CHAPTER - 2
MESOZOIC STRATIGRAPHY

2.1 INTRODUCTION

Kachchh is a peri-cratonic rift basin that preserved a complete succession of rocks ranging from Aalenian/Bajocian to Holocene. The Mesozoic and Cenozoic succession is demarcated by a period of non-deposition and Deccan volcanism at the end of the Cretaceous period. The Mesozoic successions ranging in age from Middle Jurassic to the Lower Cretaceous are well exposed in the Mainland Kachchh, the Island Belt Zone, and Wagad Highland. The Mesozoic succession of the Mainland Kachchh is exposed along the northern periphery in domal form, around Bhuj city and Katrol Hill ranges, and their southern extension is capped by a Deccan trap and by Cenozoic deposits towards the east. The Mesozoic succession of the Kachchh basin comprises highly fossiliferous and bioturbated beds deposited in an environment ranging from marginal marine to open marine.

2.2 PREVIOUS WORK

Kachchh basin preserved an excellent record of the geological past in the form of lithified rock succession, biogenic structures and body fossils from the Middle Jurassic to the Recent. Its most complete and continuous Mesozoic record with abundant and diverse body fossils fascinated many geologists around the world. The first comprehensive geological report on Kachchh was made by Grant (1840). A much detailed account of the geology of Kachchh was recorded by Blanford (1867) who recognized the E-W trending master faults along the northern margin of major uplift for the first time. Wynne and Fedden (1868-1872) systematically mapped and investigated the geology of Kachchh, identifying the Mesozoic and the Tertiary succession and was Published by Wynne (1872). He assigns the Mesozoic succession into marine for lower Jurassic and non-marine for the upper Jurassic succession. This publication along with the accurate geological map laid the foundation for all future geological research in Kachchh.

Stoliczka introduced a fourfold classification - Pachham, Chari, Katrol and Umia groups for the exposed Mesozoic succession in his 1867 field diary based on field observation and fossil content which was later published by Waagen (1871). Wagen (1873-1876) studied the ammonites collected by Stoliczka and introduced the first time chronostratigraphy by

correlating the Stoliczka's fourfold classification with the European zones based on ammonite assemblage zones. According to him, the Pachham, Chari, Katrol and lower part of Umia corresponded with the "Lower Series" and the upper part of the Umia with the "Upper Series" of Wynne (1872). Kitchin (1900), Cox (1940) and Gregory (1906) studied brachiopods, bivalves, echinoids and corals mainly in the highly fossiliferous sections of Western Kachchh with more emphasis on taxonomy rather than the biostratigraphy. Rajnath (1932), on the basis of the study of ammonites, lamellibranchs and plant fossils introduced the Bhuj series by redefining the Umia series. He restricted the Umia to the lower Umia of Wagen and classified the Mesozoic succession of Kachchh into five stratigraphic units. The youngest Bhuj series is equivalent to the non-marine deposits of Wagen's upper Umia.

Oil and Natural Gas Company Ltd. has carried out extensive geological studies, both on land and offshore for hydrocarbon exploration. They have made surface mapping, geophysical surveys (2D seismic survey) and deep drillings. Their findings which were published contributed a lot to understanding the depositional and tectonic history of the Basin. Tiwari (1948) and Arkell (1956) modified the age of the Jurassic rocks while Agrawal (1957) modified the stratigraphic nomenclature replacing Chari Series with Habo Series and Mebha Oolites for the Dhosa Oolite. Pascoe (1959) compiled Spath's (1927-33) classification and describe a more systematic classification with proper uses of stratigraphic nomenclature such as series, stage, etc. Bernberg and Schott (1963) assigned the Bathonian age to Kuar Bet beds, the Callovian age to the Khavada Nala section of Pachham Island and the upper Oxfordian age to the Dhosa Oolite band of the mainland on the basis of fossil assemblages. Poddar (1964) replaced the rank 'Series' of Rajnath's (1932) classification with 'Formation' and consider Ukra Beds as Formation. Rao (1964) and Gosh (1969) modified the age based on fossils assemblage while Hardash (1968) assign the depositional environment of the Bhuj Formation from infra-littoral to fluvial. Krishnan (1968) modified Rajnath's classification by reintroducing a four-fold classification by including Bhuj Series with Umia Series while adopting the age of Arkel (1956).

