CHAPTER - 8

DISCUSSION AND CONCLUSIONS

8.1 DISCUSSION

The Jurassic succession of Khadir, Bela and Chorar Islands are exposed in the southern flank along the strike of the Island Belt Fault as an isolated high ground. These deposits are penecontemporaneous but show wide variation in lithology, thickness, sedimentary structures and biological activities. The Jurassic rocks of the Khadir, Bela and Chorar Islands comprise of 692 m, 263 m and109 m thick succession respectively and are characterized by clastic, non-clastic and mixed siliciclastic carbonate sediments ranging in age from Aalenian?/Bajocian to early Oxfordian (Biswas, 2016). These successions are broadly classified into Khadir and Gadhada formations. The Khadir Formation is comprised of Cheriya Bet Conglomerate, Hadibhadang Shale and Hadibhadang Sandstone members while Gadhada Formation includes to Ratanpur and Bambhanka members.

The Cheriya Bet Conglomerate comprises approximately 42 m thick polymictic conglomerate dominated succession with few bands of sandstone showing fining upwards sequence and is exposed only in a small islet, Cheriya Bet. This polymictic conglomerate is deposited in a distal fan delta complex environment which marks the beginning of sedimentation in the sub-basin during the Aalenian?/Bajocian time (Fig. 8.1) and represents LST-I. The succession is non-bioturbated and is deposited during the early phase of rifting.

The Hadibhadang Shale Member is deposited during the Bajocian age and is exposed at the foothills of Khadir, Bela and the core of the Chorar dome marking the onset of transgression within the sub-basin. In Khadir Island, this member is developed in a pro-delta environment where the succession comprises of 180 m thick shale-dominated succession often truncated by thick, cross-bedded micritic sandstone. Thinly bedded sandy allochemic limestone, bioclastic wackestone/packstone and grainstone often occur within the shales. The succession is bioturbated by *Diplocraterion, Arenicolites*, *Rhizocorallium, Skolithos* and *Thalassinoides* forming *Skolithos* and *Diplocraterion* assemblages. Similar to Khadir Island, the Hadibhadang Shale Member of Bela Island is also developed in a pro-delta environment where the succession is exposed at the foothills of the north-facing scarp of the Island. It is characterized by 46 m

thick, shale-dominated succession with thin bands of micritic sandstone and packstone. However, in Chorar Island, the Hadibhadang Shale Member is a developed shoreface environment where the succession is characterized by 23 m thick, gypseous shale at the base with cross-bedded micritic sandstone (Patel et al., 2018) suggesting that the delta that developed in Khadir and Bela Islands does not extend towards the east during the Bathonian age.

