CHAPTER 2

THE REGION OF KACHCHH

2.1 HISTORICAL CONSIDERATION

Kachchh is an ancient land of great antiquity and takes its name from its geographical characteristics and topographical features resembling a tortoise. Kutch, the name by which it has been refereed in the ancient literature, has been defined by Mallinath as marshy region of waste land (in Sanjivani his commentary on Amarkosh). It is also by this name that it has been referred to in the Puranas; in the various notes on this region by foreign travelers that visited this country in olden times; as also in stone inscriptions and copper plates; and in old writing and manuscripts. Prior to the dawn of christianity, this region lying between Sindh and Saurashtra has been described as 'Abhir" by which name it has also been referred to in the Mahabharata. A Greek traveler and military commander named this region as Abira or Abir from its original name of Abhir, during the second century before the Christ. Till the third and fourth A.D. and even thererafter; it came to be referred to by both the names kutch as well as Abhir. First known as Abhir from its original inhabitants, the Ahirs, who resided in this area, it later on came to be known as Kutch because of its unique geographical set up. Considerable importance from the point of view of geological, archeological and historical background is thus attached with the region of Kutch.

2.2 PHYSIOGRAPHY

The district of Kachchh (Fig. 2.1) in State of Gujarat is the Western-most district of India bordered by West Pakistan and approximately covers 44,200 sq. km. area. It covers an area between latitude 22^0 44' and 24^0 41' N and longitude 68° 09' to 71° 31' E. It is the southern fringe of the Thar Desert and generally presents a spectacle of desolate, brown, rugged terrain with scanty vegetation. Kachchh is a semi-desert region, surrounded by Thar Desert to north, by part of Banaskantha districts of North Gujarat to the east, Arabian Sea to west and Kathiawar peninsula to the south. It has a 352 km. long coastline that could be further divided into two: Lakhpat to Mandvi called the Arabian Sea and Mandvi to Shikarpur called Gulf of Kachchh. The extreme climate of the desert of south-western Rajasthan is moderated by the proximity of the sea in Kachchh. The shallow Gulf of Kachchh separates the peninsulas of

Kachchh and Kathiawar. Region of Kachchh is further divided into below mentioned physical/geographical features (Fig. 2.2).

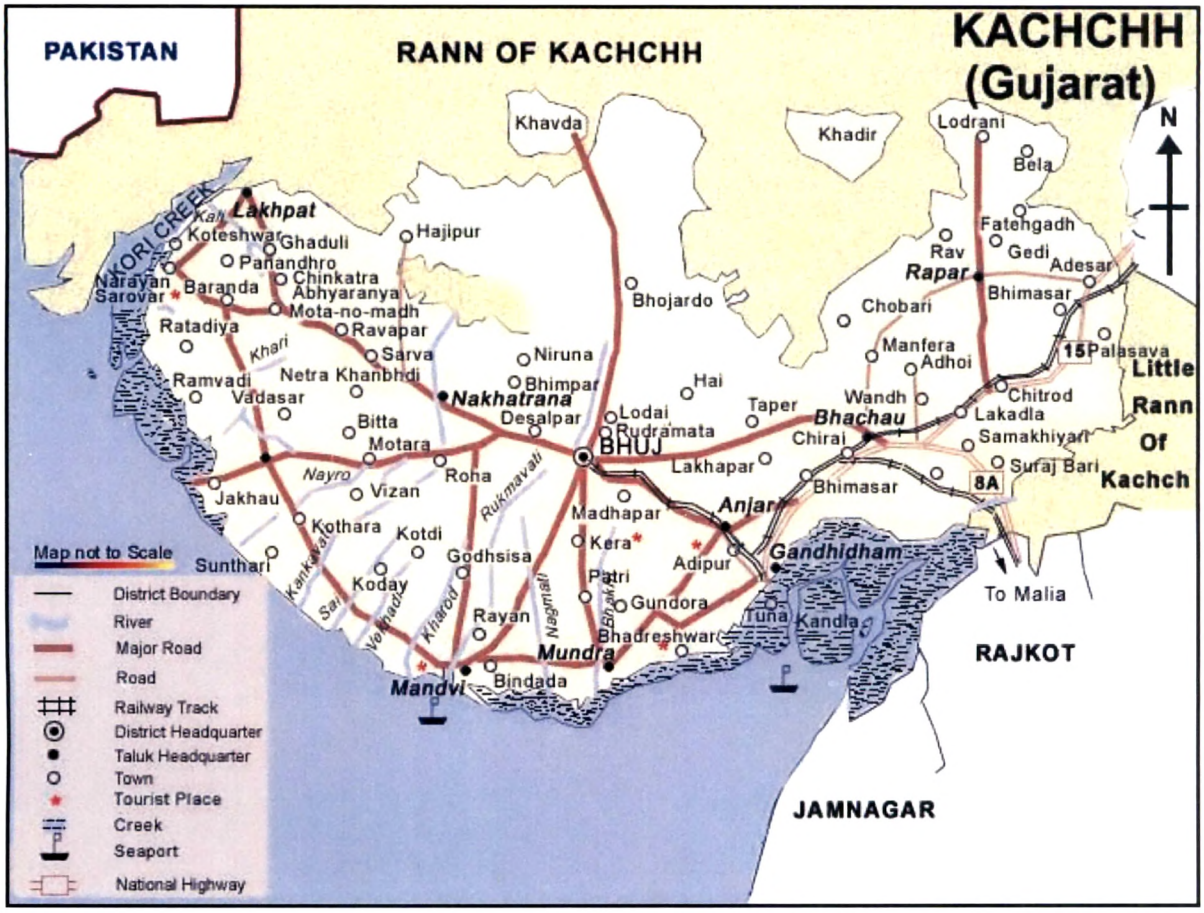

Fig. 2.1 The District of Kachchh

2.2.1 The Mainland

The Mainland is separated from surrounding region by Great Rann and Banni plain in north, Little Rann in the east and Arabian Sea in the south and west (Fig. 2.2). Two main prominent east-west running hill ranges are giving the typical topography to the region. One is in extreme north (northern range) which separates the Mainland and Banni, and the other (central range) is in the center of the Mainland. Northern Range, the longest range in the mainland runs from Ghuneri in the west to Bhachau in the east. Jhurio hill is the highest hill (325 meter) in the middle of the northern range and the other hills include Kas, Habo, Keera, Kaya Dongar (Manzal), Jumara and Jara from east to west. To the further south of Northern range, Dhinodhar, Varar, Bhujia and Arara hills formed as igneous intrusions, occur on the plains.

The Central range is known as Charwar hill range which comprises of Katrol and Chaduva hills; the Deccan Trap hills occur further south of Charwar range. Nakhtarana-Bhuj lowland sandy plain transpires in between Northern range and Charwar line of hills.

Extensive coastal plains border the Mainland to the south as well as to the west. The western coast is exhibits muddy flat creeks such as Sir, Sugar, Nirani and the largest Kori. A well developed sandy beach occurs in the south which joins the muddy tidal flats of Kandla creek in the east, situated at the head of the Gulf of Kachchh.

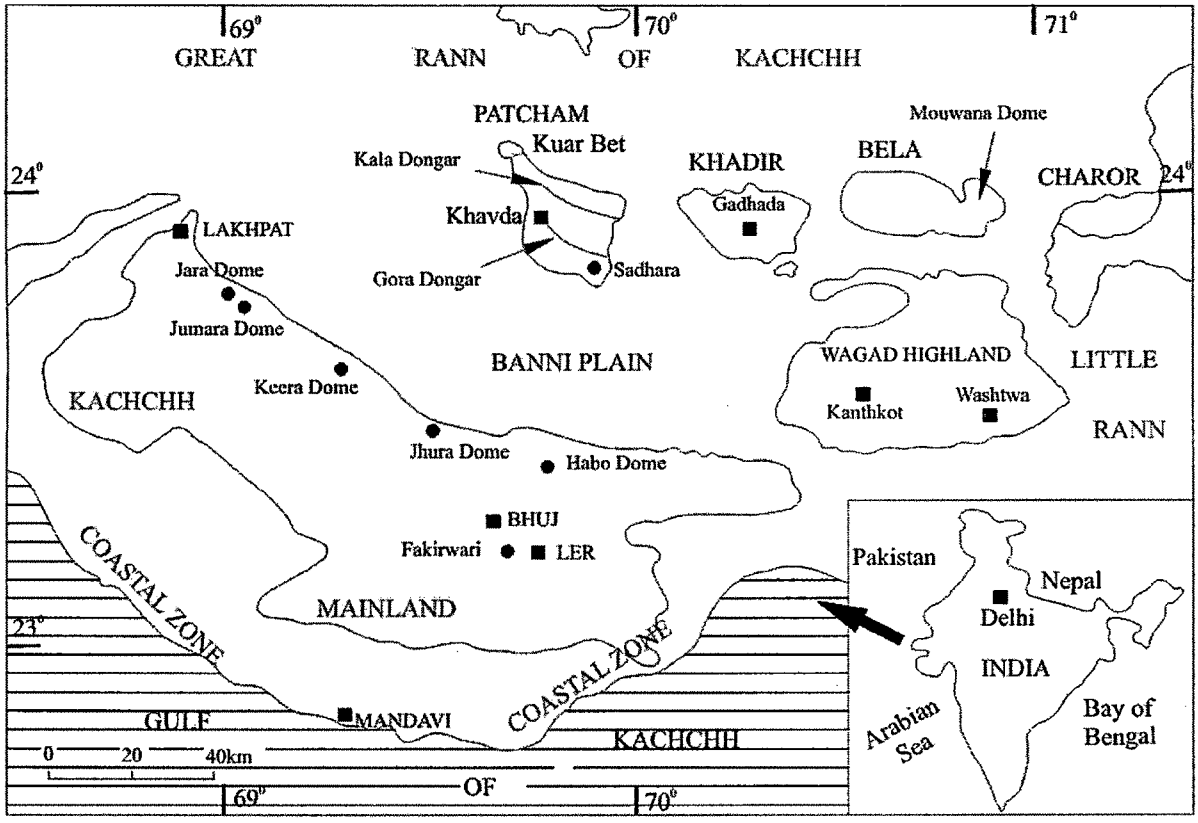

Fig. 2.2 Geographical and Geomorphological map of Kachchh

2.2.2 The Island Belt and Wagad Highlands

The island belt comprises four highlands viz. Patcham, Khadir, Bela and Chorar. These highlands are commonly described as "islands" as they stand out amidst the Ranns / plains, which are submerged during the monsoon. These four islands occur in east-west line to the south of the Great Rann and North of Banni plain (Fig. 2.2). 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 (Fig. 2.2).