The scientific contribution toward stratigraphy of the Kachchh basin witnessed a huge hiatus after Wagen (1857) and Rajnath (1932), until Biswas (1971, 1977) made a huge contribution by proposing 'Lithostratigraphy' in accordance with the International Code of Stratigraphic Nomenclature. A separate nomenclature for the Kachchh Mainland, Patcham Island, Eastern Kachchh (Island Belt Zone) and Wagad Highland was introduced due to the lack of lateral

facies continuity and common marker beds among the sub-basins. This lithostratigraphic classification is based on detailed mapping, and surface and subsurface studies. However, several workers opined on the retention of the old four-fold classification of Wagen and Rajnath (Howard and Singh, 1985; Jai Krishna, 1983; Krishna et.al., 1983; Mitra et.al., 1979), He also made a series of publications (1971, 1977, 1978, 1980, 1981, 1982, 1983, 1987, 1991, 1993, 2005, 2016) describing the basin architecture, tectonic and depositional histories, and introducing the concept of monoclinal flexures and domes aligned along the margin of all the major faults of the region i.e. Nagar Parkar Fault (NPF), Island Belt Fault (IBF), Kachchh Mainland Fault (KMF) and Katrol Hill Fault (KHF) and revision of lithostratigraphy. Biswas and Deshpande (1968, 1970, 1973, 1983) published a detailed geological and structural map of the Kachchh basin.

A continuous modification is made towards the ages and stratigraphy of the Kachchh basin. Singh et al., (1982) reported the earliest deposit of Kachchh in Patcham Island based on Ammonite. Krishna (1984), Krishna and Cariou (1986) and Krishna and Pathak (1991, 1993) proposed biostratigraphy based on ammonites while Pandey and Dave (1993) constructed foraminiferal biostratigraphy. Fürsich et al., (2001, 2014) study the marker beds, correlate the entire basin, and constructed a detailed lithostratigraphy by integrating Biswas (1980) and the traditional Wagen (1875). Biswas (2016) updated his original classification (Biswas, 1971, 1977) and formalized the lithostratigraphic units of the all the sub-basin by incorporating Biswas, (1977, 1993); Fürsich et al., (2001); Krishna et al., (2009) and Deshpande and Merh, (1980) classification schemes.

The scientific approach to unraveling the geological past of the Kachchh basin diversified. Ichnological approach dated way back to the time of Wayne (1872). However, it gains momentum when Howard and Singh (1985) decipher the paleoenvironment based on trace fossils. Shringarpure (1984 and 1986) study the ethology, palaeoecology, animal-sediment relationship, event stratigraphy and depositional environments of the Wagad Highland based on trace fossils. Badve and Ghare (1978), Ghare and Kulkarni (1986), Kulkarni and Ghare (1989, 1991) also contributed significantly to the study of trace fossils in Kachchh. Patel et al., (2008a, 2008b, 2009, 2010, and 2012 a and b), Patel (2012), Desai et al (2008), Patel and Patel, (2015) Joseph et al, (2012), and Darngawn et al., (2018) also made a significant contribution in the ichnology of Mesozoic rocks of the Kachchh Mainland and the Island Belt Zone of Kachchh basin. Fürsich et al., (1991, 1992, 1994, 2001) described the ichnology, correlation

of marker beds across the basin, sequence stratigraphy and depositional environment of various exposure to Kachchh Mainland. Patel et al., (2010) and Joseph and Patel (2015) describe the significance of sequence stratigraphy and the Ichnology of Patcham Island. Patel et al., (2018) described the stratigraphy of Chorar Island for the first time while Darngawn et al., (2019) reconstructed the genetic sequence stratigraphy of Chorar Island based on ichnology and sedimentology.

2.3 MESOZOIC STRATIGRAPHY

The Mesozoic succession of the Kachchh basin is exposed in six isolated patched which include the Mainland Kachchh, Patcham Island, Khadir Island, Bela Island, Chorar Island and the Wagad Highland (Biswas 1971, 1977). The succession range in age from Aalenian? /Bajocian to Albian (Biswas, 2016). In the Mainland Kachchh, they are exposed along the northern periphery along with disconnected domes and in and around Bhuj city. The Island Belt zones which include Patcham, Khadir, Bela and Chorar Islands lie along the northern border of the basin bounded by the Island Belt Fault and Wagad Highland in the east. Owing to their patchy outcrop, lack of common marker beds and unique facies association, a separate lithostratigraphic classification had been proposed by Biswas, (1971, 1977, and 2016). Accordingly, Mainland Kachchh, Patcham Island, Eastern Kachchh (Khadir, Bela and Chorar Islands) and Wagad Highland are recognized individually.

