Summary of the Thesis entitled

'Sedimentology, Ichnology and Sequence Stratigraphy of Jurassic Sediments of Khadir, Bela and Chorar Islands, Island Belt Zone, Kachchh, Western India'.

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‘Sedimentology, Ichnology and Sequence Stratigraphy of Jurassic Sediments of Khadir, Bela and Chorar Islands, Island Belt Zone, Kachchh, Western India’.

The Kachchh basin is an E-W oriented pericratonic rift basin formed by the reactivation of a primordial fault in the Precambrian Delhi fault belt during the Late Triassic Gondwanaland breakup (Biswas, 1987). The Mesozoic sediments of the basin were deposited in isolated patches, namely, Mainland Kachchh, Patcham, Eastern Kachchh and Wagad Highland. The present study is carried out in the Eastern Kachchh consisting of the Khadir, Bela and Chorar Islands where Jurassic rocks are exposed. These islands lie along the southern flanks of the Island Belt fault between latitude N 23°46'50 to N 23°56'37″ and longitude E70°10′12" to E70°29′15", latitude N 23°45'54" to N23°57'22", and longitudes of E70°32'10" to E70°55'37" and latitude N 23°41'06" to N 23°57'00" and longitude E71°00'55" to E71°18'36" for Khadir, Bela and Chorar Islands respectively. The first marine encroachment in the sub-basin occur during Aalenian?/Bajocian transgression and is represented by the polymictic conglomerate at Cheriya Bet on the northern tip of Khadir Island. The successions are wholly deposited in marginal marine to offshore conditions and are characterized by clastic, non-clastic and mixed siliciclastic-carbonate sediments.

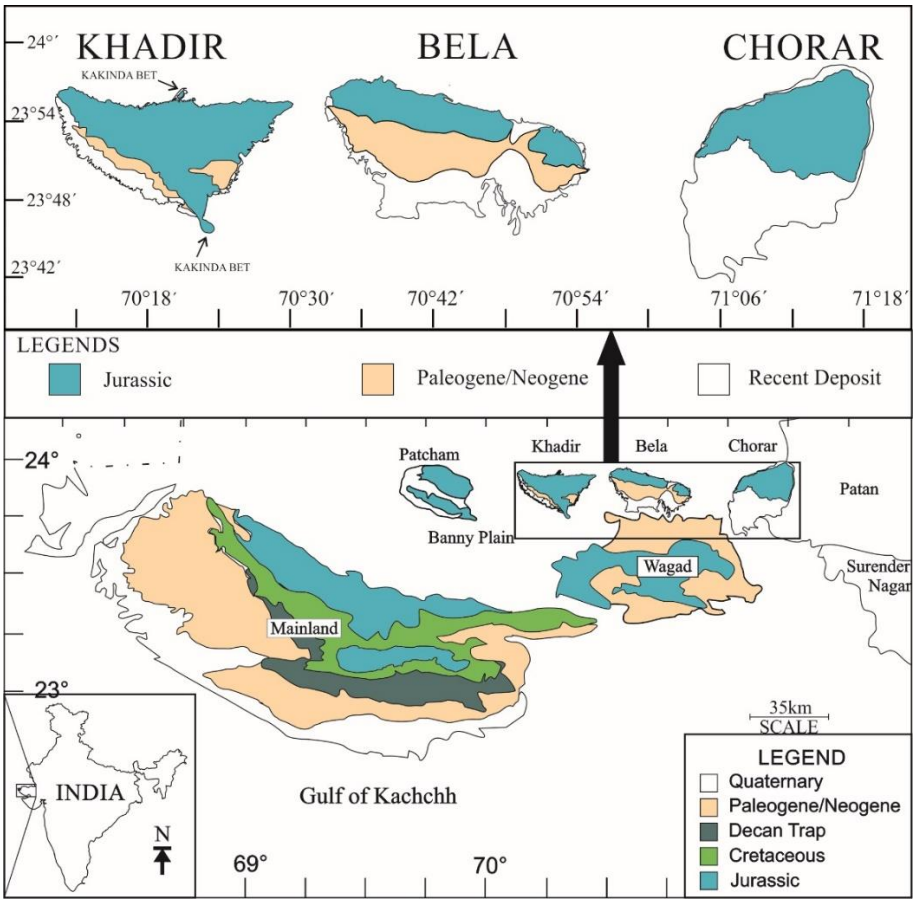

Fig. 1 Location map of the study area.