Pachcham Island is 80 km. away from the Bhuj city in the northern direction. Khavda is the single major famous town in the island. It has also two east-west running hill ranges, Kaladongar hill range in North and Goradongar hill range in south. Both the hill ranges are separated by a Central valley. Kaladongar hill range is the highest hill range in the Kachchh, in which Babia being the highest (468 meter) peak. Both the hill ranges have striking escarpment on both the sides. Many high hills like Raimalro, Gadapata, and Kank in the Goradongar and Babia and Dingy hills in the Kaladongar have given rise to a fascinating topography. The Dingy hill is isolated from Kaladongar and Rann, in-fact it is located in between Kaladongar and Rann. One desert-island called Kuar bet situated to the north-west of Pachcham Island is the most northward exposed rocky landscape in the region.

Khadir Island is found in the north-west direction from the Rapar city. Khadir Formation is named after this island where the oldest rocks of the eastern Kachchh are exposed. There is a hill range in its northern side, showing northern prominent escarpment like high cliffs facing the Rann. Entire island appears to be tilted down to the south with a gentle slope.

Bela island is situated in northern side of the Rapar town and has similar geographical features to Khadir island. It is east-west running hill range with prominent escarpment on northern side facing Great Rann of Kachchh.

Chorar hill is at eastern most side of the island belt area and covers the part of the Kachchh and Banaskantha district of north Gujarat. It forms a low relief hill on the north-western fringe of Gujarat plains close to the Little Rann. The Chorar hill has cliffs on the northern side facing the Rann and gentle slope towards the south. The ridge runs from Eval on the west to Phangli on the east.

Wagad Highland is situated on the northeastern side of the Mainland Kachchh and consists of number of small domes. There is one long narrow hill range running in the southern margin of Wagad from Wamka on the west, through Adhoi, to Gon on the east.

2.2.3 The Ranns

These unique features occupy eastern and northern parts (Fig. 2.2) 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 up to 4 meters above mean sea level. In rainy season the western and northwestern parts of Rann are inundated by saline water. During the summer and winter seasons, practically the whole region is covered with a fairly hard salt encrustation. The Ranns are geomorphologically divisible into following four 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).

Bet zone forms a slightly uplifted area in the north of Allah Bund. 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 up to 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 a thin sheet of 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. It is situated at the head position of Gulf of Kachchh and in the North of Rajkot district. There are many small bets occurring in between Wagad Highland and Kathiawar Plateau in the Plain of Little Rann, of which the Mardakh and Kesmari bets are significant.

2.2.4 The Banni Plain

The plain of Banni forms a low alluvial tableland between the Mainland of Kachchh and the Great Rann (Fig. 2.2). It occurs 3-10 meters above the level of the Great Rann. It is more or less flat and almost gradient less 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.

2.3 GEOMORPHOLOGY

The Kachchh is uniquely featured by rugged highland topography standing amidst vast plains of the Great and Little Ranns of Kachchh, which are extensive playas with local saline (Biswas et. al. 1983). Geomorphologically, Kachchh can be categorized into five major E-W trending zones (Fig. 2.2):

- Coastal Zone - demarcating the southern fringe
- Kachchh Mainland - divided into the central portion comprising rocky upland, and northern hill range
- Banni Plains (less than 5 meter MSL)-marked by raised fluviomarine sediments, mud flats and salt pans
- The two Ranns - Great Rann (~ 2 meter MSL) in the north and Little Rann in the east comprising vast saline wasteland
- The Island Belt and Wagad Highlands

The boundaries of these main geomorphic zones are bounded by the major E-W trending faults. The variety of the geomorphic facets of the Kachchh peninsula such as the present surface configuration, its landforms, the drainage characteristics and the relief pattern reveal a complex interplay of tectonism, sea level changes, lithology and the Cenozoic processes of erosion and deposition. Interestingly, within the 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, the Kachchh region is made up of east-west trending hill ranges i.e. the island belt, the Kachchh Mainland and the Wagad. The hill ranges 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 Kaladongar (~ 468 meter) in the Pachcham Island. On the Kachchh Mainland there are several peaks, the Nanadongar showing the maximum altitude of 430 meters.

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.

2.4 GENERAL GEOLOGY

2.4.1 Introduction

Geologically the peninsula of Kachchh occupies one of the most important and unique, sedimentary basins of India. The total area of the Kachchh basin is 16,640 square miles of which only 5,264 square miles is the outcropping area (Biswas 1993). About two third of the total area is covered by recent sediments (Great and Little Rann). The stratigraphy of the Kachchh includes the rocks ranging in age from the Bajocian (Middle Jurassic) to Recent. These are deposited in various environmental set ups like marine, inter-tidal, non-marine, brackish and estuarine conditions. The complete sequence is exposed only in the Mainland of Kachchh. However, Rhaetic – Liassic horizons are present in the subsurface in Kachchh (Koshal, 1984). Earlier, Rajnath (1934), Poddar (1959), and Venkatachala (1969) have suggested proximity of even Permian horizons.

The Mesozoic sediments in Kachchh are almost a continuous sequence of transgressive and regressive facies distributed over the Island Belt (Pachham, Khadir, Bela and Chorar) Wagad, and most part of the Kachchh Mainland. The granitic boulder conglomerate and the rocks overlying it in Cheriya bet and Khadir are thought to be the oldest Mesozoic sediments laid down on a Pre-Cambrian basement, exposed as syenitic rocks in Meruda hill, which are

believed to be equivalent to Erinpura Granites (Biswas and Deshpande 1968). A total Mesozoic succession is deposited in various parts of Kachchh including the following six disconnected uplift zones viz. (1) Kachchh Mainland, (2) Pachham Island, (3) Khadir Island, (4) Bela Island, (5) Chorar hill and (6) Wagad region

The rocks are both, clastics and nonclastics in nature include gypseous shales, micaceous and felspathic silty to gritty sandstones, siltstones and bands of limestones mostly intercalated with shale. They possess abundant fossils like Cephalopods, Brachiopods, Bivalves, Gastropods, Bryozoa, Corals, Echinoids, Foraminifera and many other varieties of microfossils, vertebrate remains and last but not least trace fossils. Numerous basic dykes and sills are known to have intruded these sediments at various localities.

Although, the Mesozoic sedimentation was interrupted during the Cretaceous – earliest Paleocene times by an extensive basic igneous phase having the same duration with the Deccan Traps of the peninsular India. These igneous rocks were both intrusive (laccoliths, sills and dykes – most likely they preferred orientation conforming to the stress/strain pattern built-up as a result of the fragmentation of the Gondwanaland and subsequent collision of the Indian Shield against the northern Asian block; occurring mainly in the domal chains, etc., in the central and eastern Kachchh), and extrusive (Mesozoic sediments to the west and south) in nature.

The Tertiary rocks are exposed along the western and southern parts of Kachchh and along the areas bordering the south of the Islands of Pachham, Khadir, Bela and Wagad highlands. They contain silty claystones, gypseous shale, siltstone, micaceous sandstones, foraminiferal limestone and argillaceous limestones. Very often these rocks are highly fossiliferous and contain fossils of Bivalves, Gastropods, Echinoids, Bryozoa, Corals, Foraminifera, Ostracoda and many other varieties of microfossils, vertebrate remains and trace fossils. They are almost free of structural disturbances indicating their formation after the structural evolution of the Mesozoic strata.

All types of soils viz., lateritic-red, black, alluvial marshy, saline, alkaline and desertic are present and noticed in parts of Kachchh. Sand dunes are common features on the southern coastal plains.

2.4.2 PREVIOUS WORK

Author has attempted to present an assessment of the available literature on these important work assemblages and found that the earlier workers on Mesozoic Geology of Kachchh are Grant (1840); Blanford (1867); Wynne (1869, 1872); Oldham (1893); Waagen (after Stoliczka,1871-1986); Meddlicott and Blanford (1879); Gregory (1893,1906); Kitchin (1900); Vredenburg (1910); Spath (1924, 1933); Rajnath (1932, 1933, 1942); Cox (1940) and Pascoe (1959). Then after Poddar (1959 and 1964); Vyas (1968-69); Biswas (1970, 1971, 1977, 1978, 1980, 1981, 1982, 1983, 1987, and 1991); Mehra, Verma and Srivastava (1979); Ghevaria and Srikarni (1990) etc. have carried out systematic geological mapping and classify the different stratigraphic.

In addition to these, Rao (1957); Sahni and Prasad (1957); Agrawal (1956, 1957); Singh et al (1963); Ritchter Bernberg and Schott (1963); Mitra and Ghosh (1964); Ghosh (1969a,1969b); Roy (1967); Mathur et al (1970); Biswas and Deshpande (1968, 1970); Patil (1971); Balgopal (1973); Venkat Raman and Patil (1975); Badve and Ghare (1978); Biswas (1978, 1980, 1981, 1982, 1987, 1991); Kanjilal (1978); Agrawal and Kachhara (1979); Mitra et al (1979); Kumar et al (1982); Singh et al (1982); Casshyap et al (1983); Jaitly and Singh (1983); Jaikrishna (1983); Jaikrishna et. al. (1983); Shringarpure (1985, 1984, 1986); Koshal (1984); Howard and Singh (1985); Bose (1986); Ghare and Kulkarni (1986); Krishna (1987);Jai Krishna and Pathak (1989); Singh(1989); Kulkarni and Ghare (1989, 1991); Ghevaria and Srikarni (1990); Shukla and Singh (1991); Singh and Singh (1992); Fursich et al (1991, 1992), have carried out significant work.

Grant (1840) was first to produce a report on Geology of Kachchh with different maps along with the list of fossils. Although too generalized, the report has provided a platform for further investigations.

Blanford (1867) recognized the E-W trending master faults along the northern margin of major uplift for the first time. A detailed account of geology of Kachchh along with classification of Mesozoic and Tertiary rocks including a geological map [1 inch = 4 Miles Scale] was published by **Wynne** (1872). He divided the Mesozoic sequence into two subdivisions lower Jurassic (marine) and upper Jurassic (non-marine), and denoted it as

equivalent to the Oolites of England. The map proposed by him is quite perfect and has provided basis of reference to all the subsequent geological work in Kachchh.

Immediately following Wynne, stratigraphic subdivisions of the Mesozoic rocks of Kachchh were suggested by **Stoliczka** on the basis of mineralogical and palaeontological characters. He put forth a fourfold classification which includes Pachham, Chari, Katrol and Umia `Groups' from oldest to youngest.

The ammonites fossils were studied in great detail by **Waagen** (1871, 1873-1876), and on the basis of ammonite assemblage zone, he correlated fourfold classification of Stoliczka with the European zones for the first time (Table 2.3). In this way a chronostratigraphic classification came into existence. Such a classification has been followed till now with various modifications by later workers particularly depending on palaeontological observations. According to him, the Pachham, 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 (1872).

