is sandwiched between the basalts of the Deccan Trap and the Tertiaries, and forms a terrain that is characterized by 10 to 15 m high elongated ridges separated by broad intermittent valleys. The intervening low ground is usually littered with boulders and debris of laterite. Like Mainland and Saurasthra, these rocks in Kachchh have also been derived from the underlying basalts by "in situ" pedogenic processes (Patel, 1978) leading to geochemical separation of Si, Al and Fe. The laterite profiles show all the three major soil horizon in the descending order (1) a horizon rich in oxides-

Box (Fe.Al), (2) a horizon rich in silicates (Saprolite-B), and (3) a horizon of parent rock-C.

The topmost lateritic layer contains large reserves of economically workable bauxite and are located at the contact with the Tertiaries. On the other hand, the saprolite zone is the source of viable deposits of high-grade bentonitic clays. It is interesting that the two economically important minerals of Kachchh occur at the two opposite ends of the lateritic profile.

TERTIARY ROCKS

The rocks show a more or less complete sequence from Paleocene to Pliocene. Wynne and Fedden (1872) studied these rocks for the first time and correlated them with the type area of Sindh, now in Pakistan. In their classification they considered lithological and palaeontological characters and compared the Kachchh faunas with that of Sindh-Baluchistan, and tried to correlate the former with the time rock units of the latter, but their stratigraphic divisions were essentially lithologic groups.

Biswas and his associates of the O.N.G.C. subsequently remapped the Tertiaries and found the earlier classification to be a mix up of lithostratigraphic and biostratigraphic nomenclatures. Biswas (1973) 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. During Paleogene, deposition was restricted to the western part of the Kachchh

Mainland, the thickest parts being exposed in the southwestern coastal plains which was the deepest part of the basin. During the Middle Miocene, the sea transgressed and crossed over the Radhanpur eastward joining with the Cambay basin. It is relevant to mention here that the Cambay basin joins up further north into Rajasthan basin, which forms the eastern flank of the Indus Shelf; thus the Tertiaries of Kachchh are only indirectly connected to those of Sindh-Baluchistan through Rajasthan basin.

The Tertiary sediments in Kachchh were deposited on the eroded surface of the Deccan Trap and the Mesozoic sedimentaries, and deposition started with a marine transgression during Lower Eocene and ended in Pliocene.

The Kachchh can be considered as the type area for the marine Tertiary rocks of India where a more or less complete sequence has developed. Biswas (1973) has provided details of the Tertiary sequence giving various details in respect of thickness lithology and paleontology, which have been summarized below.

Madh Series

The type areas of the rocks of this series is the well known village of Mata-No-Madh in western Kachchh. The outcrop pattern is irregular and follows the post-trappean topography. It has a total thickness of 37 m and consists of volcanoclastic sediments deposited in variable environments, ranging from fluviatile to littoral. The sediments were mainly derived from the Deccan Trap and the pyroclastics ejected during the waning phase of the volcanism. The Madh series overlies the basalt but underlies the Kakadi Stage which correlates well with the Lower Eocene Laki rocks of Sindh Baluchistan.

On the basis of plant fossils, the rocks of Madh Series have been assigned a Paleocene to Lower Eocene age (Biswas, 1973).

Berwali Series

The type section of this series is exposed along the Berewali Nadi in southwestern Kachchh, between the villages Baranda and Ber-Nana. The series is divisible into two stages, the lower consisting of gypseous and ochreous clays and marl containing several varieties of molluscs and foraminifers, and is seen in Kakdi Nadi section (Kakdi Stage), and the upper stage is well exposed in Babia hill in western Kachchh comprising a fossiliferous fragmental limestone with a basal calcareous clay bed (Babia Stage). The base of Kakdi Stage indicates an unconformity with the underlying volcanoclastic rocks of the Madh Series. The top of this stage is marked by a disconformity below the calcareous Nummulitic clay of the Babia Stage.

