CHAPTER 2

REGIONAL GEOLOGY

The Indian subcontinent is classified into three physiographic entities, that include (a) the Extra Peninsula (b) the Indo-Gangetic alluvium plains and (c) the Indian Peninsula. The present-day geomorphic characteristics of the peninsular India is a result of prolonged phases of tectonic uplifts, erosion and denudation (Roy and Purohit, 2018). The subcontinent is a dynamic crustal plate with heavier lower layer spreading in the ocean around and lighter upper layer moving north-eastward (Valdiya and Sanwal, 2017). The collision of the leading edge of the plate with Eurasian counterpart resulted in the development of fragmented crust with numerous faults and fractures within the Indian subcontinent. The older faults developed millions of years before along with the newer faults in the fragmented crust have reactivated at several places resulted in the uplift, sinking and development of landforms in the Indian subcontinent (Valdiya and Sanwal, 2017). The Western Continental Margin of India (WCMI), is a passive continental margin that evolved during the early stages of eastern Gondwana breakup (Corfield et al. 2010). The northern part of the WCMI is highly fractured with three intersecting rift system, the Kachchh rift, the Narmada rift and the Cambay rift. The Kachchh rift forms the oldest among the three major rift systems of the WCMI that have opened up in the Early Jurrassic period.

The Kachchh basin, because of the unique characteristics, forms one of most important paleo-rift basins among the other rift generated basins in the Indian subcontinent. The location of the basin to the trailing end of the Indian plate makes it more important and peculiar in the contest of tectonic and geodynamic studies. The basin is composed mainly of sedimentary suite of rocks which apron the Precambrian crystalline basement (Biswas, 2016b). The sedimentary sequence of the basin is unique in the country and one of few basins in the subcontinent where the Mesozoic section is well exposed. The thick sedimentary sequence holds stratigraphic record from Mid Jurassic to recent. This makes the basin important in stratigraphic point of view when compared to the other similar basins of the Indian subcontinent. The major rock unit in the basin, i.e., the Mesozoic suite of rocks, is exposed in all the major highland regions of the basin. Meanwhile, the Tertiary and Quaternary rocks are exposed in the structural lows and intermontane plains. Apart from the stratigraphic significance, the basin is also unique for the structural setup and tectonic evolution in the country.

STRUCTURAL SETUP

The structure of Kachchh Rift Basin is a unique geological layout of its own and similar structural setting cannot be found elsewhere in the country (Biswas, 1982, 1987). The geometry of the basin is analogous to an asymmetrical rift with a southward tilt (Biwas, 2005). The basin's structural configuration is dominated by highlands and plains, which are the structural uplifts and half grabens respectively. The rift basin is defined by multiple E-W striking faults that are bounded to the north and south by Nagar Parker Fault (NPF) and North Kathiawar Fault (NKF) (Fig. 2.1). The basin is bounded to the east by the NNW-SSE trending Radhanpur Arch, which also forms the western boundary of the Cambay graben. The E–W striking master faults are the primary structures, which controls the structural evolution of the basin (Biswas, 2005). The sub-parallels, vertical to quasi-vertical faults of the basin includes the Island Belt Fault (IBF), South Wagad Fault (SWF), Gedi Fault (GF), Katrol Hill Fault (KHF) and Kachchh Mainland Fault (KMF) which strike east-west in the eastern part of the basin but swings to WNW-ESE towards the west (Biswas, 1987, 1993, 1999, 2005; Maurya et al., 2017). The E-W trending structural highs are bounded on one side by faults and on the other side by peripheral plains or residual depression (for eg. vast plains of the Great and Little Rann of Kachchh) (Biswas, 1987). The basin is characterized by six major uplifts (Biswas, 1993; Maurya et al., 2017). The major uplifts include, Pachham, Khadir and Bela, Chorar islands, Wagad uplift and the Mainland uplift. Among these uplifts, the Mainland Kachchh is the largest uplift located at the central part of the basin. The Wagad uplift is the second largest uplift and is positioned between the chain of islands (Island-Belt) to the north and the Mainland on the south. Four individual uplifts make up the Island Belt uplift, which are Pachham, Khadir, Bela and Chorar from west to east respectively (Biswas, 1982, 1987). The echelon arrangement of the uplift is suggested by the gradual northward shift of the individual uplifts from west to east. The Great Rann of Kachchh is the most extensive plain that divides the Nagar-Parkar uplift and the uplifts of the Island-belt (Biswas, 1982).