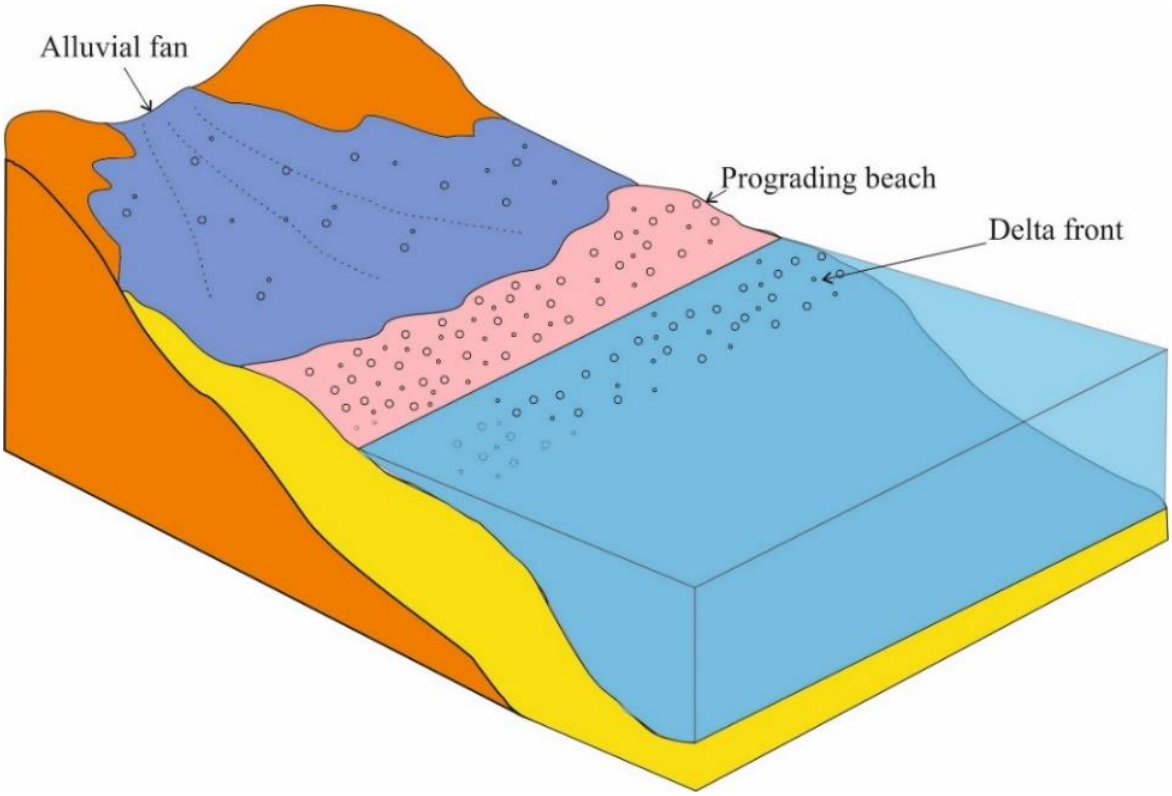

Fig. 8.1 A depositional model of fan delta complex – a representative of Cheriya Bet Conglomerate during Aalenian?/Bajocian age.

The Hadibhadang Sandstone Member was deposited in the delta front/prodelta to an offshore environment in Khadir and Bela Islands (Fig. 8.2) while in the shoreface to an offshore environment in Chorar Island during the Bathonian age (Fig. 8.3). This member is deposited during a continuous rise in the sea level with a temporal progradational shoreline in Khadir and Bela Islands. This progradational shoreline is due to an active building of a prograding delta during early Bathonian where the sediments were deposited in a delta front environment which is overlain by an offshore deposit at the end of the Bathonian. This progradational shoreline coincides with the temporal regression of Haq et al., (1987). However, Chorar Island shows

continuous transgression with no progradation. In Khadir Island, Hadibhadang Sandstone Member succession is represented by 85 m thick succession with micritic sandstone at the base overlain by non-clastic (carbonate) rocks which include bioclastic wackestone/packstone and peloidal wackestone/packstone sandy allochemic limestone facies with negligible shales. The succession is exposed along the vertical cliff of the north-facing scarp of the island. The peloidal wackestone/packstone of offshore deposits mark the top of the formation in Khadir Island while in Bela Island, the Hadibhadang Sandstone Member is characterized by 79 m thick, mostly dominated by micritic sandstone of delta front/prodelta deposit with less occurrences of shales and overlain by packstone of offshore deposit which marks the top of the Khadir formation. The continuous transgressive deposits of Chorar Island are characterized by a 31 m thick succession dominated by mixed siliciclastic-carbonate rocks including micritic sandstone, sandy allochemic limestone and allochemic sandstone intercalated with shales deposited in the shoreface environment overlain by coralline limestone of offshore deposits (Patel et al., 2018).

