CHAPTER 2

GEOLOGY AND STRUCTURE

Regional Geology

The geology of Kachchh Peninsula is very intriguing as it comprises rocks ranging in age from Jurassic to Recent and the basement rocks are not exposed (Fig.2.1). However the basement rocks occur to the north of Kachchh in Nagar Parkar area which lies in Pakistan (Biswas, 2005). The Mesozoic rocks of Kachchh have attracted the attention of geologists from world over mainly because of exceptionally rich fossil records of Jurassic Period. The Mesozoic rocks range in age from Middle Jurassic to Late Cretaceous (GSI, 2001) and are bordered by the Deccan Traps to the south and by saline marsh of the Rann of Kachchh to the north. Based on the fossil assemblage and petrographic characters, these rocks have been identified as representing a near-shore, shallow marine deposits fluctuating from neritic, lagoonal to littoral environments (Biswas, 1971; GSI, 2001). The Tertiary rocks of the Kachchh basin are known for their economic importance. They have yielded good quality limestone, clay, lignite and bauxite deposits. Rann of Kachchh is also getting importance due to its salt and brine producing capabilities.

Waagen et al. (1875) subdivided the Mesozoic rocks of Kachchh into Patcham, Charee, Katrol and Oomia Groups and correlated them with the European equivalents. However, a much more comprehensive account of the Mesozoic stratigraphy of Kachchh was proposed by Rajnath (1932) and Krishnan (1982). Krishnan (1982) classified the Mesozoic succession of Kachchh as presented in Table 2.1.

Table-2.1: Jurassic Succession of Kachchh (after Krishnan, 1982)

Unit	Age	Sub-division	Lithology
UMIA (1000 m)	Post-Aptian	Bhuj beds (Umia Plant beds)	Sandstone and shale
	Aptian	Ukra beds	Marine calcareous shale
	Upper Neocomial	Umia beds	Barren sandstone and shale
	Valanginian	Trigonia beds	Barren sandstone
	Upper Tithonian	Umia ammonite beds	Shale and sandstone
KATROL (300 m)	Middle Tithonian	Upper Katrol Shales	Shale
	Middle Tithonian	Gajansar beds	Shale
	Lower Tithonian	Upper Katrol (Barren)	Sandstone
	Middle Kimmeridgian	Middle Katrol	Red sandstone
	Upper Oxfordian	Lower Katrol	Sandstone, shale, marl
CHARI (360 m)	Oxfordian	Dhosa Oolite	Green and brown oolitic limestone
	U. Callovian	Athleta beds	Marl and gypseous shale
	Middle Callovian	Anceps beds	Limestone and marl
	Middle Callovian	Rehmani beds	Yellow limestone
PATCHAM (300 m)	Lower Callovian	Macrocephalus beds	Shales with calcareous bands and golden oolites
	Lower Callovian	Coral bed	Shale and limestone
	Lower Callovian to Bathonian	Patcham shell limestone Patcham basal beds (Kuar Bet beds)	Limestone, shale and marl

Biswas (1971) while revising the stratigraphy of Kachchh proposed new nomenclature and classified the Mesozoic rocks of Kachchh into Jhurio, Jumara, Jhuran and Bhuj Formations corresponding to Patcham, Chari, Katrol and Umia Groups / Series of Waagen (1872, 1875), Rajnath (1932) and Krishnan (1982). The revised Mesozoic stratigraphy of Kachchh as given by Biswas (1971) is presented in Table-2.2.

Table-2.2: Mesozoic Stratigraphy of Kachchh (after Biswas, 1971)

Age	Litho-Unit	Lithology	Environment
I. Kachchh Mainland			
Cretaceous (Neocomian to Santonian)	Bhuj Formation (400 – 900 m +)	**Upper Part:** Coarse grained, felspathic sandstone **Lower part**: Brown and reddish felspathic sandstone, ironstone and kaolinitic shale	Fluviatile to deltaic
Argovian to Neocomian	Jhuran Formation (375 – 850 m)	**Upper Member**: Pink and yellow sandstone with minor shale **Middle Member**: Grey shale with thin sandstone **Lower Member:** Shale and sandstone with calcareous bands	Infra-littoral
Callovian to Oxfordian	Jumara Formation (300 m)	Grey gypseous shale with thin oolitic marl bands (Dhosa Oolite bands)	Sub-littoral
Upper Bathonian to Callovian	Jhurio Formation (325 m +)	**Upper part:** Bedded white limestone with Golden Oolite in the lower part. **Middle part**: Golden Oolite limestone with shale **Lower part**: Thinly bedded limestone, shale and Golden Oolite limestone	Sub-littoral
II. Pachchham Island:			
Callovian	Goradongar Formation (150 m +)	**Upper part:** Sandstone with minor shale **Lower part**: Sandstone, conglomerate, shale	Sub-littoral
Bathonian	Kaladongar Formation	**Upper Part:** Yellow-massive sandstone with calcareous beds **Lower part:** Sandstone, shale and conglomerate	Littoral
III. Eastern Kachchh:			
Argovian to Albian	Wagad Sandstone	Brown, current bedded felspathic sandstone with ferruginous bands and shale	Sub-littoral
Bathonian to Oxfordian	Khadir Formation	Shale and sandstone with wedges of granite cobble-conglomerate	Littoral to infra-littoral

