SEDIMENTOLOGY, ICHNOLOGY AND SEQUENCE STRATIGRAPHY OF JURASSIC SEDIMENTS OF KHADIR, BELA AND CHORAR ISLANDS, ISLAND BELT ZONE, KACHCHH, WESTERN INDIA

A SYNOPSIS OF THE THESIS SUBMITTED TO
THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (GEOLOGY)

BY
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UNDER THE GUIDENCE OF
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AUGUST, 2019

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To,
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Through Proper Channel

Ref: Ph. D. Registration **No.FOS/1944 date 22/08/2015.**

Subject: Submission of the Synopsis Entitled "Sedimentology, Ichnology and Sequence Stratigraphy of Jurassic Sediments of Khadir, Bela and Chorar Islands, Island Belt Zone, Kachchh, Western India" by Jehova Lalmalsawm Darngawn"

Sir,

Please find herewith four copies of the synopsis submitted by the Mr. Jehova Lalmalsawm Darngawn for your kind perusal.

Thanking You,

Yours faithfully

(Satish J. Patel)
Guide

Head
Department of Geology

Dean
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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 Mesozoic succession of Kachchh Basin ranges in age from Middle Jurassic to Cretaceous and are exposed in six disconnected areas which form the highlands viz. Kachchh Mainland, Patcham Island, Khadir Island, Bela Island, Chorar Island and Wagad highland. The lithofacies vary from one part of the basin to the other and are detached; faults bounded and are separated by covered plains making it difficult to trace a set of rock units. Therefore, for a systematic description and proper representation of the stratigraphy, a separate lithostratigraphic classification is proposed by Biswas (1977). Accordingly the lithologically correlatable areas of Wagad, Bela, Khadir and Chorar, collectively known as the Eastern Kachchh, the Mainland Kachchh and Patcham Island were recognized.

The Jurassic succession of Kachchh preserved excellent record of the geological past in the form of lithified rocks succession, body fossils and trace fossils. Various works on geological aspects (sedimentological, ichnological and sequence stratigraphical) had been carried out in Mainland Kachchh (Patel et al, 2009, 2018; Bhatt et al., 2012) Wagad (Shingarpure *et al* .,1976; Kulkarni and Ghare, 1989; Bhattacharya *et al*.,2013, Joseph et al., 2019), and Island Belt zone (Patel et al., 2010, 2012, 2014, 2018; Darngawn et al., 2018, 2019). However, the study area Khadir, Bela and Chorar Islands have remain greatly neglected due to patchy outcrop and unfriendly terrain.

The proposed study was carried out in Khadir, Bela and Chorar Islands located in the Island Belt Zone, Kachchh, Western India (Fig.1). Khadir, Bela and Chorar islands are located 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” respectively (Fig. 1) seperated by graben where recent evaporites were deposited. The Jurassic rocks of Khadir, Bela and Chorar Islands were deposited in an isolated sub-basin ranging in age from Aalenian? to Oxfordian and comprises of two formations namely, Khadir and Gadhada formations characterised by clastic, non-clastic and mixed siliciclastic-carbonate rocks. The succession shows wide vertical and lateral variation in sedimentary facies, structures and often highly bioturbated.