2.3.1 Mainland Kachchh

The Mesozoic succession of Mainland Kachchh is characterized by 3000+ m thick succession ranging in age from Aalenian/Bajocian to Albian (Biswas, 2016). This succession is broadly dived into Jhurio, Jumara, Jhuran and Bhuj formations chronologically. The base of the oldest member is not exposed while the youngest Bhuj Formation is unconformably overlain by Deccan Trap and Paleogene-Neogene sedimentary.

2.3.1.1 Jhurio Formation

Jhurio Formation is named after Jhurio (Jhura) dome where it is well developed and exposed attaining a maximum thickness of about 291 m. This formation range in age from Aalenian-Bathonian and is also exposed in the cores of Habo, Jura and Jumara domes along the northern margin of the Mainland Kachchh. Jhurio Formation is chiefly composed of white to grey limestone with fine to medium crystalline texture with lenses of golden oolite intercalated with

shales. The base of the formation is not exposed while the upper boundary is marked by a conformable yellow limestone/greenish shale contact with the overlying formation.

Jhurio formation comprises seven members which include Member A-G chronologically. Member A consists of a lithologic association of greenish shales and limestone with golden oolite. Members B, C, D and E form an association of grey to greenish calcareous, quartzose shale and golden oolite. Member B is characterized by grey shales, overlain by the massive bed of golden oolites with thinly bedded limestone at the base of Member C. Member D is a shale-dominated succession similar to Member B but is more calcareous in nature. Member E is comprised of banded brown and grey limestone with golden oolites in the lower part. However, it can be differentiated from the golden oolites of Member C as the latter gives brick-red colouration on weathering. Member F is characterized by thickly bedded golden oolite on top followed by thinly bedded yellowish limestone. Member G consists entirely of well-bedded limestone comprising micrite and sparite with a little allochemical constituents.

The Jhurio Formation is particularly rich in fossils in the Jumara dome where the shales and biostromes are packed with corals (Gregory, 1900). The *Alectryonia-Rhychonella* assemblage is common throughout the formation with a decrease in *Alectryonia* towards the lower members. The corals of the lower members are described as a Jumara coral-bank (Pascoe, 1959) where 61 species are described (Gregory, 1893). The lithological association of quartzose shale, limestone, and golden oolite with terrigenous materials indicates a nearshore deposition in a slowly transgressive sea under relatively stable conditions (Biswas, 1993).

2.3.1.2 Jumara Formation

The Jumara Formation is named after Jumara Dome which forms a dome adjacent to Rann where the succession is best developed and exposed. The exposure of this formation is restricted mainly within eroded domes such as Jara, Jumara, Manjal, Keera, Jhurio, Gangeshwar, Bharasar and Habo. The succession comprises of ~290 m thick sequence ranging in age from Callovian to Oxfordian. This formation lies conformably on the underlying Jhurio Formation with gradational contact and is capped by a Dhosa Oolite band with local disconformity (Biswas, 1993).

The Jumara Formation mainly comprises quartzose shale and gypseous clayey shales with hard beds of marlites and calcareous quartzose sandstone. The shales are generally greenish-grey to olive green, often flaky to thinly laminated and highly gypseous in nature. The occurrences of gypseous in the form of veins suggest a secondary origin. This argillaceous shale is intercalated with sandstones which are hard, pale, brown, grey or greenish coloured, coarse-grained with occasional pebbles. They show cross laminations and oscillation ripple marks.