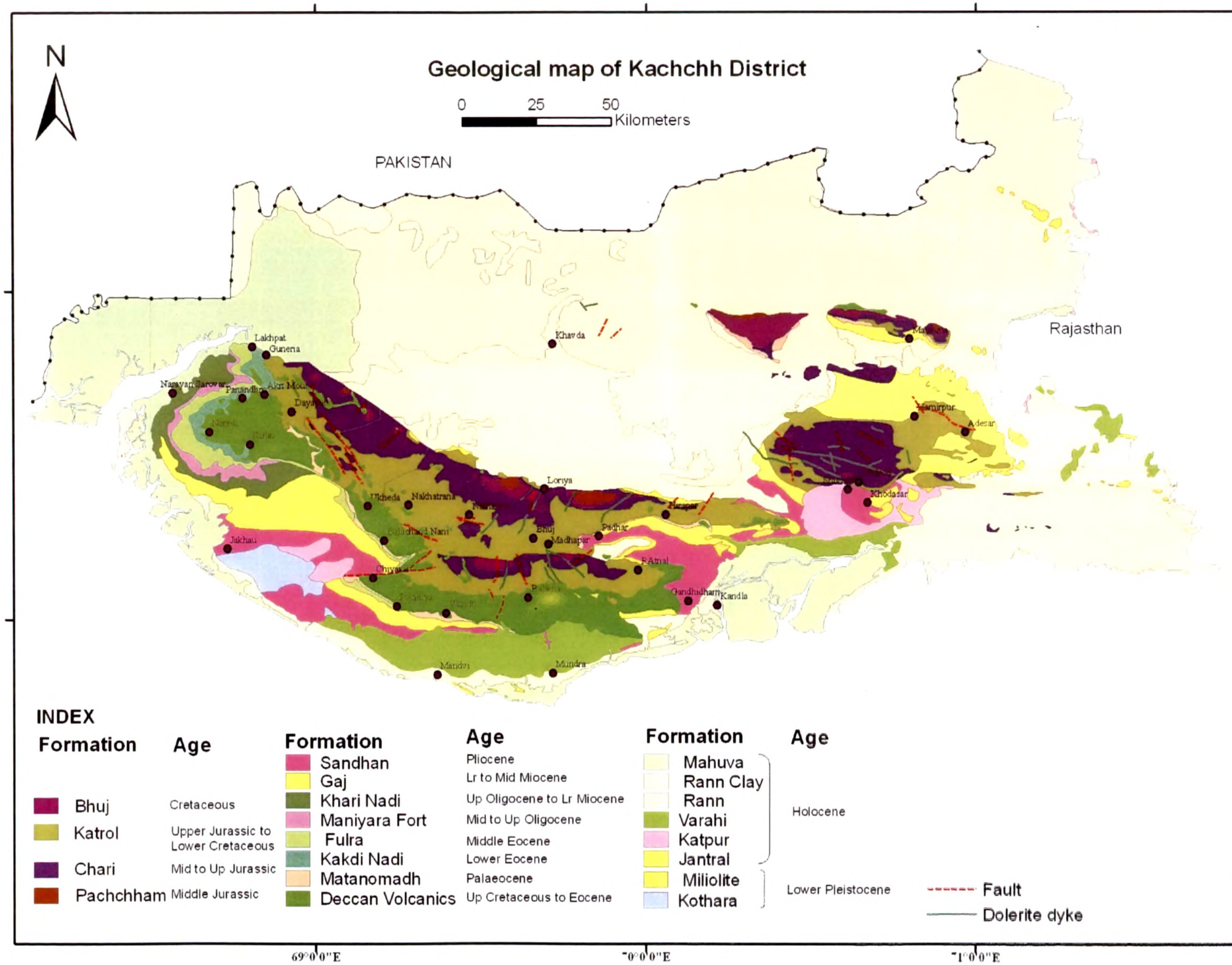

Fig. 2.1: Geological map of Kachchh (modified after GSI, 2001).

Later, Ghevariya (1987), Ghevariya and Srikarni (1991) and Ghevariya et al. (1984), provided details on these rocks retaining nomenclature of Waagen (1872), Rajnath (1932) and Krishnan (1982). The description of each of the four different formations representing the Mesozoic rocks of Kachchh along with their broad equivalents based on the classification of Biswas (1971) is given in the following pages:

Pachchham Formation

Pachchham (also spelt as Patcham) Formation is named after the Pachchham Island in the Rann of Kachchh. This is roughly equivalent to the Jhurio Formation of Biswas (1971). It is about 400 m in thickness and is exposed in parts of Pachchham (Kuar Bet, Kaladongar and Goradongar), Khadir, Bela and Chorar Islands. Pachchham Formation comprises intercalated sequence of siltstone, shale, marlite, claystone, coralline limestone, calcareous sandstone and grey to pink limestone. Small outcrops of these rocks are also seen at Jara, Kira, Jumara and Habo domes in the northern edge of Mainland Kachchh and south of Kachchh Mainland Fault. It extends from Lakhpat in the west to the north of Bhachau in the southeast. The formation is divisible into three litho-stratigraphic units (Krishnan, 1982). The basal unit, comprising calcareous sandstone, siltstone, and coralline limestone, is exposed in Kuar bet and Chhapri bet areas. These rocks have yielded rich assemblage of bivalves, brachiopods, cephalopods, corals (mainly solitary and sedentary forms) and dinosaurian bone fossils (Ghevariya, 1987; Jaitly, 1986). The basal unit is overlain by a sequence of shale with intercalations of limestone, thickly-bedded calcareous sandstone and conglomerate. These rocks also contain bivalves and a rich assemblage of corals and brachiopods (GSI, 2001). The uppermost unit comprises shale and limestone. Siltstone is exposed in southern part of Kaladongar and northern part of Goradongar. These rocks contain corals, cephalopods and bivalves (GSI, 2001).

Chari Formation

Chari, spelt earlier as Charee, derives its name from village Chari and unconformably overlies the rocks of the Pachchham Formation. This formation is roughly equivalent to the Jumara Formation of Biswas (1971). Rocks of the Chari Formation are exposed in the southern parts of Kaladongar and Goradongar ranges in Pachchham Island, southern part of Khadir in the Rann of Kachchh and in the northern part of Wagad highland. The rocks of the Chari Formation are exposed as inliers and lenses along the axis of East-West trending domal anticlinal ridges (south of Kachchh Mainland Fault) at Jara, Jumara, Jhura, Habo and other domes (GSI, 2001, Biswas, 1974). The other lensoid outcrops occur in Charwar and in other ridges located immediately south of the Katrol Hill Fault. KHF brings the rocks of the Chari Formation in juxtaposition with the rocks of the Bhuj Formation, near Sukhpar and Madhapar. It comprises about 350 m thick sequence of fossiliferous shale, golden oolite, fossiliferous limestone and calcareous sandstone containing ferruginous and calcareous nodules with ammonite fossils (Waagen, 1875). The Chari Formation is subdivided into four units based on lithology. The basal unit comprises a sequence of shale, siltstone and thinly-bedded sandstone alternating with golden oolite bands around Jara, Jhura, Jumara, Khirsara and Habo domes (Krishnan, 1982). These rocks contain bivalves, brachiopods, cephalopods, gastropods, corals and plant fossils (GSI, 2001; Jaitly, 1986). This unit is partly developed in Pachchham Island on the southern slopes of Kaladongar and Goradongar ranges and is about 25 m thick. The overlying second unit, about 100 m thick, dominantly comprises thickly-bedded, argillaceous sandstone with ocherous nodules bearing ammonites in lower section and forming minor cuesta with steeper slopes in northwestern part of Lakhpat, Jumara and Nara areas (GSI, 2001). The third unit, which is about 80 m thick, forms depressions and low-lying areas and comprises shales with calcareous nodules encasing fossils within gypseous layers. It forms relatively low ground with scattered low mounds. This unit laterally passes into the rocks of arenaceous character in central Kachchh. The youngest unit has variable thickness. Thickest exposed section (about 40 m) is seen around Sukhpar. It comprises alternate sequence of olive green oolites, gypseous shale, siltstone and greenish sandstone.

Katrol Formation

The rocks of the Chari Formation are unconformably overlain by about 400 m thick intercalated sequence of gypseous shale with cyclically repeated sequence of calcareous sandstone and shale, constituting the Katrol Formation, which roughly corresponds to the Jhuran Formation of Biswas (1971). Rocks of this formation are exposed in the form of two sub-parallel continuous exposures in the Mainland Kachchh. The first one forms a vast northwest-southeast trending outcrop from Guneri to Jhura which extends eastward up to Khirsara. The other one extends from Deshalpar to Malingara and south of Katrol Hill Fault in central part of Kachchh Mainland. These rocks are also exposed in the Wagad Mainland and in the Island belt. The Katrol Formation is divisible into four lithostratigraphic units (Krishnan, 1982). The basal unit comprises intercalated sequence of grey, gypseous shale and siltstone with ocherous nodules. The second unit is dominantly calcareous sandstone with intercalations of shale in the western Kachchh, which passes into dominantly argillaceous facies in east central Kachchh. These units contain rich assemblage of pelecypods, gastropods, ammonites and fossil wood (Ghevariya, 1987; Pandey and Westermann, 1988). The third unit comprises a dominantly gypseous shale horizon with minor silty and sandy intercalations and ocherous bands. The black shale horizon of this unit contains Upper Gondwana plant fossils, fossil fruits, cones and fronds along with shells of Trigonia and other bivalves (GSI, 2001). The uppermost unit forms conspicuous ridges at the periphery of domes at Guneri, Jara, Jumara, Jhura and Habo and in the southern vicinity of Katrol Hill Fault. It comprises an 80 m thick sequence of hard, compact, calcareous, quartzitic-sandstone and conglomerate intercalated with lenses of shale and burrowed siltstone. The intercalated sequence, at times, becomes very thick and forms transitional zone between the rocks of the Katrol and the overlying Bhuj Formation. This transition zone has been included as a part of Katrol Formation. The calcareous sandstone contains dinosaurian bone fossils, footprints and foot tracks of dinosaurs near Tharauda (Ghevariya, 1987).