Bermoti Series

This series forms a well exposed continuous belt south of Lakhpat in northwestern Kachchh. It is divisible into two stages, the lower Ramania Stage consists of greenish-grey marl and argillaceous limestone with a basal bouldary clayey marl bed. This lithology points to deposition in an epineritic environment of a slowly regressive sea. Its uppermost part is marked by the appearance of the basal oolitic band of the overlying Waior Stage. Named after the village Waior, the constituent rocks of this stage are banded fossiliferous marl, the base comprising of rusty oolitic marl. Biswas and

Deshpande (1973) has assigned an Oligocene age to the Ramania Stage. The Waior Stage has been considered as Aquitanian.

Khari Series

An unconformity separates the Bermoti Series from the overlying Khari Series. The latter shows good exposure in the cliffy banks of the Khari river in southwestern Kachchh. The Khari Series is made up of two distinct stages distinguishable on the basis of lithologic and faunal characters. The lower Aida Stage is composed of variegated siltstone, the lower 16 m of which is barren, but the upper part contains Lower Burdigalian fossil assemblage. The upper parts of the series namely, Vinjhan Stage consists of grey to kahkhi-coloured gypseous clay with hard marl bands packed with fossils. This stage forms the main bulk of the Lower Miocene of Kachchh. The clays of this stage contain a rich assemblage of Upper Burdingalian fossils.

Significantly, this series is seen overlapping the Deccan Trap directly and obviously this marine transgression was the most powerful one in the history of the Tertiary sedimentation in Kachchh.

Kankawati Series

Well exposed around Kankawati river section between Samdhon and Vinjhan, this series consists of grey micaceous and calcareous sandstone, lenticular bands of conglomerate and Khakhi grey clay. The upper part is mainly pinkish hard calcareous grit and conglomerate containing abundant foraminifers. This series has been tentatively assigned a Pliocene age and has been correlated with the Manchhar Series of Sindh-Baluchistan. The possibility of the upper parts of Kankawati Series, being Pleistocene cannot however be ruled out.

QUATERNARY DEPOSITS

Quaternary record in Kachchh is rather poor and fragmentary. Pleistocene marine rocks are nowhere encountered and the related marine sediments are represented by aeolian accumulations of miliolites far inland from the coastline.

Pleistocene

Early Pleistocene rocks are difficult to recognize. The conglomerate and grit of the Kankawati Series that represent fluvial sediments were probably deposited during this period of low strandline. The only undoubted Pleistocene rocks are represented by miliolite deposits occurring as outliers within the rocky mainland mostly comprising wind-blown accumulations. Biswas (1971) was the first worker to study these rocks and according to him all the occurrences were aeolian, the material has been transported from Saurashtra. Subsequently, Baskaran,et. Al., (1990) carried out detailed investigations on these rocks. Allahabadi and Patel (1986) mapped practically all the miliolite occurrences and described their modes of accumulation, petrography, faunal aspects, depositional pattern and consolidation phenomenon. They recorded more than seventy outcrops scattered in the region extending from Nakhatrana in the west to as far as Bhachau in the east, and from the southern foothills of the Central Highlands upto the northern foothills of Northern Hill Range bordering the Banni plains. Miliolite occur as obstacle dunes and as sheet deposits and occupy low grounds at the base of the hills, topographic depressions within the hilly areas and hollows on the slopes of big hills and ridges. Although Biswas (1971) invoked a dominant role of aeolian transport, he was of the opinion that some sheet miliolite, especially those containing cobble and pebbles, pointed to a fluvio-aeolian deposition. The constituent rock is quite identical to that of Saurashtra except that it has got a somewhat higher lithic content.

Holocene

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.

The Great Rann and the Little Rann comprise unique examples of Holocene sedimentation. The two Ranns represent filled up gulfs and mark the site of accumulation in an estuarine delta environment that was marked by a fluctuating strandline since the advent of Holocene (Ghosh, 1982). During the last 10000 yr., the area came under the influence of glacio ecstasy and seismicity-related tectonism, the two factors influencing the strandlines and sedimentation.