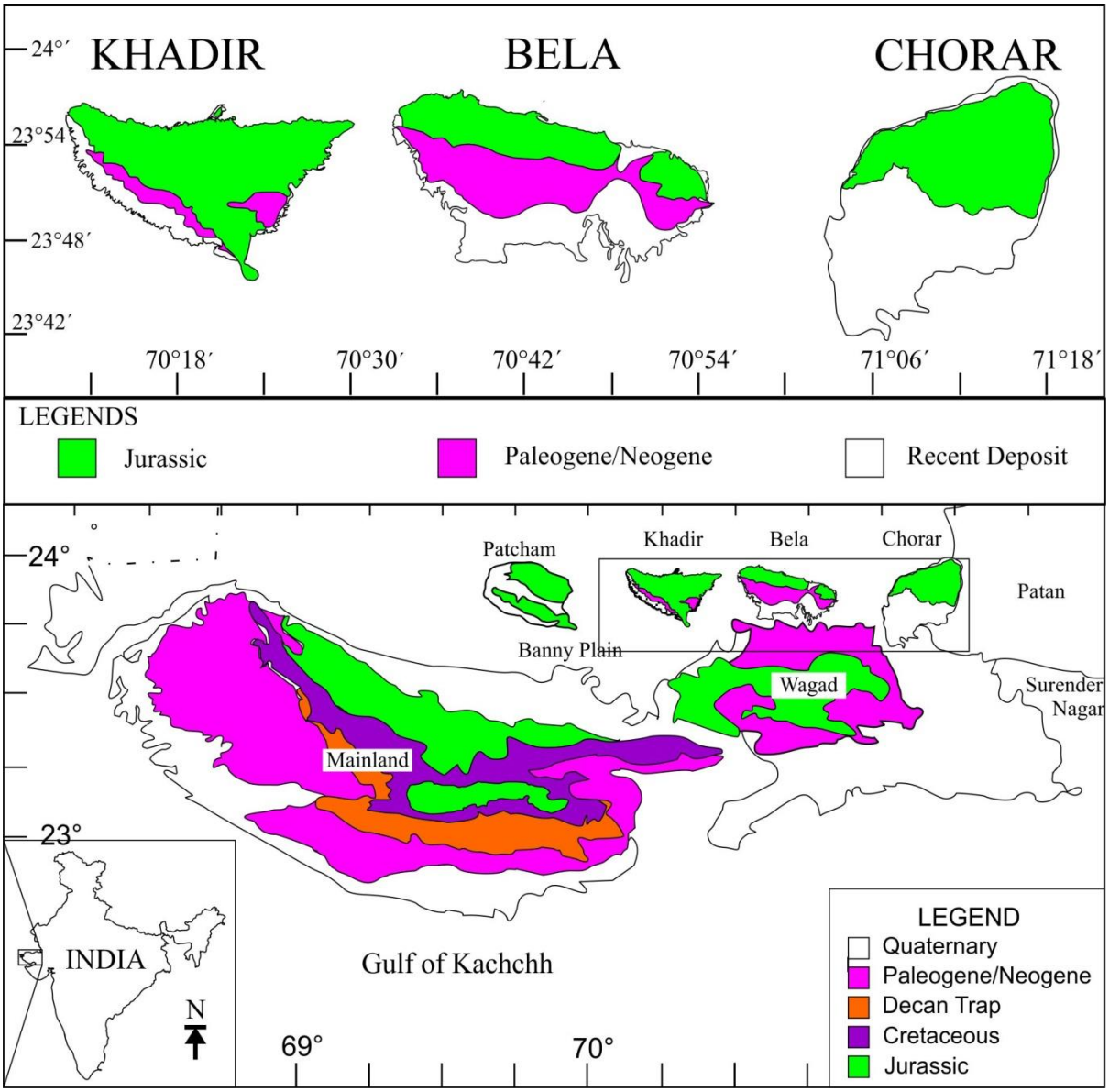

Fig.1Generalised geological map of Kachchh showing locations of the island belt, study area.

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

i. Delineation with sedimentary facies in the framework of environmental facies and mark their lateral and vertical continuity and correlate them between the Khadir, Bela and Chorar islands.
ii. Recognition of the substrate controlled ichnofacies and analysis of vertical ichnological successions.
iii. Integration of the sedimentological and ichnological data for genetic interpretation of sequence stratigraphic surfaces/boundaries and their associated system tracts.

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

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

i. Stratigraphic sections have been measured at different places and generalized lithologs will be prepared.
ii. Systematic sampling will be done for laboratory analysis. Trace fossils have been photographed, collected and identified at species level.
iii. Lateral and vertical continuity of facies have been mapped and correlations have been made.
iv. Quantification of bioturbation, ichnofabric, ichnocoenoses and ichnofacies analysis have been made to infer the ichnological events.
v. Sedimentological and ichnoichnological data have been integrated for genetic interpretation of sequence stratigraphic surfaces/boundaries and their associated system tracts.
vi. Basinal history will be reconstructed for the Mesozoic sediments of Khadir, Bela and Chorar Islands.

To achieve the above objectives, Survey of India toposheets nos. 41 I/1, 41 I/5, 41 I/9, 41 I/13, and 41 M/1 were taken as the base map to study Khadir, Bela and Chorar Islands Several traverses have been taken at different localities to study and document the stratigraphic boundaries, lateral and vertical facies variation and continuities along with the physical and biogenic signatures. Systematic sampling of the exposed rocks was done for petrographic study. Trace fossils were photographed and collected wherever possible for identification upto species level. The boundary of Khadir and Gadhada formations was marked considering the lithological and paleontological characteristics. Petrographic analysis of the collected rock samples were made to study the composition, texture such as sorting roundness etc. The field observation data, sedimentological data and the ichnological data are integrated to deduce the depositional system to understand the processes and process response of the sediments, their cyclicity and relationship with base level changes. The data from each island is then correlated to understand the sequential filling of the sub-basin.

The stratigraphy of the eastern Kachchh basin is represented by inter-related coeval rock units exposed in the disconnected outcrops of Wagad, Khadir, Bela and Chorar Islands. The study area, Khadir, Bela and Chorar Islands exposes rocks of Jurassic which are divided in to Khadir and Gadhada formations (Table-1).

The name Cheriya Bet (Fig.2) is derived from the small Islet in the north of Khadir Island where polymictic conglomerate is mono dominantly exposed. The clast mainly consists of pink, brown to black pebbles and cobbles of granites and syenites. The pebbles and cobbles are angular and faceted suggesting to have been dumped together after a very short distance of transport.

<table>
<tr><td colspan="4">EASTERN KACHCHH (KHADIR-BELA-CHORAR)</td></tr>
<tr><td>Age</td><td>Formation</td><td>Member</td><td>Lithology</td></tr>
<tr><td>Oxfordian</td><td rowspan="2">Ghadada</td><td>Bambhanka/Gangta</td><td>Shale and Sandsotone</td></tr>
<tr><td>Callovian</td><td>Ratanpur Sandstone</td><td>Sandsotone, Limestone and shale</td></tr>
<tr><td rowspan="3">Bathonian
Aaelenian?</td><td rowspan="3">Khadir Formation
Khadir Island
(650m)</td><td>Hadibhadang Sandstone</td><td>Sandstone, Limestone, Mixed siliciclastic carbonate sediments</td></tr>
<tr><td>Hadibhadang Shale (280m)</td><td>Shale, Micritic Sandstone</td></tr>
<tr><td>Cheriya Bet Conglomerate (25m)</td><td>Petromict Granite, Cobble, Conglomerate and arkose</td></tr>
<tr><td>Precambrian</td><td></td><td colspan="2">Granitic Basement</td></tr>
</table>

Table 1: Generalized lithostratigraphy of Eastern Kachchh (Khadir-Bela-Chorar Island). (Biswas, 1977, 2016)

Hadibhadang Shale Member is observed at the north facing scarp of the Khadir and Bela Island, and core of the Chorar Island. Thickness of the member is highly variable in different islands and maximum being of 180m in Khadir Island. This thick shale dominated succession often intercalated with thickly cross-bedded micritic sandstone with thin bands of bioclastic packstone/grainstone and sandy allochemic limestone belongs to Bajocian age. This member witness wide lateral facies variation with interfingering of micritic sandstone

and shales as well as increase in argillaceous content from west to east. The thick shale succession is often intercalated with thickly cross-bedded micritic sandstone with thin bands of bioclastic packstone/grainstone and sandy allochemic limestone in Khadir Island where western part of the island is dominated with thickly bedded, friable, cross-bedding micritic sandstone containing huge log of wood fossils and the eastern part of the Island is dominated with shale intercalated with bedded micritic sandstone. In Bela and Chorar Islands, this member is dominantly shally in nature barring few thin bands of micritic sandstone and limestones. The top of the member is marked by a facies transition from argillaceous shale to thick micritic sandstone.