The Jumara Formation is broadly divided into four members viz. Member I-IV chronologically. The member I-IV was renamed as Shelly Shale, Ridge Sandstone, Gypseous Shale, and Dhosa Oolite members by Biwas (2016). The Shelly Shale Member consists of ~90 m thick succession characterized by greenish-grey to yellowish-grey, laminated gypseous, clayey shales with thin red nodular hematitic bands and numerous thin greenish-grey marlite and yellowish-white fossiliferous limestone. The ridge Sandstone Member consists of ~50 m gypseous shale with fossiliferous white marlite and ferruginous bands. The ridge Sandstone Member comprises ~107 m of intercalated gypseous shale and while marlite bands constitute the Gypseous Shale Member. The top of the formation is marked by the Dhosa Oolite Member which is characterized by gypseous shales with highly fossiliferous oolitic limestone bands called the Dhosa Oolite bands. This band serves as the key marker bed for lithological correlation of Mesozoic succession in the Mainland Kachchh. The Jumara Formation preserves varieties of body fossils which include ammonites, nautiloids, belemnites, brachiopods, bivalves, corals, echinoids and gastropods throughout the formation with abundant trace fossils. The lithological and biological entities suggest a sub-tidal environment (Biswas, 1977).

2.3.1.3 Jhuran Formation

The Jhuran Formation comprises of ~792 m thick intercalated sequence of shale and sandstone ranging in age from Kimmeridgian to lower Berriasian. The succession is sandwiched between the lower Dhosa Oolite (Member IV) bands of Jumara and the upper nonmarine sequence of Bhuj Formation (Biswas, 1993). This formation constitutes more than half of the exposed Mesozoic outcrop and is well exposed in the northern range of Mainland Kachchh and along the southern flanks of the two hill ranges, Jara Hills on the west to Khirasra on the east. To the east, beyond Khirasra, they occur as an inlier within small domes north of Dudhai. The well-developed Jhuran Formation also was observed in Kas Hills, the eastern side of the Habo Dome. They also occur as inliers at the core of the Mundhan anticline and Ghuneri dome. The

southern strip extends along the Katrol Hill Fault from Nana Dongar Hill on the west to Nigal on the east.

