PART : 1

CHAPTER : I

GENERAL ASPECTS OF STUDY

PURPOSE AND SCOPE OF INVESTIGATION :

Published literature on geology of Khadir Island is rather scanty. It is limited to either general summaries on lithological and paleontological data or descriptions of incomplete stratigraphic sections with particularly no sedimentonogical details. There have been no serious attempts previously to synthesize and interpret the trace fossil data. Despite the fact that many invertebrate species have been reported from the Khadir Island, virtually nothing has been known of the vertical and lateral distribution of the organic traces and their sedimentary facies controls.

The present study is based chiefly on the author's fieldwork during the years 1986-1989. Formost among the goals of the field investigation by the author is, [a] to gain a complete and detailed knowledge of the stratigraphic sections exposed throughout the entire region of the Khadir Island; [b] to study the vertical and lateral facies changes; and [c] to synthesize the stratigraphical, lithological, ichnological and paleoecological data gathered from all such observations.

The other second objective of the study has also been to revive and update the systematic nomenclature of the trace fossils and to obtain accurate geographic and stratigraphical distributional data, with description on the mode of occurrence of each of these ichno taxa.

Prior to this investigation as mentioned earlier, no attempts had been made to interprete the depositional environments and the conditions of origin of sedimentary rocks of Khadir; achievements of this end will be the third objective by the Author. Finally, it is proposed that such an approach may provide a framework for the future study in the Island of Khadir and the region of Kutch in particular where Mesozoic sediments are exposed.

IMPORTANCE OF ICHNOLOGICAL INVESTIGATION :

The Mesozoic rocks exposed in Khadir Island bear wide potential for the ichnological investigations. Excellent suite of ichnofossils are found well preserved in practically all types of sediments deposited in wide range of environmental conditions in the Island zone. A brief introduction to highlight the importance of such studies is therefore attempted in the following paragraphs.

The field of ichnology, in a sense is both old and new. It's basic guiding principles were known to few workers many years ago, and these principles are now being rediscovered by source of current workers including palaeontologists, stratigraphers, sedimentologists, paleoecologists, biologists and others who are adding refinements to the subdiscipline.

Ichnology as expressed by Frey [1975], is the study of all manner of gouges, scraps, and traces made by living or ancient organisms. At the first glance, according to him these oddities might seem to offer little encouragement for serious study. But many looks later, a surprisingly

sophisticated body of information begins to emerge, most of it unavailable from any other source.

Most traces are made post depositionally, although some are contemporaneous with deposition [e.g. escape structures]. Trace fossils differ from body fossils in that they are indicative of an organism's behavioural activity in response to substrate and other paleoecological parameters rather than being part of an organism skeleton. Ichnofossils are preserved in numerous places where body fossils are not, and they document behavioural, ecological, and sedimentological traits that body fossils cannot.

Like most developing fields, ichnology has its problems. Because the study of traces attracts zoologists, paleontologists, and the sedimentologists, the literature remains scattered through several journals, bulletins and books. At present no universal agreement exists on terminology employed in trace fossil work. The problem is still unresolved for many ichnogenera and species. Furthermore, trace fossils like other fossils, generally are inseparable from the rock and thus they are difficult to collect and curate. As a result, interested geologists are required to go to field and see many trace fossils in a variety of different ways, preserved under a variety of different conditions, to build a working expertise on such structures.

WORK AND STUDY PLAN :

Geological maps of Wynne [1872], Biswas and Deshpande [1970] and Biswas [1971, 1977], were used during preliminary reconnaissance studies.

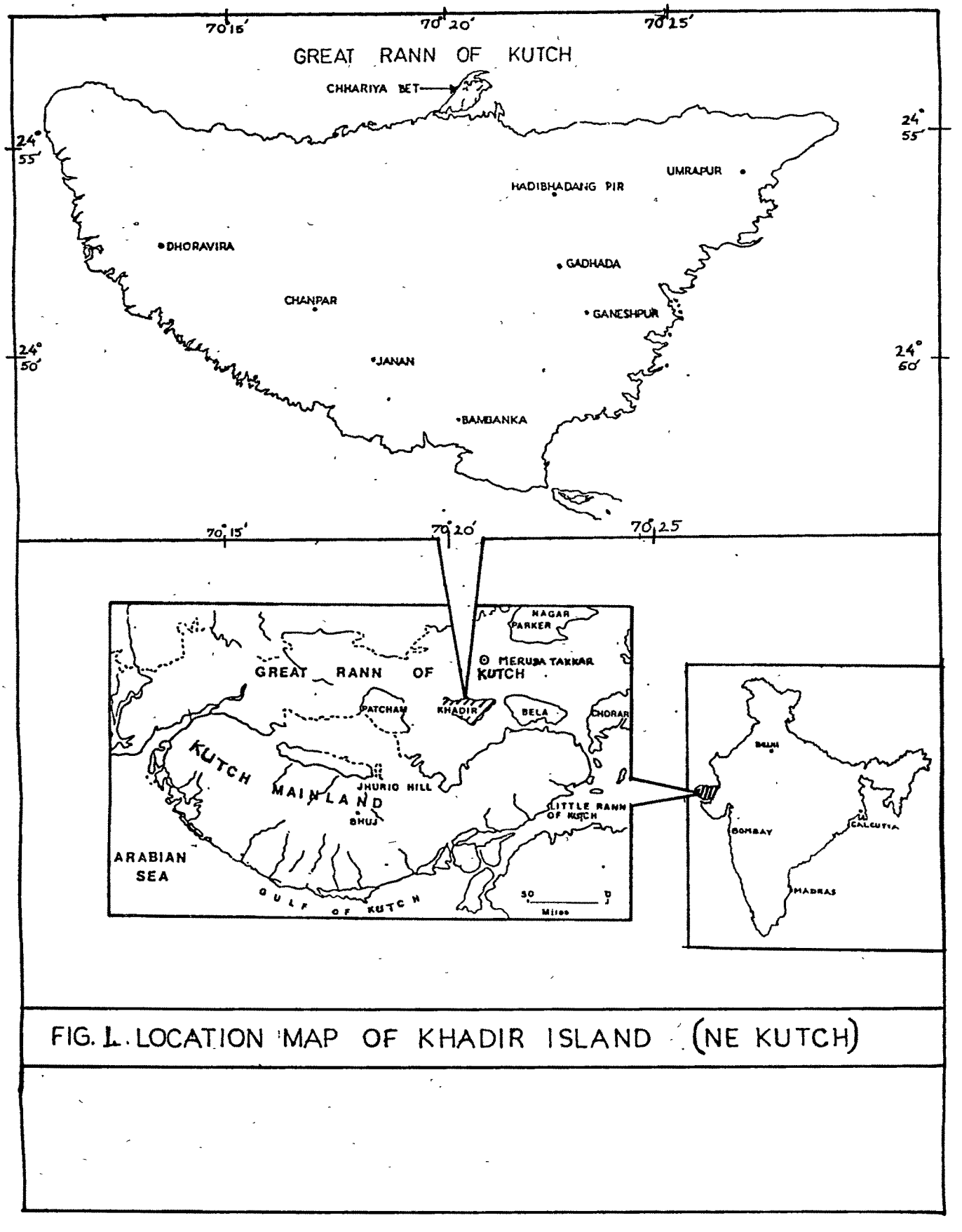


FIG. 1. LOCATION MAP OF KHADIR ISLAND (NE KUTCH)

Geological field work was carried out on survey of India Toposheet No. 41.I/5 and part of 41.I/1 on 1:50,000 scale.