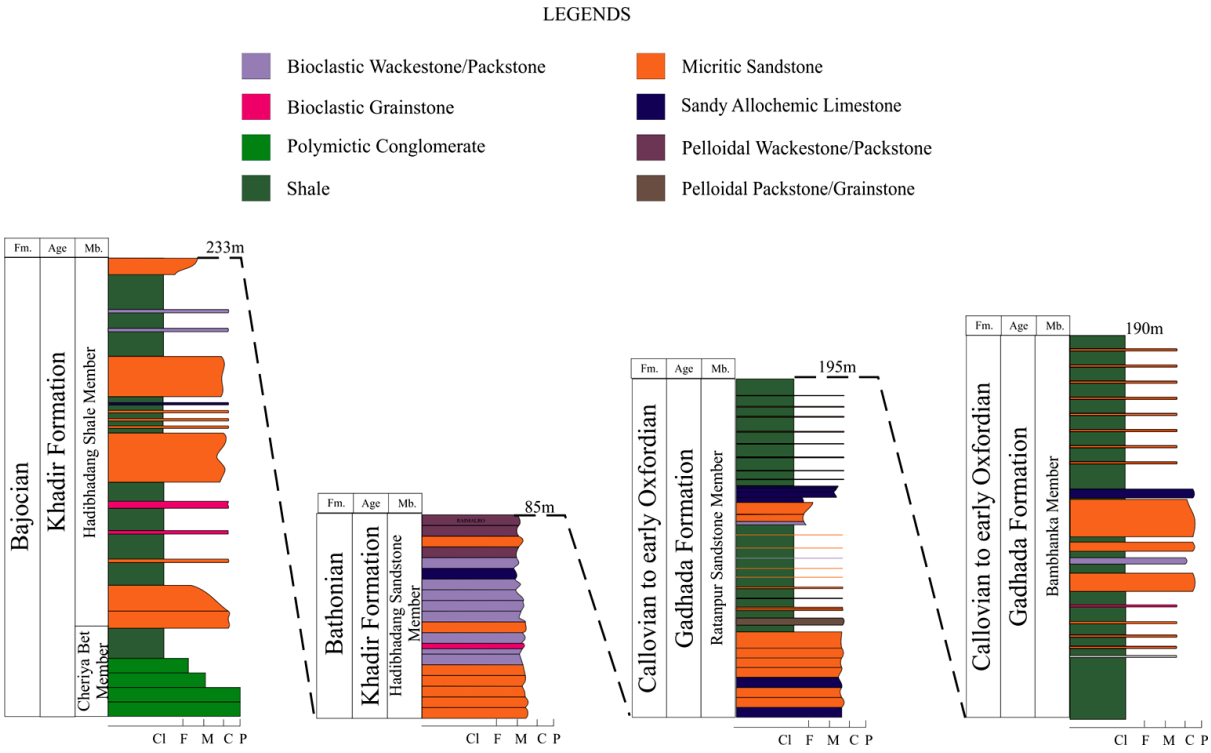

Fig.2 Generalized lithosection of the Khadir Island.

Hadibhadang Sandstone Member forms north facing vertical cliff as well as upper part of the back slope of the Khadir, Bela and Chorar Islands. This member shows wide lateral facies variation from island to island with maximum thickness of 85m clastic and non clastic deposits in Khadir Island belonging to Bathonian age. In Khadir Island this member is characterised by thick grey friable micritic sandstone showing gradation from shales to sandstone marks the base of the member overlain by thick yellowish micritic sandstone. This micritic sandstone is cross-bedded, fine to coarse grain in nature with pockets of polymictic conglomerate. The carbonate component increases towards the top and grades in bioclastic/pelloidal packstone. The top of the member is marked by thinly bedded pelloidal

packstone with cherty noodles which is a facies variant of Raimalro Limestone Member of Patcham Formation. In Bela Island, thick cross-bedded, friable, grey to pale yellow micritic sandstone capped by bioclastic packstone characterised the member while in Chorar Island it form an intercalation of mixed siliciclastic-carbonate with shales.