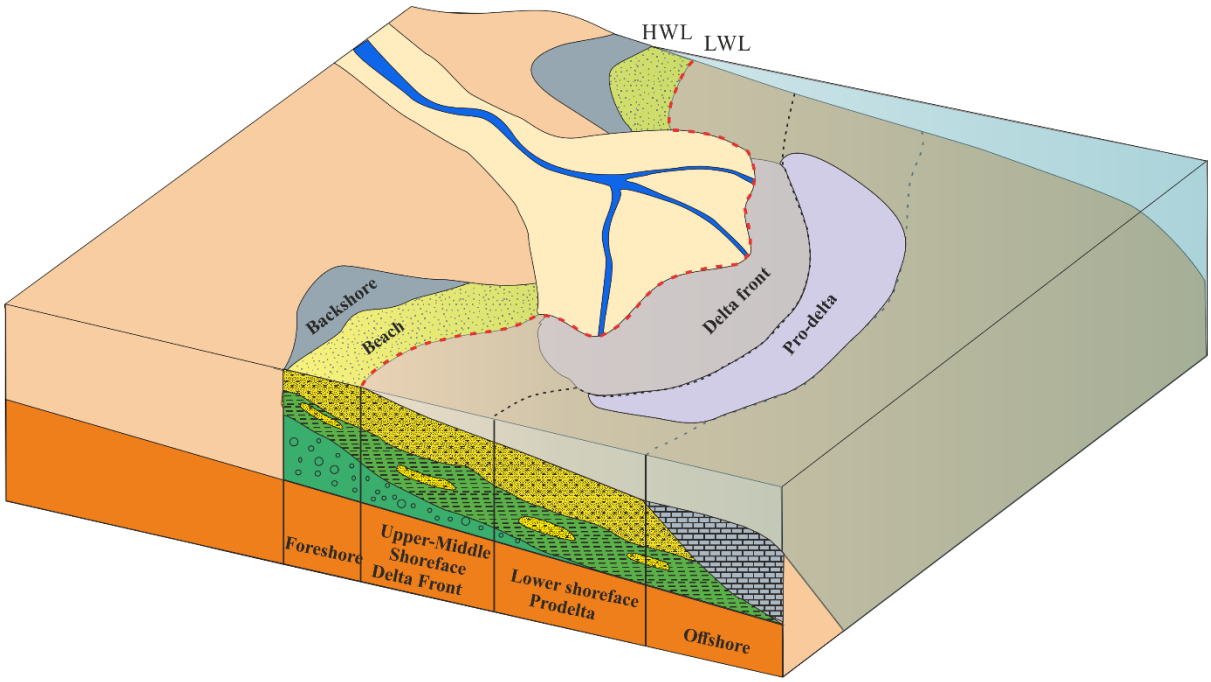

Fig. 8.2 A depositional model of a delta system – a representative of Hadibhadang Shale and Hadibhadang Sandstone members during the Bajocian-Bathonian age.

The succession of Hadibhadang Sandstone Member shows the mono occurrence of *Monocraterion* in Bela Island while it is intensely bioturbated throughout Chorar Island

forming four recurring ichnoassemblages which include *Hillichnus, Rhizocorallium, Thalassinoides* and *Gyrochorte* belonging to *Cruziana* Ichnofacies.

The Hadibhadang Shale and Hadibhadang Sandstone members witness a continuous rise in the sea level in all three islands with temporal progradational shoreline in Bela and Khadir Islands during early Bathonian. This continuous rise in the sea level marks TST-I of model-dependent genetic sequence stratigraphy. The peloidal wackestone/packstone, packstone and coralline limestone of offshore deposits in the Khadir Island, Bela and Chorar Islands mark the MFS and form the sequence boundary of the first genetic sequence cycle.