Exposures of rocks were located by reference to published work and by systematic traverse of the outcrop beds as shown in the geological map of Khadir Island [Fig.2]. Sections were measured with steel tapes. Most measurements are given to the nearest centimeters. Precise measurements of beds have proved very useful as an aid in tracing persistant layers of rocks and their content trace fossils. Each measured section for convinence is further divided into sedimentation unit, uniform lithology, limited vertically by changes that are detected readily in the field. Units thus distinguished are described separately in relation to their lithology, biogenic and physical sedimentary structures. Field photographs were obtained at important stratigraphic locations for outcrops, and sedimentary and biogenic structures.

Collection of samples including those of trace fossils were made at nearly all important localities. Numerous specimens were collected for laboratory analysis.

Laboratory studies included examination in hand specimen, under the binocular and petrographic microscope. Representative trace fossils specimens were photographed for more details using magnifying photographic equipments.

Grain size analysis of representative samples from important stratigraphic localities were carried out. Likewise, the data on trace fossil and their

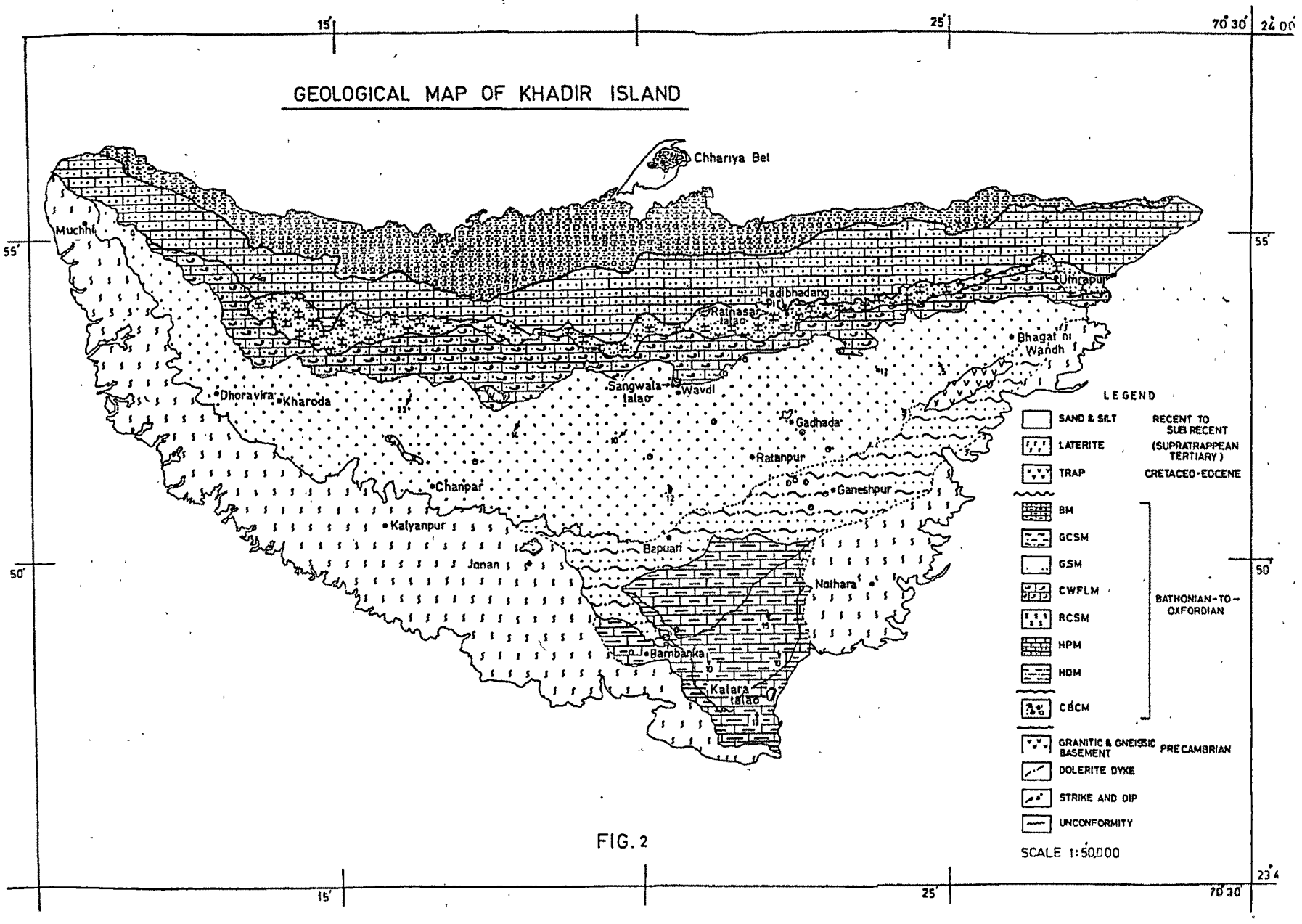

GEOLOGICAL MAP OF KHADIR ISLAND
15'
25'
70 30'
24 00'
55'
50'
23 4'
Chhariya Bet
Muchhi
Umrapur
Hadibhadang Pir
Ratnasar talao
Bhagat ni Wandh
Sangwala talao
Wavdi
Dhoravira
Kharoda
Gadhada
Ratanpur
Ganeshpur
Chanpar
Kalyanpur
Bapuari
Jonan
Nothara
Bambanka
Kalara talao
LEGEND
SAND & SILT
RECENT TO SUB RECENT
LATERITE
(SUPRATRAPPEAN TERTIARY)
TRAP
CRETACEO-EOCENE
BM
GCSM
GSM
CWFLM
RCSM
HPM
HDM
CBCM
BATHONIAN-TO-OXFORDIAN
GRANITIC & GNEISSIC BASEMENT
PRECAMBRIAN
DOLERITE DYKE
STRIKE AND DIP
UNCONFORMITY
SCALE 1:50,000

FIG. 2

implications has been plotted in different graphs and charts. Finally the whole data has been interpreted in the form of a sedimentation model.

OBSERVATIONS AND RECORDING OF ICHNOFOSSILS :

Observations and Recording :

In order to observe, measure and record the ichnofossils effectively the following set of questionnaire was prepared [After Collinson and Thompson, 1982].

The first set [Q.1] attempts descriptions of the morphology of preservation, the second [Q.2 to Q.3] the mode of preservation and the last group [Q.4 to Q.8], the position and process of preservation.

Q.1 What is the morphology of the trace fossils ? Are these identifiable shapes of organisms or part of them ?

[a] Single shape [e.g. a print or track made by a foot];

[b] Several similar shapes repeated to form a pattern [e.g. a track made during locomotion];

[c] a trail [i.e. a continuous groove made during locomotion];

[d] a radially symmetrical shape developed in a horizontal plane [e.g. by the resting of a starfish];

[e] a tunnel or shaft caused by a burrower seeking food and/or refuge;

[f] a series of spreiten, which are U-shaped closely related,

concentric laminae caused by an animal shifting the location of its burrows as it grows or moves upwards, downwards, forewards and backwards by excavating and backfilling;

[g] a pouch shape, for example caused by the resting of bivalves;

[h] a network pattern.