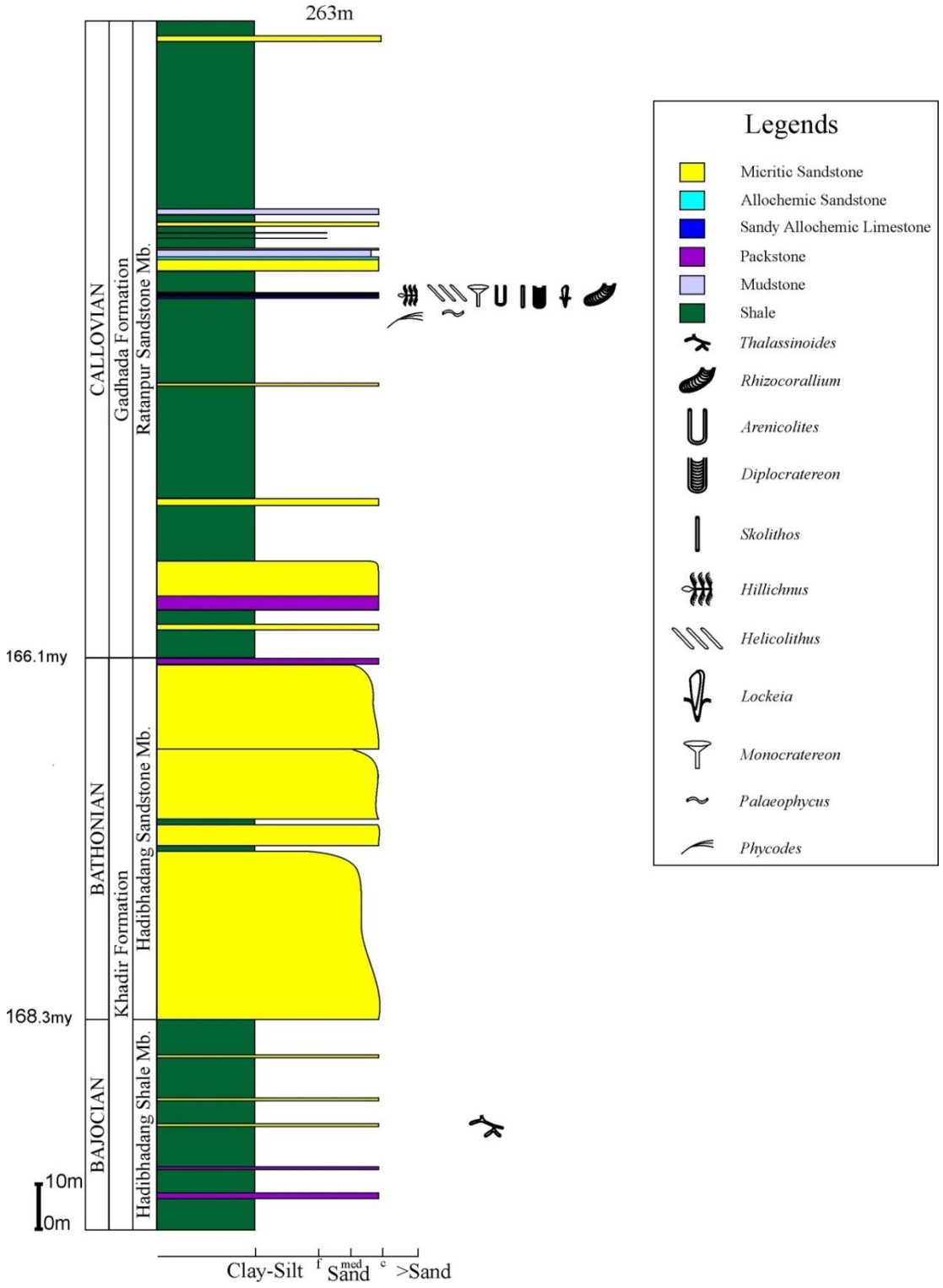

Fig.3 Generalized lithosection of the Bela Island showing lithofacies and occurrence of trace fossils.

Gadhada Formation comprises of 385m thick succession which is broadly divided into Ratanpur Sandstone and Bambhanka members belonging to Callovian to early Oxfordian age. This formation is sandstone dominated which shows gradual increase in the argillaceous content towards the top.