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. Because of excessive salinity and long dry spells, the Rann sediments show poor development of organic life. The sediments have yielded some worn out transported foraminiferal shells. The Banni plains are made up of fluvial deposits and in all probability, consists of a Sub-Recent river mouth-bar. According to Shrivastava (1971) the surfacial Rann sediments are underlain by light grey and bluish micaceous non-calcareous clay which turns yellowish brown due to oxidization(Gupta 1970).

Coastal Mud-flats and Beaches

The Kachchh coastline has remained practically uninvestigated. Sharma (1990) has described raised mud-flats and raised beaches deposited during the high Holocene strandline, and the present-day coastal deposits. On the basis of different morphological features, nature of sediments and their depositional history, he has divided the coastal Holocene into three well defined segments. 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.

REGIONAL TECTONIC SETTING

The present structural trend of the Kachchh basin, Narmada rift, Cambay graben (Fig.2.4) as well as the rate of the migration of Indian subcontinent along with the obvious evidences of the upliftment of Mesozoic sediments in Kachchh suggests that the evolution of the Kachchh basin is related to the breakup of Gondwanaland in the Late Triassic/Early Jurassic and the subsequent spreading history of the Eastern Indian Ocean (Biswas,1982, 1987).

The present continental margin evolved when India's drift motion along an anti-clockwise path slowed down considerably after its collision with Eurasia in Late Eocene-Oligocene time (Fig.2.5). The main tectonic events

