CHAPTER 8

DEPOSITIONAL MODEL OF THE STUDY AREA

8.1 INTRODUCTION

The Middle Jurassic (Bathonian to Oxfordian) sequence of the study area (Jhura dome) comprises both carbonate and mix carbonate-siliciclastic sediments. The shallow marine carbonate rocks occur in three setting: platforms, shelves and ramps and their facies patterns and sequences in these settings are distinctive (Tucker 198). Many sedimentologists have worked on the field of carbonate facies and facies models (Wilson 1975, James 1978, and Flugel, 1982) of Precambrian and Phanerozoic carbonate sediments. The separate view of the mixed carbonate-siliciclastic sediments is best illustrated by the manner in which sedimentology texts are divide into chapters (1970). Recently, the sedimentologists are paying their attention on mixed carbonate-siliciclastic sediments of modern and ancient environment because the mixed sediments are not simply the odd exception, but it is quite common in shallow water marine environments. In shelf environments the formation of sediments composed of mixtures of siliciclastic and carbonate material involves a variety of biologic and sedimentologic processes (Mount, 1984). Although many studies dealing with recent mixed carbonate-siliciclastic systems discuss the flora and fauna that are present, most studies addressing ancient systems concentrate on physical depositional processes, and only peripherally consider trace and body fossil assemblages.

The objectives of the present study are to: 1) describe the depositional environments in context to associated lithofacies (BLs; CSSL; GOs; NWWLs; RMCSSL; DOs), 2) describe the distribution and diversity of trace fossils within the various lithofacies variation; 3) to assess the controls influencing deposition within carbonate and mixed carbonate-siliciclastic shallow marine environments and; 4) present a depositional model for the sediments of the Jhura hill area.

8.2 FACIES ASSOCIATION AND DEPOSITIONAL ENVIRONMENTS

Different studies have been carried out which include lithofacies, ethology, ichnoguilds, ichnoassemblages and ichnofacies that accord a generalized the shallow marine environment of the deposition of the mixed siliciclastic-carbonate, and carbonate sediments of the Jhura hill area. The palaeo-shoreline trends suggested by Biswas (1991); Fursich and Oschmann (1993) at the time of Early Callovian and Early Oxfordian with respect to Jhura dome has been illustrated in Fig. 8.1, which also gives some idea about onshore-offshore position of the study area within the Kachchh basin.

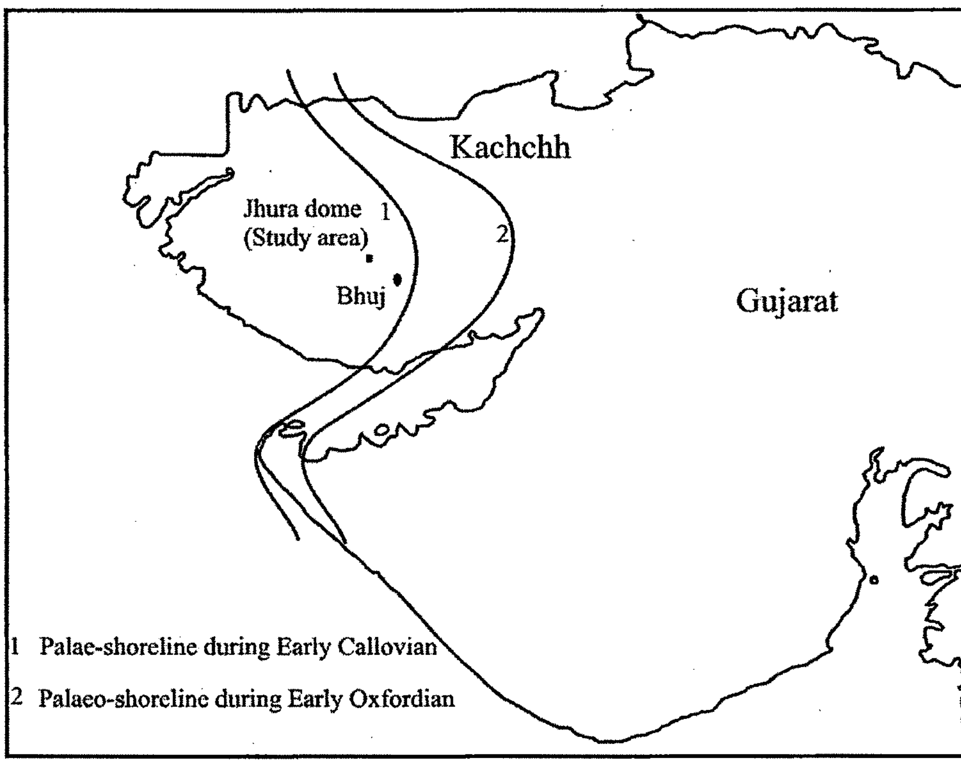

Fig. 8.1 Palaeo-shoreline during Callovian-Oxfordian time (After Biswas, 1991, Fursich and Oschmann, 1993)

As could be recalled, there are in all six lithofacies, 18 ichnoguilds, six ichnoassemblages and three ichnofacies, fully described and interpreted. Each of this facies appears to have deposited in a unique set of physical parameters that has left its imprints on the sediments. All these can now be taken in to consideration according to their associations or mutual relationships with each other and then interplay of the total depositional environments could be postulated. In all, seven depositional environments are identified for the entire depositional setup in the area of study as shown in Table 8.1. have been described in successive paragraphs.