Q.2 Is the trace fossil preserved as a cast or mould ? Is there evidence that the fill was "passive", i.e. by normal sedimentation, or "active" by for example, the backfilling action of a burrower ?

Q.3 Is the trace fossil preserved as a diagenetic concretion ? **Chondrites, Rhizocorallium, Thalassinoides** and **Ophiomorpha** are often preserved as calcite and siderite nodules in shales or limonite nodules in sand. Small diameter burrows are often preserved in pyrite which oxidises to red-brown geothite, in flint or chert. These features are often distinguished by burrow margins with different and physical compositions.

Q.4 Is the trace fossil preserved in an interfacial positions ? The top of the casting medium as an epichnial trace, trace like a ridge [positive feature] or a groove [negative feature] ? Are there any markers on the top or bottom of the ridges and grooves ?

Q.5 Is the trace fossil preserved in an interfacial position on the bottom of the casting medium as a hypichnial trace, e.g. a ridge or groove ? If so, is there any evidences that this was a sediment/ water interface ? Was the trace fossil preserved at a sediment/

sediment interface, possibly between contrasting lithologies, possibly at concealed junction ? Are the underlying and overlying laminae deformed ?

Q.6 Is the trace fossil preserved within a bed but outside the main body of the casting medium as an exichnial trace ? Here the traces of one lithology [e.g. sandstone] are isolated in a different lithology [e.g. shale].

Q.7 Is the trace fossil preserved in an internal position with the main body of the casting medium as an endichnial trace ? Are the burrows very densely distributed and interpenetrating ? If so, the sediment should be refferred to as having a bioturbate texture. Are the burrows common but distinct ? If so, the term burrow mottling may be more appropriate. Are the structures preserved in full relief ? Is the wall of the cast of different composition from the body of the cast; as and when a burrow in sand is lined by a layer or layers of mucus and/or faceal pellets made of mud. Does the trace contain internal structures, e.g. spreiten ?

Q.8 Is the trace preserved by burial following erosion, i.e. Is it a derived trace fossil ? This arises when, after burrowing, erosion takes place and currents winnow away a soft matrix leaving the mucus bound burrow linings as sediment filled "gloves". These can be covered by later, possibly different sediments. Alternatively currents may scour out burrows made in mud and afterwards fill them with sand.

Technique Used :

The study of ichnofossils requires one to try to relate fragmentory two dimensional patterns to complex three dimensional records and behaviour left by a diverse range of organisms. A wide range of techniques has been developed. These include acid etching, base etching, sand blasting, staining, serial sectioning, X-ray radiography, infra-red photography; peeling by polyster resin, lacquer, epoxy relief, casting using plaster of paris, silicon rubber, polyster resin etc. Relative merits of each of this techniques depends on the likely problems one has to encountered.

In the present study the author has concentrated on the following cheaper and simpler techniques.

Most of the ichnofossils were photographed in the field. Such samples that could be conveniently be removed were photographed in the laboratory for their finer details. It should be noted that the photography of trace fossils requires a style slightly different from that adopted with body fossils. Burrows are generally accentuated by wetting the rock surface or by smearing ink over it and then washing it off. Ink smearing produces a stain controlled by differences in porosity. Alixerin Red and Methylene Blue are preferentially absorbed by clay minerals and thus are useful in dealing with trace fossils in fine-grained sediments. In instances, tracing having delicate claw scratches or other fine details whitening by chalk dust and photographing in strong side light advantageously produced good results. Many of the staining techniques normally performed indoors were also applied for the outdoor photography. Spraying carbonate

cemented rocks with dilute HCl or siliceous rocks with KOH was advantageously used to increase relief on fresh facies or rock surfaces.

Having given the general layout of the techniques and the work or study plan the Author now intends to briefly deal with the geology, geomorphology, stratigraphy, structure and tectonics of the region of Kutch. Such an approach the Author feels will be important in understanding the regional set up of the Khadir Island which in fact forms a small fraction of the entire Kutch basin.

CHAPTER : II

KUTCH - GENERAL INFORMATION AND REGIONAL SETTING

HISTORICAL CONSIDERATION :

Kutch 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 referred in the ancient literature, has been defined by Mallinath as a marshy region of waste land [In Sanjivani, a commentary on Amarkosh]. It is also by this name that it has been referred to in the Puranas; in various notes on this region by foreign travellers that visited this region in olden times; as also in stone inscriptions and copper plates; and in old writing and manuscripts. Prior to the dawn of Christinity this region lying between Sindh and Saurashtra has been described as 'Abir' by which name it has also been referred to in the Mahabharata. A greek traveller and military commander named this region as Abiria or Abir from its original name of Abhir during the second century before the Christ. Till the third and fourth A.D. and even thereafter; it came to be referred to by both the names Kutch as well as Abir. First known as Abir from its original inhabitants, the Abirs, who resided in this area, it later on come 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 to the region of Kutch.

GEOGRAPHICAL FEATURES :

The Crescent shaped region called Kutch forms the north-western portion

of the State of Gujarat, and roughly covers an area of about 44,203 sq.km. It occupies an area between latitude 22°44'11" to 24°41'25" north, and longitude 68°09'46" to 71°51'40" east. It is bounded on the north and north-west by Sindh [Pakistan]; on the north-east by Rajasthan; on the east by districts of Banaskantha and Mehsana; on the south-east by Surendranagar; on the south by the Gulf of Kutch and the Rajkot district; and on the south-west and west by the Arabian sea. It is separated from the mainland by Great Rann in the north-east and by Little Rann in the east [Fig. 1].

The entire region of Kutch can be broadly classified into three zones from north to south. The Rann; the centrally hilly region, and the southern coastal plain. The Rann of Kutch is covered with a thick salt layer mixed with fine sand and clay, devoid of vegetation and habitation. The hills of Kutch spread widely in the west are narrow towards the east, and contain the noticeable peak of Dhinodhar, about 387 m. high above the mean sea level reputed to have once been a legendary volcano. The hilly elevations along the Rann contain their highest point in the Patcham ridge [458 m].

The territory of Kutch has a stratagic coastline of 352 kms. The coast is generally flat and broken by small and big creeks. It can be divided into two stretches viz., one from Lakhpat to Mandvi, called the Arabian sea, and the other from Mandvi to Shikarpur [Bhachau taluka] called the Gulf of Kutch.

As far as the climate of Kutch is concerned it is semi-arid or the

"steppe-bush-type". The steppe is a transitional belt, bordering a real desert and separating it from a humid region beyond. The tropic of cancer is passing through the geographical limits of Kutch and hence the area records extreme of temperatures typical of an arid climatic zone. The average maximum temperature in May is about 39°C which sometimes goes as high as 47°C and, average minimum temperature in January is 9°C, which can go even as lower as 1°C. The average rainfall is about 35 cms., most of which falls from June to September during the north-west monsoon.

In Kutch special weather phenomenon resulting into thunderstroms occur during the monsoon season. Dust stroms occur occassionally during the summer particularly in the interior parts of the mainland.