Kitchin (1900), **Cox** (1940) and **Gregory** (1906) studied brachiopods, bivalves, echinoids and corals. Their focus was mainly towards highly fossiliferous sections of Western Kachchh. The stratigraphic classification that came into existence was primarily the outcome of these studies. They put more emphasis on taxonomy than the biostratigraphy. **Cox** (1940, 1952) recorded species of Trigonia, and correlated them to those found in Europe and South Africa.

A major contributor, **Rajnath** (1932), on the basis of study of ammonites, lamellibranches and plant fossils, established a succession (Table 2.1 and Table 2.3) somewhat different from the previous ones. He restricted the term 'Umia' only to the lower Umia of Waagen and divided the stratigraphy of the Mainland into five units; the upper Umia made up of non-marine beds with plant fossils was named by him as Bhuj Series of Middle Cretaceous or even slightly younger age. He further investigated in detail the Jumara Dome section in western Kachchh and described 26 beds from Chari and Pachham Series. He re-defined Umia Series and created a fifth stratigraphic unit, the Bhuj Series.

Since more than four decades O.N.G.C. India has carried out extensive geological field mapping in Kachchh basin. During the course of their investigation, the O.N.G.C. officers

have carried out subsurface exploration by geophysical surveys and deep drilling, both, on land and in off-shore using sophisticated instruments. The results have been published which brought out important contribution in understanding the depositional and tectonic history of Mesozoic rocks of Kachchh. Enormous literature related to the cultural, geographical, economical, archeological and geological aspects of the previous princely state of Kachchh providing mere preliminary data on the rock types and topography of the region have been published during last two centuries.

Bathonian to Argovian age was assigned to the Jurassic sequence of Habo hills by **Tiwari** (1948) on the basis of Gastropods and Lamellibranches fossils evidence.

Arkell (1956) published a book 'Jurassic Geology of the World' wherein he has given modified age to Pachham, Chari, Katrol and Umia series.

Agrawal (1957) mapped the Jhura Dome area and modified the stratigraphic nomenclature based on bio-stratigraphy and suggested Habo Series instead of the Chari Series and Mebha Oolites for the Dhosa Oolite.

Pascoe (1959) compiled the classification mainly after Spath (1933) which is more systematic with respect to the usage of stratigraphic terms like series, stages and zones on the basis of lithological and palaeontological characteristics (Table 2.2). Further, in his published a book 'A Manual of Geology of Kachchh' gave detailed lists of fossil assemblages occurring in different horizons.

Bernberg and Schott (1963) assigned Bathonian age to Kuar Bet beds, Callovian age to the Khavada nala section of Pachham island and upper Oxfordian age to Dhosa Oolite band of the mainland on the basis of fossil assemblages. Further, they mentioned that the Katrol series belongs to Kimmeridgian age and the Trigonia beds (lower Umia) to lower Cretaceous age.

Poddar (1964) modified the classification of Rajnath (1932) changing the rank term-suffix 'Formation' in place of 'Series' in the stratigraphy and also considered Ukra Beds as a formation.

FORMATION	AGE	SUB-DIVISION	LEADING FOSSILS
Bhuj Stage	Post- Aptian	Bhuj-beds(Umia plant beds) Sandstones /shale	*Palmoxylan in upper beds ptylophyllum Flora,*
Ukra beds	Aptian	Ukrabeds-Marine Calcareous Shales	*Australiceras,Colombiceras, Cheloniceras,etc.*
Umia (1000m)	U.Neocomian	Umia beds-Barren Sandstones and shales	*Unfossiliferous*
	Valaginian	Trigonia beds Barren sandstones	*Trigonia Unifossiliferous*
	U.Tithonian	Umia ammonite bed	*Virgatosphinctes,Umiatites, Micracathoceras,etc.*
Katrol (300m)	M.Tithonian	U.Katrol shales	*Hildoqlochiceras, Dorsoplanites, Haploceras*
	M.Tithonian	Gajansar beds	*Belemnopsis,Streblites,Phylloceras, Hildoglochiceras*
	L.Tithonian	U.Katrol(Barren) Sandstones	*Autocosphinctoides, Virgatosphinctes*
	M.Kimeridgian	M.Katrol (Redsandstone)	*Waagenia,Katroliceras,Panchysphinctes, Aspidoceras*
	M. Kimeridgian	L.Katrol(sandstones, shales, marls)	*Torquastisphinctes,Aspidoceras, Ptychophylloceras,*
	U.Oxfordian	Kanthkot sandstone (Bimammatum zone)	*Epimayaites,Prograyiceras,Ataxioceras, Bipilices,Trigonia*
Chari (360m)	U.to L. Oxfordian	Dhosa oolites(green and brown oolites)	*Tramelliceras,Discosphinctes,Perisphinctes, Mayaites, Epimayaites, Paracenoceras.*
	U.Callovian	Athleta beds(marls& gypseous shales)	*Peltoceras,Orionodes*
	M.Callovian	Rehmanni beds(yellow Lst)	*Perisphincts,Indosphinctes, Reineckiea, Kinkeliniceras*
			Reineckiea, Sivajiceras, Idiacycloceras,Kellawayssites.
	M.Callovian	Macrocepahlus beds(shales with calc. bands, with golden oolites-diadematus zone-in the up. part)	*Macrocephalites, Dolichocephalites,Indocephalites, kamptocephalites,Pleurocephalites,Belemites*
Pachham (300m)	L.Callovian	Pachham coral beds	*Macrocephalites,Sivajiceras,Proceraites, Stylina,Montivaltia.*
		Pachham shells limestone	*Macrocephalites, trigonia, Corbula,*
	L.Callovian to Bathonian	Pachham basal beds(Kuar Bet beds)	*Corbula,Eomiodon, Trigonia,etc.*

Table 2.1 Bio-stratigraphic succession of Mesozoic Rocks of Kachchh (Rajnath, 1932)

Rao (1964) suggested a Bathonian or lowest Callovian to post-Aptian age of deposition on the basis of faunal evidences where as **Ghosh** (1969a) recommend an age from middle Bathonian to Argovian (Ghosh 1969b) on the basis of mega fossil assemblage which is matching with East and South African assemblages rather than Himalayas or European Jurassic.

Hardas (1968) carried out detailed sedimentology in the South and SW of Bhuj and proposed depositional environments varying from infra-littoral to fluvial for the Mesozoic rocks of this area.

Krishnan (1968) modified the classification of Rajnath (1932, 1942) with age according to Arkell (1956) in his text book. He followed the original fourfold classification with little modification of Bhuj series as 'Bhuj stage' within his Umia series (Table 2.2).

Through time, many geologists contributed on the basis of stratigraphic correlation of Waagen (1875) or Waagen (after Stoliczka, 1893) and further on the basis of Rajnath (1932). However, till 1970's no significant work was initiated dealing with the stratigraphy of Kachchh.

Biswas (1971, 1977) made an opening beginning in the concept of stratigraphy and their corresponding nomenclature and for the first time proposed Lithostratigraphy (Table 2.3 and 2.4) based on International stratigraphic standards through a series of important publications. As per his views, the earlier suggested fourfold classification did not fit in the modern stratigraphic concept. Further, the variation in lithofacies from one part of the basin to the other and detached fault-bound outcrop areas separated by covered plains made it difficult to trace a set of rock units recognized in one area strike wise to the other areas. This prevented the use of uniform rock unit sequence throughout the basin and created inter-basin correlation problem. He therefore recognized three main lithologic provinces within independent classification.

Biswas and Deshpande (1968, 1970, 1973 and 1983) published the detailed geological (Fig. 2.3) and structural / tectonic maps (Fig. 2.4) of Kachchh.

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Bhuj Stage	Post- Aptian	Bhuj-beds(Umia plant beds) Sandstones /shale	*Palmoxylan in upper beds ptylophyllum Florä,*
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	M. Kimeridgian	L.Katrol(sandstones, shales, marls)	*Torquastisphinctes,Aspidoceras, Ptychophylloceras,*
	U.Oxfordian	Kanthkot sandstone (Bimammatum zone)	*Epimayaites,Prograyiceras,Ataxioceras, Bipilices,Trigonia*
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	L.Callovian to Bathonian	Pachham shells limestone Pachham basal beds(Kuar Bet beds)	*Macrocephalites, trigonia, Corbula, Corbula,Eomiodon, Trigonia,etc.*

Table 2.2 Mesozoic Rock Stratigraphic classification of Pascoe (1959) and Krishnan (1968)

Time Unit	Biswas 1971			Waagen (after Stoliczka 1893)	Rajnath 1932
	Mainland Kachchh	Pachcham Island	E.Kachchh		
Paleocene to Upper Cretaceous	Deccan Trap Formation	(Top not exposed)	(Top not exposed)	Deccan Trap	Deccan Trap / Bhuj Stage
	----------				
Albian to Santonian	Disconformity			Beds with Crioceras etc. Ukra beds	Ukra beds
Aptian	Ukra Member				
	Bhuj Formation			Umia Group	Umia Series

Neocomian to Tithonian	Disconformity		Wagad Sandstone Formation		
	Jhuran Fm.			Katrol Group	Katrol Series
Kimmeridgian			Kanthkot Sandstone Member		
Argovian				Kanthkot Sandstone of wagad	
	Local				

Oxfordian	Disconformity (Dhosa Oolite Member)		Washtawa Formation (Occurs in central Wagad)	Dhosa Oolite	Kanthkot Sandstone of wagad Dhosa Oolite
		Goradongar Formation			
Callovian	Jumara Formation			Chari Group	Chari Series
	Jhurio Formation		Khadir Formation		
		Kaladongar Formation		Pachcham Group	Pachcham Series
Bathonian	Base not exposed	Base not exposed	Precambrian ? Erinpura Granite and Aravalli rocks exposed in Meruda Hill and Nagar Parkar.	Base not exposed	Base not exposed

Table 2.3 Lithostratigraphic units of Biswas (1971); Waagen (1893) and Rajnath (1932)

Jai Krishna (1983, 1984 and 1987) carried out extensive work on ammonoid stratigraphy as well as ammonoid Biochronology and put forth a Biostratigraphy of Callovian – Albian sequence on the basis of ammonoid occurrences (Table 2.5).

As known, majority of the geologists have continued to use older fourfold chronostratigraphic classification (Pachham, Chari, Katrol and Umia) of Waagen and Rajnath, which is widely referred and followed in the books of Indian Geology. However, the lithostratigraphic classification of Biswas (1977) provided the basic framework for the study of the depositional model of the basin and its evolution (Biswas, 1981).