The Ratanpur Sandstone Member shows wide lateral facies variation in each of these islands where it is developed in the shoreface environment during the Callovian age. In Khadir Island, this member is represented by a 190 m thick succession characterized by thinly bedded sandy allochemic limestone at the base overlain by thick micritic sandstone which is in turn overlain by a shale-dominated succession where the shale is intercalated with thinly bedded micritic sandstone, peloidal packstone/grainstone and sandy allochemic limestone while in Bela is a 138 m thick succession characterized by a shale-dominated succession where the shale is intercalated with thinly bedded micritic sandstone, packstone, allochemic sandstone, sandy allochemic limestone and mudstone. In Chorar Island, it comprises of 55 m thick succession, characterized by thinly bedded mudstone and allochemic sandstone intercalated with shales overlain by very thick cross-bedded white sandstone and ferruginous sandstone at the top (Patel et al., 2018).

The Ratanpur Sandstone Member is intensely bioturbated in all three islands. This member shows maximum diversity in trace fossils. Khadir Island shows four ichnoassemblages which include *Lockeia, Planolites-Palaeophycus, Rhizocorallium* and *Hillichnus,* Bela Island shows two ichnoassemblages including *Monocraterion* and *Hillichnus* while Chorar Island shows a recurring *Skolithos* assemblage. The ichnoassemblages of the Khadir, Bela and Chorar Islands of Ratanpur Sandstone Member typically show shallow marine assemblages, where *Skolithos* Ichnofacies suggest agitating and shifting substrate above fair-weather wave base and *Cruziana* ichnofacies suggest moderate-low energy between storm weather wave base to fair-weather wave base.

The Ratanpur Sandstone Member is developed over the offshore deposits after maximum transgression when the continuous transgression retards. Though Callovian witnessed a continuous rise in the global sea level (Haq et al., 1987, Hallam, 1988), the Khadir, Bela and Chorar Island's succession display a progradational shoreline during early Callovian. These progradational deposits/normal regression above the MFS is typical for HST (Catuneanu, 2017). Thus, the Ratanpur Sandstone Member of Khadir, Bela and Chorar Island are deposited during HST-II.