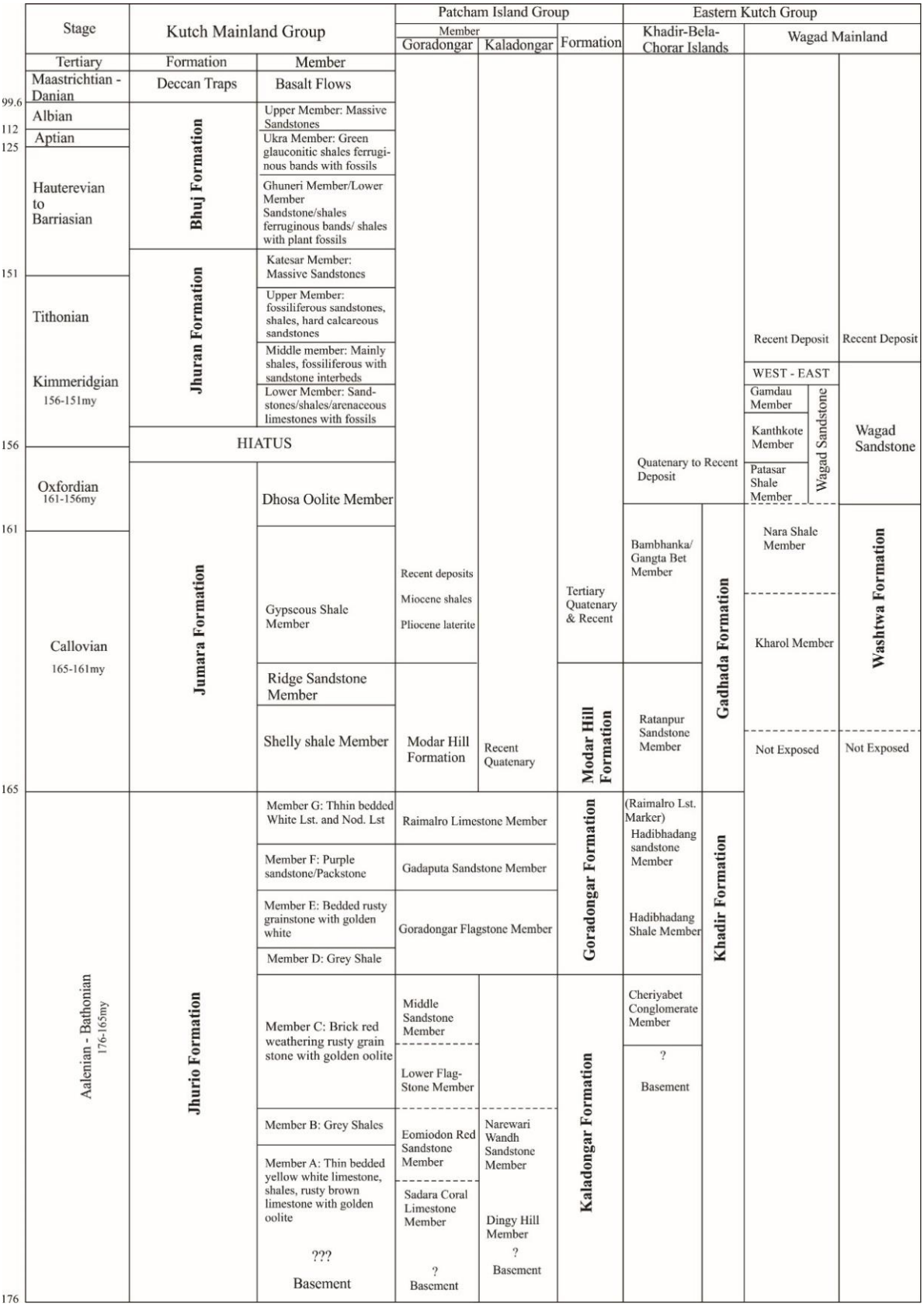

Table 2.1 Mesozoic stratigraphy of Kachchh (Biswas, 2016)

The Jhuran Formation is a shale-dominated succession intercalated with thin layers of red and yellow, fine to medium-grained calcareous sandstone with thin red and purple bands of ferruginous sandstone. The sandstones are often friable in nature. The lithological association can be easily distinguished by the alternations of shale and sandstone with gradational contacts. The succession is predominantly shale in the lower and middle part while sandy in the upper part where it is often difficult to differentiate it from the overlying Bhuj Sandstone.

The Jhuran Formation is broadly divided into four informal members viz. Lower, Middle, Upper and Katesar members. A composite stratotype is assigned for the formation by Biswas (1977, 2016) where the Jhuran River for Lower and Middle members, Mundhan anticline for upper member and Katesar River for Katesar member is assigned.

The Lower Member consists of alternating shale with sandstone almost in equal proportions where the sandstones are yellow and purplish, current-bedded, thinly bedded to massive and friable in nature. The Middle Member is shale-dominated intercalated with thinly bedded sandstone with few bands of marlite. The Upper Member is dominated by sandstone with a subordinate amount of shales. The sandstones are mainly arenites which are yellowish-grey, purple to brown at times. They are medium to coarse-grained with lenses of intraformational conglomerates and often contain ferruginous nodules. The Katesar Member is characterized by distinctly green sandstone, exposed only between Jara Hills and Ghuneri Dome. The succession comprises yellow to olive green, fine to medium-grained well-sorted, compact, massive and current bedded sandstone. The top of this member is marked by ferruginous and gypseous bands. The succession of the Jhuran formation shows a wide range of environments; sub-littoral environment for the Lower Member, shoreface environment below wave base in Middle Member; high energy wave zone and littoral zone in the Upper and Katesar Member. The lithological characteristics of the formation suggest regression and the final withdrawal of the sea in the Kachchh basin.

2.3.1.4 Bhuj Formation

The Bhuj Formation is a nonmarine deposit bounded by the underlying marine the Juran and the overlying volcanic Deccan trap. It comprises 366 m thick sandstone dominated succession ranging in age from Neocomian to Albian. The succession is exposed extensively in two wide belts stretching from Bachau on the east to Ghuneri on the west, occupying lowlands between

the two hill ranges of the Mainland Kachchh.The Bhuj Formation is predominantly comprised of friable sandstone which is brownish red, buff to orange in color containing sedimentary structures such as current bedding and cross-stratification. The sandstones are soft, friable, massive, medium to coarse-grained, well sorted and loosely cemented with felspathic and ferruginous cement. The sandstone is rhythmically interbedded with thin beds of shales and hard bands; ferruginous sandstone, pebbly, laterite and ironstone indicate cycles of sedimentation.