Bhuj Formation

The rocks of the Bhuj Formation include the Umia Group of Waagen (1872) and are named after Bhuj Township. It unconformably overlies the rocks of the Katrol Formation in the western Mainland Kachchh and forms a thick sequence of friable, felspathic and ferruginous sandstone showing graded-bedding, ironstone, clays and trap-pebble conglomerates with many fossiliferous horizons (Ghevariya, 1985; Singh et al., 2008). These rocks are exposed in the form of continuous outcrop in the Mainland Kachchh with a maximum width between Lakhmipur and Roha. This outcrop extends from Guneri in the northwest to Deshalpar in the southeast, where it takes a turn and extends further up to Khirsara (GSI, 2001). A continuous and broadly elliptical exposure, bordering the Katrol Formation, extends from Andhon in the west to Fatehgarh and Deshalpar in the north. Besides this, small isolated outcrops occur in Pachchham Island, Goradongar and Kaladongar, Bela and Mardek Islands as inliers within younger volcanics and Tertiary rocks (GSI, 2001). In the east, a thick intervening transitional zone has developed in central Kachchh. The rocks of the Bhuj Formation contain a rich assemblage of Upper Gondwana plant fossils and many intervening fossiliferous marine bands, in the western and central parts (Rajnath, 1932). The Bhuj Formation is sub-divided into three members (i) lower-Guneri Member, (ii) middle- Ukra Member (limited to Guneri-Ukra area) and (iii) Upper Member (Krishnan, 1982). The Guneri Member comprises cyclically repeated intercalated sequence of burrowed ferruginous gritty sandstone, grey and black, carbonaceous shale and siltstone with coal partings. The ironstones and shales show rhythmic alternations. The ferruginous sandstone and shale contain tracks and trails of various invertebrates. Dinosaurian footprints are recorded from ferruginous sandstone near Pakhera. The Ukra Member occurs as a lensoid marine intervention between the Guneri Member and the Upper Member of the Bhuj Formation in the Ukra area and comprises a sequence of about 30 m thick hard, lateritic ferruginous sandstone, conglomerate, green glauconitic clay, shale, siltstone green friable sandstone and bands of fossiliferous limestone (GSI, 2001). The Upper Member comprises a sequence of coarse, gritty, variegated sandstone, siltstone, fossiliferous shale and clay with ferruginous and ocherous bands. Most part of Bhuj sandstone includes sandstone of the Upper Member overlain by intercalations of trap-pebble conglomerate and sandstone forming part of volcano-sedimentary sequence. The rocks of Bhuj Formation are overlain by Deccan lava flows.

The Mesozoic sediments of north-western Kachchh show interstratified volcano-sedimentary sequence. Several intertrappean beds are recorded interstratified with the Deccan lava flows in Anjar area (Ghevariya, 1985; Ghevariya and Srikarni, 1987, 1991). Some of these intertrappeans contain skeletal remains of dinosaurian fossils (Khosla and Sahni, 2003).

Deccan Traps

The Deccan Traps are exposed mainly in the southern part of Kachchh along a 10-20 km wide belt trending NW-SE. They overlie the Bhuj Formation. Normally the flows are plateau-type tholeiitic basalts in the west at Dayapar and Matanomadh and are alkaline at Baladia, Anjar and Bhachau. However, occurrence of highly alkaline intrusive rocks like nephelinite, essexite, olivine analcite basalt within the Mesozoic is also reported from a few places (Melluso et al., 2006; Mukherjee et al., 1988). Nine flows have been reported from southern part, where the total thickness of the trap section amounts to 140 -150 m (GSI, 2001). At most of the places, the lava is of pahoehoe type. Numerous alkali-type and tholeiitic-type intrusives occur in the Mesozoic sediments and Deccan Trap flows. Gabbroic rocks and pyroxenite constitute the main alkali body at Nirwandh and Kuran with metallic sulphide disseminations. Dykes and apophyses of hornblendite, ankaramite, granophyre, trachyte, andesite and syenite are found at the outer margin of the main body. In Kachchh Mainland, mantle-derived peridotite nodules are also reported from the alkaline plugs at Bhuj, Vithoniya and Dinodhar (Mukherjee et al., 1988). These xenolithic peridotite nodules occur as oblate, ellipsoidal fragments with long axis up to 2.5 cm. These xenoliths are distinct with coarser grain size and characterized by deep bottle-green colour in comparison to host basalt (Guha, 1998). Crustal xenoliths are also present. Compositionally all plugs are similar, but on the basis of presence or absence of mantle xenoliths, two groups can be distinguished. The absence of mantle xenoliths in the plugs may be indicative of slow rate of emplacement. Tholeiitic-type of plugs and dykes are confined to the Kachchh Mainland and they comprise olivine basalt and dolerite (Mukherjee et al., 1988; Paul et al., 2007).

Tertiary Rocks

Almost all the Mesozoic outcrops are accompanied by Tertiary patches on their flanks in Kachchh region. Tertiary rocks of Kachchh are well known for their rich marine fossil assemblage. After the eruption of lava flows of the Deccan volcanic activity there was a period marked by a phase of extensive lateratization under tropical conditions. Subsequently, the Tertiary sediments were deposited over the Mesozoic sedimentary rocks and Deccan Traps along the coastal strip of the Kachchh Mainland (GSI, 2001). The first detailed study of this region was made by Wynne (1869, 1872). Wynne (1872) classified the Tertiary rocks of Kachchh mostly on the basis of abundant nummulitic fossils and lithology. The Tertiary formations of Kachchh consist of three distinct facies; the lower one is volcanic and is represented by the lavas of the Deccan Traps. The middle and main part is typical marine transgressional facies and represents stratigraphic unit equivalent to the Laki, Kirthar, Nari and Gaj Series of Sind-Baluchistan (Krishnan, 1982). The upper part is fluviatile and represents the stratigraphic unit equivalent to Manchhar Series of Sind-Baluchistan (Krishnan, 1982). The Tertiary rocks are exposed all along the western, southern and southeastern parts of Kachchh, extending from Lakhpat in the west to as far as Vondh in the east. Some isolated outcrops of these rocks occur in the northern and eastern parts of Kachchh Peninsula. The Tertiary rocks overlie the denuded laterites and traps, and at places these directly rest on the Mesozoic formations (Chatterjee and Mathur, 1966). The succession of Tertiary rocks as exposed in Kachchh is given in Table-2.3.