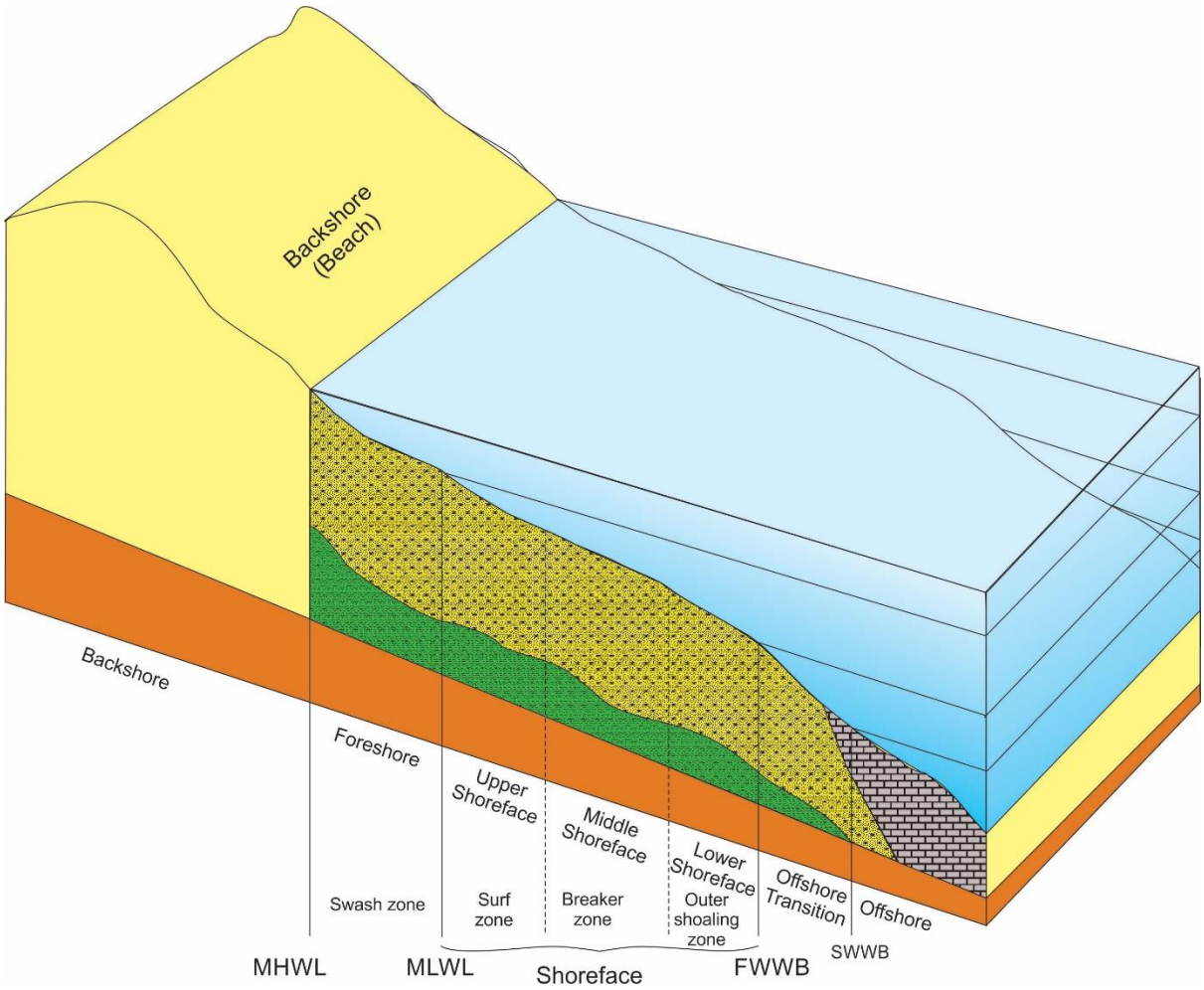

Fig. 8.3 A depositional model of clastic shoreline environments a representative of Hadibhadang Shale, Hadibhadang Sandstone and Ratanpur Sandstone members of Chorar Island, and Ratanpur Sandstone and Bambhanka members of Khadir Island and Ratanpur Sandstone Member of Bela Island.

The Bambhanka Member is exposed only in the Kakinda Bet, south of Khadir Island. The succession comprises 195 m thick shale-dominated succession intercalated with thinly bedded peloidal packstone/grainstone, bioclastic packstone, sandy allochemic limestone and thinly to

thickly bedded micritic sandstone deposited in the shoreface environment (Fig. 8.3). The thickly bedded micritic sandstone and sandy allochemic limestone are intensely bioturbated characterized by *Rhizocorallium* and *Protovirgularia* assemblages respectively. The shaly succession of Bambhanka Member is deposited in a calm aggrading shoreface environment with the occasional change in the energy condition. Thus, the succession of Bambhanka Member represents aggradation during HST-II.

The Jurassic succession of Khadir Island is characterized by 36 ichnospecies belonging to 19 ichnogenera. These ichnogenera include *Arenicolites, Chondrites, Curvolithus, Didymaulichnus, Diplocraterion, Gyrochorte, Hillichnus, Laevicyclus, Lockeia, Monocraterion, Ophiomorpha, Palaeophycus, Phycodes, Planolites, Protovirgularia, Rhizocorallium commune, Skolithos, Taenidium* and *Thalassinoides.* The traces fossils observed in Bela Island comprise of 23 ichnospecies belonging to 17 ichnogenera which include *Arenicolites, Chondrites, Didymaulichnus, Diplocraterion, Helicolithus, Hillichnus, Lockeia, Monocraterion, Ophiomorpha, Palaeophycus, Phycodes, Planolites, Protovirgularia, Rhizocorallium, Skolithos, Taenidium* and *Thalassinoides* while Chorar Island is characterized by 20 identifiable ichnospecies belonging to 16 ichnogenera which include *Aesterosoma, Arenicolites, Curvolithus, Didymaulichnus, Diplocraterion, Gyrochorte, Halopoa, Hillichnus, Lockeia, Megagrapton Palaeophycus, Planolites, Protovirgularia, Rhizocorallium, Skolithos,* and *Thalassinoides.*