The Bhuj Formation is subdivided into three formal members viz. Ghuneri, Ukra, and Upper members (Biswas, 2016). The cyclic repetition of ferruginous/lateritic bands, shale and sandstones occurred in Ghuneri/Lower Member. The Ghuneri Member is overlain by a sequence of inter-tonging marine and non-marine lithosomes which constituted the Ukra Member. This member is equivalent to the lower part of the Upper Member in the type section. This member is characterized by olive green to dark green glauconitic sandstone, hematitic bands with greyish sandy shale and fissile sandstone bands with fossils. The dark green glauconitic sandstone is the characteristic of this member. The Ukra Member is conformably underlain by the Upper Member with a sharp contact between basal green sandstone of the Ukra Member and pebbly sandstone of the Upper Member. The Upper Member is characterized by pale yellow to pale brown coloured, massive, current bedded, coarse-grained and well-sorted sandstones.

The dominance of sandstones, absence of marine fauna barring Ukra Member, oxidized ferruginous bands, abundant plant fossils, less development of shales with a poor degree of sorting and tabular current bedding suggest non-marine deposits (Biswas, 1993). The Ukra Member, however, is characterized by marlite bands, glauconitic sands, and ferruginous mudstone bands with gypseous shales suggesting shallow marine deposits. The intertonguing of shallow marine and non-marine deposits suggests a deltaic environment.

2.3.2 Patcham Island

The succession of the Patcham Island is characterized by a distinctive suite of rocks and is correlatable with the Mainland Kachchh only through indirect and paleontological evidence (Biswas 1993). Hence a separate lithostratigraphic classification is proposed by Biswas (1977, 1980) which includes Kaladongar Formation and Goradongar Formation. Fürsich et al (2001) attempted to merge the Biswas's (1977, 1980) classification with the former traditional

classification (e.g., Krishna et al., 1983, 1984; Bardhan and Datta 1987; Singh 1989; Fürsich et al., 1992; Fürsich and Oschmann 1993; Bhalla & Talib 1991) by retaining Jhurio Formation and extending Patcham Formation to the Mainland Kachchh and the Eastern Kachchh. Biswas (2016) redefines the term Patcham Formation to Patcham group which includes Kaladongar, Goradongar and Modar Hill formations.

2.3.2.1 Kaladongar Formation

The Kalaldongar Formation comprises a thick sequence of conglomerate, shale and sandstone that constitute the oldest stratigraphic unit of the Bajocian age in the Kachchh basin. They are exposed at Kaladongar and Goradongar hill ranges where the oldest stratigraphic unit is exposed in the Dingi hills, Chhappar bet and Kuar Bet islets. The section exposed in the lofty scrap facing the Rann, below the highest Babia Peak (456 m), and along the stream west of Narewari Wandh is designated as the type section. It is also exposed in the Sadhara Dome of the Goradongar hill ranges. The base of the formation is not exposed while to top of the formation is marked by ferruginous-oolitic limestone of the overlying Goradongar Formation The Kaladongar Formation comprises of ~465m thick sequence and is subdivided into three formal members; (i) Dingy Hill/Kuar Bet Member, (ii) Narewari Wandh Sandstone Member, and (iii) Babia Cliff Sandstone Member (Biswas, 2016).

The Dingy Hill Member (Bajocian) shows an intercalated succession of thinly bedded green and red siltstones with hard massive calcareous sandstone containing lenses of granite pebble-conglomerate and shales in the lower part of the member. Abundant plant fossils are observed in the sandstone units. Narewari Wandh Sandstone Member formerly known as Kaladongar Sandstone Member comprises non-fossiliferous but bioturbated massive sandstone and siltstone with an exception of the sandstone-shale band that is highly bioturbated and fossiliferous (*Corbula*) calcareous units in Kaladongar and Goradongar Range. Babia Cliff Sandstone Member is characterized by a thick succession of siltstone overlain by massive and cross-bedded sandstone. The lower part of the succession is highly bioturbated and fossiliferous containing bivalves and gastropods. The upper part of the succession shows the presence of conglomerates locally. The lithological attributes in association with the sedimentary structures and biological attributes such as body fossils and ichnofossils suggest that the Kaladongar Formation was deposited in a littoral to the infra-littoral environment in a transgressive regime.