Further, Biswas made a series of publications (Biswas 1978, 1980, 1981, 1982, 1983, 1987, and 1991) and discussed litho-stratigraphy, structure, basin framework, palaeo-environment and depositional history, rift-tectonic and sedimentary evolution of Mesozoic rock sequences of Kachchh on a regional scale. He also developed the concept of monoclinal flexures and domes aligned along the margin of all the major faults of the region i.e. Nagar Parkar Fault (NPF), Island Belt Fault (IBF), Kachchh Mainland Fault (KMF) and Katrol Hill Fault (KHF).

Many workers (Howard and Singh, 1985; Jaikrishna, 1983; Jaikrishna et.al., 1983; Mitra et.al.1979), raised their concerns and objections on the new nomenclature of Biswas and suggested consideration and retention of old classification and nomenclature of Waagen and Rajnath.

Bose et al (1986) studied the facies of Bhuj Formation and Ghuneri Member and produced detail information of each litho-unit creating the depositional model of a basin.

The Ichnological studies in the Kachchh region also started long back, at the time of Wynne (1872). **Howard and Singh** (1985) interpreted environments based on mainly trace-fossils with some supporting evidence from gross lithology of Mesozoic sediments and proposed a depositional model for Jurassic-Cretaceous rocks.

Shringarpure (1976, 1984, and 1986) examined the rocks of the Wagad region of Eastern Kachchh, from ichnological point of view during his work on foraminifers and for the first time interpreted these structures in terms of their ethology, palaeoecology, animal sediment

relationship, event stratigraphy and depositional environments. He, for the first time recorded in detail more than 45 ichnogenera and 73 ichnospecies.

Singh (1989) studied the sedimentology, paleontology and ichnology of Dhosa Oolite member of Chari series and proposed that, it is a transgressive condensation horizon of Oxfordian age.

Badve and Ghare (1978), Ghare and Kulkarni (1986), Kulkarni and Ghare (1989, 1991) added further data on the ichnology from the Kachchh region.

Patel, S.J. (1990) described more than 67 ichnospecies from the carbonate sediments of the Tertiary age in the Western Kachchh region.

Bhatt (1996) investigated the area south of Bhuj in detail to study the Mesozoic sediments and described 50 ichnogenera and 75 ichnospecies. He has also described ichnocoenoses, palaeoecology and paleoecological considerations in detail.

Fursich et. al. (1991, 1992, 1994 and 2001) has discussed paleoecological and palaeoenvironmental conditions of Chari rocks covering various exposures in the Kachchh Mainland; Bathonian stratigraphy and depositional environment of Sadhra Dome; using Marker beds of Jurassic. He inferred their depositional environment and sequence stratigraphic significance. Moreover, Fursich (1998) provided an account of the environmental control of the trace fossils of the Mesozoic rocks of the Kachchh region.

A detailed review of structure and tectonic of Kachchh Basin, Western India has been discussed by **Biswas** (2005) with special reference to Earthquakes.

Diwakar Mishra (2008) discussed about high energy transgressive deposits from the Late Jurassic of Wagad, Eastern Kachchh. **Diwakar Mishra and Biswas** (2009) also described sequence stratigraphy and sedimentology of Wagad.

AGE	MAINLAND			PATCHAM			E. KUTCH (KHADIR-BELA-WAGAD)		
	Formation	Member	Litho	Formation	Member	Litho	Formation	Member	Litho
NEOCOMIAN -ALBIAN	BHUJ (815M.)	Upper (260m.)	X-bedded Sst., clay-stone.						
		Ukra (30m.)	Sst, Sh, Fossilifer-ous						
		Ghuneri (w) or Lower (E) (525m.)	Sst. & sh., Plant, fossils				WAGAD SANDSTONE (365M.)	Gamdu (+ 165 m.)	Felds.-Sst., Sh., red iron-stone + plant Fossil
KIMMERIDGIAN TO TITHONIAN	JHURAN (760M.)	Katesar (180m.)	X-bedded Sst.,						
		Upper (300m.)	Thin-bedded calc Sst.,					Kanthkot (200m.)	(Upper) Sst. & Sh.
		Middle (160m.)	Shales						(Middle) X-massive Sst.
		Lower (120m.)	Shale / sst Fossils						(Lower) Silty Shale (?)Paracon-formity
OXFOR-DIAN	JUMARA (275M.)	Dhosa Oolite (115m.)	Shales with Oolitic-Lst. bands				WASHTAWA (WAGAD)	Bambhanka Shales (160 m.)	Mainly Shale having fossils
CALLOVIAN		Middle (75m.)	Sst, (E) – Lst., Golden Oolite (W)	GORADONGAR (154M.)	Modar Hill (+130m.)	Up.Sst. & Lr. Shales		Gadhada (185m.)	Shales and Sst.
		Lower (85m.)	Green Shales, fossilifer-ous		Raimalro (9m.)	Cherty Lst.		Hadibhadang (280m.)	(Upper) Cherty Lst.
	JHURIO (290M.)	Upper (70m.)	Bedded limestone		Gadaputa (6m.)	Sandstone			(Middle) Sst.
BATHONIAN		Middle (85m.)	Shale with Golden Oolitic Limestone		Flagstone (8m.)	Lst. With Golden Oolite	KHADIR KHADIR ISLAND (650M.)		(Lower) Shales + Fossils
		Lower (135m.)	Lst. & Shale, interbed--ded	KALADO-NGAR (470M.)	Kala Dongar Sst. (180m.)	X-bedded Sst.		Cheriyabet (25m.)	Petromict Granite-Cobble-Conglo. and arkose
					KuarBet (290M.)	Shale & Sst.			
								Precambrian	Granitic basement

Table 2.4 Mesozoic rock-stratigraphic classification of the Biswas (1977)

TITHONIAN	Late	Densiplicates Zone	Frequens Subzone 141.2 MY Oppeli Subzone Densiplicatus Subzone	17 Horizons
	Early	Communis Zone	Subfrequens Subzone Communis Subzone	
		Natricoides Zone	Krafti Subzone Pumpeckji Subzone Doghlaensis Subzone Natricoides Subzone	
		Virgatosphinctoides Zone	Biplicatus Subzone Rajnath Subzone Perrismithi Subzone	
		Pottingeri Zone	Sparsicosta Subzone Pottingeri Subzone	
KIMMERIDGIAN	Late	Katrolensis Zone	Infundibulum Subzone 148.2 MY Inversum Subzone Pressulum Subzone Katrolensis Subzone	19 Horizons
		Bathyplocus Zone	Linguiferous Subzone Bathyplocus Subzone	
		Intermedius Zone	Acanthicum Subzone Ipheceroides Subzone	
	late Early	Alterneplicatus Zone	Kachhensis Subzone Alterneplicatus Subzone	
	early Early	Mostly Hiatus in the distal part. Ammonoids collected in proximal part from 120 levels (study in progress)		
OXFORD-IAN				
CALLOVIAN	Late	Ponderosum Zone	Ponderosum Subzone 159.2 MY	25 Horizons
		Athleta Zone	Depressum Subzone Pseudorion Subzone	
	Middle	Obtusicota Zone	Obtusicota Subzone Catillus Subzone	
		Anceps Zone	Paramorphum Subzone Kleidos Subzone Ramosa Subzone	
	Early	Semilaevis Zone	Opis/Eucyclum Subzone Semilaevis Subzone Formosus Subzone	
		Chrysoolithicus Zone	Diadematus Subzone Chrysoolithicus Subzone Transitorius Subzone	
		Madagascariensis Zone	164.3 MY	

Table 2.5 Ammonoid Chronostratigraphy in the Jurassic of Kachchh (Jai Krishna 1983)

Patel et al. (2008a, 2008b) and **Deasi et al** (2008) have described the trace fossils and discussed their utility in the interpretation of palaeoecology and palaeoenvironment of the Mesozoic sediments of Mainland Kachchh. Recently, Patel et al (in press) has described the trace fossils and discussed the paleoenvironmental significance of the Dhosa Oolite Member of the Jumara Formation.

2.4.3 Stratigraphy

The oldest exposed sediments in Kachchh are Bajocian (lower Middle Jurassic) in age (Jaitly and Singh, 1983; Singh et al., 1982). However, Rhaetic – Liassic horizons are present in the subsurface in Kachchh (Koshal, 1973). Earlier, Rajnath (1934) and Poddar (1959) have suggested possibility / proximity of even Permian horizons. Stratigraphy of Kachchh is represented by a complete sequence of strata ranging from Middle Jurassic to Holocene. The Mesozoic of Kachchh includes sediments ranging in age from Bathonian? to Santonian (Biswas 1977). The Mesozoic rocks consist of marine sediments from Bathonian to ?Valanginian and non-marine sediments upto Albian (?Santonian). The Mesozoic rocks ranging in age from Middle Jurassic to Early Cretaceous occur conspicuously in the various major uplifts, and are exposed in the highlands while the Upper Cretaceous has been encountered only in the off-shore wells in Kachchh continental shelf. The Deccan Trap lavas occupy the time gap between Early Cretaceous and Paleocene sedimentations. A period of non-deposition, followed by diastrophism, erosion and volcanism, during the close of the Late Cretaceous time separates the Mesozoic and Cenozoic rocks of Kachchh. Tertiary sediments are mainly marine throughout with the exception of the Paleocene rocks which are continental volcano-clastics deposits. Quaternary formations include sediments of varying origin-aeolian, marine and fluvial.

2.4.3.1 Mesozoic Stratigraphy (Age: Middle Jurassic to Early Cretaceous)

The basin has been filled up with 3000+ meter of Mesozoic sediments. Mesozoic rocks are exposed in the following six disconnected areas which are major uplift zones and form highlands amidst extensive plain land- (1) Kachchh Mainland, (2) Pachham Island, (3) Khadir Island, (4) Bela Island, (5) Chorar Island and (6) Wagad Highlands. These are separated by vast sediment covered plains, which comprise the great and Little Ranns of Kachchh, and Banni (grassland) plain. The total area of the Kachchh sedimentary basin is

about 16,500 sq. miles of which outcrop areas include only 5000 sq. miles. The oldest sequence from Bathonian to Callovian is exposed in the northernmost 'island' outcrops- Pachham, Khadir, Bela and Chorar, collectively referred as the 'Island Belt' and in the Northern hills (i.e. Habo, Jhurio and Jumara) of Kachchh Mainland . In Pachham Island Bathonian to Callovian rocks are exposed and Bathonian to Oxfordian are exposed in Khadir, Bela and Chorar. The Wagad, placed in between the Mainland and the Island belt, exposes intermediate sequence between Oxfordian to Portlandian.