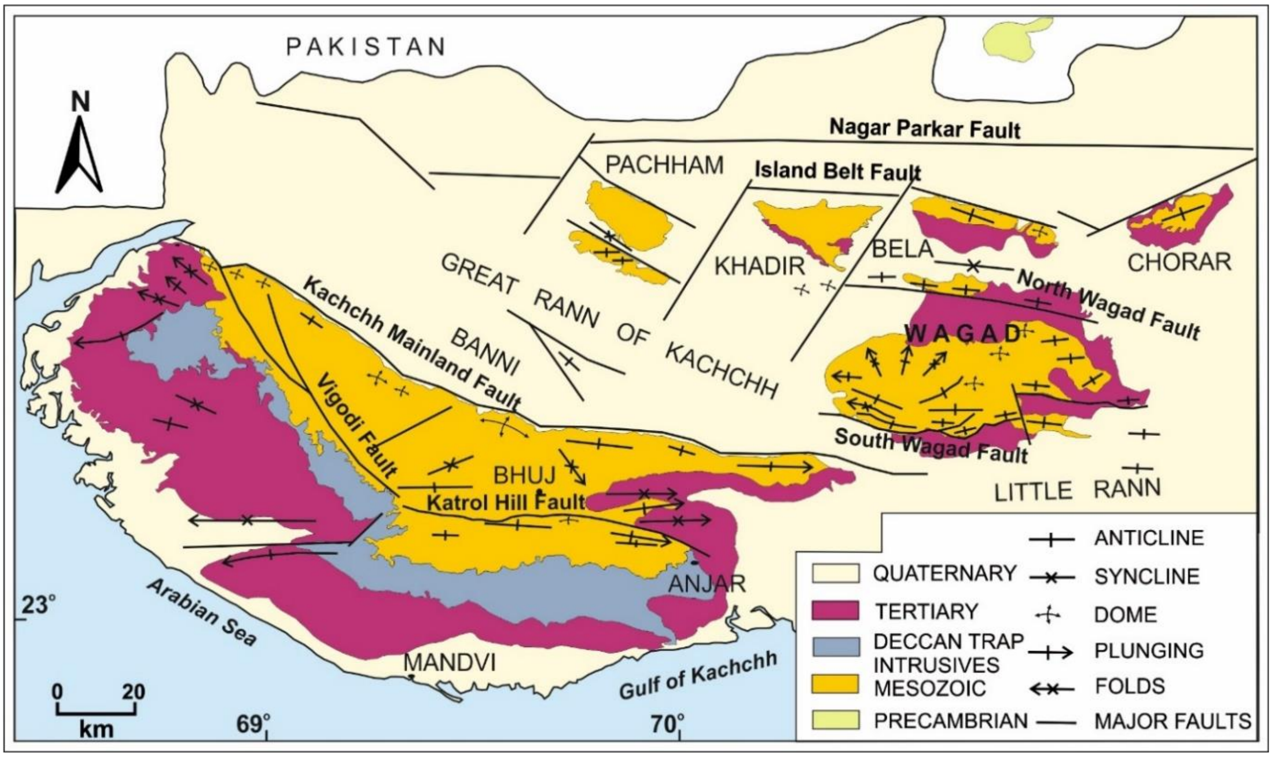

Figure 2.1 Structural map of Kachchh Rift Basin showing the major anticlines and synclines in the basin (after Biswas and Khatri, 2002). Map redrawn by Patidar (2010).

The narrow linear flexure zone along its faulted-up margin is common for each uplift in the basin. The low intensity folds in each uplift are characterized by a gently dipping limp and steep to near vertical limp. The structure resembles an asymmetrical anticline in geometry. The steep to near vertical limp is generally developed close to the marginal fault. The flexure zones are often shifted across the strike by the cross-faults or transverse faults that cuts and displaces the marginal faults (Biswas, 1982, 1987; Maurya et al., 2017**)**. The Mainland uplift consist of two major E-W trending flexure zone, the Northern Hill Range Flexure and the zone Katrol Hill Range flexure in the north and south respectively. The Northern Hill Range Flexure form the largest flexure in the basin in terms of areal extend and length.

Tectonic evolution

The rift basin evolved through the reactivation of pre-existing fault systems along E-W trending Aravalli-Delhi (NE-SW) fold belt in the Late Triassic period (Biswas, 1987; Biwas, 2005). The tectonic phases in the KRB were correlated with the major movements of the Indian plate (Biswas, 2016a). The basin evolved through two stages after breakup of the Gondwanaland. The two stages are extensional rift phase and compressive inversion phase. The extension phase in the basin led to formation of horst and graben structure and widespread synrift Mesozoic sedimentation. The end of the rift stage in the basin during Late Cretaceous period is resulted in the initiation stage tectonic cycle. Transition of rift stage to inversion stage is marked by series of igneous intrusions ranging in age from 120Ma to 61Ma (Sen et al., 2009; Sen et al., et al., 2016; Biswas, 2016a). The Deccan volcanism rose upward through the weak zones of the major E-W trending fault systems and preferentially domed and uplifted the overlying Mesozoic sequence (Sen et al., 2009; Maurya et al., 2017). Intrusion of the magma led to vertical movements along major fault systems and formation of fault-parallel flexure zones. The inversion compressive tectonic cycle continued to the present as a result of stress generated by the India-Eurasian plate collision. The post collision continuation of the compressive regime in the basin amplified the asymmetry of major domal structures and upward growth of the domes and anticlines in the flexure zones (Maurya et al., 2017). The present first topography with steeply sloping faulted limb and gently dipping other limb is a product of the continued compressive regime and neotectonic movements. The major fault systems of the basin including KMF were active during the rift phase as well as the post rift inversion phase (Biswas, 2005).