Most of the rivers of Kutch start from its central part and flow towards the sea in the south and the Great Rann in the north. The south flowing important rivers are the Kankawati, the Kharod, the Khari the Mithi, the Rukmavati and the Bhukhi. All these utlimately empty into Gulf of Kutch and the Arabian sea. The north flowing important rivers are the Kali, the Godhated, the Dhudud, the Nara and the Kaiki, which flow to north and ultimately merge into the Rann.

The meagre rainfall in the region of Kutch has resulted in a very poor natural vegetation. The vegetation in major portion of the area is scanty and if present it is mostly xerophytic. The forests are characterized by thorny and non-thorny tree growth. Due to long continued maltreatment, the wild tree-growth has become these days almost entirely confined to

thorny species of Baval, Kher etc.

Kutch lying as it does in the poor rainfall area lacks thick forests and is thus a home of desert and dry, scrap jungle loving animals, best suited to the climate and open land.

The fauna of the area is varied but not plantiful. It includes animals like jackels, wolf, deer etc. and domestic animals like camels, asses, cows, sheeps, goats etc. The land of Kutch is well known for its migratory flamingoes, which arrive here during the winter months.

The Kutch region has been greatly affected by many earthquakes. The recent ones are of 1819, 1844, 1845, 1864, 1882, 1898, 1903, 1940 and 1956. Such earthquakes and the neotectonic movements are thought to have been responsible for the change in the course of the river Indus; creation of Allah Bund; changes in Sindhdi lake; devastation of Lakhpat and Anjar; and change in other such minor physical aspects in the region.

The local residents of Kutch probably represent a mixed race between Arabs and Hindus and follow both Hindu and Muslims faiths. Good harmony exists among the local people. The main occupation is cattle breeding and farming. The common language is "Kutchi" with no script. People are religious and highly superstitious. Literacy is very low. Economically and culturally the area is quite backward and underdeveloped. Acute water shortage and lack of communications have affected population and has left them in poverty.

"Narayan Sarovar", one of the five holiest lakes in the country is situated in Kutch. The temples of Trivikramrai and Koteshwar Mahadev [Narayan Sarovar] and Ashapuri Mata [Matano Mudh] attract many pilgrims throughout the year.

GEOMORPHOLOGY :

The geomorphological analysis for the entire region of kutch were carried out by Biswas [1977]. As emphasized by him topography of Kutch is comparatively very young having undergone a very late uplift. As further suggested by him, the region of Kutch can be divided into six disconnected locations which in fact represent six major uplift zones and form highland areas amidst extensive plainlands - These include [1] 'Patchham Island'; [2] 'Khadir Island'; [3] 'Bela Island'; [4] 'Chorar Hills' [The chain of these four uplifted zones is recognised as 'Island Belt']; [5] 'Wagad Block'; and [6] 'Kutch Mainland'. All these rocky areas are separated by vast sandy plains including the Great and the Little Ranns of Kutch, and the plains of Banni.

Island Belt :

The Island belt which includes the four uplifted Islands of Patchham, Khadir, Bela and Chorar hills display a characteristic development along an east-west axis on the northernmost extremity of Kutch. Most of these hills have dendritic cum parallel type of drainage with deeply incised valleys. It is thus a common site in most of these islands to have sharp escarpments alongside the Rann in the north and gentle slope faces on the south. The scarp forming faces, cliffs and megas are the common

landforms over most of the island zones.

Details of geomorphic features observed in the Khadir Island are fully discussed in Chapter : III.

The Wagad Block :

The Wagad block in eastern Kutch comprises three main hill ranges termed [1] the Southern hill range; [2] the Kanthkot hill range; and [3] the Northern hill range.

The Southern and the Kanthkot ranges are roughly east-west trending. The vitrio peak [755'] occurring in the central part is the highest of all the peaks of the Wagad. As far the Northern hill range is concerned most of the drainage of the Wagad owes its origin to this hill. The entire area shows a radiating type of drainage ultimately disappearing in the Great Rann.

Mainland :

The mainland of Kutch comprises hills mainly Jhurio, [Jhura], Jumara Ukra, Habo etc. These are in fact large domal structures along the northern margin of the mainland. In Jhurio hill, the steeply dipping hard rocks form whitish country of high relief featured by cuestas and annular valleys. Jumara hill is having more or less circular and elliptical out-crops. Topographically, the mainland as a whole is an undulating country of low relief. However, monotonous sandy plains ribbed with cuestas formed by hard ironstone or lateritic bands or dotted with residual hills, some

of which are capped by trap flows, are the typical expressions of topography very often meet in low land areas between the adjacent hill ranges.

Rann of Kutch :

The Great Rann has three geomorphic units such as [1] Bet Zone; [2] Kori Creek Depression; and [3] Great Barron Zone. The north and north-western part of the Great Rann is called the Bet Zone which bears numerous elevetated "bets" and relief network of stream channels are found to exist in inter-bet depressions.

Kori creek is the most depressed region of the Rann situated south of the Bet zone and comes under the influence of tidal water.

The Great Barron Zone is the eastern most zone that forms a vast shallow depression within which numerous smaller depressions occur. This region acts as a 'bowl' which gets flooded during the monsoon by rainwater.

The Great Rann basin is the most extensive structural low between Nagarparker - Tharad and Island belt ridges [Biswas 1977]. To the west of Patcham and Banni, the Great Rann merge into an extensive residual depression.

GEOLOGY AND STRATIGRAPHY :

The territory of Kutch is well known for its Jurassic sedimentary rocks deposited in a peri-continental basin [Biswas 1977]. The basin as advocated

by Biswas [1983] is an east-west embayment opening and deepening to the west towards the Arabian sea. The basin fill comprise the Mesozoic [2430 m] and Tertiary [300 m] sediments laid on an unexposed granitic basement. The Mesozoic deposits range in age from Bajocian to Aptian.

Reference to the existing literature on Mesozoic of Kutch, reveals four main stratigraphic divisions namely Patcham, Chari, Katrol and Umia, worked out on the basis of physical contrast in rock strata and their contend fossils. These original stratigraphic sub-divisions virtually qualify requirement of rock-stratigraphic units as per the modern stratigraphic concepts. However, some of the inappropriate usage of terms have created confusion in understanding their field relationships. These confusions are further compounded by later workers who altogether have changed the earlier names of the established divisions. For instance, in the mainland Kutch, where the Mesozoic rocks are best developed, the stratigraphic units recognised are ; Patcham Formation; Chari Formation; Katrol Formation; Bhuj Formation; and Deccan Trap in ascending order. The age of the rocks of these formations ranges from Bajocian to Aptian.

In order to overcome the above mentioned difficulties Biswas [1977], proposed Mesozoic rock-stratigraphic classification and recognised three main lithologic provinces - [1] Kutch mainland; [2] Patcham 'Island'; and [3] Eastern Kutch [including Wagad, Khadir and Bela "Islands" and Chorar Hill]. The correlation between the strtigraphic columns of each province was first established by him by lithologic markers [defined horizons which were then verified on available biostratigraphic data and inferred time limits].

For the rock units exposed in eastern Kutch [unconnected outcrops of Wagad, Khadir, Bela and Chorar], Biswas [1977] recognised three formations, namely the Khadir, the Washtawa and the Wagad sandstone. Here, the earliest Mesozoic sedimentation begins with the base of Khadir Formation, the lower limit of which is marked by polymictic basal granite - boulder conglomerate resting presumably on a Precambrian basement [Biswas and Deshpande, 1968].