2.4.3.1.1 Mainland Kachchh

The stratigraphic sequence of Mainland is divided into four formations formally named as the Jhurio (Jhura), Jumara, Jhuran and Bhuj formations in ascending order (Biswas 1977, 1981 and 1983). The Bhuj formation is dis-conformably overlain by the basic flows of the Deccan Trap Formation (Biswas, et al., 1973) on the south while the base of the Jhurio Formation is unexposed and is best exposed in the Jhura (Jhurio) dome. Jhurio and Jumara formations are exposed as inliers at the centers of the domal and anticlinal hills along the northern edge of the Mainland and in central Charwar Range in more or less circular and elliptical outcrops (Biswas 1977).

Jhurio Formation (Age: Bathonian to Lower Callovian)

The Jhurio formation consist of thick sequence of limestones and shales with bands of 'Golden-Oolites' in the lower part of the mainland stratigraphy (Biswas 1977). The maximum thickness estimated in the type section is about 290 meters. In Jumara and Habo Hills the exposed thickness is only 75+ meters and 15+ meters respectively. It has been named as the Jhurio or Jhura Formation after the type section in Jhurio (Jhura) Hill in north-central Mainland. The topmost bed of Limestone below the dominantly shaly beds of the Jumara Formation marks the upper boundary, easily recognizable in the field. The upper part of the formation is made up of thinly bedded white to cream colored limestones with thin bands of "golden-Oolite". The middle part is composed of thick beds of grey, yellow weathering shales alternated with thick beds of golden oolitic limestone and the lower part comprises thin beds of yellow and grey limestones occasionally containing golden oolites, in grey shales. The formation has been divided into seven informal members marked A to G

from bottom to top on the basis of the occurrences of the limestone, golden oolite, and shale (Biswas 1977).

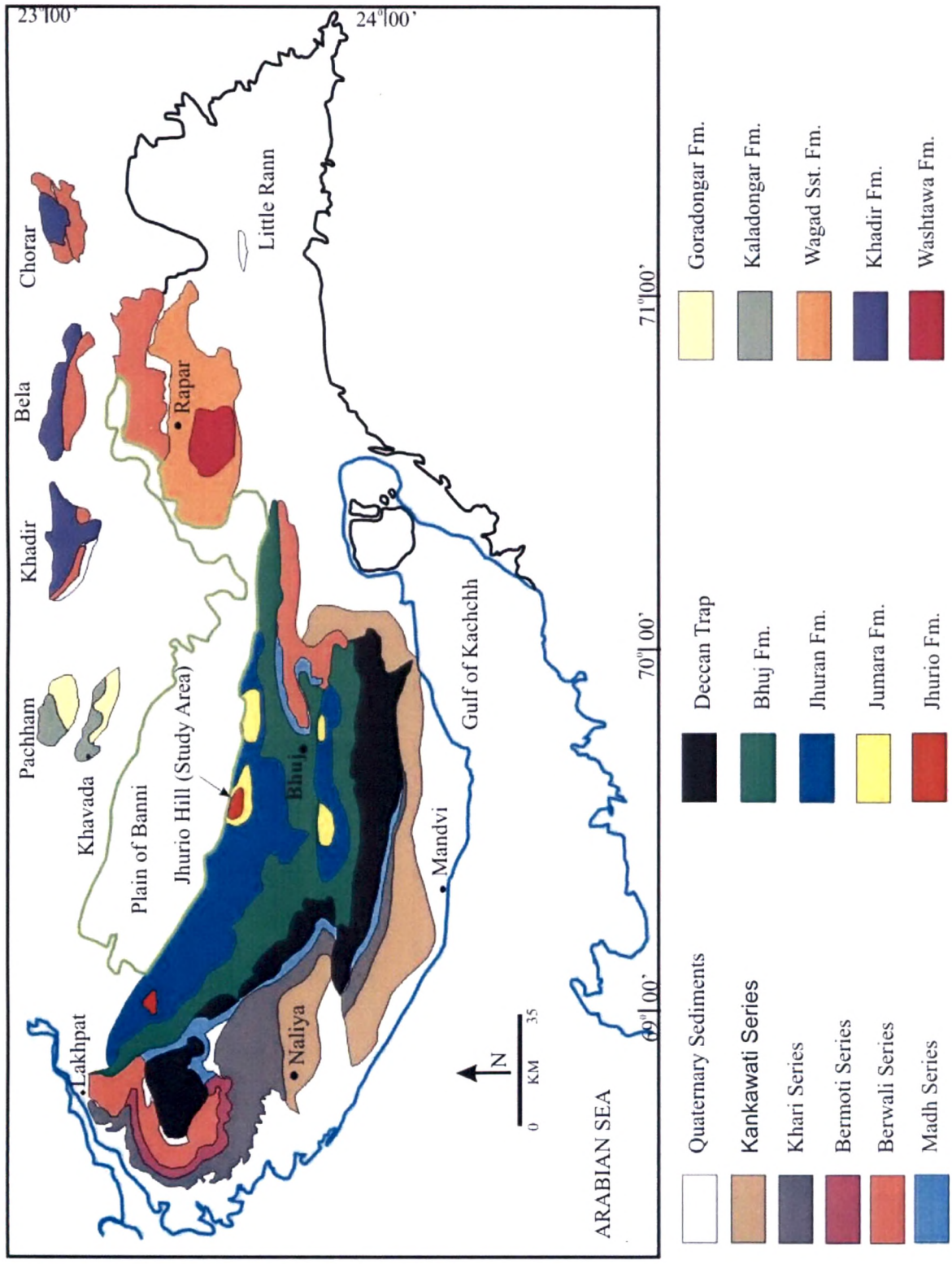

Fig. 2.3 Geological Map of Kachchh region, after Biswas and Deshpande (1971-72)

In Habo hill only the topmost member G is exposed. In Jumara section member G is underlain by olive-grey gypseous shale with thin bands of coral biolithite which constitute a biostromal lithotope equivalent to member F of the type section comprising limestone and golden oolite (Biswas 1993). The important fossils include *Belemnites, Ammonites* (*Macrocephalites*), *Rhynchonella, Terebratula, Allectryonia, Ostrea, Astarte,* and *Trigonia.* This formation is particularly rich in fossils in Jumara dome where the shales and biostromes are packed with corals, brachiopods, pelecypods and ammonites. The physical and biological aspects of the formation indicate littoral to infra-littoral environment (Biswas 1977). A Bathonian to Callovian age has been assigned to the coral limestones described as Patcham Series by various workers (Rajnath 1932, Pascoe 1959, Ghosh 1969a). Further, Agrawal (1957) has also included all the Macrocephalus beds in Callovian and Ghosh (1969a or b?) fixed the lower limit of these rocks in Jumara as Middle Bathonian. Therefore, the formation ranges at least from Bathonian (?Middle) to Lower Callovian (Biswas 1977).

Jumara Formation (Age: Callovian to Oxfordian)

A thick (~280 meter) argillaceous formation overlying the Jhurio Formation has been named after its type section in Jumara Hill near the Rann, north of Jumara village, Kachchh Mainland. Besides the type section it also exposed in the domal hills along the northern edge of the Mainland and in central Charwar Range. It consist monotonous shales (laminated, olive-grey and gypseous) with thin silty bands (red ferruginous) and alternating beds of limestone and occasional sandstone inter-beds are also present. The type section has been sub-divided into four informal members numbered I to IV from below on the basis of the limestone or sandstone interbeds dividing the continuous shale sequence. Thin fossiliferous oolitic limestone (sandy oomicrites) bands occur in the shales near the top of the member IV, which were called "Dhosa Oolite Beds" or "Stage" by earlier workers. These are very characteristic and used as the main key-bed in the Mainland stratigraphy which forms the upper boundary of the Formation. In this classification the member IV is named as the Dhosa Oolite member defined strictly by lithologic characteristics. The old name is retained with redefinition considering its importance as a datum for comparison with the old classification. The Jhurio and Habo dome sections to the east of the type section are important reference sections. In these sections and in Charwar Range outcrops, more sandstone beds appear in the lower part. East of the type section, in Manjal dome, the lowest exposed bed is a limestone developed locally embracing the lower and upper parts of the members III and II

respectively. Farther east in Keera dome, a major portion of the member I has been replaced by a Golden-Oolite-shale. These resemble the middle part of the Jhurio Formation.

This Formation is the richest of all in fossil content. The type-section and Keera dome need special mention for their rich crop of fossils. Varieties of ammonites, belemnites, brachiopods, pelecypods, corals and gastropods are found throughout the formation. Lithologic and biologic aspects it appears to have been deposited below the in circa-littoral environment. Boundaries of Rajnath's Chari formation are almost matching with the Jumara Formation. It has been defined Callovian to Oxfordian age on the basis of the ammonites assemblages.

Jhuran Formation (Age: Kimmeridgian to Early Neocomian-Valanginian)

It comprises a thick sequence of alternating beds of sandstone and shale. The formation is overlain by the Dhosa Oolite bed and underlain by the non-marine sandstones of Bhuj Formation. The formation is divided into four informal members- Lower, Middle (Rudramata shale), Upper and Katesar members (Biswas 1977). The section exposed along the stream near Jawahar Nagar village between Lothia dam and Roha hill has been referred as a type section for the Lower and Middle members. For the Upper and Katesar members, Mundhan anticline and Kateser River sections has been designated as type sections respectively. The formation is thickest in Jara-Mundhan area of NW Mainland where it is 790 meter. thick but thins down eastward to 415m. in the type section after attaining the minimum 350 meter. in the Central Mainland. The Lower member consists of alternating yellow and red sandstone and shale beds in almost equal proportions with thin bands of hard, yellow, fossiliferous, pebbly, calcareous sandstones. In its type section a 12 meter thick bed of grey weathering yellow calcareous sandstone with large Belemnites (so called "Juran Belemnites Marl") occurs on the top of the member. The middle member is predominantly shaly comprising monotonous succession of dark grey to black well laminated gypseous shales weathering in olive-grey color. Thin, red bands of ferruginous sandstone, laminated, micaceous siltstone and yellow ochreous mudstone are common in shales. The ferruginous bands are concretionary encasing ammonites at many places. The shales are highly fossiliferous in the western part but less so in the eastern part. The unfossiliferous shales contain macerated – plant fragments. This member is very well developed throughout and serves as a marker defined para- stratigraphic unit. The upper member is predominantly arenaceous and

composed of red and yellow, massive current bedded sandstones with intercalations and alternations of shale, siltstone and calcareous sandstone bands in the middle. In its type section three ridge-forming, conglomeratic, calcareous sandstone beds, 2-3 feet thick, containing large shells of Trigonia (Trigonia Ridge Sandstones) occur in the lower part. Its contact with the middle member shales is gradational and interdigitating. The Katesar member consists of greenish grey to yellow, massive, current-bedded, sandstones with minor intercalations of shales. Lenticular, hard, calcareous bands, some fossiliferous, are common. The formation is uniform in lithologic character throughout accepting the interfingering relationship between the members as well as the sandstone and shale beds.