MESOZOIC STRATIGRAPHY

This particular sequence of rocks form the major lithology of the basin. More than three-quarters of the landmass of Kachchh is composed of Mesozoic rocks (Fig. 2.2). Rocks from the Mesozoic Era that range in age from the Mid Jurassic to the Lower Cretaceous can be found exposed in six uplifted areas – Kachchh Mainland, Pachham Island, Khadir Island, Bela Island, Chorar Hills and Wagad Highland (Biswas, 2016b). The lower Mesozoic of Kachchh are represented by rocks of Bathonian and Callovian age. The Khadir, Bela and Chorar rocks represent the period between Bathonian to Oxfordian. The Wagad area comprises of rocks of Oxfordian to Portlandian or perhaps Neocomian age (Biswas, 1977). The Island belt region and the Wagad are portions of the basin, where the oldest units in the sequence are exposed, with ages ranging from the Bathonian to the Callovian (Biswas, 1977). Granitic boulder conglomerate, which can be found in the Cheriya Bet, is the oldest rock in the Mesozoic of Kachchh (Biswas, 2016b). The basement for the Mesozoic sequence of rocks is the Precambrian-aged syenite that may be found in the Meruda hill of the basin (Biswas, 1977). The Mesozoic stratigraphy that is exposed in the basin can be classified into three zones viz, Mainland, Pachham island and Eastern Kachchh. (Table 2.1) The previous

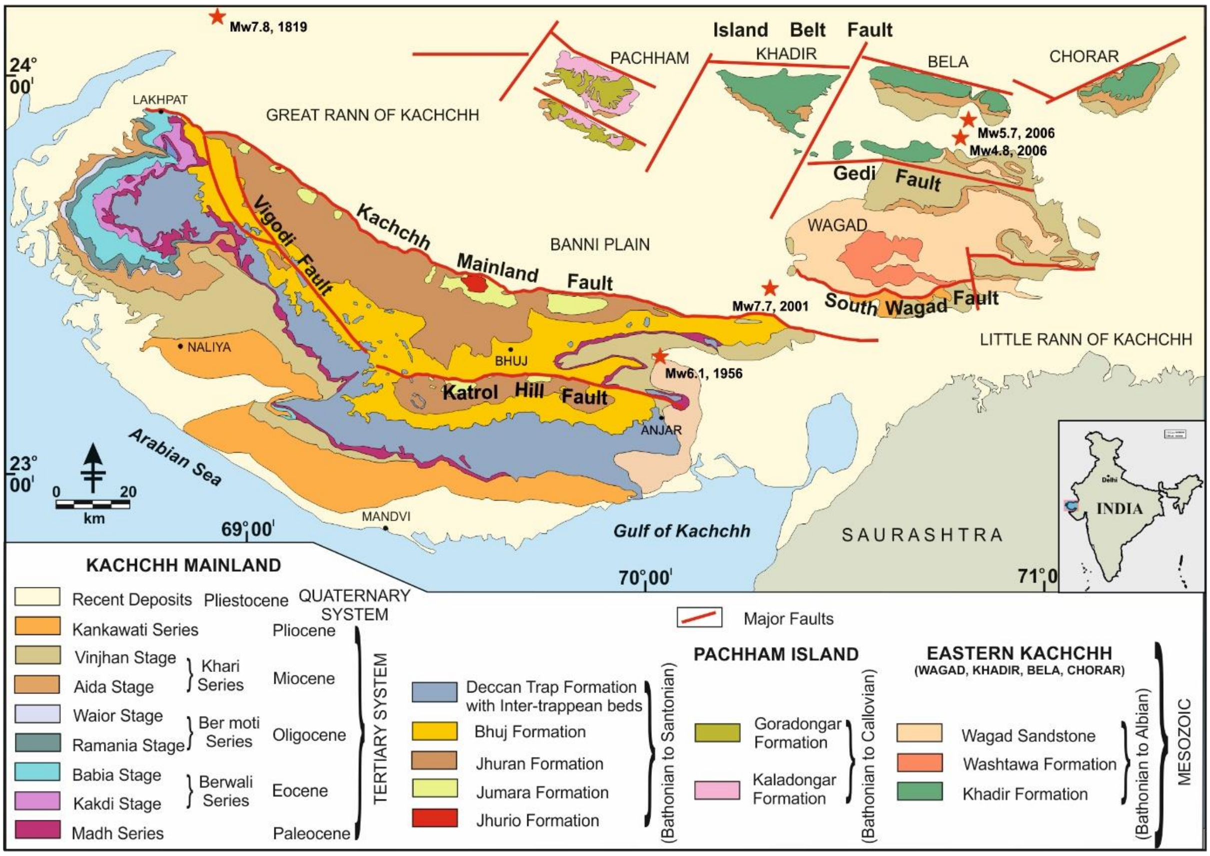

Figure 2.2 Geological map of Kachchh showing major lithological and structural features (after Biswas & Khattri, 2002). Map redrawn by Patidar (2010).