Washtawa Formation is a lithologically distinct unit and occurs below the Wagad sandstone. It is named Washtawa Formation [Biswas 1977] after its type section in Washtawa dome. The formation is shaly in western part and arenaceous in its eastern part. It consists of alternations of cross-laminated, brown, red sandstone and gypseous shale in lower part, current bedded sandstone in the middle, and flaggy to fissile sandstone and laminated gypseous shales in the upper part. The shales in the upper and lower parts contain thin fossiliferous limestone bands, which include pelecypods, gastropods, belemnites etc. Several red ferruginous marlstone bands called Kanthkot ammonite bands, occur in the uppermost shale bed near Kanthkot. The rocks of this formation suggest shallowing of the depositional basin from west to east. Biswas [1977] suggested an Argovian age to these rocks on the basis of ammonite fauna from the Kanthkot ammonite bands.

The predominant sandstone unit of Wagad sandstone formation overlie the Khadir and Washtawa Formation at various localities. It is divisible into a lower marine [Kanthkot] and an upper non-marine [Gamadau] units. The Wagad sandstone according to Biswas [1977] is equivalent to the Jhuran

Formation and lower member of the Bhuj Formation.

The Kanthkot Member comprises grey, gypseous fossiliferous shale interlaminated with red ferruginous sandstones in lower part and mainly sandstone in upper part. Ripple marks are found mostly in calcareous and ferruginous bands.

The upper Gamadau Member comprises current bedded, buff and pinkish white quartz arenite with lenticular conglomerates, concretionary ironstone and lateritic conglomerate.

The Kanthkot Member is rich in fossils such as pelecypods and cephalopods. The age of this formation ranges from Upper Oxfordian to Lower Cretaceous [Pre-Aptian].

The Patcham Island bears two formations namely Kaladongar, and Goradongar. The oldest stratigraphic unit of Kutch in Kaladongar Formation consists of conglomerate, sandstone and shale. The presence of granite-cobble-conglomerate bed indicates the closeness of the basement which is exposed 50 miles N-E of Patcham Island. The lowest beds are exposed in Dingy Hill. This formation is divided into three members : [1] Dingy Hill Member; [2] Kaladongar Sandstone Member; [3] Babia Cliff Sandstone Member.

Lithologic, structural and fossil characteristics of the rocks of these members according to Biswas [1977] indicate littoral environment of slowly transgressing sea over a granitic terrain. On the basis of the occurrence

of **Corbula lyrata**, the age of this formation is fixed as Bathonian.

Goradongar Formation consists of sequence of limestone, shale and sandstone. It is divided into four informal members in ascending orders as - [1] Goradongar Flagstone Member; [2] The Gadapura Sandstone Member; [3] Raimalro Limestone Member; and [4] Modar Hill Member.

The fossiliferous bands of Gadapura Flagstone Member and flagstones in Khavda shale are full of pelecypods. Alongwith Rhynchonellids, occurrence of Crinoid stems and plates, and occasional starfish are found. According to Biswas [1977], this formation, indicating infra-littoral environment, has a time range from Lower Callovian to Argovian.

Mainland :

The stratigraphic sequence of Mainland is divisible into four stratigraphic units formally named as Jhurio, Jumara, Jhuran and Bhuj formations [Biswas 1977].

Jhurio [Jhura] Formation consists of limestone and shale sequence with bands of "Golden-Oolites". This formation is particularly rich in fossils and indicate according to Biswas [1977] littoral to infra-littoral environment, and Bathonian to Callovian age.

The argillaceous Jumara Formation overlie the Jhurio Formation. The formation is characterised by gypseous laminated shales with thin, red, ferruginous bands, alternating bands of limestone, and occasional sandstone

interbeds. This formation is the richest of all in fossil content. Varieties of ammonites, belemnites, brachiopods, pelecypods, corals and gastropods are found throughout the formation. The rocks of this formation have been deposited below the wave base in circa-littoral environment [Biswas 1981]. The formation ranges in age between Callovian to Oxfordian.

Jhuran Formation comprises a thick sequence of alternating beds of sandstone and shale. The formation is divisible into four informal beds namely lower, middle, upper and Katesar members. The lower member consists of alternating yellow and red sandstone and shale beds with thin bands of pebbly, calcareous sandstone. The middle member is predominantly shaly. The shales are highly fossiliferous. The upper member is predominantly arenaceous and composed of massive current bedded sandstones with intercalations and alternations of shale. The Katesar member consists of massive current bedded sandstones with minor intercalation of shales. The formation is richly fossiliferous in western Mainland and becomes less fossiliferous towards east. This formation indicate shifting in environmental condition from sub-littoral to supra-littoral and finally displays epicontinental deposition [Biswas 1977]. A Kimmeridgian to Valanginian age is fixed for this formation.

Bhuj Formation is defined by the marine beds of the Jhuran Formation below and Deccan Trap flows above. It is divided into three informal members - Ghuneri; Ukra and upper members. The Ukra Member is a massive limestone developed locally within the formation. The lower member consists of ferruginous or lateritic bands, shales and sandstones and upper one - whitish to pale brown, massive, current bedded

sandstone. The Ghuneri Member consists sandstones, fissile or laminated sandstones and shales. The Ukra Member contains glauconitic sandstones, "Green Sands" and shales and fossiliferous bands of ironstone, mudstone and limestone.