The Jurassic succession shows wide lateral and vertical facies variation in each of the islands. An active delta was developed during Bajocian till Bathonian in Khadir and Bela and terminates at the end of Bathonian transgression but did not reach Chorar Island. An attempt has been made to deduce the basinal history using sedimentology, ichnology and sequence stratigraphy proxies.

AIMS AND OBJECTIVES

The aim of the study is to describe and interpret the sedimentary facies, ichnofacies, various sequence stratigraphic boundaries/surfaces of exposed Mesozoic sequence in the proposed study area and reconstruct the 3D-depositional model. The main objectives of the investigations are as follows:

i. Delineation with sedimentary facies; mark their lateral and vertical continuity; interpret them into the framework of environmental facies and correlate them between the Khadir, Bela and Chorar Islands.

ii. Identify the trace fossils and analyzed them for ethology, ichnoassemblages and ichnofacies to interpret the various palaeoecological parameters.

iii. Integration of the sedimentological and ichnological data for genetic interpretation of sequence stratigraphic surfaces/boundaries and their associated system tracts.

iv. To determine the depositional environment and basinal history of the Jurassic rocks of Khadir, Bela and Chorar Islands.

Methodology

The following methodologies have been adopted to achieve the above-mentioned objectives:

i. Stratigraphic sections have been measured at different places and generalized lithologs have been prepared.

ii. Systematic samplings have been done for laboratory analysis. Trace fossils were photographed, collected and identified at the species level.

iii. Lateral and vertical continuity of facies have been mapped and correlations was done.

iv. Ichnoassemblage and ichnofacies analysis were made to infer the paleoecological parameters.

v. Sedimentological and ichnological data were integrated for genetic interpretation of sequence stratigraphic surfaces/boundaries and their associated system tracts.

vi. The basinal history is evaluated and 3-D depositional model was reconstructed for the Mesozoic sediments of Khadir, Bela and Chorar Islands.

The present Thesis contains an original work that was carried out and contains 8 chapters which are briefly described as under:

Chapter-1. Basic Concepts

This chapter contains two parts. The first part described the basic concepts of the proxies that are used which include Sedimentology, Ichnology- the characteristics of trace fossils and its application, Sequence Stratigraphy; its definition, and types of sequence methods of sequence stratigraphic analysis. The second part introduces the Kachchh basin, including climate and biota, communication and transport, geomorphology, general geology, structures and tectonics and its mineral wealth. This chapter is concluded with the introduction of the study area, its aim and objectives and the methodologies.

Chapter-2 Mesozoic Stratigraphy

This chapter describes the Mesozoic stratigraphy of Kachchh basin that is exposed at the Mainland Kachchh, Patcham Island, Eastern Kachchh (Khadir, Bela, Chorar Islands and Wagad Highlands). The Mesozoic succession Kachchh Mainland group comprises four formations viz. Jhurio, Jumara, Jhuran and Bhuj; The Patcham Island Group comprises Kaladongar, Goradongar and Modar Hill formations; stratigraphy of the Khadir, Bela and Chorar Islands are include Khadir and Gadhada formations while Wagad Highland comprises of Washtwa and Wagad Sandstone. These formations and their components members are also described in brief.

Chapter-3 Stratigraphy of the Study Area

This chapter describes the stratigraphy of the study area, Khadir, Bela and Chorar Islands in detail along with measured sections. Khadir Island shows the maximum sedimentary thickness of 692 m clastic, non-clastic and mixed siliciclastic carbonate succession. The Khadir Formation (307 m) is further dived into three members viz. Cheriya Bet Conglomerate (42 m), Hadibhadang Shale Member (180 m) and Hadibhadang Sandstone (85 m) members while the Gadhada Formation is further divided into Ratanpur Sandstone (190 m) and Bambhanka (195

m) members. The thickness of these stratigraphic units reduced towards the east. In Bela Island, Khadir Formation is characterized by Hadibhadang Shale (46 m) and Hadibhadang Sandstone (79 m) members while Gadhada Formation by only Ratanpur Sandstone Member (138 m). In Chorar Island, the thickness is further reduced where Khadir Formation is characterized by Hadibhadang Shale (23 m) and Hadibhadang Sandstone (31 m). Similar to Bela Island, the youngest Bambhanka Member is not exposed and Gadhada Formation is represented only by Ratanpur Sandstone Member (55 m) (Patel et al., 2018). Field photographs and a table are also provided to support the data.