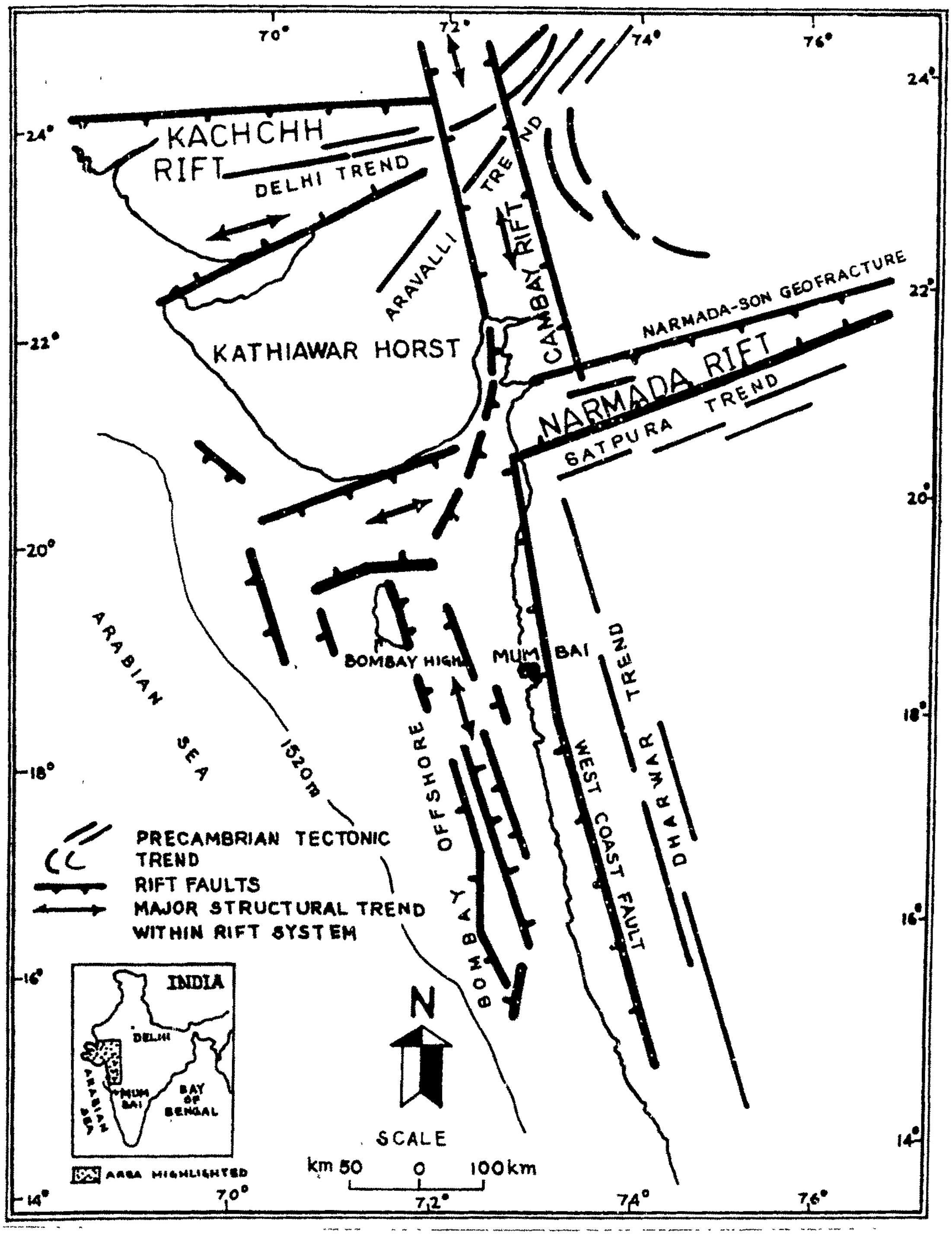

Fig. 2.4 Major tectonic trends and rift basins of western India (after Biswas, 1982).