The biological activities inscribed in the Jurassic successions of Khadir, Bela and Chorar Islands shows ethologically similar yet morphologically varying groups of trace fossils. Hence, a morphological classification (ichnotaxobase) of Knaust, (2012) was adopted which includes **sub-horizontal** (*Asterosoma* isp**.,** *Curvolithus multiplex, C. simplex, C.* isp., *Didymaulichnus lyelli, Gyrochorte comosa, Halopoa imbricata, Helicolithus sampelayoi, Laevicyclus parvus, Megagrapton irregularie, Palaeophycus haberti and P. tubularis, Phycodes curvypulmatum, P. palmatus, Planolites baverleyensis, P. montanus, Protovirgularia oblitrata, P.* isp., *Rhizocorallium commume var auriform, R. commune var irregulare, R. commune* isp., *Taenidium serpentinum* and *T.*isp.); **Sub-Vertical** (*Arenicolites carbonarius, A.* isp., *Chondrites targionii, C. intricatus Diplocraterion* isp., *Lockeia silliquaria, Monocraterion tentaculatum, Skolithos verticalis, S. linearis* and *Skolithos* isp.) and **Complex (***Hillichnus lobosensis, Ophiomorpha annulata, O. irregularie, O. nodosa, O.* isp., *Thalassinoide horizontalis, T. paradoxicus* and *T.* isp.) structures.

The sequence stratigraphic analysis of Khadir Island, Bela and Chorar Islands succession shows two cycles of genetic sequences which include LST-I, TST-I and HST-II. LST-I is represented by a polymictic conglomerate of Cheriya Bet Conglomerate Member of distal fan delta complex deposits. TST-I is represented by Hadibhadang Shale and Hadibhadang Sandstone members. The shale-dominated succession of Hadibhadang Shale Member in Khadir and Bela were deposited in a pro-delta environment while shoreface environment in Chorar Island. The Hadibhadang Sandstone Member of Khadir and Bela islands are of delta front deposits overlain by offshore deposits while shoreface deposits are overlain by offshore deposits in Chorar Island. This suggests that the delta developed during the Bajocian-Bathonian age, restrict to Khadir and Bela Island only and does not extend up to Chorar Island in the east. The offshore deposits of each island mark the MFS and thus the sequence boundary. The HST-II is represented by an initial progradation followed by aggradation of Ratanpur and Bambhanka members during Callovian-Early Oxfordian. The overall shoreline projection is given in Fig. 8.4 where LST-I is developed during the early rifting phase, TST-II with initial retrogradational shoreline during Bajocian, progradational shoreline during early Bathonian, maximum flooding surface at the end of Bathonian overlain by progradational shoreline during early HST-II followed aggradation. The Jurassic succession of Khadir, Bela and Chorar shows wide variation in thickness along the depositional strike from west to east giving rise to a condensed sequence of lithostratigraphic units towards the east (Fig. 7.4).