In the western Mainland the formation is richly fossiliferous and becomes less and less fossiliferous towards east. Ammonites, Belemnites, pelecypods, gastropods and locally corals and echinoids are common fossils. (1) Trigonia band near the top of the Katesar member (also top of the formation) containing species of Trigonia and Astarte seen near Ghuneri (2) Jhuran Belemnites Bands on top of the lower member (3) Three Green Oolitic Limestone bands containing ammonites (Virgatosphinctes denseplicatus) below Trigonia Ridge Sandstones and (4) Trigonia Ridge Sandstones containing *T. crassa, T. ventricosa* and *T. smeei* near the base of the upper member are considered as the most important fossiliferous bands in the Formation. Presence of plant fossils in uneven occurrence has been observed in association with bands carrying marine fossils. On the basis of fossil assemblages and sedimentary facies indicate that the environment shifted from sub-littoral to supra-littoral and finally into continental deposition of the overlying Bhuj Formation. According to Richter-Bernberg et al (1963), the presence of *Trigonia ventricosa* Krauss establish the Valanginian age.

Bhuj Formation (Age: Neocomian to Albian /? Santonian)

It is youngest formation of the Mesozoic stratigraphy of Kachchh. It has a huge thickness of non-marine sandstones of uniform character. This formation is defined by the marine beds of the Jhuran Formation below and the Deccan Trap flows above. It has named after its type locality around Bhuj (capital city) of Kachchh. In eastern and central Mainland the formation is divided into two informal members - Lower and Upper and in western Kachchh, it is divided into three informal member - Ghuneri, Ukra and Upper members. The Ghuneri and Upper members, though much thicker, are equivalent to the lower and upper members of the

type area. The lower member is characterized by cyclic repetition of ferruginous or lateritic bands, shales and sandstones. The upper member consists of whitish to pale brown, massive, current- bedded, coarse grained, well-sorted sandstones with kaolinitic shale and ferruginous band alternations at thick intervals. The Ghuneri member consists of thick beds of red and yellow sandstones alternated by "laminated zone" comprising ferruginous bands, fissile or laminated sandstones and shales. The Ukra Member contains olive green glauconitic sandstones. "Green sands" and green and grey shales with thin, fossiliferous bands of purple ironstone, ferruginous mudstone and grey limestone. These beds pinch out laterally into the sandstones of the Ghuneri and upper members. The sandstones in all the members are pale brown to buff, soft friable, usually current bedded (large-scale tabular), fine to coarse grained, well sorted and loosely cemented quartz arenites which are usually micaceous, ferruginous and/or calcareous. Some coarse-grained varieties are feldspathic arenites. Some sandstone in the Ghuneri member is glauconitic and locally contains ferruginous oolite bands. Ferruginous bands in these sandstones are very characteristic, usually concretionary hematitic or lateritic with spongy or nodular weathering and locally ripple-marked. Shales are grey, silty, laminated with limonitic partings, and locally carbonaceous in the lower and Ghuneri members with occasional thin coal bands as seen near Trumbow and Ghuneri.

Accept the fossiliferous bands of ammonites and pelecypods of Ukra member the formation is devoid of any fossil fauna. However, it is rich in fossil flora containing several plant beds in the shales of lower (Ghuneri) and upper members. Important plant beds are seen near Lakhapur, Kharesi, Jakh, Kukadbhit, Kurbi, Nangor and Manjal. The flora is typically Upper Gondwana *Ptylophyllum* flora. Common forms are species of *Ptylophyllum, Williamsonia, Brachyphyllum, Pecopteris, Aurocarites, Taeneopteris, Cladophlebis, Equisatum, Elatocladus* etc. Besides leaf impressions, large chunks of fossil wood are seen concentrated at places. Large fossilized logs are seen in red ironstone bands of Ukra member. From the lithology, absence of fauna and richness in flora, sedimentary structures, and marine tongues in the down basin direction, that the sediments represent deltaic deposits with distal part (delta front) towards the west and the proximal part (fluvial) to the east. The lower time limit of the formation is indicated by the upper limit fixed for the Jhuran Formation which is Valanginian. The lowest age indicator in the Bhuj Formation is the Ukra member whose ammonite assemblage indicates an Aptian age (Spath 1933, Pascoe 1959).

2.4.3.1.2 Pachham Island

Pachham rocks are sub-divided into - a lower Kaladongar Formation and an upper Goradongar Formation. The granite-cobble-conglomerate in Kaladongar sandstones indicates the closeness of the basement, which is exposed 80 Km. to the NE of Pachham Island. As compared to the Jhura and Jumara formation of the Mainland it shows increase in clastics and decrease in faunal content which they are partly correctable, are recognized to the nearness of the northern margin of the basin.

Kaladongar Formation (Age: Bathonian)

The oldest stratigraphic unit of Kachchh, A thick (~470 meter) sequence of conglomerate, sandstone and shale fully developed in the Kaladongar (Black Hills) Range of Pachham Island formally named as the Kaladongar Formation. The base is not exposed. The section exposed in the scarp facing the Rann below the highest Babia Peak (460 meter), and along the stream west of Narewari. The contact with the overlying Goradongar Formation is conformable and easily distinguishable by the contrasting lithology of brownish sandstone and buff limestones.

The formation is subdivided into three informal members- (1) Dingy Hill; (2) Kaladongar Member and (3) Babia Cliff Sandstone Member.

Dingy Hill Member consisting of thinly bedded alternations of green and red siltstones and brown and grey, hard, calcareous sandstones in the lower part and pink to brownish, massive current bedded sandstones containing thin bands and lenses of granite-pebble-conglomerate, inter-bedded with shales, siltstones and thin fossiliferous calcareous sandstones. Kuar bet rocks and Dingy Hill rocks are identical in gross lithology. Kaladongar Member having bands of calcareous fossiliferous sandstone and is calcareous towards the top. Wedges of granite-cobble-conglomerate in the north-eastern part of the island are present. Babia Cliff Sandstone Member shows similar sandstone as the underlying Member from which it is separated by an olive green fossiliferous silty bed. Lower part is silty shale and pink in color while upper part is fine grained, hard, compact, calcareous and yellow in color. Generally Kaladongar Formation is poorly fossiliferous accept a bed full of Rhynchonella occurs in Dingy hill where petrified tree trunks are seen in the conglomerate and sandstone beds and thin

fossiliferous bands of Kuar Bet. Rolled pebbles of corals are common in the upper beds. It shows littoral environment of slowly transgressing sea over a granitic terrain (Biswas 1977) on the basis of its gross lithology, fossil content and strati-structural position. The occurrence of *Corbula lyrata, Garvillia* etc. throughout the formation indicates a Bathonian age (Cox 1940, Arkell 1956). Pascoe (1959) has also given the age a Bathonian and place these rocks in Lower Pachham Stage.

Goradongar Formation (Age: Callovian)

A boundary between Kaladongar and Goradongar Formations is marked by the contact of flaggy limestone of Goradongar and massive sandstone of Kaladongar Formation. It has the sequence of limestone, shale and sandstone overlaying by the Kaladongar Formation is grouped under Goradongar Formation which is named after its type locality, Goradongar (White Hills) Range. The type sections are divided into four informal members in ascending order – (1) Goradongar Flagstone (6 meter.); (2) The Gadaputa Sandstone Member (9 meter.); (3) Raimalro Limestone Member (9 meter.) and (4) Modar Hill Member (130 meter.). Goradongar Flagstone Member demonstrates grey, yellow, flaggy limestones and golden oolitic bands. Gadaputa Sandstone Member has pale brown, massive, medium to coarse grained, quartz-arenitic sandstones showing current bedding. Raimalro Limestone Member defined by fossiliferous pelsparite, grey, yellow, thinly bedded limestones, where as it shows cherty nodular segregations along bedding and upper part is sandy. Modar Hill Member includes fossiliferous gypseous shale and current bedded massive sandstones.

The fossiliferous bands of Goradongar Flagstone Member and flagstones in Khavda Shale (Modar Hill, gypseous shale) are full of Pelecypods (*Corbula, Gervillia, Astarte, Trigonia Nucula, Allectryonia*). Rhynchonellids among brachiopod are seen in Goradongar flags and in Raimalro limestones. Occurrence of crinoid's stems, plates and occasional starfish Indiaster (Rao, 1957) characterizes the latter. The lithologic association and biota indicate infra-littoral environment. The ammonite assemblage in the Khavda shale bed shows that this horizon corresponds to the middle Macrocephalus zone described from the Chari Series of the Mainland and is Callovian in age (Richter-Bernberg and Schott, 1963).

2.4.3.1.3 Eastern Kachchh (Khadir, Bela, Chorar and Wagad outcrops)

The stratigraphy of Eastern Kachchh is represented by interrelated rock-units exposed in the disconnected outcrops of Wagad, Khadir, Bela and Chorar. Three Mappable rock units have been recognized which are formally named as the Khadir Formation, Washtawa Formation and Wagad Sandstone. The Khadir Formation shows the oldest beds of the sequence while the Washtawa Formation is exposed only in Wagad, appears to be equivalent of the uppermost part of the Khadir Formation because both are conformably overlain by the Wagad Sandstone. Base of Khadir Formation and the top of the Wagad Sandstone are not exposed (Biswas and Deshpande 1968).

Khadir Formation (Age: Bathonian to Callovian)

The formation is 620 meter (+) in thickness and has been divided into five members as follows:

(1) Cheriya Bet Conglomerate Member, named after a small islet north of Khadir Island, granite-cobble-conglomerate in grey arkose with pockets of red and green mottled siltstone;

(2) Hadibhadang Shale Member named after the hill of the same name, comprises mutually intercalated grey, gypseous, laminated shale and buff and massive sandstone (felspathic arenites) and become silty eastward in Bela Island.

(3) Hadibhadang Sandstone Member occupy the upper part of the northern escarpments of all the islands and named after the hill of the same name, consist of sandstones in the lower and bedded limestones in the upper part.

(4) Gadhada Sandstone member, named after the type locality around Gadhada, it comprises mainly sandstones (ferruginous quartz arenites) with purple concretionary ferruginous sandstone or ironstone bands and intercalation of shale, lamellar sandstones and flaggy fossiliferous calcareous sandstones.

(5) Bamnbhanka / Gangta Member- thick sequence of shales with thin sandstone interbeds some of which are calcareous and fossiliferous, and bands of intra-formational conglomerate containing flat pebbles and balls of sandstones, constitute Bambhanka member exposed

around Bambhanka, Kakindia Bet, Karabir and Gorabir of southern Khadir and in the Gangta Bet.