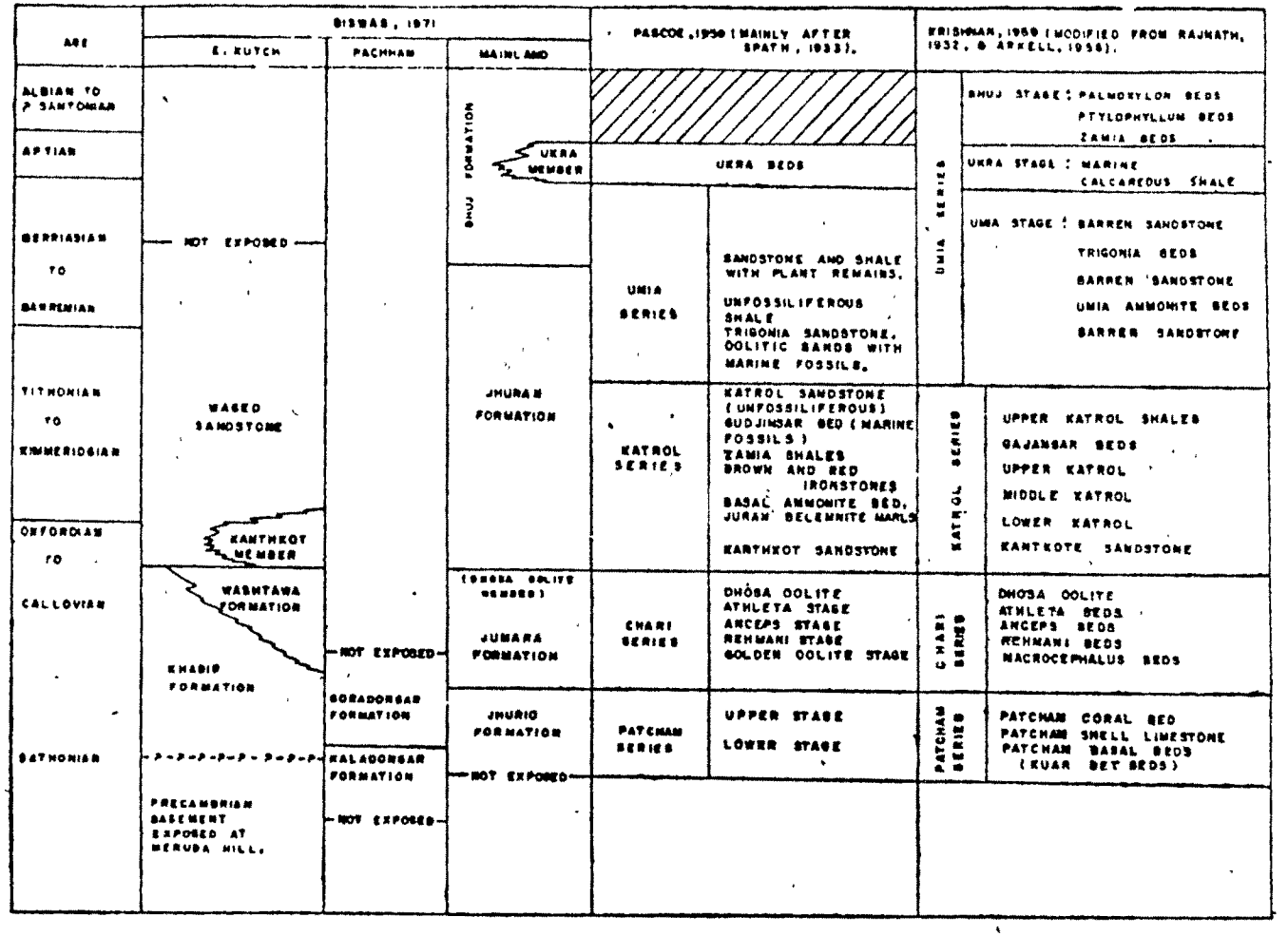
The formation is devoid of fossil fauna excepting in Ukra Member in which fossiliferous bands are full of ammonites and pelecypods. It is rich in fossil flora containing several plant beds in the shales of lower and upper members. Fossil woods are also seen. The sediments represent deltaic deposits with distal point [delta front] towards the west and the proximal part [fluvial] to the east in the direction of the land [Biswas 1981]. Tentatively a Lower Cretaceous [Valanginian] to Santonian time range is assigned to this formation [Biswas, 1977].

Mesozoic rock stratigraphy of Kutch initiated by Biswas [1977] is reproduced in Table No. 1.

STRUCTURE AND TECTONICS :

Important information on the structural and tectonics of Kutch has been discussed by Biswas and Dashpande [1982]. As postulated by them, Kutch is the northernmost pericontinental embayed basin developed between the subsurface ridge of Nagarparker [Pakistan] in the north, Radhanpur arc in the east, and Kathiawar uplift, and Gulf of Kutch in the south. Nagarparker and Kathiawar are the two bordering uplifts along marginal faults. As further claimed by Biswas and Deshpande [1968] the most important aspects of Kutch include group of east-west trending oblong

TABLE 1 : ROCK STRATIGRAPHIC CLASSIFICATION AS COMPARED TO EARLIAR CLASSIFICATIONS



AFTER BISWAS (1977)

uplifts [Highlands and Islands] surrounded by residual depressions [the plains of the Great and Little Rann of Kutch] [Fig. 1]. The major uplift zones that define the main structural trends aligned in four sub-parallel lines trending east to west in an enechelon arrangement include Patcham, Khadir, Bela Islands and Chorar Hills, Wagad Highlands, the Mainland Kutch, and the Kathiawar Peninsula. The individual uplift being separated by residual depressions. A chain of island collectively called that Island belt from west to east include Islands of Patcham, Khadir, Bela and Chorar. Each uplift is further characterised by a narrow, linear flexure zone. All such major uplifts are again bounded, at least on one side by a fault and/or a monoclinal flexure and on the other side by gently dipping peripheral plain. The general form of the major uplifts is thus an asymmetric anticline in section and more or less elliptical in ground plain. The asymmetric anticline having the geometry of a unilateral boxfold has a sub-vertical fore-limb near the faulted margin and a gently dipping back limb which forms the back slope of the ranges. Each uplift, this way has developed at least one marginal flexure and a gently dipping back-slope. The marginal faults or flexures are exposed in all the uplifts except in Khadir Island [study area] where the marginal fault is probably concealed under the Rann cover [Biswas, 1977]. All the uplifts except Wagad have northern fault and/or flexure bounded margin which has been upthrown. Such a structural geometry signifies fault blocks tilted north side up. Each uplift is surrounded by peripheral [or coastal] plains, formed of gently dipping to sub-horizontal beds of the Tertiary rocks which comparatively are much less disturbed.

As mentioned earlier, the master faults of Khadir and Chorar uplifts are

not exposed, perhaps concealed by the Rann sediments. The general trend of the master faults are E-W curving west-ward to WNW-ESE. Such faults are mainly normal faults vertical to deeply inclined and frequently changing upwards into high angle reverse faults. These faults, separating the major zones of uplift and depression, are described by [Biswas, 1977] as upthrust in the genetic sense [after Prucha et al 1965 P.970], where the relative movement changes from 'normal' to reverse type and along which dislocation takes place.

Prucha et al [1965 P.970] have very lucidly explained similar phenomenon, and have shown that "the nature of the uphrust fault exposed i.e. vertical, high angle normal or high angle reverse is a function of the level of observation relative to the corresponding structural segment of the fault".

The dominant structural style of the Kutch area is thus of block faulting similar to the one described by Prucha, Graham and Nickelson [1965 P.969] in the Wyoming province of USA.

According to the latest reports of Biswas [1982], rifting of Kutch basin took place in the late Triassic to early Jurassic time when India drifted northward in anticlockwise direction after its break-up from Gondwana land. As further argued by Biswas [1982] Kutch, Cambay and Narmada basin occupy grabens bounded by faults diverging seaward. The grabens were formed by three rift systems along major Precambrian tectonic trends. The rifting developed sequentially from north to south around the Saurashtra horst. A unique feature of the basin is an across-the-basin Median high occurring

along the basin hinge zone. The rise of the Median high at the beginning of the Late Jurassic is the earliest tectonic movement marked by the Late Oxfordian unconformity above the Jumara Formation of Kutch.

Details of the structural and tectonic pattern of the study area [Khadir Island] are separately considered in the appropriate Chapter.

MESOZOIC SEDIMENTATION IN KUTCH :

The Kutch basin has the most complete Mesozoic record ranging in age from late Triassic to Lower Cretaceous [Biswas 1981].

The basement rocks are exposed in the Meruda Hill in the Great Rann of Kutch, 16 miles [26 km.] north of Khadir Island. These older syenite rocks are thought to be equivalent to Erinpura Granites [Biswas and Deshpande, 1968]. Above these are deposited the polymictic granite-cobble-conglomerate, which form lenses and wedges and occur in cluster of small hills exposed around Chhariyabet, situated at the northernmost part of Khadir. This conglomerate is considered to be the basal conglomerate marking beginning of the Mesozoic sedimentation on a Precambrian granitic basement [Biswas and Deshpande, 1968]. No visible contact is located between the basement rock with the overlying conglomerate bed.