2.3.2.2 Goradongar Formation

The Goradongar Formation is characterized by~154 m thick sequence of limestone, sandstone and shale overlying the Kaladongar Formation ranging in age from Bathonian to Callovian (Fürsich, et al., 1994). It is well exposed all along with the Goradongar hill range and the southeastern slope of the Kaladongar and hill ranges. It can be differentiated from the underlying formation by the occurrence of richly fossiliferous limestone and shale beds in the lower part and sandstone in the upper part. This formation is covered by Paleocene laterites, Miocene shales and Rann sediments in both hill ranges. Goradongar Formation is best developed in the eastern part of Goradongar Hill Range while the members are best developed in the southern flanks of the hill range.

The Goradongar Formation is further subdivided into three formal members based on their distinctive lithology which include the Goradongar Flagstone Member, the Gadaputa Sandstone Member and the Raimalro Limestone Member. The Goradongar Flagstone Member is characterized by thinly bedded, grey, yellow and pale brown sandy pelsparites. These limestones are interbedded with flaggy calcareous sandstone which is ferruginous at times. Bands of Golden oolites are often interbedded with limestone similar to Member F of the Jhurio Formation of the Mainland Kachchh. The Gadaputa Sandstone Member is dominantly sub-arkosic arenites which are pale brown to pinkish, massive, soft and poorly sorted, medium to coarse-grained. The Raimalro Limestone Member is predominantly limestones that are light yellow to brown in color. The limestone of this member is fossiliferous in nature and often contains chert. The lithological association of ferruginous, quartzose sandstone, intraformational conglomerate and shales suggest that the Goradongar Formation is deposited in shoreface-offshore environments.

2.3.2.3 Modar Hill Formation

The Modar Hill Formation succession is lie above the Raimalro Limestone. It was initially regarded as part of the Goradongar Formation as Modar Hill Member (Biswas, 1977) which was later elevated to the formation (Biswas, 2016). This Formation is Callovian in age and equivalent to Chari Formation of Fürsich et al., (2014). Outcrops of the formation are observed in Modar hill and on lower slopes right up to the edge of Rann towards the east, low cliffs of Khavda Nala, and patches along the southeast corner of Goradongar and along the south of

Andhou village. The Modar Hill Formation comprises ~118 m thick succession overlying the Raimalro Limestone and is characterized by thick intercalated shale with pelloidal packstone grading into micritic sandstone at the base, overlain by thick mixed siliciclastic carbonate succession in the middle and capped by limestone shale sequence (Joseph et al., 2016).

2.3.3 Eastern Kachchh Group (Khadir, Bela, Chorar Islands and Wagad Highland)

The stratigraphy of eastern Kachchh is represented by interrelated rock units exposed in the disconnected outcrops in the form of isolated islands which include Khadir, Bela and Chorar Islands and Wagad Highland. A separate lithostratigraphic classification was given by Biswas (1997, 1980, 2016) due to its unique and distinctive lithology as compared to the Mainland Kachchh and Patcham Island, patchy outcrops and difficulty in tracing the lateral facies continuity. Accordingly, the successions of the eastern Kachchh Group are broadly divided into Khadir Formation and Gadhada Formation for Khadir, Bela and Chorar Islands whereas, Washtawa Formation and Wagad Sandstone for Wagad Highland.

2.3.3.1 Khadir Formation

Khadir Formation is exposed in Khadir, Bela and Chorar Islands where it forms the north-facing vertical cliff section of Khadir and Bela Islands, a small islet called Cheriya Bet in the north of Khadir and the central portion of an elliptical dome near Aaval in Chorar Island. This formation comprises 218 m thick clastic, non-clastic and mixed siliciclastic carbonate succession ranging in age from Bajocian to Bathonian age. The base of the formation is not exposed while coralline limestone marks the top of the formation. This coralline limestone is a facies variation of the Raimalro Limestone of Goradongar Formation of Patcham Island (Biswas 2016) and Patcham Formation of Fürsich et al., (2001).