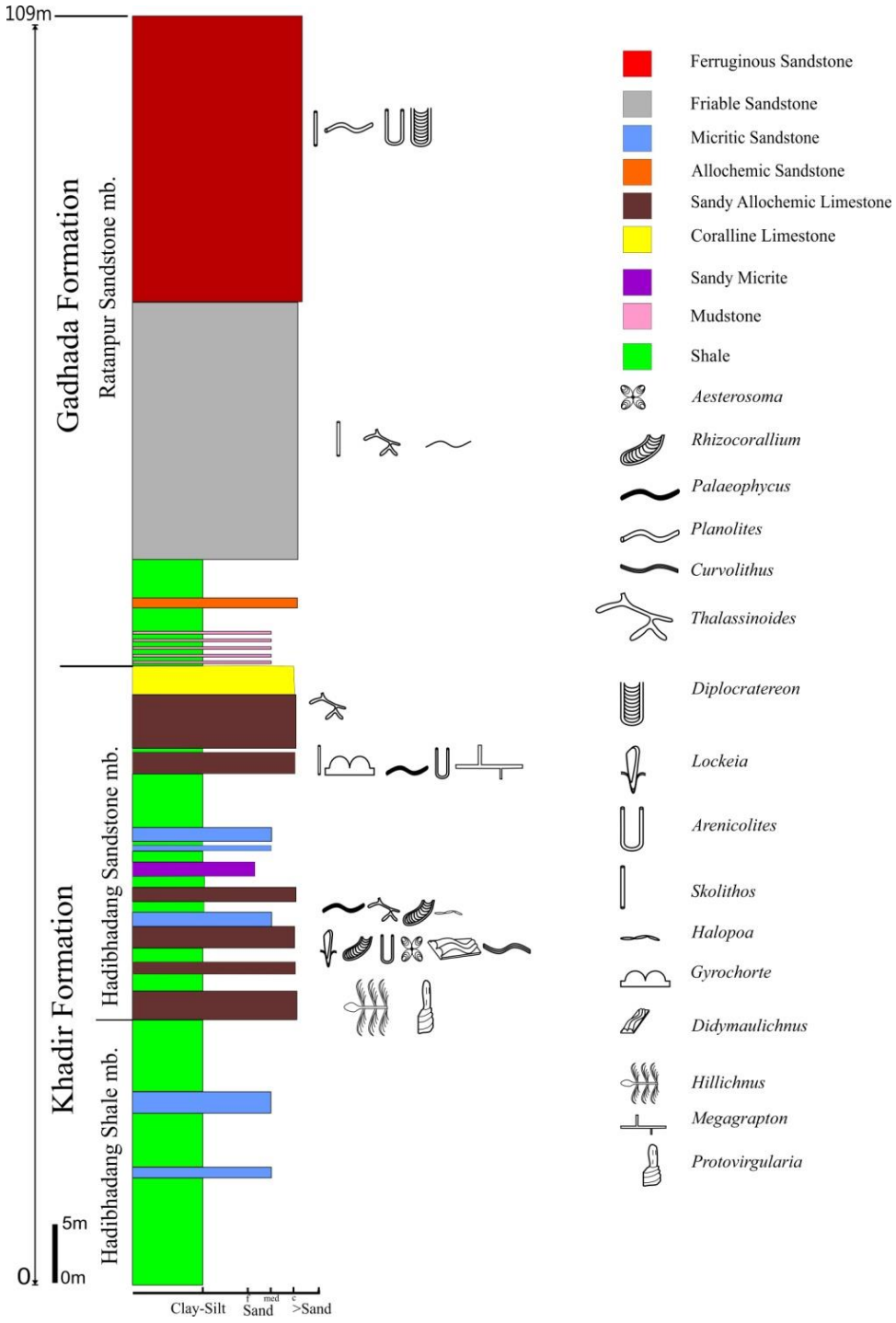

Fig.4 Generalized lithosection of the Chorar Island showing the distributions of the trace fossils.

Ratanpur Sandstone Member is the best exposed on back slope of Khadir and Bela Islands, and forms prominent peripheral part of the Chorar Island. This unit is 385m thick and well developed in all the three islands but maximum thickness is observed at Khadir Island. This member is arenaceous at the base mainly consist of micrictic sandstone which cover most of the back slope of the Island with few bands of sandy allochemic limestone. The micricitic sandstone is yellowish to brown in color with occasional cross-bedding and contain pockets/lenses of conglomerate. The Chorar Island comprises of ferruginous sandstone and friable white sandstone.

Bambhanka Member comprises of 195m thick succession well exposed in a small islet called Kakinda Bet and the southern tip of Khadir Island. The islet is intensely faulted and is preserved as half dome with beds dipping generally towards the west. This member is characterized by greyish gypseous shale at the base with thin bands of highly fossiliferous bands. The gypseous shale is overlain by highly fossiliferous limestone containing ammonite, alectronia, belemenites etc. with micritic sandstone which are bioturbated at varying intensity. The micritic sandstone becomes highly ferruginous at times with concoidal structure while at times very friable with abundant *Rhizocorallium*. The thickly bedded friable micritic sandstone is overlain by shale intercalated with thin bands of calcareous sandstone, golden oolite.

Field study and petrographic analysis exhibited both vertical and lateral variations in bed geometry, texture, structures and mineral compositions. The rock types were classified as per Dott (1964) classification of sandstones, Dunhum (1962) classification of limestones and Mount (1985) classification of mixed siliciclastic carbonates. The sequence mainly comprises of mixed siliciclastic-carbonate sediments with clastic bands of shale and conglomerates as well as non-clastic bands of packstone and mudstone.

Khadir Island exposed all stratigraphic units and shows wide range of lithological variations (Fig.2). The Jurassic succession of Khadir Island is broadly divided in to eight lithofacies, viz. polymictic conglomerate, shales, micritic sandstone, sandy allochemic limestone, bioclastic packstone/wackestone, bioclastic grainstone, pelloidal wackestone/packstone and pelloidal packstone/grainstone.

The Jurassic succession of Bela Island (Fig.3) comprises of 263m thick mixed siliciclastic-carbonate sediments with clastic bands of shale as well as non-clastic bands of packstone and mudstone. Based on field observation and laboratory analysis the succession is divided in to six facies, namely packstone, mudstone, micritic sandstone allochemic sandstone, sandy allochemic limestone and shale.

The Jurassic rocks of Chorar Island comprises (Fig.4) of 109m thick and is dominated by mixed siliciclastic-carbonate (micritic sandstone, allochemic sandstone, sandy allochemic limestone and sandy micrite facies) sediments with few bands of clastic (cross-bedded white sandstone, ferruginous sandstone and shales facies) and nonclastic (coralline limestone and mudstone facies) sediments.

The sediments of the Khadir and Gadhada formations of the study area yielded variety of trace fossil genera of diverse groups. Khadir succession is highly bioturbated and consists of most diverse group of trace fossils. Total 20 ichnogenera are identified which includes, *Arenicolites, Beaconites, Chondrites, Curvolithus, Didymaulichnus, Diplocraterion, Gyrochorte, Hillichnus, Imbrichnus, Levicyclus, Lockeia, Monocraterion, Ophiomorpha, Palaeophycus, Planolites, Protovirgularia, Rhizocorallium, Skolithos, Taenidium, and Thalassinoides.* The Bela Island sequence is also bioturbated but comprises of less diverse group of trace fossils which includes *Arenicolites, Diplocratereon, Helicolithus, Hillichnus, Lockiea, Monocratereon, Palaeophycus, Phycodes, Planolites, Rhizocorallium, Skolithos* and *Thalassinoides*.