As proposed by Biswas [1981], the sediments overlying the conglomerate are deposited in a sheltered gulf in sublittorol to deltaic environment in two major cycles. A Middle Jurassic transgressive cycles and a Late Jurassic - Early Creteceous regressive cycle.

A review of the main sedimentation units and their characteritic depositional environments is very briefly presented in the following paragraphs.

The lowermost Mesozoic stratigraphic unit in Kutch is known as the Patcham Formation best exposed around Patcham Island and partly developed on the margins of Khadir, Bela and Jhura Hill. It comprises sand/shale alternations with bioclastic conglomerate in its lower part and limestone/ shale alternations in its upper part [Jaikrishna et al. 1983]. A Bajocian age has been ascribed on the basis of **Leptosphictes** to the lower part of the Patcham Formation exposed on Kaladongar by Singh et al. 1982; Jaitly and Singh, 1983.

The next stratigraphic unit in Kutch is the Chari Formation. Macrocephalites are known to be the dominant forms in lower Chari with an endemic mitid assemblage [Upper Oxfordian] at the early stage of its deposition. The Chari Formation further reveals excellent to moderately good preservation of Coccoliths. Nannoflora of the lowermost Chari Formation has proven to be the best known in the World and indicate high energy condition as evidenced from the development of Oolites [Jaikrishna et al. 1983].

As suggested by Jaikrishna et al [1983] the upper part of Chari Formation reflects a regressive shallow marine sequence [Offshore mud and coastal sand interbedded with tidal flat deposits] indicating gradual emergence.

The Katrol Formation which overlies the Chari Formation ranges in age

from Kimmeridgian to Lower to Middle Tithonian. It comprises marl sandstone alternations in its lower part, flaggy sandstones with subordinate shales in the middle part, and coarse sandstone in the upper part. Here, the body fossils are poorly preserved and less abundant or diverse as compared to the Chari Formation.

The Katrol Formation is considered to be Kimmeridgian or Lower Tithonian to at least Middle Tithonian in age [on the basis of **Virgatosphinctin** fauna, **Toquatisphinctas**, **Pachysphinctes**, and **Katroliceres**]. Exremely scarce forms of **Hildoglochiceras** occur in its middle part, while upper part of Katrol is almost devoid of ammonoids [Jaikrishna et al. 1983].

The rocks of Umia Formation assigned to Upper Tithonian - Albian in age and consisting thick, medium to coarse, often current bedded sandstone with thin shale and interspaced glauconitic and Oolitic bands. It also contains horizons with abundant plant fossils that overlie the Katrol Formation. The Lower Umia in western Kutch contains **Virgatosphinctes** [mostly Virgatosphinctes densiplicatus] and Mioracanthoceras of early Late Tithonian age. Furthermore, new finds of Lower Albian cleoniceras and lemuroceras extend Ukra into Lower Albian. Coal and Carbonaceous shales in the middle Umia Formation represent coastal lagoons [Jaikrishna et al. 1983].

The overall pattern of sedimentation during the Mesozoic time in Kutch is thus marked by argillaceous to arenaceous depositional events with minor depositional phases of carbonate sedimentation. All these deposition phases are restricted to Bajocian and Albian periods. The sediments are

then uplifted, folded, intruded and covered by Deccan Trap basaltic flows in Late Cretaceous to Early paleocene time.

Further, as recently concluded by Jaikrishna et al [1983], all throughout the Mesozoic time, [a] the region of Kutch evidenced deposition on a shallow, tide-affected shelf; [b] the sedimentation has taken place above the wave base, with tidal influences [reflected in abundant wave-built structures like hummocky stratifications, wave ripples and interference ripples]; [c] estuarine channels and lagoons played a significant part as sites of deposition during early Cretaceous time.

CHAPTER : III

REVIEW OF PREVIOUS WORK AND HISTORY OF STRATIGRAPHIC NOMENCLATURE

The earliest reference to the geology of Kutch was made by Grant [1837], but the details of his work are not available. The most important and pioneering work on geology of Kutch is that by Wynne [1872]. A detailed account of geology of Kutch including a geological map [1 inch = 4 miles scale] was published by him in 1872. This map is quite accurate and has provided basis of reference to all the subsequent geological work in Kutch. The lithostratigraphic classification as suggested by Wynne is reproduced in Table : 2. Regarding Khadir Island [study area] Wynne [1872 P.103-108] however, has made only passing reference.

The Mesozoic rocks of Kutch in fact drew attention of the earlier workers all over the World for the wealth of mega fossils contained in them. The fossils of ammonites from these rocks were studied in great details by Waagen [1871, 1873-1876] and Spath [1933]. Subsequently, brachiopods, lamellibranchs, echinoids and corals were studied by Kitchin [1900], Cox [1940], and Gregory [1893, 1900] respectively.

The stratigraphic subdivision of the Mesozoic rocks of Kutch on the basis of mineralogical and paleontological characters was first suggested by Stoliczka. He proposed a four fold classification. This includes Patcham, Chari, Katrol and Umia "Groups" in ascending order. Waagen for the first time correlated this classification with the European Zones on the basis of "ammonite assemblage zones". Such a classification has been followed till now with various modifications by later workers particularly

TABLE : 2

LITHOSTRATIGRAPHIC CLASSIFICATION OF WYNNE, 1872

Recent	Alluvial, blown sand and sub-Recent deposits	Pleistocene
	Upper Tertiary	
- - - - - - - - - - - - - - -	unconformity	- - - - - - - - - - - - - - -
Tertiary	Argillaceous Group	Miocene to Upper Eocene
	Nummulitic Group	
	Gypseous Shale	
	Arenaceous Group	Eocene
	Nummulitic Group	
	Gypseous Shale	
Volcanic	Sub-Nummulitic Stratified traps and intertrappean beds	
Tertiary	Infra-trappean beds	
- - - - - - - - - - - - - - -	unconformity	- - - - - - - - - - - - - - -
Jurassic	Upper Jurassic Group	Oolitic
	Lower Jurassic Group	
Metamorphic Crystalline	Syenite	

dependending on paleontological observations. On the basis of fossil corals [Gregory 1893, 1900] and brachiopods [Kitchin 1900, 1903] assigned Patcham series to the European Bathonian and Chari to Lower Callovian. Spath [1924, 1927, 1933] subdivided the Mesozoic sequence of Kutch into Bathonian, Callovian, Oxfordian, Kimmeridgian, Tithonian and Neocomian stages in ascending order. Cox [1940, 1952] recorded species of Trigonia which he claimed were similar to those found in Europe, Somalia, South Africa and Tanganyika.

Rajnath [1932] defined the stratigraphic boundaries on the basis of mega fossils except the Patcham-Chari boundary which he recognised on lithologic characteristics. He further suggested the extension of the upper age limit of the Jurassic in Kutch. Tiwari [1948] assigned Bathonian-to-Argovian age to the Jurassic sequence of Habo hills on gastropod and lamellibranch fossil evidence.

Agrawal [1957] was the first to doubt the validity of the existing stratigraphic terminology. He proposed the name "Habo Series" after Habo hills to replace the name "Chari Series". From his paleontological work in Jhura Hills he concluded that all the three Macrocephalus beds are of Callovian age.