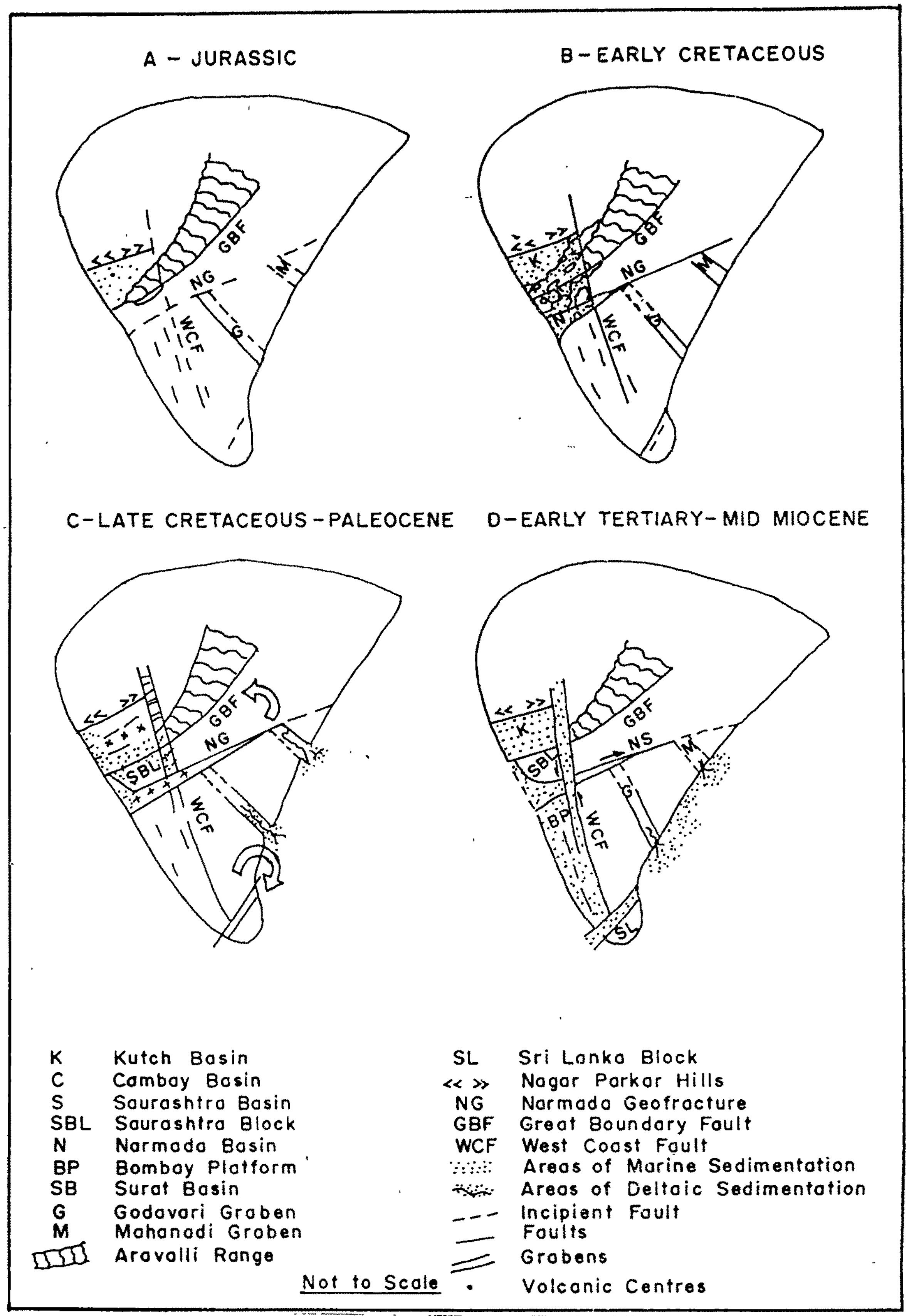

Fig. 2.5 Diagram showing sequential development of rift basins in western India. *(after Biswas, 1982)*

took place during Late Cretaceous when the drift motion was at its acme, with an average rate exceeding 15 cm/yr (Powell, 1979).

Kachchh rifting along the Delhi trend was initiated in the Late Triassic as evidenced by continental Rhaetic sediments in the northern part of the basin (Kosal, 1984). During Jurassic time in the early stages of India's northward drift from Gondwanaland, the Kachchh rift basin was formed by subsidence of a block between the Nagarparkar Hills and the southwest extension of the Aravalli Range (Biswas, 1982, 1987) Kachchh graben became fully marine basin during the Middle Jurassic period (Biswas, 1981). It appears that the "Great Boundary Fault" of the Aravalli Range extending beyond the continental margin along the northern coastline of Saurashtra acted as a principle weak zone (Roday and Singh, 1982; Das and Patel, 1984).

In the Late Cretaceous, uplift of the Jurassic sediments took place in the Kachchh Basin. Saurashtra block also separated out at this time as a result of renewed movements along the western extension of the "Great Boundary Fault". The Cambay graben came into existence as a rift valley by reactivation of its boundary faults. The Narmada rift opened up and received marine sediments. Intensive block movement gave rise to the uplifts of Kachchh. At the end of this period extensive subaerial eruption of trap lava took place through a number of volcanic craters in the Cambay graben, Saurashtra and Kachchh (Biswas and Deshpande, 1973). The present profile of the continental margins of India evolved during Early Tertiary when India collided with Asia and stabilized its present position. The Saurashtra block remained as a horst while the Kachchh, Cambay and Surat basins subsided around it for Cenozoic sediments.

The major structural elements (Fig.2.6) recorded by various workers (Srivastava et al., 1964, Biswas, 1980, 1982 and Biswas et al., 1970; Sharma, 1990) played a significant role in the post Mesozoic geological and geomorphological evolution of Kachchh Mainland. These are listed and discussed as under:

(1) Katrol Hill Fault (KHF),

(2) Vigodi Fault,

(3) Little Rann of Kachchh Fault Systems (LRKFS),

(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.