Chapter-4 Lithofacies and Depositional Environments

This Chapter describes the lithofacies, their facies association and their interpretation along with the associated trace fossils to deduce the depositional environments. The Jurassic succession of Khadir comprises eight lithofacies which include thinly bedded bioclastic grainstone, thinly bedded bioclastic wackestone-packstone, thinly bedded peloidal wackestone -packstone, thinly bedded peloidal packstone-grainstone, thinly bedded to thickly bedded micritic sandstone, thinly bedded sandy allochemic limestone and shales. The integration of these lithofacies with the ichnological data reveals four environments which include distal fan-delta complex, tide-dominated pro-delta, tide-dominated delta front and offshore-shoreface facies.

The Jurassic succession of Bela Island comprises six lithofacies which include, thickly bedded micritic sandstone, thinly bedded allochemic sandstone, sandy allochemic limestone, bioclastic packstone, mudstone and shales. The Jurassic succession is also bioturbated at varying intensities at different stratigraphic levels. The integration of lithofacies and ichnological data reveals three lithofacies associations which include pro-delta facies association, delta front facies association and offshore-shoreface facies association.

The Middle Jurassic succession of Chorar Island comprises nine lithofacies which include micritic sandstone, allochemic sandstone, sandy allochemic limestone and sandy micrite, cross-bedded white sandstone, ferruginous sandstone, coralline limestone and mudstone and shales (Patel et al., 2018). The sedimentological and ichnological data show shoreface to offshore lithofacies association.

Chapter-5 Ichnology

This chapter provides a brief historical background of ichnology, and its classification. The observed trace fossils are classified and described according to their ichnotaxobase as given by Knaust, (2012) and comprise **sub-horizontal (***Asterosoma* isp**.,** *Curvolithus multiplex, C. simplex, C.* isp., *Didymaulichnus lyelli, Gyrochorte comosa, Halopoa imbricata, Helicolithus sampelayoi, Laevicyclus parvus, Megagrapton irregular, Palaeophycus haberti, P. tubularis, Phycodes curvypulmatum, P. palmatus, Planolites baverleyensis, P. montanus, P. oblitrata, Protovirgularia* isp., *Rhizocorallium commume var auriform, R. commune var irregulare, Rhizocorallium 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, Ophiomorpha* isp., *Thalassinoide horizontalis, T. paradoxicus* and *Thalassinoides* isp.,) forms. The associated trace fossils in each lithofacies, stratigraphic position and probable trace makers are given/discussed. Field photographs of each species is also provided.

Chapter-6 Palaeoecology

Trace fossils provide a tangible animal behavioural activity that can be classified based on their behavioural pattern or ethology (Bromley, 1996). The ethological classification proposed by Seilacher (1953) consisting of five behavioural categories is adopted as they represent the basic building blocks of behavioural interpretations (Buatois and Mángano, 2011) and are presented along with their trace makers (Table. 1). Tables are also provided to show the distribution of trace fossils in different facies for each member and island.

The trace fossils of the Jurassic succession of Khadir Island comprises 36 ichnospecies belonging to 19 ichnogenera forming six ecologically related and recurring associations which include *Diplocraterion, Hillichnus, Lockeia, Planolites-Palaeophycus, Rhizocorallium* and *Protovirgularia* assemblages. The traces fossils of Bela Island comprised 23 ichnospecies belonging to 17 ichnogenera forming three ichnoassemblages which include *Monocraterion, Thalassinoides,* and *Hillichnus* assemblages while Chorar Island consists 20 identifiable ichnospecies belonging to 16 ichnogenera forming five recurring trace fossils assemblage which include *Hillichnus, Rhizocorallium, Gyrochorte, Thalassinoides* and *Skolithos* assemblages. The ichnological analysis of the Khadir, Bela and Chorar Islands trace fossils shows *Skolithos, Cruziana* and *Skolithos-Cruziana* ichnofacies.

ETHOLOGY	BEHAVIOUR	TRACE FOSSILS	PRODUCERS
Cubichnia	Resting traces	NA	NA
Domichnia	Dwelling	*Arenicolites* *Diplocraterion* *Hillichnus* *Lockeia* *Monocraterion* *Ophiomorpha* *Palaeophycus* *Skolithos*	Worms Worms Tellinacean bivalve Bivalve Worm like animal Crustacean Polychaetes Annelids and polychaetes
Repichnia	Locomotion	*Curvolithos* *Didymaulichnus* *Gyrochorte* *Halopoa*	Scavenging gastropods Molluscans Annelids Priapulid worms
Pascichnia	Grazing	*Megagrapton* *Planolites*	Graphoglyptids Polyphyletic vermiform
Fodinichnia	Feeding traces	*Asterosoma* *Chondrites* *Helicolithus* *Hillichnus* *Laevicyclus* *Phycodes* *Protovirgularia* *Rhizocorallium* *Taenidium* *Thalassinoides*	Decapod crustacean Chemosymbiotic animal Graphoglyptid Tellinacean bivalve Annelid Vermiform annelids Bivalve Crustacean or scavengers Polychaetes/Crustaceans Crustaceans

Table 1: Generalized Seilacherian ethological classification of trace fossils with their possible trace maker from Khadir, Bela and Chorar Islands.