Table-2.3: Stratigraphic succession of Tertiary rocks of Kachchh (after GSI, 2001)

Age	Formation	Lithology
Pliocene	Sandhan Formation	Friable sandstone, siltstone, calcareous clay and conglomerate
Lower to Middle Miocene	Gaj Formation	Olive green shale with gypsum and marlite
Oligocene to Lower Miocene	Kharinadi Formation	Mottled siltstone and variegated clay with marlite
Oligocene	Maniyara Fort Formation	Sandy limestone, glauconitic clay, siltstone and coralline limestone
Middle to Upper Eocene	Fulra Formation	Cream coloured foraminiferal limestone
Lower Eocene	Kakdinadi Formation	Greyish to variegated clay, carbonaceous and lignite bearing shale with fossiliferous marlite and limestone
Palaeocene	Matanomadh Formation	Lithomarge clay, laterite and lateritic conglomerate
Cretaceous to Eocene		Basalt

The oldest Tertiary rocks directly overlying the Deccan Traps belong to the Matanomadh Formation of Palaeocene age. This formation comprises laterite, lateritic conglomerate and lithomargic- and bentonitic clay, followed by gypseous and pyritous sandstone. The overlying Kakdinadi Formation (Lower Eocene) consists of greyish to variegated clay and shale with limestone bands rich in Nummulites (Biswas, 1992). The Fulra Formation (Middle to Upper Eocene) which overlies the Kakdinadi Formation comprises cream coloured limestone with abundant foraminifers. The Oligocene is represented by the overlying Maniyara Fort Formation, which consists of sandy limestone, coralline limestone, glauconitic clay, marl and siltstone (Ghevariya et al., 1991). The Kharinadi Formation (Oligocene to Lower Miocene) overlies the Maniyara Fort Formation and consists of mottled siltstone, variegated clay and fossiliferous marlite. The overlying Gaj Formation (Lower to Middle Miocene) comprises green siltstone and fossiliferous and gypseous marlites (Biswas and Raju, 1973). The Gaj Formation is overlain by the Sandhan Formation (Pliocene) which consists of micaceous sandstone, laminated siltstone, calcareous clay, marlite and conglomerate. Avian egg-shells have been reported from this formation (Jain, 1990).

STRUCTURE AND TECTONICS

Tectonics of the Kachchh Peninsula owes back to the rifting of the Aravalli -Delhi fold belt of the Gondwanaland in the Late Triassic – Early Jurassic Period (Biswas, 1987). Due to reactivation of the pre-existing faults along the NE-SW trend of Delhi Fold Belt that swings to EW in Kachchh region, several major faults resulted in the Kachchh Peninsula forming the Kachchh rift. The rift is bounded by Nagar Parkar Fault (NPF) to the north and the North Kathiawar Fault (NKF) to the south (Fig.2.2, 2.3). The graben between them is asymmetric, with a tilt to the south along North Kathiawar Fault accommodating thicker sediments towards the Kathiawar block. Several intrabasinal, sub-parallel strike faults are responsible for the tilted block uplifts, forming a series of half grabens (Biswas, 2005). The uplifted area outcrops in the form of hill ranges and the half grabens form extensive plains covered by Quaternary sediments (Fig.2.4). The E-W faults, related uplifts and drape folds form the structural elements of the Kachchh Peninsula.

The uplifts are bounded by five parallel faults from north to south (Fig.2.5, 2.6 & 2.7). These faults are Nagar Parkar Fault (NPF), Island Belt Fault (IBF), Kachchh Mainland Fault (KMF), Katrol Hill Fault (KHF) and North Kathiawar Faults (NKF). Block tilting along these faults during rift phase extension gave rise to four sub-parallel linear ridges; Nagar Parkar Uplift (NPU), Island Belt Uplift (IBU), Wagad Uplift (WU), and Kachchh Mainland Uplift (KMU). The IBU is broken into four individual uplifts viz. Pachchham (PU), Khadir (KU), Bela (BU) and Chorar (CU), probably by unexposed transverse wrench faults as evidenced by relative displacements and orientations (Fig. 2.2 and 2.3). Standing amidst the plains, these uplifts appear as a chain of *islands* and hence are collectively called Island Belt (Biswas, 1987).

The positive Bouguer anomalies along the lineaments formed by these ridges indicate that these are basement highs (Chandrasekhar, 2005). The E-W trend of the positive gravity lineaments changes to NE–SW across the Cambay basin following the trend of the Delhi fold belt (Biswas, 1987). This confirms the control of the Precambrian trends in rifting (Fig.2.4).

Maximum sediment thickness recorded close to the KMF is 2.2 km, thinning gradually towards Pachchham Uplift. About 350 m Tertiary sediments lie unconformably over the Mesozoic rocks below the Quaternary cover over Banni region (Biswas, 1992). This shows the post-Tertiary reactivation of the fault. Further, steeply upturned Tertiary beds juxtaposed with steeply folded Mesozoic beds along KMF indicating post-Tertiary movements (Biswas, 1987; Singh, 2008). The E-W striking master faults are the primary faults, which controlled the structural evolution of Kachchh basin. The fault pattern shows common characteristic of strike-slip faults (Biswas, 2002). Uplifts themselves are extensively affected by secondary faults of different generations, both normal and strike-slip and a few reverse in nature. These faults appear to be cogenetic with the primary faults. There are different generations of faults developed during episodic movements. Some of the NE-SW trending transverse faults are extensive wrench faults and dislocate the primary faults (Biswas, 1987; Maurya, et al., 2003). Kachchh Mainland Fault steps to the north as South Wagad Fault (Biswas, 1987). A transverse fault sympathetic to the Manfara Fault truncates the KMF in the east (Maurya, et al., 2003). These two faults overlap north of Dudhai-Bhachau segment (Fig.2.2). The relative position of Kachchh Mainland Uplift and

Wagad Uplift blocks suggests right lateral strike-slip. Thus, SWF is the eastward continuation of KMF after its left side stepping, with shift of uplift from south to the north. SWF is a fault zone consisting of two curved, semi-concentric marginal faults. The overlapping tips of both KMF and SWF dip steeply (80°–85°) towards each other. The KMF fades out and SWF continues eastward. It is likely that at depth KMF could be either antithetic or a down dip step over with relation to SWF (Biswas and Deshpande, 1970; Biswas, 1987).