Katrol Hill Fault and Vigodi Fault

Katrol Hill Fault and Vigodi Fault striking E-W and NW-SE respectively are confined to the central part of the Kachchh Mainland (Fig.2.6). The alignment of these faults is more or less parallel to the two marginal faults (KMF and WCF) and are supposed to have originated subsequent to the main uplift. Biswas (1980) has stated that these faults are also as important as the two marginal master faults, since they are responsible for subsidiary upliftments and belong to the same system of step faults which have not only given rise to a series of uplifts and depressions such as Charwar and Chadwa flexure zones but have also given rise to southward tilting of the southern portion of the Mainland and consequently affected the thickness of Tertiary and Quaternary sediments.

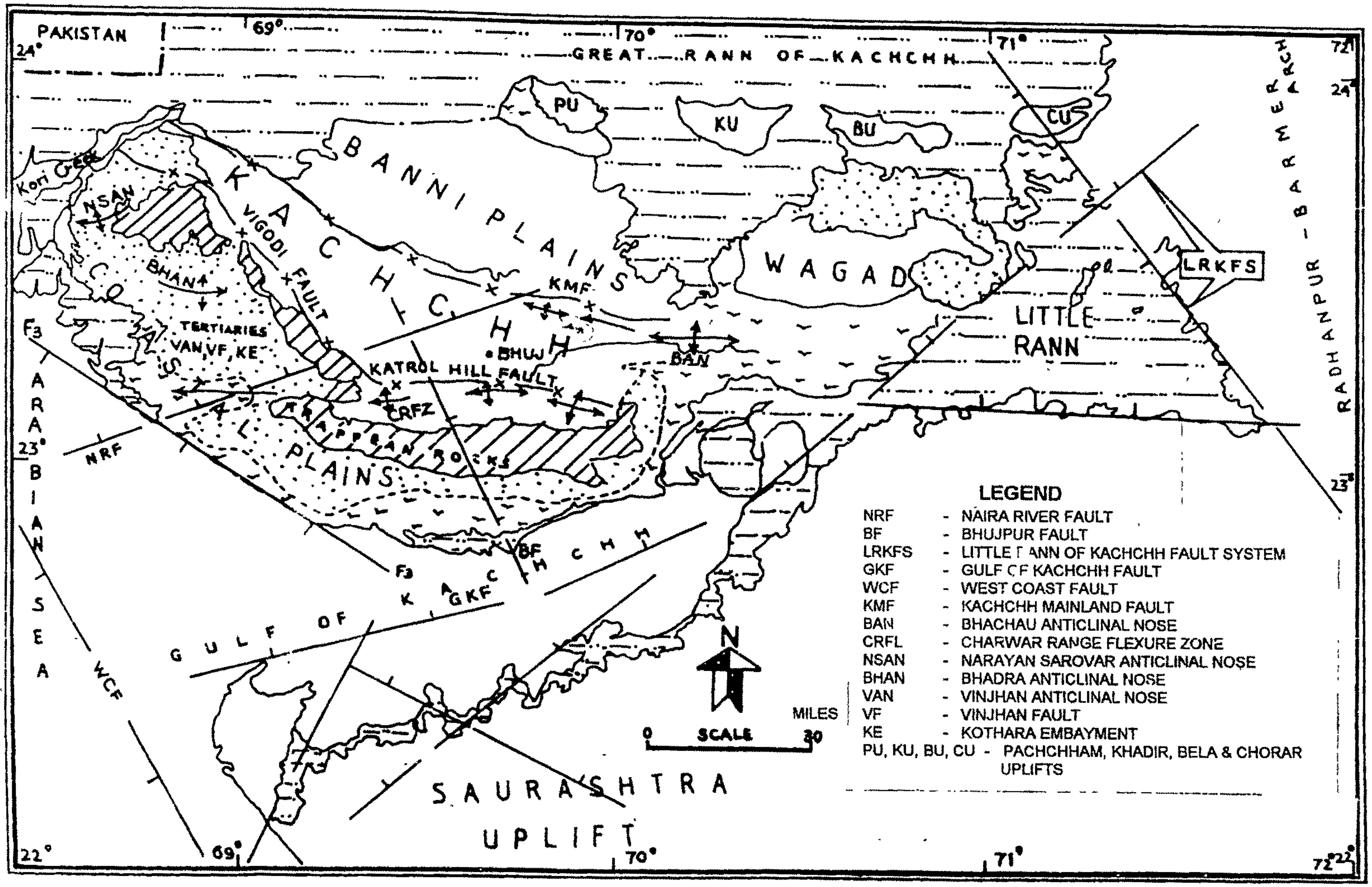

Fig. 2.6 Tectonic and structural map of Mainland Kachchh. (after Biswas, 1987)

Little Rann of Kachchh Fault System

These faults mark the triangular shaped Little Rann and appear to be responsible for its existing configuration (Fig.2.6). The upliftment of the land along these lines of weaknesses during Late Quaternary period coupled with withdrawal of the sea has led to the formation of this land mass and detached it from the Gulf of Kachchh (Ghosh, 1979, 1981, 1982). Earlier it was a portion of the Gulf and many streams from the Gujarat Mainland dumped good amount of terrestrial detritus from NE during Early to Middle Quaternary, which was winnowed and redistributed by the Gulf water (Ghosh, 1981, 1982).

Naira River Fault and Bhujpur Fault

These NE-SW and NW-SE trending transverse faults or lineaments named as Naira River Fault and Bhujpur Fault (Biswas, 1973) respectively could be taken as manifestations of reactivation of basement faults during Quaternary. These faults are responsible for the present day coastal configuration and for imparting considerable diversity in the geomorphic features and sediment characters all along the Kachchh coast. On the basis of these faults the Kachchh coast can be divided into three well defined segments (Sharma, 1991) having their own sets of distinctive land forms. Both the faults have been observed to extend offshore into the Gulf and have affected even the Gulf bottom topography (Fig.2.6).