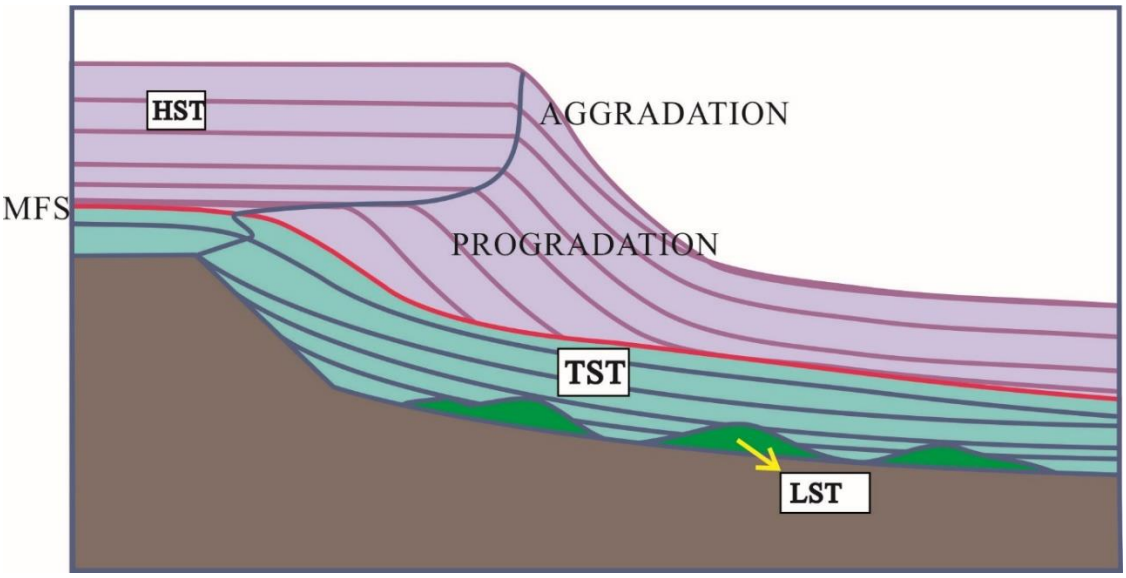

Fig. 8.4 The sequence stratigraphic model for shoreline trajectories of Khadir, Bela and Chorar Islands.

The sea-level curves have been redrawn based on sedimentological and ichnological evidence and compared with the global sea-level curves of Haq et al., (1987) and Hallam (1988). These curves are identical to the Bajocian and Late Bathonian time but differ during the Early Bathonian and Callovian suggesting that local parameter like tectonic has played an important role in the development of the sequence in the basin margin of the Kachchh Basin.

8.2 CONCLUSIONS

- The Jurassic succession is well exposed in the eastern part of the Kachchh Basin, mainly in the Khadir, Bela and Chorar dome.
- It is divided into Khadir and Gadhada formations, the former consists of Cheriya Bet Conglomerate, Hadibhadang Shale and Hadibhadang Sandstone members while the latter consists of Ratanpur Sandstone and Bambhanka members.
- The oldest Cheriya Bet conglomerate and the youngest Bambhanka Members are exposed only at Khadir Island and marked the northern and southern limit of the Mesozoic respectively.
- The exposed Jurassic rocks comprise 692 m, 263 m and 109 m thick succession in the Khadir, Bela and Chorar Islands respectively.
- This succession is mainly characterized by clastic, nonclastic and mixed siliciclastic sediments and shows a variable number of lithofacies in different islands.
- The Khadir Island succession consists of eight lithofacies which include, bioclastic grainstone, bioclastic wakestone-packstone, peloidal wackestone-packstone, peloidal packstone-grainstone, micritic sandstone, sandy allochemic limestone, polymictic conglomerate and shales deposited in an environment ranging from fan delta complex, pro-delta, delta front, offshore and shoreface environments.
- The Bela Island succession consists of six lithofacies which include, micritic sandstone, allochemic sandstone, bioclastic packstone, sandy allochemic limestone, mudstone, and shale facies deposited in an environment ranging from pro-delta, delta front, offshore and shoreface environment.
- The Chorar Island succession consists of nine lithofacies which include micritic sandstone, allochemic sandstone, sandy allochemic limestone, sandy micrite, cross-bedded white sandstone, ferruginous sandstone, coralline limestone, mudstone and shales facies deposited in shoreface to offshore environments.