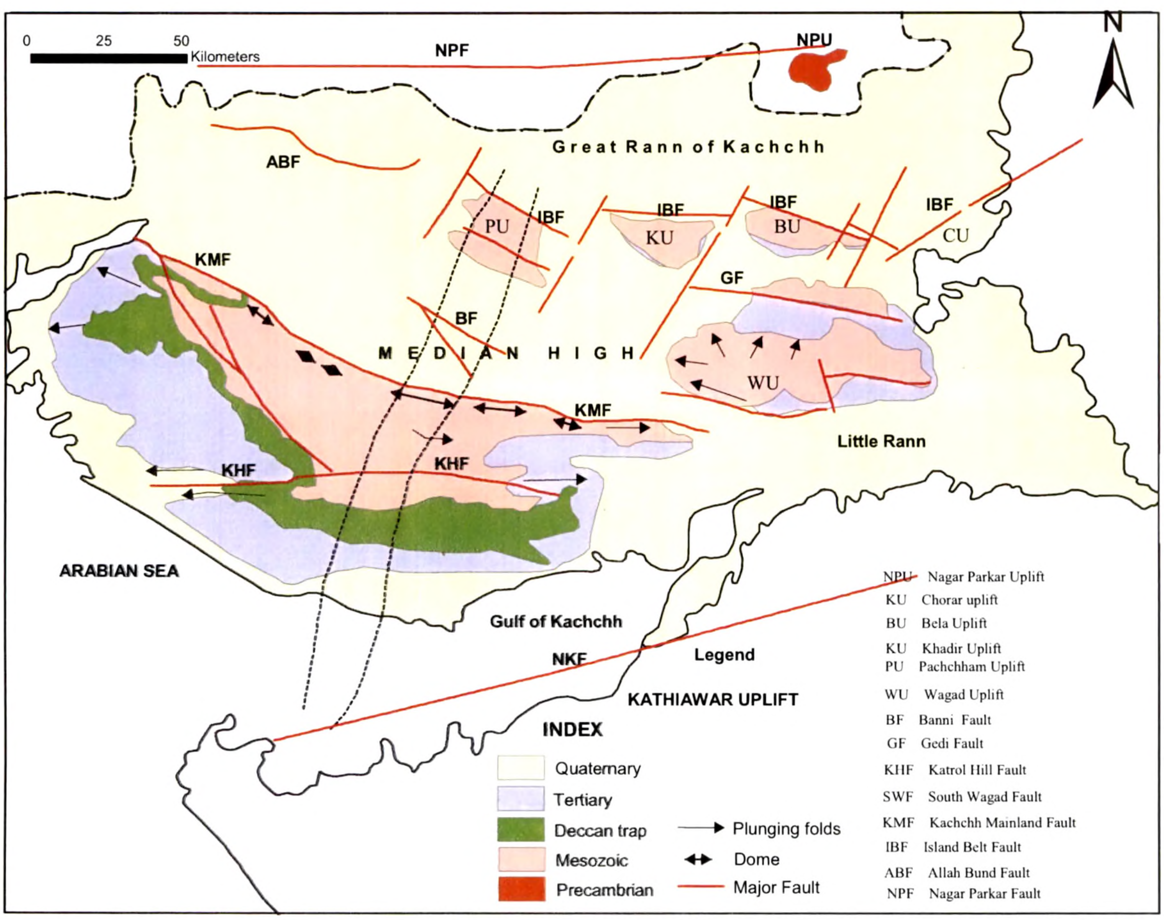

Fig. 2.2: Tectonic map of Kachchh region (modified after Biswas and Deshpande, 1970).

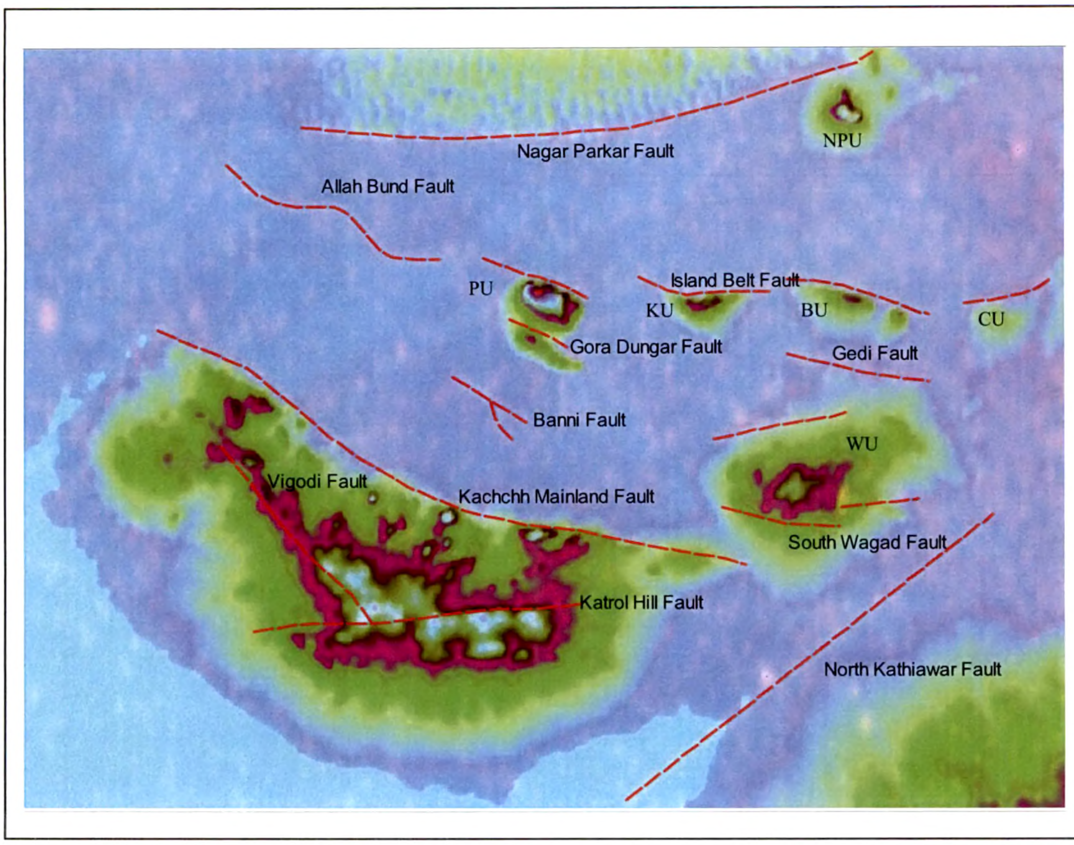

Fig. 2.3: Major Faults of the Kachchh draped over the DEM of the area.

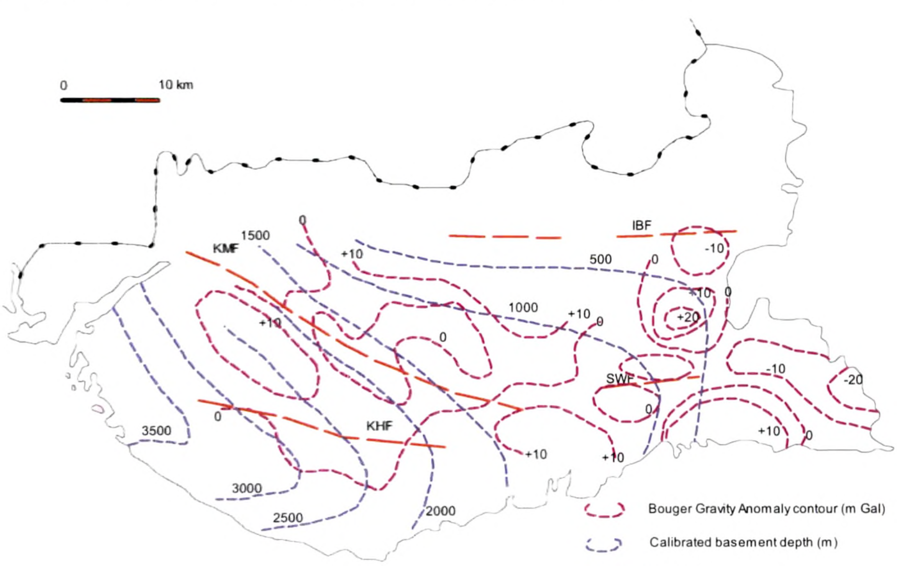

Fig. 2.4: Bouguer Anomaly map of Kachchh region (after GSI, 2001).