The Chorar sequence is bioturbated in varying intensity and comprises of 19 identifiable ichnospecies which includes, *Arenicolites carbonarius, Asterosoma* isp., *Curvolithus* isp., *Didymaulichnus lyelli, Diplocraterion* cf *parallelum, Gyrochorte comosa, Halopoa imbricata, Hillichnus lobosensis, Lockeia silliquaria, Megagrapton irregulare, Palaeophycus tubularis, Planolites beverleyensis, Protovirgularia rugosa, Rhizocorallium commune* var *irregulare, Skolithos linearis, S. verticalis, Skolithos* isp., *Thalassinoides horizontalis* and *T. paradoxicus.* The sequence is characterised by ethologically less diverse groups, mainly of dwelling and feeding structures. Presence of *Hillichnus lobosensis* in sandy allochemic limestone facies shows different feeding strategies adopted by bivalves indicating a complex organism–sediment interaction. The characteristic set of environmentally related group of trace fossil reveals five ichnoassemblages (*Gyrochorte, Hillichnus, Rhizocorallium, Skolithos* and *Thalassinoides*) which represent *Skolithos* and *Cruziana* Ichnofacies.

These trace fossils showed different behavioural patterns which grouped them into Seilacherian five classical ethological groups namely, *Domichnia, Fodinichnia, Pascichnia, Repichnia* and *Cubichnia*. The distribution of the trace fossils in the various litho-stratigraphic units with estimation of their abundance is carried out. Ichnogenera are further analysed for ichnodisparity.

The trace fossils recurred throughout the sequence and represented nine ichnoassemblages namely *Arenicolites, Hillichnus, Gyrochorte, Ophiomorpha, Planolites/*

Palaeophycus, Rhizocorallium, Skolithos and *Thalassinoides,* assemblages. The diversity of trace fossils and proportions of particular groups within the trace fossil assemblages were also studied which suggested the diversity of trace makers, their structure and preservational conditions. These assemblages are characterized by a particular association of trace fossils in a particular bed which indicate hydrodynamic condition, mode of food supply, oxygenation conditions, substrate conditions and bathymetry.

These trace fossil assemblage showed characteristics of the Seilacherian *Skolithos, Cruziana,* and mixed *Skolithos-Cruziana* ichnofacies. The highly bioturbated surfaces mainly showing horizontal structures indicates the low energy periods while the episodic storm events are represented by those belonging to the mixed *Skolithos-Cruziana* ichnofacies. High energy foreshore areas and submarine shoals are represented by members of the *Skolithos* ichnofacies such as *Ophiomorpha, Arenicolites* and *Diplocraterion*. The storm-influenced shoreface-offshore contained both members of the *Cruziana* (e.g. Rhizocorallium, *Gyrochorte, Thalassinoides, Taenidium* and *Chondrites*), and the *Skolithos* ichnofacies (*Arenicolites, Ophiomorpha and Skolithos*).

The structural and textural assessment of the sediments with associated trace fossils of the Khadir and Gadhada formations represent a wide range of depositional facies belts ranging from alluvial fandelta and foreshore to lower shoreface, shoreface to offshore and transitional to offshore region. The sedimentological and ichnological data collected were also studied for the delineation of the associated sequence stratigraphic boundaries, identification of the stratigraphic surfaces and system tracts, and interpretation of the sedimentary cycles and sea level changes during the Bajocian to oxfordian times in the Khadir, Bela and Chorar Islands.

The sequence stratigraphy approach is applied to the depositional system in order to understand the process of facies formation, their relationship and cyclicity in response to the sea level changes. The lateral correlation of the coeval depositional systems are carried out to reveal the facies predictability based on the basin-wide nature of the controls on sedimentation and a sequence stratigraphic model is constructed to explain the stratigraphic architecture and evolution of the basin. Finally, the author has synthesized sedimentological, ichnological, sequence straigraphical and palaeoecological inferences and reconstructed three dimensional depositional and two dimensional sequence stratigraphic model of the Khadir, Bela and Chorar Islands.