studies on the stratigraphic units highlighted that deposition have happened through the early, syn and the post-rift stages of the basin evolution (Biswas, 1993). These rocks are divided into four mappable rock-stratigraphic units. The following brief description of the various Mesozoic formations in Kachchh is based on the research works of S.K. Biswas, a renowned geologist of Oil and Natural Gas Corporation (ONGC) (Biswas 1977, 1982, 1987, 1993, 2016b).

Jhurio Formation

This formation is mainly composed of a thick sequence of limestone and shale units with bands of golden oolite (Biswas, 1977). The deposit forms the lower part of the Mainland stratigraphy with the type section exposed at the Jhurio hills of the Northern Hill Range (NHR). This formation is aproned by Jumara formation, where it forms a conformable contact with the formation. The base of the formation is exposed nowhere in the Mainland Kachchh. This formation is mainly exposed in three domal hill in the Mainland Kachchh, the Jhurio, Habo and Jumara domes from east to west respectively. Here the formation forms an inlier to the surrounding comparatively younger Mesozoic sequence of rocks. In Jumara Dome these rocks are exposed at the core of the dome as a circular outcrop forming the central hill. The fossil assemblage, physical and biological aspect of the formation indicates a littoral to infra-littoral environment during Bathonian to Callovian age (Biswas, 1977). The upper portion of the formation, which is composed of white limestone marks the maximum flooding surface (Biswas, 2016b).

Jumara Formation

This unit of rock is mainly characterised by olive-gray gypsaseous shale with thin red ferruginous bands (Biswas, 1977). Alternating beds of limestone with occasional sandstone beds are also common in the formation. The “Dhosa Oolite Beds” or thin bands of fossiliferous Oolitic limestone bands in the shale forms the marker horizon for the Mainland stratigraphy (Biswas, 1977). The significant exposure of Dhosa Oolite beds in the Mainland implies transgression during Jussaric period (Biswas, 2016b). The formation has a thickness of 900 to 950ft. This formation is more or less identical to the Chari formation, that ranges in age between Callovian to Oxfordian based on ammonite fossil assemblage (Rajnath 1932, Ghosh 1969). The age of Jumara formation is also assigned as Callovian to Oxfordian (Biswas, 2016b). This formation is best developed and exposed in the central part of Jumara Dome which forms a hill adjacent to the Rann, to the north of Jumara village.

Jhuran Formation

The Jhuran formation which overlies the Jumara formation and is mainly characterised by alternating beds of sandstone and shale (Biswas, 1977). The non-marine Bhuj sandstone aprons the formation. This formation is exposed mainly in the central and Northern Hill ranges as wide E-W trending strips. To be more specific, the formation is extensively exposed in the deformation zone along KHF and KMF. The formation is exposed as an inlier in the Bhuj formation in the eastern and western ends of the Mainland Kachchh. The formation can be further classified into four members, lower, middle, upper and Katewar member (Biswas, 1993). The lower member of the Jhuran formation consist of alternating beds of sandstone and shale with thin bands of fossiliferous calcareous sandstone (Biswas, 1993). The lower member of the formation is exposed in the Lothia Dam Dome and the upper member of the formation is exposed on the southern slopes of the Roha Hill. The upper member of the formation is predominantly arenaceous consisting of massive sandstone with intercalation of shale, siltstone and calcareous bands (Biswas, 1993). The Katesar member consist of massive sandstone beds with intercalation of shale. Here the

Table 2.1 Litho-stratigraphy of the Mesozoic rocks of Kachchh Basin, (after Biswas, 1977)