The fossiliferous bands in Hadibhadang Shales are full of *Corbula* and *Gervillia* besides other lamellibranches, gastropods, corals and local occurrences of Rhynchonella. The limestone bands in Hadibhadang Sandstone member are full of crinoid stems and plates besides Rhynchonellids, gastropods and Pelecypods. The lower part of the Gadhada Sandstone member is fossiliferous with *Corbula-Gervillia* bands near the base and a 4-ft. ferruginous oolitic limestone band full of Pelecypods of which P*holadomya* dominates, and some ammonites. The Bambhanka Shales are highly fossiliferous containing Belemnites, Ammonites, Pelecypods and Gastropods. Kakindia limestone band, an important fossiliferous marker band in this Gangta Member, is also highly fossiliferous with several bands containing rhynchonellids, terebratulids, ammonites, pelecypods, gastropods, belemnites and fossilwood. Gangta ammonite band is an important marker near the top of this Member. A thin ferruginous conglomerate containing ammonite and fossilwood occur at the top of the formation. The sequence of lithologic association and the biological aspects of different members show piedmont, littoral and sub-littoral environments in a vertical sequence indicating deepening of the basin with the sedimentation (Biswas 1977). Occurrence of *Corbula lyrata* and *Gervillia* sp. assemblage (Cox, 1940) in the lower part of the Khadir Formation can be established Bathonian to Callovian age.

Washtawa Formation (Age: Oxfordian)

A lithologically distinct unit occurs below the Wagad Sandstone in similar stratigraphic position as the Bambhanka / Gangta Members of Khadir Formation. This unit is named as the Washtawa Formation (+206 meter) after its designated type section in Washtawa dome, north of Washtawa. The section is exposed across the valley ridges of Washtawa stream, which flows along the strike. The type section consists of thickly bedded, cross-laminated, brown and red sandstone and grey, gypseous shale alternations in the lower part; buff current-bedded, massive sandstone in the middle part and yellow, flaggy to fissile sandstone and grey laminated gypseous shales in the upper part. Shales in the upper and lower parts contain thin fossiliferous limestone bands. In general, the formation is shaly in the area west of Washtawa and arenaceous east. The type section represents the intermediate lithofacies of the formation.

The shaly facies in the western part is richly fossiliferous while the sandy facies in the east is almost barren barring a few calcareous bands containing pelecypods and gastropods. Several red ferruginous marlstone bands, called Kanthkot ammonite bands, occur in the uppermost 30 meter. shale bed near Kanthkot. They yield a rich crop of ammonites together with belemnites, lamellibranches, gastropods and fossilwood. It is doubted that the bulk of the ammonite fauna reportedly collected from the "Kanthkot Sandstone" by the earlier workers might have come from these beds exposed at the foot of the scarp of sparsely fossiliferous Kanthkot Sandstone, and labeled as so called "Kanthkot ammonites". All these fossiliferous bands disappear east ward towards the type area where only the topmost band, which has been replaced by yellow hard calcareous sandstone, containing pelecypods, belemnites, fossil wood and occasionally star-fish. The facies pattern, lithological association, fauna and its distribution tend to suggest shallowing of depositional environment from sub-littoral from west to east which should be the direction of the shore. Jai Krishna et al. (1998) described late Oxfordian ammonite from the Kanthkot ammonite bands and found that the Washtawa Formation represents a complete succession of Oxfordian.

Wagad Sandstone (Age: Late Oxfordian to pre-Aptian)

The sandstone conformably overlying the Khadir and Washtawa Formation, in Northern and Central Wagad respectively have been included in this formation named after Wagad where it is extensively and exclusively exposed. In Western Wagad, the formation has two distinct component members- a lower marine and an upper non-marine, whereas in Eastern Wagad it is represented only by the non-marine sandstones. The Formation is divided into two: (1) Kanthkot Member and (2) Gamdau Member. The thickness of this formation estimated in SW Wagad is 370 meter (+) and 185meter (+) in Eastern Wagad.

The lower part of the Kanthkot Member comprises grey, splintery gypseous, fossiliferous shale interlaminated with fine grained red ferruginous sandstones and concretionary layers. The shale pinches out in sandstones towards the east. The upper part of the member is mainly sandstones. Two distinct sequences of sandstone beds are separated by a 24 ft. fossiliferous calcareous bed, Kanthkot fossiliferous band – a good marker. The upper sandstones contain thin inter-beds of grey, gypseous shale and are capped by 15 ft. bed of fossiliferous, calcareous sandstone bands referred as Bharodia Astarte Bands as it is very well developed in the scarp near Bharodia (Iddurgurh Scarp of Wynne, 1872). Most calcareous and ferruginous

hard bands in this Member are characterized by ripple-marks, some showing mega, ripples. The Gamdau Member resembles the Bhuj Formation of the Mainland in gross lithofacies. It comprises current bedded, buff and pinkish white, medium to coarse-grained quartz arenite with lenticular conglomerate, purple concretionary ironstone and lateritic conglomerate bands, lamellar sandstone, and grey silty and white kaolinitic shale in inter-bedded repetitive sequence. In the eastern part the entire formation shows similar facies as the Gamdau Member.

Kanthkot fossiliferous and Bharodia Astarte Bands have rich assemblage of *Astarte, Trigonia, Ostrea, Modiola* and *Gryphea* of Pelecypods, besides Belemnites and pieces of fossil wood. At the base of the Bharodia Bands a ferruginous oolitic band is packed with ammonites besides Pelecypods. Ammonite also occurs in the basal shale bed of the Kanthkot Member. Impressions of *Ptylophyllum* spp. are occasionally found in shaly beds of the Gamdau Member. The Wagad Sandstone shows the facies of Bhuj Formation indicating a similar- deltaic environment of deposition. The age of the Formation ranges from Late Oxfordian to Early Cretaceous (Pre-Aptian) on the basis of ammonite assemblages of Kanthkot Sandstones and Bharodia bands (Jai Krishna et al. 1998).

2.5 STRUCTURE AND TECTONICS

2.5.1 Introduction

The Kachchh basin is an East-West oriented pericratonic rift basin at the westernmost periphery of the Indian craton (Biswas, 1987). The sedimentary rift basin of Kachchh occupies the entire district of Kachchh in Gujarat State of Western India close to its western border with Pakistan, between Lat. 22^0 30' and 24^0 30'N and Long.68^0 and 72^0 E.

Important contributions to the study of structure and tectonics (Fig. 2.4) of the region of Kachchh have been made by Biswas and Deshpande (1975), and Biswas (1980, 1982). The basin is a relic rift at the southern end of the Indus shelf and is bordered on the north by the fossil rifts of Thar and Southern Indus basins (Zaigham and Mallick, 2000). To the south occurs another parallel rift basin, the western offshore extension of Narmada rift, with the Saurashtra horst between them. The north-south trending Cambay rift crosses the two parallel

rifts. Together the three rifts form an interconnected rift system around the foundered cratonic block of Saurashtra at the trailing edge of the Indian continental plate.

The Nagar Parkar uplift in the north and Kathiawar uplift (Saurashtra horst) in the south along Nagar Parkar and North Kathiawar faults respectively delimit the E–W rift. The Kachchh rift was initiated during the Late Triassic breakup of the Gondwanaland by the reactivation of primordial faults in the Precambrian Delhi fold belt. The rifting was aborted during Late Cretaceous pre-collision stage of the Indian plate. During post-collision compressive regime of the Indian plate, the Kachchh rift basin became a shear zone with strike-slip movements along sub-parallel rift faults (Biswas 2005).

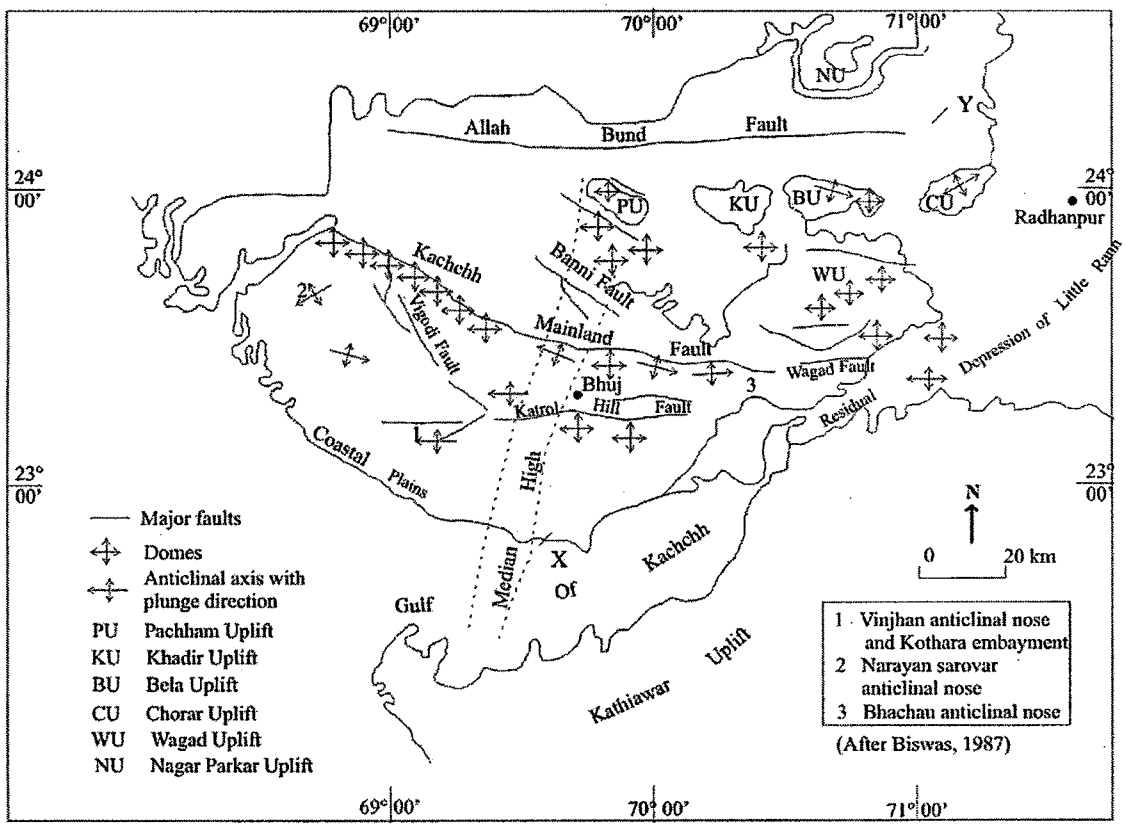

Fig. 2.4 Structural Map of the Kachchh (Biswas 2005)

The regional slope of the basin is towards WSW. The depositional axis passes close to the present day coastline to the south. Basinal hinge zone is marked by a first order basement high (Meridional High) across the middle of the basin running NNE-SSW. This hinge zone is the extension of the Indus Shelf hinge perpendicular to the depositional axis (Biswas,

1987).The raised ground of the Banni above the Rann surface is an expression of Median high (Fig. 2.4).