On the basis of lithological and paleontological characteristics Pascoe [1959] compiled a classification which is more systematic with respect to the usage of stratigraphic terms like series, stages, substages and zones.

Poddar [1959] considered Patcham Series to be Bathonian or slightly older, Chari Series to be Callovian-Oxfordian, Katrol Series to be Kimmeridgian-Tithonian, and Umia Series to be Neocomian-Aptian in age.

Mitra and Ghosh [1964] stressed individual ammonite fauna being over emphasized by the earlier stratigraphers and advocated the use of assemblage zones instead of ammonite index fossils in correlation and classification. Mitra and Ghosh [1964] were once again first to realise the significance of environment and facies changes in the shallow-marine shelf deposits of Kutch.

According to Rao [1964] the faunal evidences in Kutch suggest a Bathonian or Lowest Callovian to post-Aptian age of deposition.

Krishnan [1968] in his text book adopted the classification of Rajnath [1932, 1942] with modifications of age according to Arkell [1956]. He followed the original four-fold classification with little modification of Bhuj series as "Bhuj Stage" within his Umia Series.

As suggested by Ghosh [1969a] the mega fossil assemblage of Kutch shows more affinity with the East and South Africa assemblage than those of Himalayas or European Jurassic and ranges in age from Middle Bathonian to Argovian [Ghosh, 1969b].

A concise version of all the above work and their European equivalents are summarised in Table : 3 following Bhalla and Abbas [1980].

TABLE : 3

MESOZOIC SUCCESSION IN KUTCH

Series	Thickness [in mts]	European Stratigraphic Equivalents
Bhuj	450	Post-Aptian
Umia	900	Upper Tithonian to Aptian
Katrol	300	Upper Oxfordian to Middle Tithonian
Chari	366	Lower Callovian to Lower-Upper Oxfordian[Part]
Patcham	300	Upper Bathonian to Lower Callovian [Part]

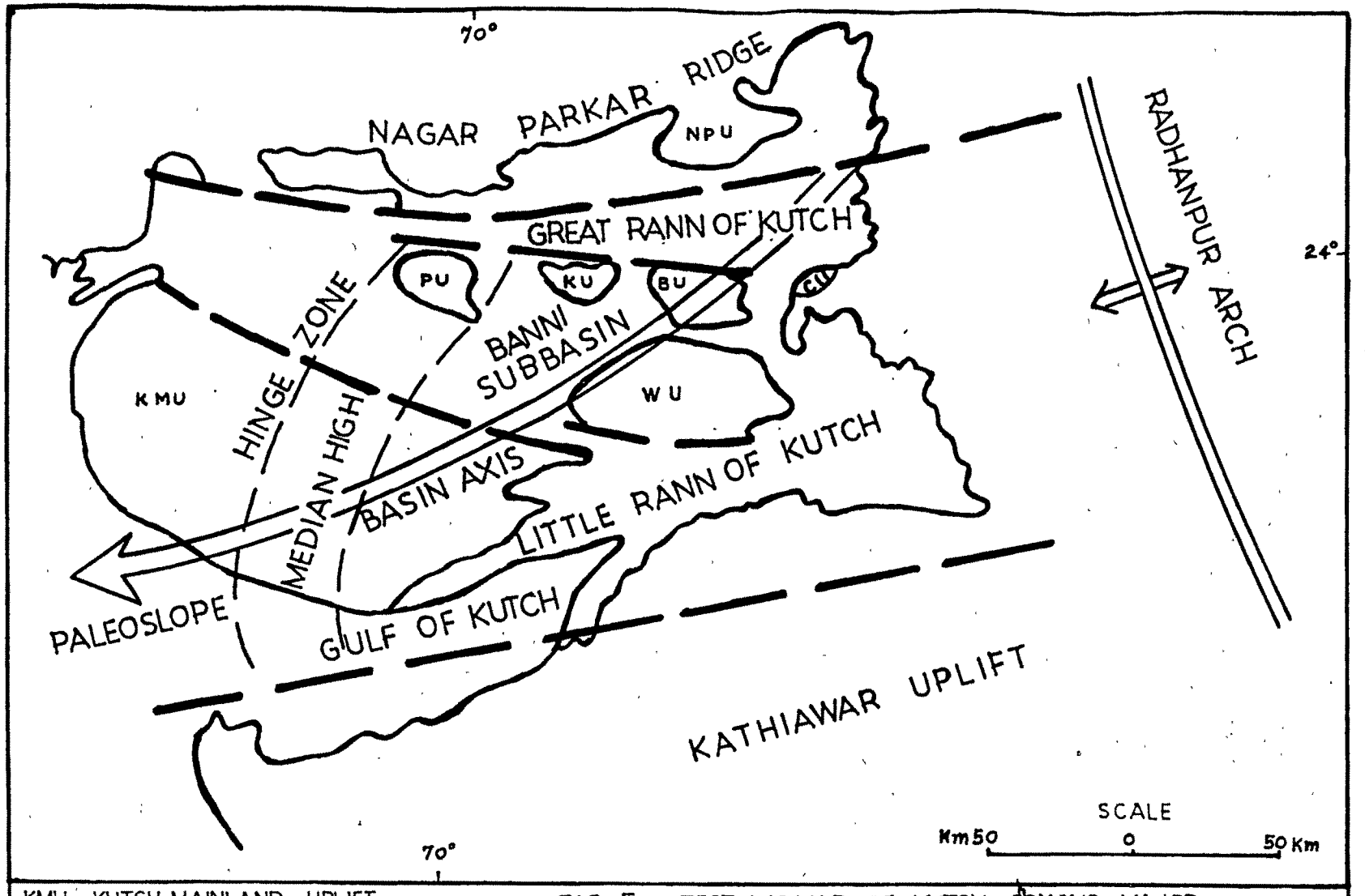
Archaean Granites and Gneisses

Recently, Biswas and Deshpande [1970, 1982] published comprehensive and detailed geological and tectonic map of the entire region of Kutch, which are reproducd in Figs. 3, 4 and 5.

Through a series of important publications, Biswas [1971, 1977] proposed for the first time a rock stratigraphic classification following recommendations of the International Code of Stratigraphic Nomenclature [Hedberg, 1972]. The work contain description of units, proposed stratigraphic sections and a geological map. As further claimed by Biswas [1977], the variations in lithofacies from one part of the basin to the other make it difficult to trace a set of rock units, recognised in one area, strikewise to the other areas.

Shringarpure [1985] for the first time investigated the rocks of the Eastern Kutch [Wagad Block] from ichnological point of view, and interpreted

these structures in terms of their ethology, paleoecology, animal sediment relationship, event stratigraphy and depositional environments. He has for the first time recorded in detail more than 45 ichnogenera and 73 ichnospecies.



KMU — KUTCH MAINLAND UPLIFT
WU — WGAD UPLIFT
PU — PACHHAM UPLIFT
KU — KHADIR UPLIFT
BU — BELA UPLIFT
CU — CHORAR UPLIFT
NPU — NAGAR PARKAR UPLIFT

FIG. 5 TECTONIC MAP OF KUTCH SOWING MAJOR TECTONIC ELEMENTS

(AFTER BISWAS, 1982)