<table>
<tr><th colspan="2">Mainland</th><th colspan="2">Pachham Island</th><th colspan="2">Eastern-Kutch (Khadir-Bela-Wagad)</th></tr>
<tr><th>Formation</th><th>Member</th><th>Formation</th><th>Member</th><th>Formation</th><th>Member</th></tr>
<tr><td rowspan="3">Bhuj</td><td>Upper</td><td colspan="2" rowspan="9"></td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Ukra</td></tr>
<tr><td>Ghuneri</td><td rowspan="5">Wagad Sandstone</td><td>Gamdau</td></tr>
<tr><td rowspan="4">Jhuran</td><td>Katesar</td><td rowspan="4">Kanthkot</td></tr>
<tr><td>Upper</td></tr>
<tr><td>Middle</td></tr>
<tr><td>Lower</td></tr>
<tr><td rowspan="4">Jhumara</td><td>Dhosa Oolite</td><td rowspan="9">Washtawa
Khadir (Khadir Island)</td><td>Bhambhanka shale</td></tr>
<tr><td rowspan="2">Middle</td><td rowspan="3">Gadhada</td></tr>
<tr><td rowspan="4">Goradongar</td><td>Modar hill</td></tr>
<tr><td>Lower</td><td>Raimalro</td></tr>
<tr><td rowspan="5">Jhurio</td><td>Upper</td><td>Gadaputa</td><td rowspan="2">Hadibhadang</td></tr>
<tr><td rowspan="2">Middle</td><td>Flagstone</td></tr>
<tr><td rowspan="3">Kaladongar</td><td rowspan="2">Kaladongar Sandstone</td><td rowspan="3">Cheriya bet</td></tr>
<tr><td rowspan="2">Lower</td></tr>
<tr><td>Kuarbet</td></tr>
<tr><td colspan="4"></td><td colspan="2">Precambrian</td></tr>
</table>

lower, middle and lowest part of the upper member are well exposed in the central and western part of the Mainland. The Kharinadi and Rudramadha sections north of Bhuj show well exposed outcrops of the middle member of the Jhuran formation. The appearance of younger beds towards the west below the surface of disconformity shows that the beds offlap in that direction and is evidence of the regressive sea. The shales and sandstones of the Lower Member represent a deeper water facies in continuation with the underlying shales of sub-littoral environment. The upper member of the formation indicates transition to deltaic environment in paralic environment (Biswas, 2016b).

Bhuj Formation

The formation constitutes the youngest of the Mesozoic stratigraphy. The formation is characterised by non-marine sandstone of age between Lower Cretaceous to Santonian (Biswas, 1977; 1993; 2016b). The type section of the formation is well exposed round the city of Bhuj. The formation is sandwiched by marine Jhuran formation and the Deccan basalt. The formation is classified into three members, the Ghuneri (lower member), the Ukra and the upper member (Biswas,1993, 2016b). The lower member of the formation is characterised by alternated repeating beds of ferruginous or lateritic bands of shale and sandstone. The Ukra member is characterised by Olive green Gluconitic sandstone and gray shale with thin fossiliferous bands of purple ironstone, mudstone and gray limestone. The upper member consists of white to pale brown massive sandstones with kaolinitic shale and ferruginous bands. The absence of fauna, richness in flora and sedimentary structures and marine tongue in the down basin direction indicates a fluvio-deltaic depositional environment for the formation. The sediments represent more deltaic nature towards the western and fluvial nature towards the land in the eastern side (Biswas, 2016b). The prevalence of red sand sandstones, iron-oxide bands, presence of felspathic shales and claystones, absence of marine fossils, abundant plant fossils in carbonaceous shales, poor degree of sorting also point towards the non-marine depositional environment (Biswas, 1977).

TERTIARY STRATIGRAPHY

The Tertiary rocks of Kachchh mainly occurs as a narrow strip fringing the Mesozoic rocks exposed at the highland areas. The sediments were laid down in a post-rift marginal sag basin (Kingston et al., 1983). The deposits are nearly horizontal except near the Mesozoic structures where they show upwarping. A complete sequence of Palaeocene to

Pliocene sediments attains a thickness of about 900 m. The thickness of the Tertiary sediments indicates that a major subsidence occurred during the Tertiary period. In which, the Neogene part constitutes 800m of the sequence indicating that the subsidence was most intense during the Neogene time of Tertiary period (Biswas, 2016b). The rocks of this particular age are well exposed in the Pachham, Kadhir and Bela bets of the Island bet. The Tertiary rocks are also found fringing the Wagad and Mainland uplifts. At the same time, the thick sedimentary cover of the Banni, Great Rann, Little Rann and Samakhiali-Lakadia plain blankets the Tertiary deposits in these regions. The best outcrops of the Tertiaries of Kachchh are observed at the costal strips in the south western parts of Mainland Kachchh high. The first detailed classification of these Tertiary sequence of rock in the basin was proposed by Wayne (1872). In 1965, S. K. Biwas proposed a new classification for the Tertiary rock of Kachchh based on chronostratotypes (Biswas, 1965). This was later modified by Biswas and Raju (1973). Later, Biswas (1992) updated the scheme and proposed a clear and ordered lithostratigraphic classification. The lower Tertiary rocks overlie the hard Deccan Trap flows in southern and western Kachchh Mainland while in other areas they occur directly over the Mesozoic rocks. The Tertiary formation can be classified as follows, Matanomadh, Naredi, Harudi, Fulra Limestone, Maniyara Fort, Khari Nadi, Chhasra, and Sandhan. The Tertiary Formation could be classified further into members. The sedimentary characteristics of the Tertiary deposits suggest that the basin had undergone phases of marine cycles, uplift and erosion (Biswas, 1993). The brief summary of the Tertiary deposits is furnished in the Table 2.2.