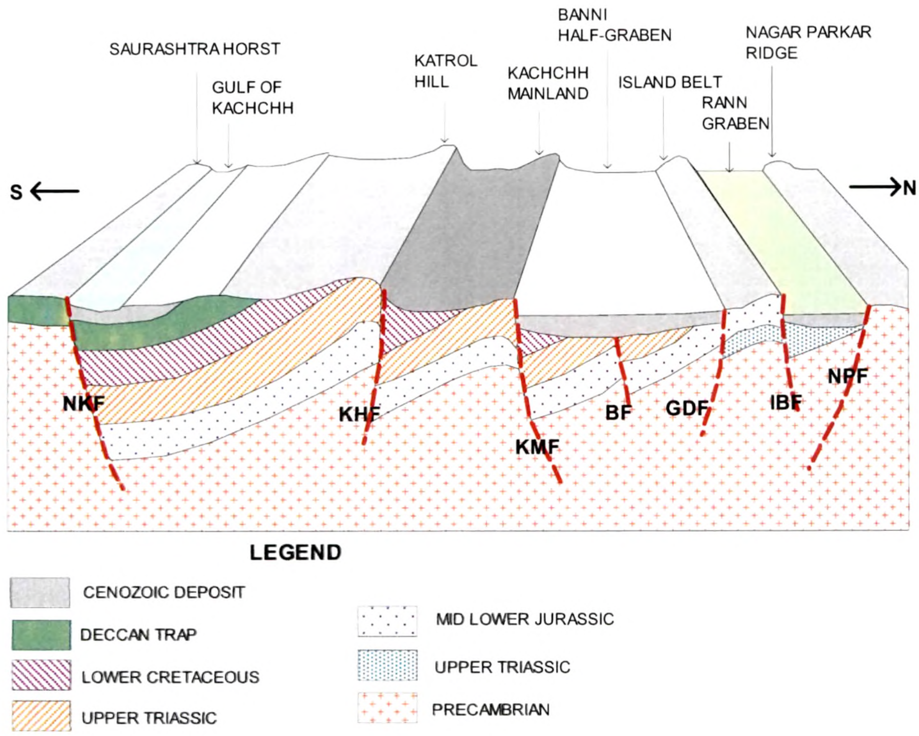

Fig.2.5: Geological Cross section across Kachchh basin along the median high (after Pande, 2007).

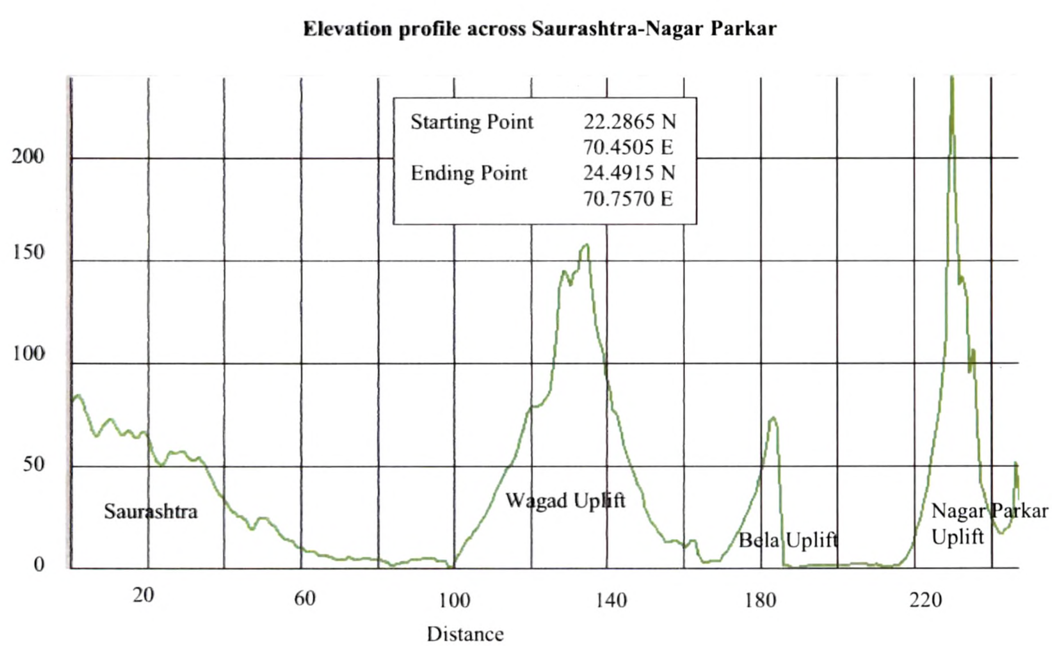

Fig.2.6: Elevation profile across Saurashtra-Nagar Parkar (generated from SRTM data).

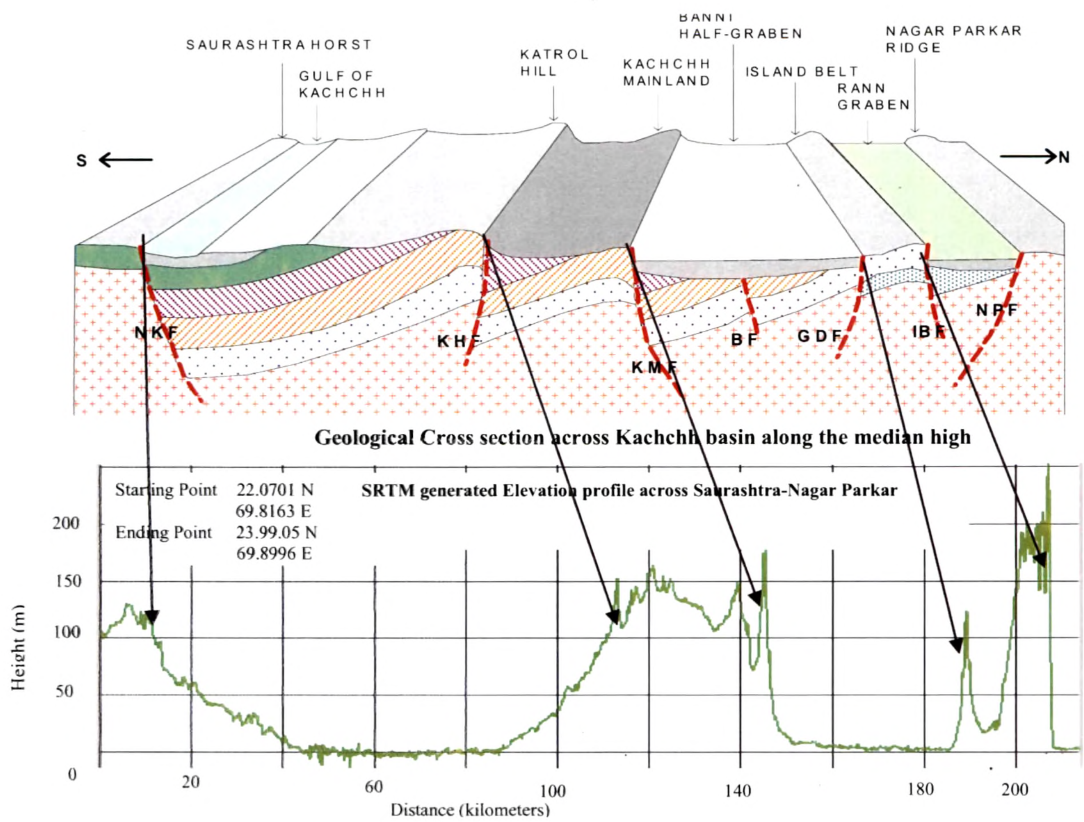

Fig.2.7: Correlation of major faults of Kachchh with the elevation profile of the area.