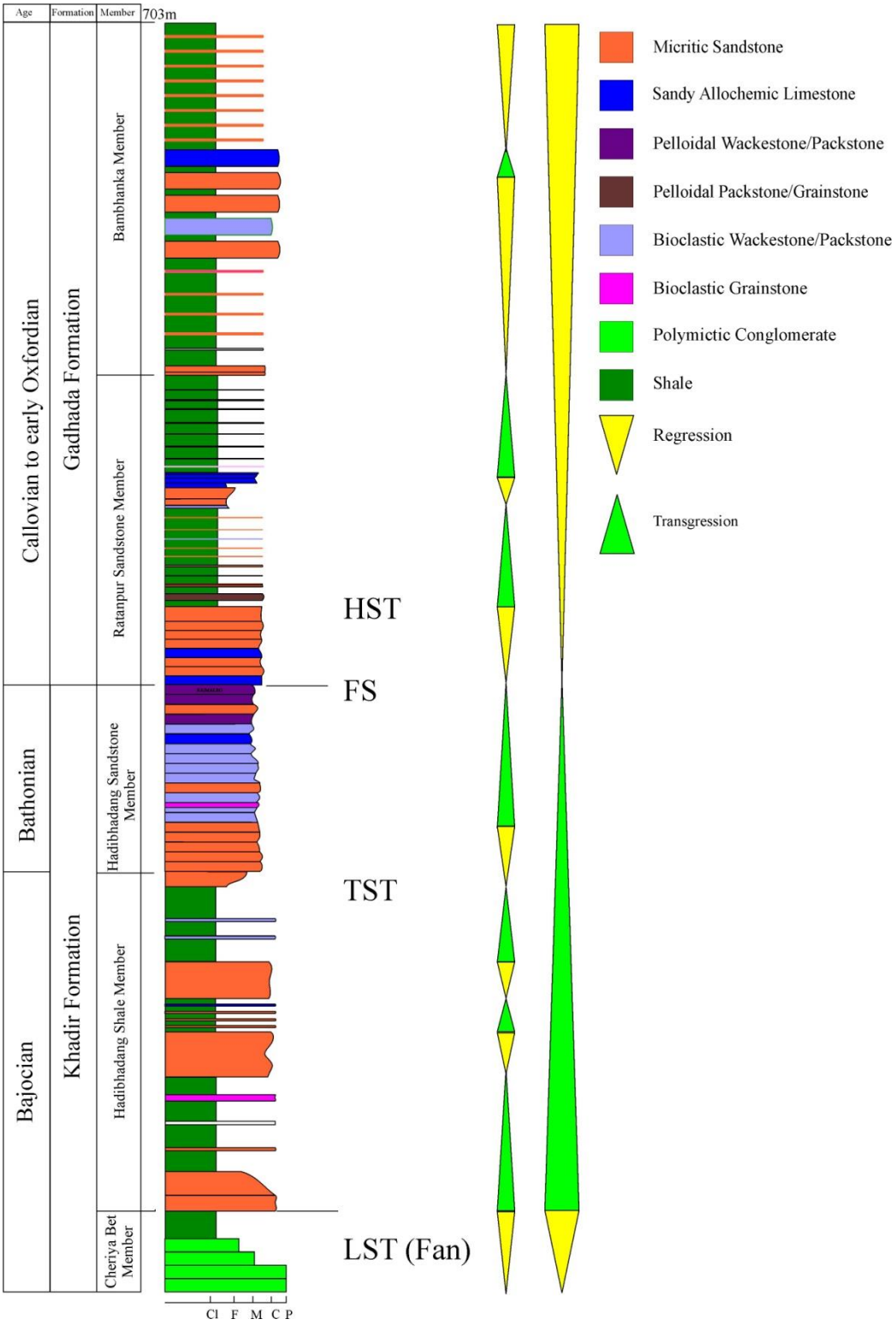

Fig.5. Composite litholog of Khadir Island showing process response relative to sea level changes.

The Jurassic succession of Khadir, Bela and Chorar Islands comprises of Khadir and Gadhada formations characterised by various lithofacies and trace fossils content. Genetic Sequence Stratigraphic Model (Galloway 1989) is used to deduce depositional sequence with

MFS as the bounding surface. The Jurassic succession of Khadir Island comprises of LST, TST-I and HST-II; The LST (Fig.5) is only observed in the northern tip of Khadir Island characterised by Polimictic conglomerate of alluvial fan deposit. TST-I and HST-II separated by MFS at the Hadibhadang Sandstone (Bathonian) and Ratanpur Sandstone (Callovian)