Matanomadh Formation

Overlying the Deccan Trap Formation, occur a variety of rocks consisting of Trap derivative, pyroclastic and sedimentary clastic in various degree of admixture. They form a conspicuous unit marking the base of the Tertiary sequence. The Matanomadh Formation aprons the Deccan traps forming a nonconformable contact with the Deccan Trap (Biswas, 1992). Distinctive types of volcano-clastic rocks are deposited in continental to supra-littoral environment. The best type section is exposed in the Bhuj-Lakhpat road section east of Matanomadh (Biswas, 1993). Good exposures of the formation is also exposed in the badlands around the Matanomadh village, and in Madhwali and in the Nadi section, south of the village. The age of the formation is Palaeocene to Lower Eocene. Rocks found here are extremely irregular, soft and friable. The common rock types are red laterite, bauxite,

Table 2.2 Stratigraphy of Tertiary sediments of Kachchh basin (after Biswas, 1992)

Age	**Formation**	**Members**
Pliocene	Sandhan	
Lower Miocene (Burdigalian)	Chhasra	Siltstone
		Claystone
Lower Miocene (Late Aquitanian)	Khari Nadi	
Oligocene	Maniyara Fort	Bermoti
		Coral Limestone Lumpy clay Basal member
Late Middle Eocene	Fulra Limestone	
Middle Eocene	Harudi	
Late Paleocene	Naredi	Ferr. Claystone Assilina Limestone Gypseous Shale
Upper Paleocene	Matanomadh	
Cretaceous–Lower Plaeocene	Deccan Trap	

laterized trap-pebble and conglomerate, trap-wash/ wacke, variegated plastic bentonitic clays, red and yellow ferruginous clays, grey and white tuffaceous shales and red, current bedded, tuffaceous sandstones and occasional layers of lignite. The thickness of the succession is extremely variable with a maximum thickness of 50m. The formation is generally devoid of fossils, however locally rich in fossil flora. The lithologic characteristics indicate that these volcanoclastic sediments were deposited during the waning phase of the Deccan volcanicity in different terrestrial environments (Biswas, 1992).

Naredi Formation

Naredi formation overlies Matanomadh Formation. This formation is named as Naredi Formation after its stratotype in the cliffs of the Kakdi Nadi near the village of Naredi (Biswas, 1992). The type section is best exposed in the cliffs along Kakdi Nadi south of Naredi and partly (upper part only) along Guvar stream NNW of Naredi. The formation generally nonconformally overlies the Deccan trap or discomformally overly the MatanoMadh Formation. The formation forms a disconformity with the Harudi Formation. The disconformity between Naredi and Harudi formation is characterised by a red ferricrete erosional surface (Catuneanu and Dave, 2017). It occurs in a narrow sinuous belt of outcrop from Lakhpat in the north to Jhulrai in the south (Biswas, 1993, 2016b). Age of the formation is Late Palaeocene to Early Eocene. Lithology of this formation can be distinctly divided in three members: Gypseous shale member, Assilina-limestone member and Ferruginous claystone member. The lower and middle members locally develop black shale facies comprising black pyriteous shales and lignite beds. The Naredi Formation is rich in microfaunna fossils like, the *Assilina spinosa*, Lockhartia, species, Nummulites species, Globigerina species, and Globorotalia species, varieties of bivalves, gastropods and corals are seen. The series consist of various depositional environment due to its variety in lithology. The depositional environment includes shallow water environment and stable shelf tectonic environment in sunlit photic zone of sub littoral environment (Biswas, 1992).

Harudi Formation

This formation is named as the Harudi Formation after its type section near Harudi village (Biswas, 1992). The formation is very well exposed in an impressive escarpment to the west of Harudi village (Biswas, 1993). Age of the formation is Mid Eocene. The formation consists of green and greenish grey, splintery shale with yellow limonitic partings in the lower part and calcareous claystone and siltstone with occasional layers of gypsum and carbonaceous shale in the upper. This series is highly fossiliferous with fossils like *Truncorotaloides topilensis, Nummulites obtusus, N. acutus, Brarrudosphaera biglowi, Dictyoccites bisectus*, Bolis and Xancus (Biswas, 1992). The thick ferruginous, gypseous clay marlite band with *Nummulites obtusus* forms the marker bed for the formation

(Catuneanu and Dave, 2017). Formation is also rich in pelecypods, gastropods and coral fossils. The depositional environment of the formation is littoral to lagoonal in the lower part to inner self in the upper part (Biswas, 1992).