2.5.2 Uplifts and Faults

The Kachchh region is conspicuously featured by uplifts surrounded by lowlands. The main structure include six major uplift zones running East-West including the areas of Mainland Kachchh, Wagad Uplift, Pachcham Uplift, Khadir Uplift, Bela Uplift and Chorar Uplift (Fig. 2.4). These uplifts are surrounded by residual depressions (Beloussov, 1962) or sub-basins which is present as plains, alluvial or muddy land; salt flats (Ranns) and grassy flat (Banni). The uplifts are oriented E-W along five parallel faults from N to S (Biswas, 1980). (1) Nagar Parkar Fault (NPF), (2) Island Belt Fault (IBF), (3) South Wagad Fault (SWF), (4) Kutch Mainland Fault (KMF) and (5) North Kathiawar Fault (NKF). All these master faults (upthrusts) are following the Delhi tectonic trend, which are reactivated during different geologic times. Several unconformities and diastems have been recorded in the stratigraphy of Kachchh basin, each of which can be correlated with periods of uplift and erosion (Biswas, 1974). All these discontinuities appear to provide a track of tectonic movements in the stratigraphic record.

2.5.3 Outline of Structure and Tectonics

Subsequent to the complete rift opening and in it's extension setting, block tilting phenomena arrives and justify the present day four sub-parallel linear ridges: Nagar Parkar uplift (NPU), Island Belt uplift (IBU), Wagad uplift (WU) and Kutch Mainland uplift (KMU) along the five parallel major faults. The Kathiawar uplift along NKF is a quadrangular block bound by faults on all sides. The IBU is broken into four individual uplifts: Patcham (PU), Khadir (KU), Bela (BU) and Chorar (CU) presumably by unexposed transverse wrench faults as evidenced by relative displacements and orientations. Standing a mist the plains, these uplifts appear as a chain of islands and hence collectively called Island Belt. Several small fault related uplifts occur in line with the bigger ones, e.g., Kuar Bet, NW of PU and Kakindia, Karabir, Gorabir and Gangta Bets (small uplands), which occur between KU and WU. Fault-bounded domes and/or faulted anticlines define these small uplifts. The faulted margins of the uplifts are characterized by narrow linear zones of folding. Igneous intrusions, such as laccoliths, plugs, sills and dyke swarms are localized in these zones. The tilted blocks form a

system of step faults, giving rise to a series of one-sided horsts and half-grabens within the basin. These faults reactivated at certain intervals causing major earthquakes in 1819, 1844, 1845, 1864, 1882, 1898, 1903, 1940, 1956 and 2001.

The Kachchh Mainland Fault (KMF) along the rift axis became the active principal fault. Presently, this right lateral strike-slip fault is overstepped by the South Wagad Fault (SWF) in the eastern part of the basin. The overstep zone between the two wrench faults is a convergent transfer zone undergoing transpressional stress in the strained eastern part of the basin. The epicenters of two big earthquakes as well as the aftershock hypocenters of Bhuj earthquake are located within this zone. The study of the intrusive rocks, rift geometry and seismic tomography indicates presence of a large ultramafic body in the lower crust (Biswas 2005).

The left-stepping KMF/SWF seems to be the principal strike slip-fault and main architect of the structural style. It divides the basin into two main domains of sedimentation, the Banni half graben (BHG) and Gulf of Kachchh half graben (GOKHG). WU block is apparently shifted dextrally with respect to KMU block. In fact, all the uplift blocks are located in the eastern part of the basin, east of MH (Median High) and their occurrence in the map view (Fig. 2.4) shows a stratum arrangement with respect to KMU and right lateral shift along respective faults. The change of up-throw side in case of right lateral KMF left stepping as SWF suggest convergent wrenching with transpression in the step over zone. The horsting of BU against down tilted WU (Rapar half graben) along GF (Gedi Fault) also suggests convergent wrench movement. Further, breaking up of the marginal flexures into faulted closed anticlines and domes, appear to be caused by transpressional tectonics which modified the original flexures during late stage compressive episode. Some of these folds which are highly faulted, e.g. Jhurio Dome (study area) at the northern edge of KMU, could be flower structures formed during this stage (Fig. 2.5).

The rifting was initiated during Late Triassic as evident from the occurrence of Rhaetian early rift stage deposit. The rift expanded from north to south by extensional activation of E–W striking primordial faults. The GRG formed first and remained shallow with initial fan conglomerate and continental sediments of Rhaetian age. Successive southward young half graben formed with increasing thickness of sediments towards the master fault, NKF. This is evident from outcropping of the oldest sediments (Late Triassic/ Early Mid Jurassic) in the

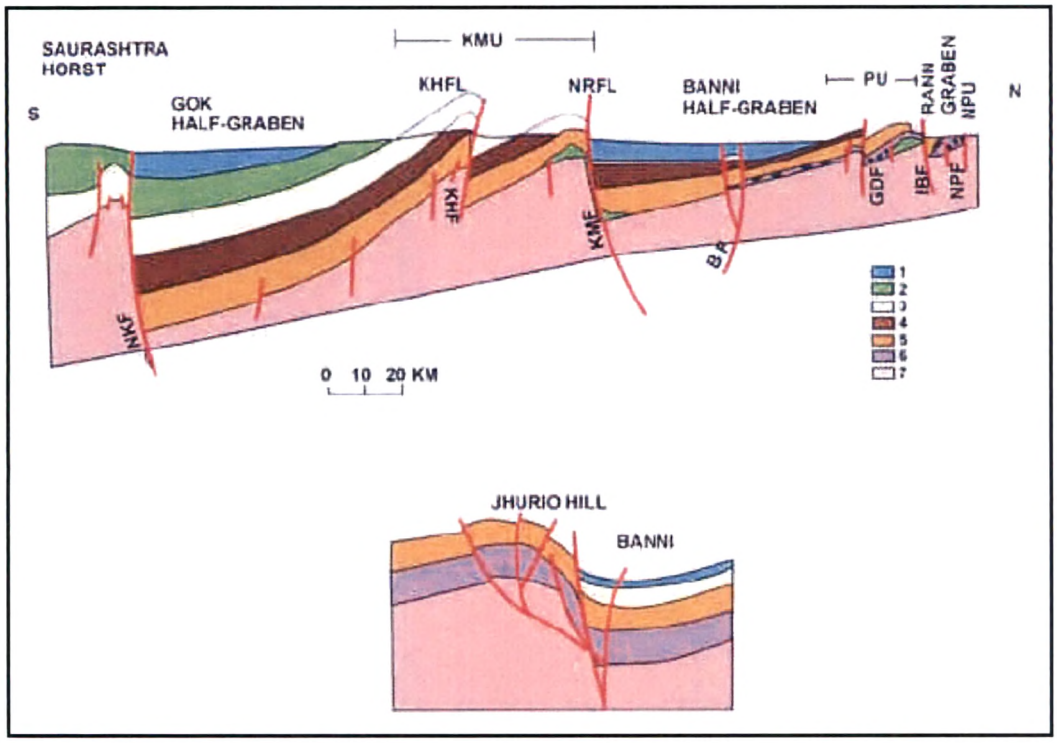

Fig. 2.5 Geological cross section along the axis of Median high in Fig. 2.4 (Biswas 2005)

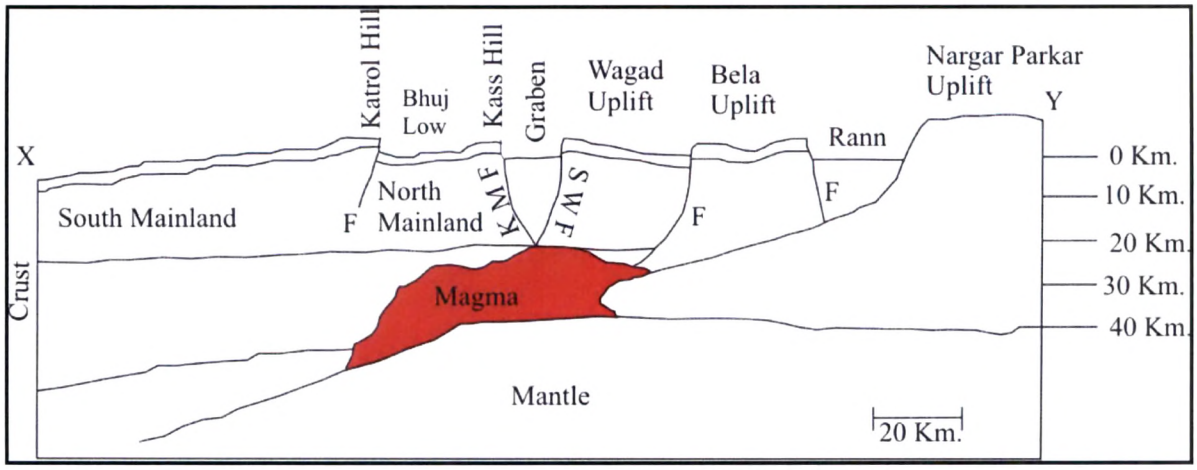

Fig. 2.6 Geological section along the line X – Y in Fig. 2.4 (Biswas 2005)

northernmost IBU and successive younger rocks in WU and KMU. GOK HG subsided most along the master fault and accommodated the thickest sediment fill. Evidently, the basin evolved in two stages: (1) an extensional rift phase, when Mesozoic sedimentation took place and (2) a compressive inversion stage when the present structural style evolved (Fig. 2.6).

From north to south, the Great Rann sub-basin is a narrow graben (GRG) between NPF and IBF, the Banni half graben (BHG) is formed by southward tilting of the IB block, similar tilting of the KM block formed the Gulf of Kutch half-graben (GOKHG). In the eastern part the WU, placed in level to KMU is tilted to the north along Gedi fault (GF) forming Rapar half-graben (RHG) (Fig. 2.5).

Several intra-basinal sub-parallel strike faults are responsible for the tilted block uplifts, forming a series of half grabens. Structurally, the basin contains footwall uplifts and half-grabens along intra-basinal strike faults (Fig. 2.5 and 2.6). The uplifts are the outcropping areas and the grabens/ half-grabens form extensive plains covered by Quaternary sediments. The plains (structural lows) around the uplifts (structural highs) form 'residual depression'. The graben/half-grabens are different depositional domains for rift-fill sedimentation (Biswas 2005).