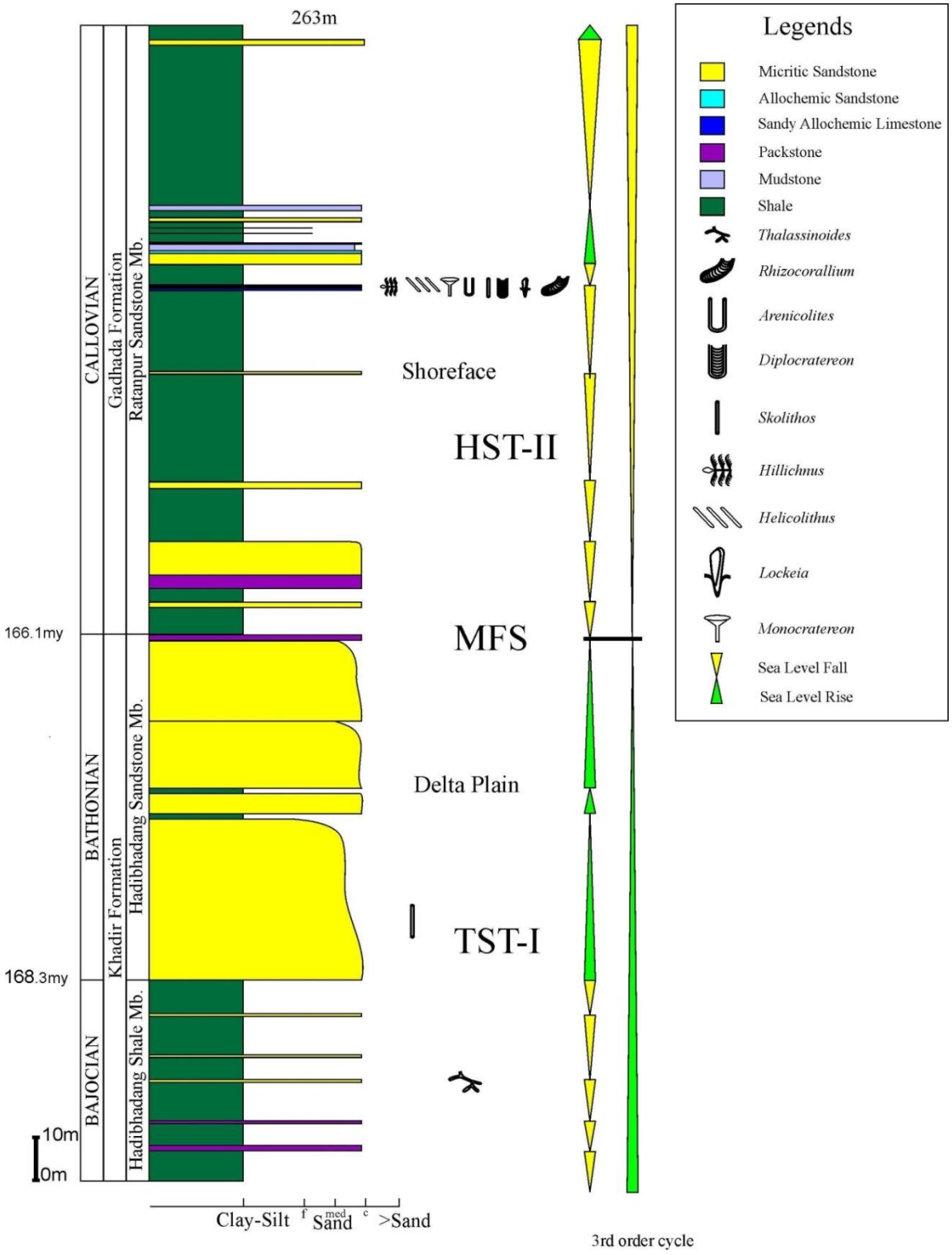

Fig.6. Composite litholog of Bela Island showing System Tracts.

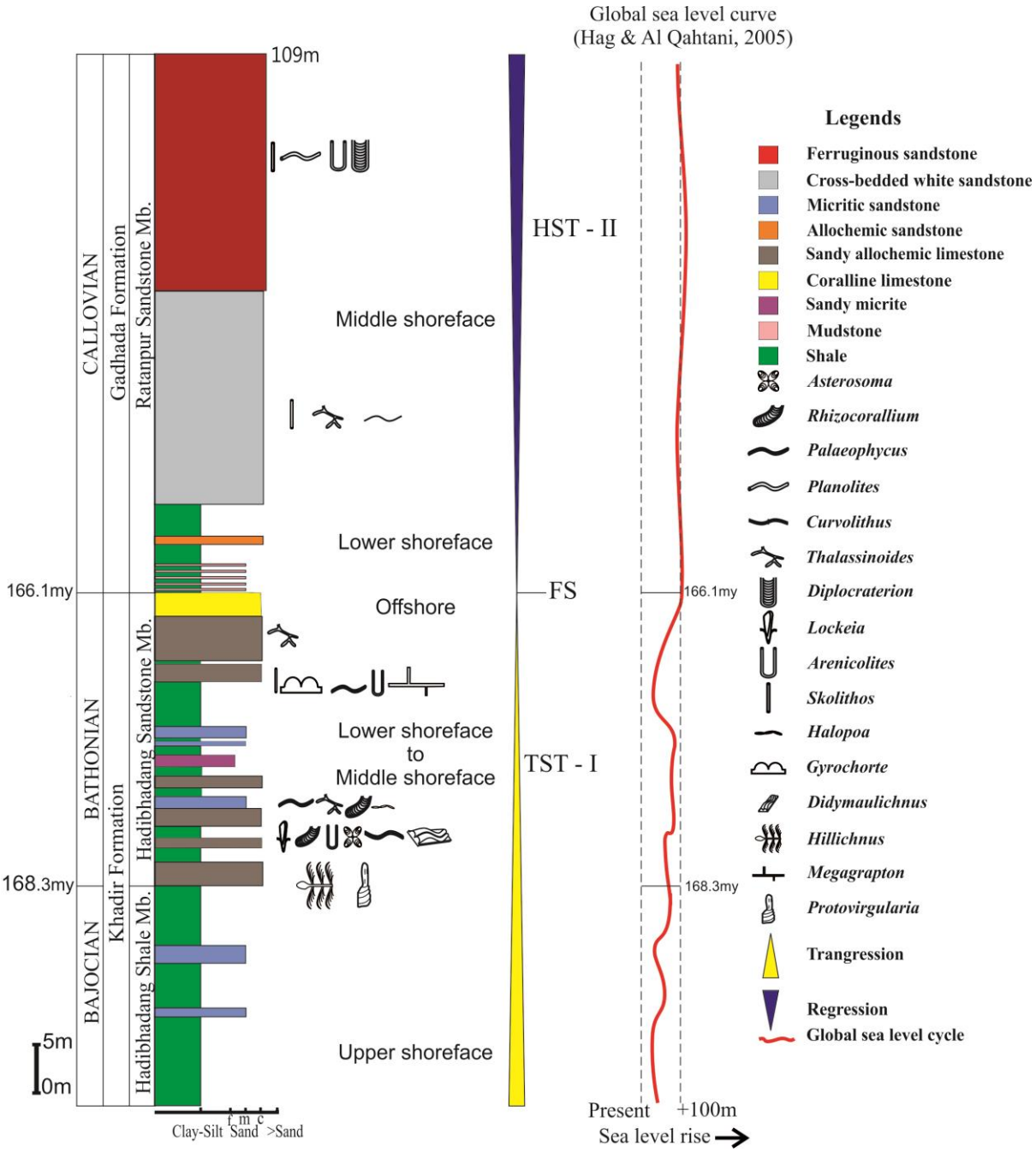

Fig. 7. Composite litholog of the Middle Jurassic succession of Chorar Island, showing facies and associated ichnofossil genera response to the sea level cycle within each genetic cycle.

members interface is observed throughout the study area and served as a marker bed for inter-Island correlation (Fig. 5, 6 & 7). The TST-I characterized by low terrigenous influx and high carbonate productivity that marked an increase in the accommodation space while and HST-II characterized by high terrigenous influx and low-carbonate productivity which marked the decrease in accommodation space. Fluctuations in the energy condition, sediment influx,

environmental changes, associated trace fossils, depositional regime and the sea level conditions are reflected in the sedimentary facies and the depositional stacking patterns during the Bajocian-Oxfordian age. The succession of the study area represents Lowstand Systems Tract (LST) aggraded in fandalta environment and marine sequence shows aggradational and progradational Transgressive Systems Tract overlain by aggrading Highstand Systems Tract.

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