Fulra Limestone Formation

This formation has been named as the Fulra limestone after its designated type section near Fulra village in western Kachchh (Biswas, 1992). Type section of this formation is best exposed in the southern flank of Babia Hill near to Fulra village. This formation is well exposed only in the western part of Kachchh around Narayan Sarovar, Dedhadi, and Lakhpat noses in a 6.5 to 10 km wide belt of outcrop. Age of the formation is Late Middle Eocene. The entire formation is made up of massive to thickly bedded, white, and buff coloured foraminiferal limestone. The maximum thickness of the formation is 60m and is exposed in the Berwali stream (Biswas, 1992). The limestones are fossiliferous micrites, biomicrites and biomicrosparites. Planktonic foraminifera like *Orbulinoides beckmanni*, *Truncorotaloides rohri*, *Discocyclina sowerbyi*, *Fasciolites elliptica*. Besides the microsfossils, the formation is rich in megafossils like oysters, turritellids, Pecten, echnoides, and fossil carbs (Biswas, 1992). The formation is rich in vertibrate fossils like whales, sea cows and fishes. Foraminiferal assemblage and lithology are indicative of a low energy, clear waters probably under marine-self environment (Biswas, 1992).

Maniyara Fort Formation

This formation is named after Maniyara Fort. The type section is continuously exposed along Bermoti Nadi (stream) flowing between Maniyara Fort and Bermoti village (Biswas, 1992). Besides the type section, this formation is also well exposed in Ramania stream, Waior stream, Berwali Nadi, Bermoti stream and also in the area around Lakhpat and Narayan Sarovar. Age of the formation is Oligocene. The basal member is about 14ft. thick and consists of alternating beds of foraminiferal, glauconitic, brownish to yellowish siltstone and calcareous, gypseous claystone (Biswas, 1993). Followed by a lumpy clay member, which is about 15 ft. thick and consists of cement coloured to brownish calcareous, lumpy claystone, occasionally containing thin limestone and marlite beds. The lumpy clay member is overlined by a Coral limestone member about 30ft thick consisting of dirty white nodular limestone. The upper Bermoti member is about 36 feet thick and is best developed in the stream SE of Bermoti and also NNE of Waior (23°05'002"; 68°41'45"). It is also well exposed on top of Maniyara Fort Hill. Altogether the formation is 35m thick. The formation is richly fossiliferous with variety with variety of echinoids, pelecypods, gastropods, corals and carbs. Well preserved skeletons of reptiles, whales etc. are seen between layers of foraminiferal limestone. Nummulites and Miogypsina are the characteristic foraminifera present. The depositional environment of the formation is marginal marine, i.e., littoral to shallow inner self. The marine transgression caused resulted in the transition from lagoon to high energy open self-condition (Biswas, 1992).

Khari Nadi Formation

This formation is named after Khari Nadi. The type section is exposed along cliffs and banks of Khari Nadi between its confluence with Sugandhi Nadi (locality: 23°25'45"; 68°49'40") near Goyela and the prominent elbow bend (23°23'00"; 68°48'00") about 2 km (Biswas, 1992). North of Laiyari-Rampura cart-track. The maximum development of the formation is seen on the southern flank of the Narayan Sarovar nose between Waior and Jangadia. Good exposures are seen in the high cliffs of the Waior, Barkhan, and Khari streams. Age of the formation is Early Miocene. The lithology consists predominantly of laminated to very thin bedded red and yellowish mottled to variegated siltstone and very fine-grained sandstones with occasional grey and brown gypseous claystone. A bluish grey claystone bed occurs consistently near the base in every section. Cross bedded, fine grained, micaceous sandstone is present in the middle part, while a few thin fossiliferous marl and limestone beds are present in the middle and upper part of the type section. The lower part of the formation does not contain much invertebrate fossils, at the same time lower part is rich in fossil flora. Foraminifera fossils like *Miogypsina tani, M. dehartti*, *Nephrolepidina* and *Austrotrillina* are characteristics of the formation (Biswas, 1992). Turitella, Ostrea and echinoids are common mega fossils present in the formation. The depositional environment of the formation is tidal flat, littoral to shallow inner-self in a slowly transgressive sea over a stable shelf (Biswas, 1992).

Chhasra Formation

This formation is named after Chhasra Village. The type section is exposed along Khari Nadi from the top of Khari Nadi Formation near Laiyari to a locality 1 km south of Chhasra village (Biswas, 1992). The formation is also well exposed in southern and eastern Kachchh and also seen as patchy outcrops in the low plains between the highlands. It also occurs as outlier in the peripheral structural lows of the Mainland and Wagad highland. Age of formation Early to Mid-Miocene. A lower claystone member, consists of grey and khaki coloured, laminated to splintery, gypseous shales and claystones with alternations of thin, hard yellowish, highly fossiliferous argillaceous limestones. An upper siltstone member consists predominantly of alternating micaceous siltstone and laminated silty shales of monotonous khaki colour. The upper part is generally reddish. The formation has a thickness of 294m and is highly fossiliferous. Gastropods species like Turritella, Murex, Natica, Cyprea, Physa, Conus are the common gastropod fossils identified in the formation (Biswas, 1992). The formation also has abundance of Arca, Pecten, Venus and echinoids. The formation is rich in foraminiferal assemblages. Rich biota and lithology indicate deposition in sublittoral environment during highest stand of sea. Foraminiferal assemblage suggests a fluctuating marginal marine to shallow inner-self conditions of depositional environment (Biswas, 1992).