Vinjhan Fault, Vinjhan Anticlinal Nose and Kothara Embayment

All these E-W trending structures are mutually related. The Vinjhan Fault is vertical to slightly overturned outward (Biswas,1973). According to Biswas (1973) the fault goes further west towards Naliya, below the cover of the Tertiary sediments and its effects are seen in the form of drag folds in the overlying Tertiary sediments. According to Srivastav et al., (1964), a half graben embayment (Kothara embayment) was formed due to gravity faulting along the Vinjhan Fault before the initiation of the Tertiary sedimentation which gradually sank northward due to increasing thickness of Tertiary sediments. The Kothara Syncline and Vinjhan Anticlinal nose essentially represent the drag features developed in the overlying Tertiary blanket (Fig.2.6).

The Gulf of Kachchh Embayment

The Gulf of Kachchh Embayment is somewhat comparable with the Kothara Embayment. Biswas (1982) invoked an ENE-WSW trending deep seated fault extending from onshore into the Gulf passing at some distance in the north of the present day Saurashtra shoreline. Seismic reflection studies of the Gulf of Kachchh by Gopala Rao (1990) have revealed two parallel ENE-WSW to E-W trending faults in the central part of the Gulf forming a graben structure.

Narayan Sarovar Anticlinal Nose

A broad, gentle swing of the Tertiary rocks form the Narayan Sarovar anticlinal nose. This nose is about 15 km long and 30 km wide. There are several minor anticlinal noses and synclinal depressions superimposed on this general regional trend and they have developed around the Trap ridges and humps, and in the embayments between the Trap high (Biswas,1973).

Bhachau Anticlinal Nose

The Bhachau Anticlinal Nose constitutes the eastern half of the middle anticline of the Kachchh whose western half is known as Lakhpat Anticlinal Nose. The general trend of the structure is ESE - WNW but it becomes E - W in the middle portion. The 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 to the south by the gently dipping Tertiary rocks. The northern limb has a steeper dip ranging between 55 to 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 shape to the anticline.