Khadir Formation is divided into Cheriya Bet Conglomerate, Hadibhadang Shale and Hadibhadang Sandstone members. Cheriya Bet Conglomerate Member is characterized by a polymictic conglomerate with thin layers of friable sandstone. This member is exposed only in a small islet called Cheriya Bet in the north of Khadir Island. Hadibhadang Shale Member is exposed on the northern escarpment and the foothills of the Khadir and Bela Islands while in Chorar Island it is exposed at the core of an elliptical dome near Aaval village. It is a shale-dominated succession where the shales are intercalated with thickly bedded, grayish, friable sandstone. The arenaceous content increases from east to west. At the western tip of the Khadir

Island, the Hadibhadang Shale Member is entirely friable sandstone containing a huge log of fossilized wood. The Hadibhadang Sandstone Member forms the vertical cliff section of the Khadir and Bela Island while in Chorar it is exposed in the interior slope of the elliptical dome near Aaval village.

2.3.3.2 Gadhada Formation

Gadhada Formation comprises 385 m thick succession ranging in age from Callovian to early Oxfordian. It is characterized by clastic, non-clastic and mixed siliciclastic carbonate succession. This formation is demarcated from the underlying Hadibhadang Sandstone Member by coralline limestone. It is a sandstone dominated sequence at the base while it becomes argillaceous at the top.

The Gadhada Formation is subdivided into Ratanpur Sandstone Member and Bambhanka Member. Ratanpur Sandstone Member of Gadhada Formation forms the backslope of Khadir and Bela Islands while in the Chorar Island, it mostly forms the periphery of the dome. It is dominated by micritic sandstone and ferruginous sandstone at the base while it is intercalated with thin bands of fossiliferous limestone and shale towards the top. The shale-dominated succession is not exposed in Bela and Chorar Islands. Bambhanka Member is exposed only in a small islet called Kakinda Bet, south of Khadir Island and at the southern tip of Khadir Island. It is characterized by gypseous shale at the base and mixed siliciclastic carbonate rocks at the middle part of the sequence and is topped by thick shales.

2.3.4. Wagad Highland

The Mesozoic succession of Wagad Highland is sandstone dominated succession and divided into two formations, the lower Washtawa Formation and the upper Wagad Sandstone deposited in distinct environments of marine and deltaic respectively (Biswas, 2016; Joseph and Patel, 2018). Wasthawa Formation is further subdivided into lower Kharol and Upper Nara Shale members while Wagad Sandstone Formation is subdivided into Patasar Shale, Kanthkot and Gamdau members.

2.3.4.1 Washtawa Formation

The Washtawa Formation comprises 188 m thick succession (Joseph and Patel, 2018) ranging in age from Callovian to Early Oxfordian. This Formation is extensively developed and well

exposed in the Washtawa dome and also occurs in the eastern part of the Desalpur-Fatehgadh hills of Northern Wagad between Gedi and Mora. The formation is further divided into Kharol and Nara Shale Member. Kharol Shale Member is composed of thickly bedded rippled, cross-bedded sandstones and shale alternations at the base. The middle part consists of massive feldspathic sandstone with shale alternations, and the upper part consists of thick cross-bedded quartz arenite intercalated with grey-coloured shale. Nara Shale Member comprises flaggy and fissile to bedded red to yellow coloured micritic sandstones intercalated with laminated gypseous shales. It is capped by a conglomeratic band marking the top of the Washtawa Formation.

2.3.4.2 Wagad Formation

The Wagad Sandstone Formation comprises of 154 m thick succession (Joseph and Patel, 2018) ranging in age from Late Oxfordian to Kimmeridgian. This formation is formerly described as Kanthkot Formation by Deshpande and Merh (1980) which is renamed Wagad Sandstone by Biswas (2016). It consists of three distinct members viz. Patasar Shale, Kanthkot and Gamdau. The Patasar Shale Member is well exposed in the western part of the area comprising grey to dark grey, shales intercalated with micritic sandstone bands. The micritic sandstone is thinly bedded and flaggy in nature in the lower part while it gradually thickens and coarsens in the upper part of the sequence. Kanthkot Member comprises yellowish red to white coloured micritic sandstone in the lower part of the sequence and quartz arenite in the upper part of the sequence with the shale unit. The member also consists of two highly fossiliferous, conglomeratic and calcareous bands, referred to as the Lower *Astarte* band and the Upper *Astarte* band. Gamdau Member comprises white coloured mudstone overlain by thick cherry red quartz arenites which are often highly bioturbated.