Sandhan Formation

This formation is named after Sandhan village. The type section is exposed along the Kankawati river from one km south of Vinjhan to south of Sandhan where it is overlain by Quaternary and recent deposits (Biswas, 1992). The formation marks the youngest of the Tertiaries of Kachchh. Age of the formation is Mid Miocene to Early Pliocene (Biswas, 1992). The lower part of the formation consists of well sorted, medium to coarse grained, massive, micaceous sandstones, overlain by clayey, laminated siltstones and topped by thin yellow fossiliferous limestone beds. The middle part comprises conglomerates and coarse-grained sandstones with lenticular bodies of conglomerates. The upper part consists mainly of hard, calcareous grits, overlain by pink and grey mottled silty sandstone with calcareous nodules. Foraminifera like Ammonia sp., Pararotalia sp., Elphidium sp., miliolids are common in the layer (Biswas, 1992). Lenticular pockets of oyster debris and thin oyster bands are common in the upper conglomerate sandstone. This formation is also rich in vertebrate fossils like Anthracotheroids and suids. The basal conglomerate with fossil wood and channel fills over the underlying Vinjhan shales clearly suggest an erosional break in the deposition followed by fluvial sedimentation. The sandstone appears to be littoral sand of advancing sea after major regression. The depositional environment thus appears to be supra-littoral to deltaic or fore-shore environment (Biswas, 1992).

TERTIARY MARINE CYCLES

The Kachchh basin has witnessed several cycles of advancement and withdrawal of the sea during the Tertiary period. Each cycle of transgression and regression was mapped in the basin using lithological and faunal characteristics (Biswas, 1993; Catunaue and Dave, 2017; Saraswati et al., 2018). Among the marine cycles, the Burdigalian transgression is significant one and highest sea stand during the Tertiary period in the basin. The transgressing sea attained the maximum level during the time (Biswas, 1993). The end of Oligocene period in the Kachchh basin is marked by the withdrawal of the sea. The Burdigalian transgression occurred in the basin during the Early Miocene period. The Burdigalian transgression and high sea stand is common phenomenon in the marginal basins of the India as well as in the global marginal basins. The transgression led to extensive sedimentation in the basin. The thickness of the sediments deposited during the period is the highest when compared to the sedimentation and thickness occurred during different period in the Tertiary of Kachchh. Shales and marlites with rich marine fauna were the major lithology deposited during the Burdigalian high sea in the Kachchh basin. The high sea level led to inundation of major part of the basin. The major low lands and areas having low relief were inundated in the marine water during this time. The Burdigalian high sea also led to the submergence of the Radhanpur-Barmer arch in the east of the Kachchh basin which led to the development of a free connection between the Kachchh and Cambay basin. Biswas (1993) also envisioned that the shore-line of the Burdigalian sea extended almost to the margin of the Mesozoic highlands and shield areas. The post-Burdigalian period between the Late Miocene-Pliocene is a period of major transgression in the basin. The present coast line of the Kachchh region began to take final shape during this period (Biswas, 1993).

PALAEO-EROSIONAL SURFACES

The deposition of rocks in the basin are separated by intermittent by episodes of erosional cycles. These palaeosurfaces or planation surfaces potentially provide evidences to nature of the macro-scale process as well as the rate and timing of uplift and erosion which have occurred in the geological past (Widdowson, 1997). These erosional cycles were mapped and reported from the Kachchh basin. Biswas (1974) identified major erosional breaks in the Tertiary and Quaternary periods. These erosional breaks are surfaces formed by erosional dominance in the landscape as a result of peak tectonic uplift. During the Tertiary period the Palaeocene was marked by intense erosion of the landscape and formation of peneplanation surface. The Palaeocene peneplanation surface formed the platform for the deposition of the marine sequence during Tertiary period. This is followed another cycle of erosional dominance and peneplanation during the Early Eocene period (Biswas, 1993). The magnitude of the Early Eocene break is not well established. However, the onset of the Miocene is characterised by a major phase of uplift and erosion of the topography. The Early Miocene uplift and erosion is followed by post-Burdigalian withdrawal of the sea and widespread erosion of the landscape. The post-Burdigalian erosion was followed by the deposition of Pliocene sediment. The period of deposition was followed Quaternary erosional cycles. The major Quaternary erosional surfaces of the Kachchh include, Early Pleistocene surface, Early to Mid Pleistocene and Late Pleistocene surfaces (Biswas, 1974).