- The trace fossils of the Jurassic succession of Khadir Island comprise of 36 ichnospecies of 19 ichnogenera, representing ethologically diverse groups dominated by fodinichnia, but forming ecologically related and recurring assemblages which include *Diplocraterion, Hillichnus, Lockeia, Planolites-Palaeophycus, Rhizocorallium* and *Protovirgularia.*
- The traces fossils of Bela Island comprised 23 ichnospecies of 17 ichnogenera representing ethologically diverse groups dominated by fodinichnia, but forming ecologically related and recurring ichnoassemblages which include *Monocraterion, Thalassinoides,* and *Hillichnus* assemblages.
- The trace fossils of Chorar Island comprise of 20 identifiable ichnospecies of 16 ichnogenera representing ethologically diverse groups dominated by fodinichnia but forming ecologically related and recurring ichnoassemblages which include *Hillichnus, Rhizocorallium, Gyrochorte, Thalassinoides* and *Skolithos* assemblages.
- The ichnoassemblages of the Khadir, Bela and Chorar Islands typically show shallow marine assemblages where the association represents agitating and shifting substrate above fair-weather wave base and moderate-low energy between fair-weather wave base and storm-weather wave base of *Skolithos* and *Cruziana* Ichnofacies respectively. The mixed ichnoassemblages also often occur together as combined *Skolithos-Cruziana* Ichnofacies representing intermittently poor substrate consistency and stressed environments.
- The sequence stratigraphic analysis of Khadir Island succession reveals two cycles of genetic sequences which include LST-I, TST-I and HST-II systems tracts. The Bela and Chorar Islands succession are characterized by similar systems tracts which include TST-I and HST-II.
- The LST-I of Khadir Island is characterized by a polymictic conglomerate of distal fan environment and is observed in the Cheriya Bet, north of Khadir Island.
- The TST-I has developed in the delta front/prodelta environment and is observed in Hadibhadang Shale and Hadibhadang Sandstone members of the Bajocian-Bathonian age in Khadir and Bela Islands, however, the TST-I of the Chorar Island is characterized by shoreface environment.
- In Chorar Island, the TST-I is observed in Hadibhadang Shale and Hadibhadang Sandstone members are characterized by an intercalated sequence of shale and mixed siliciclastic carbonate rocks of the shoreface-offshore environment during Bajocian to Bathonian age.

- Chorar Island witnessed no progradational shoreline during TST-I like the neighbouring Khadir and Bela Islands suggesting that the delta did not extend up to Chorar Island in the east.
- The top of Hadibhadang Sandstone Member is characterized by nonclastic sediments of the offshore environments in Khadir and Bela Islands marked the MFS. The coralline limestone facies of offshore deposits with well-developed corals marks the MFS in the Chorar Island.
- The HST-II developed during the Callovian-Early Oxfordian time is observed in Gadhada Formation. The Ratanpur Sandstone Member shows a progradational shoreline at the base due to the rejuvenation of sediments after MFS which is typical during early HST deposits followed by aggradation.
- The HST-II in the Ratanpur Sandstone and Bambhanka members of Gadhada Formation during Callovian-early Oxfordian time is characterized by shale-dominated succession with thickly bedded micritic sandstone at the base.
- The Khadir and Bela Islands witness a continuous transgression till the end of the Bathonian age where the MFS developed with a progradational shoreline during early Bathonian. This progradational shoreline during transgression is due to the sediments supply outpacing the accommodation space resulting in the formation of the delta front environment.
- The HST-II is characterized by thinly bedded mudstone and allochemic sandstone intercalated with shales, overlayed by thick cross-bedded white sandstone and ferruginous sandstone. This marks the typical progradational shoreline of HST during the Callovian age.
- The sea-level curves show that Jurassic deposits are influenced by the eustacy as well as local tectonics.
- The thicknesses of the lithostratigraphic units of the Jurassic of the Khadir, Bela and Chorar Islands decrease toward the east resulting in a condensed sequence in the basin margin deposits.

The sedimentological, stratigraphical and ichnological data have helped in inferring the genetic sequence stratigraphy and interpreting the depositional environment which has further assisted in the evaluation of the basinal history of the condensed basin margin Jurassic sequence of the Khadir, Bela and Chorar Islands of the eastern Kachchh Basin.