Chapter-7 Sequence Stratigraphy

This chapter presented the model-dependent genetic sequence stratigraphy of the Jurassic successions of Khadir, Bela and Chorar Islands. Two genetic cycles are described in each of the islands. In Khadir Island, the genetic sequence comprises of LST-I, TST-I and HST-II with MFS as a sequence boundary on top of TST-I. The Bela and Chorar Islands show similar systems tracts with include TST-I and HST-II with MFS separating the two cycles/systems tract (Darngawn et al., 2019). The shoreline projection is also compared with the global sea-level curve given by Haq et al., (1987) and Hallam, (1988) to shed a light on the role of the rate of sedimentation and local tectonics. The successions of Khadir, Bela and Chorar Island show condensation in the thickness along the depositional strike and accordingly, basin margin condensed sequence as well as lithostratigraphy is also described.

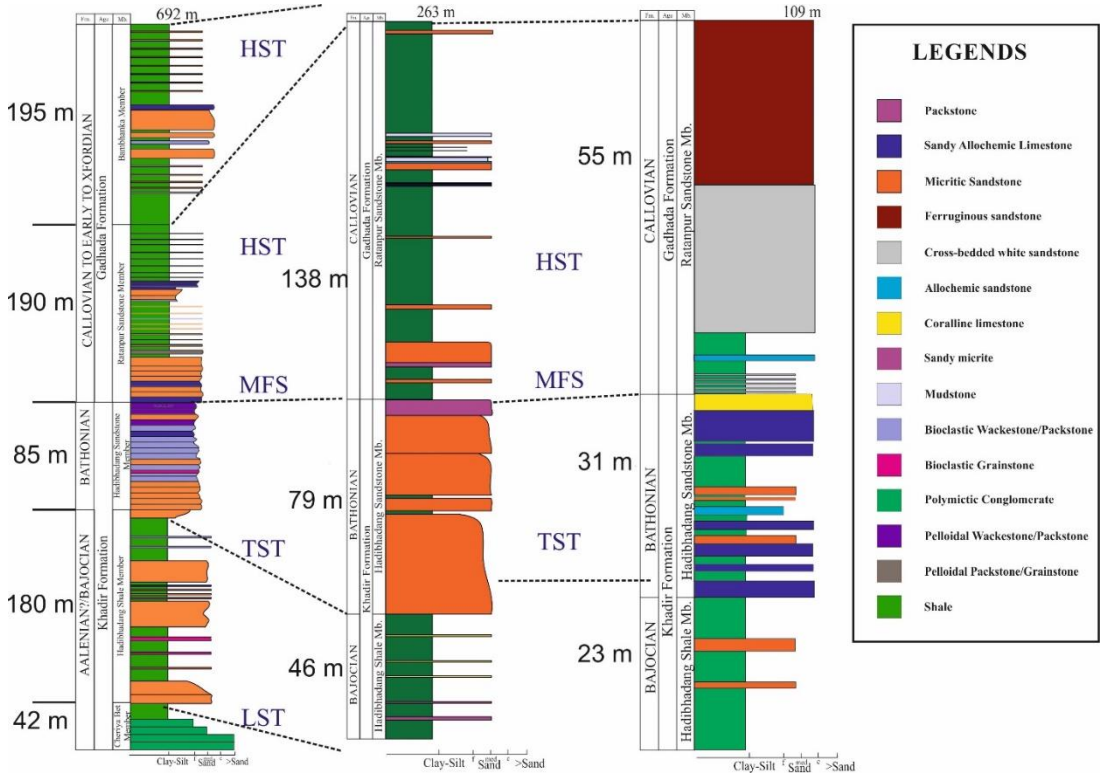

Fig. 1 Litholog of Khadir, Bela and Chorar Island show the developed and exposed sequence of the Jurassic which are correlated amongst each other depicting the condensed stratigraphic units.

Chapter 7 Discussion and Conclusions

In this chapter, the overview of the lithostratigraphy, the lithofacies and its depositional environments, ichnology, palaeoecology and genetic sequence stratigraphy is discussed in brief. The conclusions are drawn from various studied aspects of lithostratigraphy, sedimentology, ichnology, and sequence stratigraphy.

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