Igneous activity in the Kachchh region and its relationship with tectonics:

Igneous activities are always associated with deep rifts in any area. In Kachchh igneous intrusions are fairly common in all the uplift areas. All known forms of intrusive bodies are present and are mainly concentrated in the narrow deformation zones accompanying the master faults (Biswas, 1980, 1993). The maximum intensity of igneous activity is seen in the northwestern part of Kachchh Mainland, west of median high and in the northern part of Kaladongar Hill. A series of igneous plugs occur along a belt in the central region of Kachchh Mainland (Karmalkar et al., 2008). These plugs are the main feeders of Deccan Trap flows now exposed by erosion. These plugs consist of alkaline basalts with xenoliths of spinel lherzolite (Karmalkar, et al., 2003) and olivine (De, 1964) indicating that they are derived from upper sub-crustal lithospheric mantle. The intrusive bodies associated with marginal deformation zone in the western KMU are composed of ultramafic rocks (Ray, et al., 2006). The associations of different groups of basic and ultramafic rocks are suggestive of different phases of igneous activity. The various forms of intrusive bodies exposed at the surface are the manifestations of rift-related magmatism. These intrusives represent only a fraction of the large volume of melt that was generated during rifting (Biswas, 2005).

The orientation of the dykes and the faults recorded from the Kachchh may indicate the palaeostress conditions as the dykes show some relationship with rift and ruptures resulting into faults in the area.

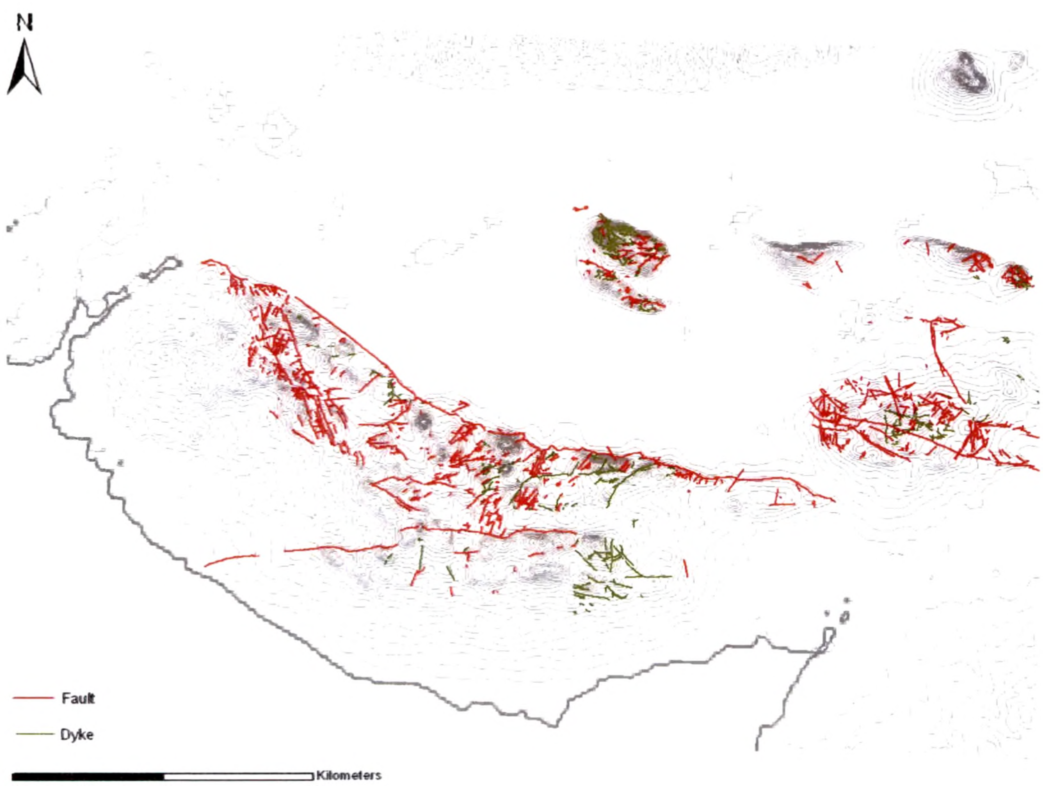

Fig.2.8: Spatial distribution of the dykes and faults in the Kachchh region.

Dykes of the Kachchh Peninsula

There are about 517 dykes recorded in the Kachchh Peninsula with cumulative length of about 783 km (Singh et al., 2010). They have intruded the Mesozoic rocks exposed in the various islands in the Rann as well as in the Kachchh Mainland areas

(Fig.2.8). The spatial orientation of these dykes has been shown and compared using rose diagram (Fig.2.9).

The dykes of the Kachchh Mainland are mineralogically similar to the tholeiitic basalts. Foid bearing doleritic dykes (theralite), fine grained mafic dykes and lamprophyre dykes, all of which fall in alkaline clan, are also reported from the Kaladongar area (Paul et al., 2007). Density of the dyke occurrence is more in the northern part of Kachchh Mainland while they are scarce in the southern part. A few sills are also reported from Kachchh Mainland and Pachchham Island. Major class of the dykes falls along NE-SW trend (25% of the dykes) while second largest group (19.5%) along E-W trend, followed by WNW-ESE trending pattern (17.5%).

The dykes at various places in the Kachchh Peninsula have been found in the vicinity of faults or along the faults, suggesting syntectonic nature of the intrusive rocks (Maurya et al., 2003). These activities took place after the deposition of Bhuj Formation (Late Cretaceous), but before the onset of Deccan Trap volcanic activity. This was followed by a major diastrophic cycle, which accompanied the main volcanic activity of Deccan trap, peaked around 65 Ma (Guha et al., 2005).

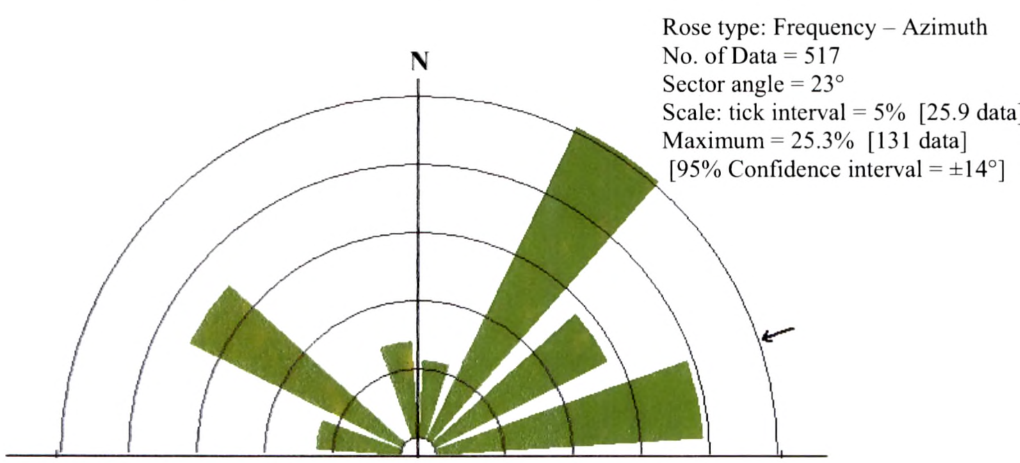

Fig.2.9: Rose diagram showing the orientation of the dykes in Kachchh.

Faults and folds showing change in the stress regime in the Kachchh Peninsula

Apart from the NPF, ABF, IBF, SWF, KMF and KHF, the major faults controlling the tectonic framework of Kachchh, there are several faults in the area recorded from the rocks of the age from Mesozoic to Holocene. During the extensional regime of stress condition in the Mesozoic Period normal faults were developed which have been recorded in abundance from the Mesozoic sequences of the area. All the major faults along with several sympathetic faults are of this nature. After the collision of the Indian plate with the Eurasian plate in the early Tertiary Period, the stress condition changed into compressional regime (Biswas, 1987).

Low-angle thrust faults are seen, abutting with asymmetric folds at one end. Examples of fault-bend folds are frequently seen in the interior parts of the highland (Karanth and Gadvi, 2007). Shearing is evident at the base of bedding parallel thrust sheets. Several structures developed on account of compressive stresses such as arching of beds of hanging wall and formation of contractional wedges is seen a few kilometres inside the margins of highlands (Karanth and Gadvi, 2007).

A number of transverse faults have been reported across the master faults which are very active and play an important role in the recent seismic activities in the Kachchh region. The total number of observed and inferred faults recorded from the Kachchh Peninsula is about 1100 with cumulative length of about 2400 km (Singh et al., 2010). The orientation of these faults has been plotted in the form of rose diagram (Fig.2.10).

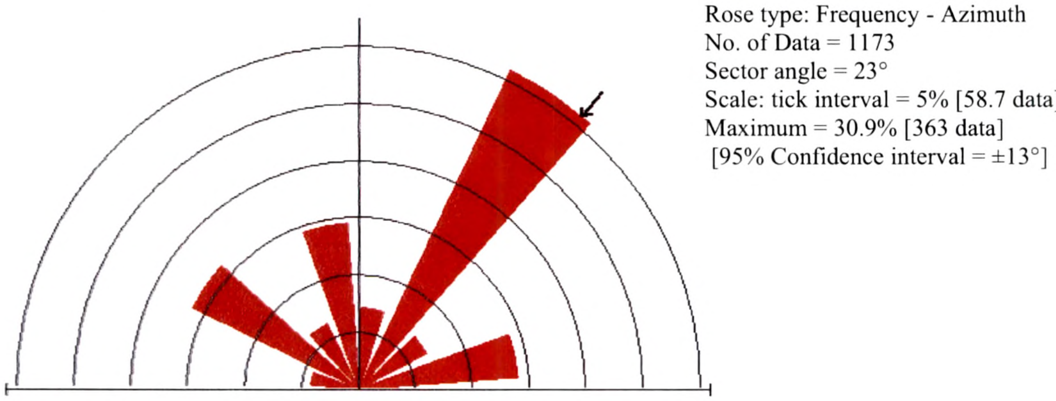

Fig.2.10: Rose diagram showing orientation of faults of Kachchh region.

The orientation of these transverse faults coincides with the trends of the dykes of the area. Major class of the faults (31%) shows NE-SW trend, while the second largest class (16.4%) fall in the WNW-ESE trend followed by N-S trending class (14.6%). Thus it is evident that the dyke emplacement in the area is influenced by the transverse fault system developed due to the stress release mechanism in the course of north ward movement of the sub-plate. The vicinity and coincidence of faults and dykes at several places suggest syntectonic origin of these dykes in the region.

Thickness of Quaternary deposits to the north of KMF

A gravity survey was conducted in the Rudramata-Loriya-Bherandiyara section to understand the subsurface geology of the area across the Kachchh Mainland Fault. The geophysical results along this traverse corroborate the existence of KMF; demarcated in the geological mapping between Nokhania and Loriya village where the evaluated throw is 310 m. High fluctuation in the gravity values with steep gradient suggest shallow subsurface structural features as shown in the inferred geological model (Fig.2.11).

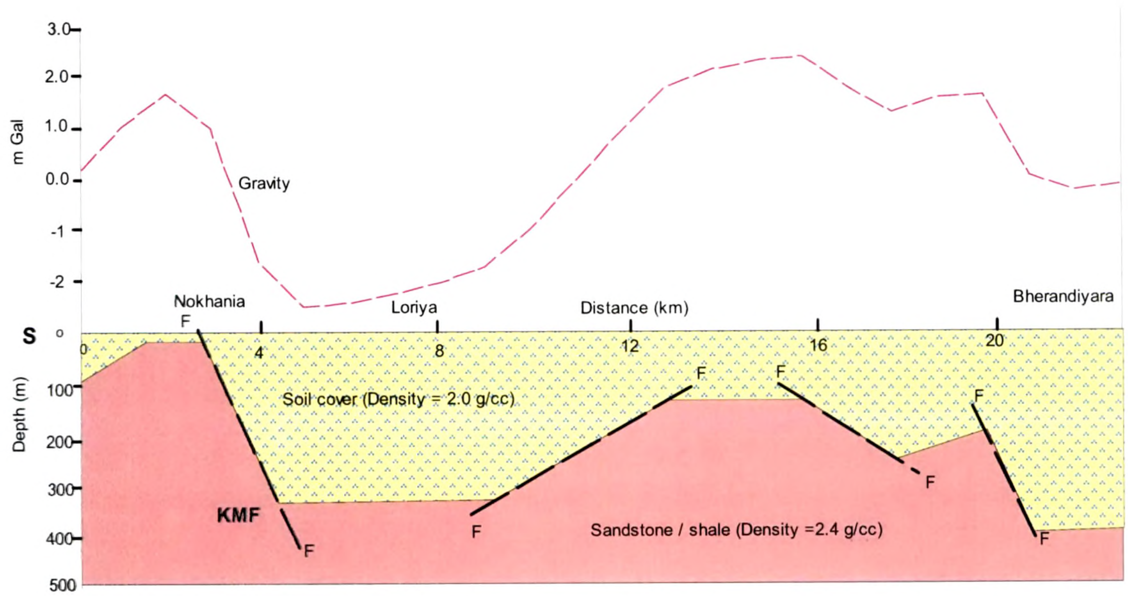

Fig.2.11: Gravity section across KMF (between Nokhania-Bherandiyara) and inferred geological model (after Singh and Lal, 2008).

The thickness of inferred soil cover is about 350 m in the north of KMF. Three more faults have been interpreted in the north of KMF making two grabens separated by a horst structure at shallow depth. The magnetic response along this section has brought out a broad magnetic high near Loriya. The source of this magnetic high may either be denser intrusive basic rock or the variation in concentration of magnetite content in the underlying layer of rocks.