Lithofacies	Physical sedimentary structures	Trace-fossils	Body fossils	Depositional Environment
DOs	Conglomeratic towards top; Oolites	Zo, Th, Pa, Ch, Sk, Rh, Gy, Pl	Highly fossiliferous; Ammonoids and Belemnites;	Upper Offshore
RMCSSL	Wave ripples; Cross stratification Coarse to granules and pebbles	Op, Th, Rh, Pl, Pi, Py, Pa, Par, Mo, Ma, Le, Gy, Gyl, Go, Di, Ca, Ch, Ar, An, Sk, Pa	Highly fossiliferous; Bivalvia; Brachiopods; Belemnites and Gastropods	Lower Shoreface to Middle Shoreface
NWWLs	Thin parallel lamination; Well bedded	An, Be, Ch, Co, Cos, Ke, Lo, Pa, Ph, Pr, Sc, Th, Zo	Bivalvia; Brachiopods; Belemnite and Crinoids	Lower Offshore to Shelf
GOs	Mega ripple marks; Low angle cross stratification; Parallel lamination Oolites; pebbly towards top	Ke, Ta, Op, Sk, Rh, Ch, Pl, Pa, Pi, Di, Dy, Go, Ar, Be, Sa, Ma, Mo, Py Th	Bivalvia; Brachiopods; Belemnite; Crinoids and Corals	Lower Shoreface above FWWB
CSSL	Parallel lamination;	Rh, Ur, Th, Sc, Sa, Pl, Pi, Py, Mo, Ma, Pa, Le, Gy, Di, Ca, Ch, Bi, Be, Ar	Belemnites and Ammonoids	Upper Offshore to Lower Offshore
BLs	Parallel lamination; Bedded	Zo, Ur, Th, Rh, Op	Bivalvia; Brachiopods; Gastropoda; small ammonoids and Bryozoans	Shelfal below SWWB

Table 8.1 Sedimentary facies and their corresponding sedimentary structures, trace-fossils, body-fossils and depositional environments. (An=*Ancorichnus,* Ar=*Arenicolites,* Be=*Beaconites,* Ber=*Bergaueria,* Bi=*Biformites,* Ch=*Chondrites,* Co=*Cochlichnus,* Cos=*Cosmorhaphe,* Ca=*Calycraterion,* Did=*Didymaulichnus,* Di=*Diplocraterion,* Go=*Gordia,* Gy=*Gyrochorte, Gyl=Gyrolithes,* Ke=*Keckia,* Le=*Laevicyclus,* Lo=*Lockeia* , Ma=*Margaritichnus,* Mo=*Monocraterion,* Op=*Ophiomorpha,* Pa=*Palaeophycus,* Par=*Parahentzscheliana,* Ph=*Phoebichnus,* Py=*Phycodes,* Phy=*Phymatoderma,* Pi=*Pilichnus,* Pl=*Planolites,* Pr=*Protovirgularia,* Rh=*Rhizocorallium,* Sa=*Sabularia,* Sc=*Scolicia,* Sk=*Skolithos,* Ta=*Taenidium,* Th=*Thalassinoides,* Ur=*Urohelminthoida,* Zo=*Zoophycos*).

8.2.1 Shelfal below SWWB

Bedded Badi Limestone Lithofacies has shown typical characteristics of shelfal below SWWB depositional environment. This portion is subaqueous, dominated by marine processes and deposition of finer clastics and non-clastic, and subordinately influenced by shallow turbidity currents. Finer grain size, predominance of non-clastic material, absence of ripple marks, presence of thin lamination of shales and occurrence of ichnoguilds like *Zoophycos, Rhizocorallim* and *Thalassinoides* show characteristics of shelf sedimentation under calm conditions mostly from suspended finer crystalline calcareous particles. It comprises of an entire Transgressive system tract – I. The associated ichnofossils are mainly *Zoophycos, Thalassinoides, Rhizocorallium, Urohelminthoida* and rarely *Ophiomorpha* (Table 8.2) recommend *Zoophycos* ichnofacies of Seilacher (1967) suggest shelf environment of deposition.

Ichnological Parameters of Shelfal Below SWWB Environment

Intensity of bioturbation: Zero to low
Ichnodiversity: Low to medium
Important ichnotaxa: *Zoophycos* and *Thalassinoides*
Tiering: Shallow to deep tiers
Ichnofacies: *Zoophycos*

8.2.2 Transition to Lower Shoreface

Silty shale along with Oolitic facies (GOs), mix siliciclastic-carbonate facies has revealed coarsening-shallowing upward sedimentation trend and underlying Transgressive system tract emphasize cyclicity followed by regression within Highstand system tract called HST – I. The lower shoreface ends at the upper limit of fair-weather wave base (FWWB), but where offshore processes continue to operate (Reinson, 1984). Fair-weather wave generated oscillation oolites reflect lower shoreface, also the underlying silty shale facies indicate slightly deeper transition environment of deposition. Biogenic features are dominated by both *Skolithos* and *Cruziana* ichnofacies. *Cruziana* ichnofacies elements include *Rhizocorallium, Palaeophycus, Planolite, Phycodes, Sabularia,* and *Thalassinoides* (Table 8.2). *Skolithos* ichnofacies element includes *Diplocraterion, Arenicolites, Skolithos, Calycraterion, Margaritichnus,* and *Monocraterion*.

Ichnological Parameters of Transition to Lower Shoreface Environment

Intensity of bioturbation: Medium to high

Ichnodiversity: Medium, high locally

Important ichnotaxa: *Arenicolites, Rhizocorallium, Palaeophycus, Diplocraterion, Planolite* and *Skolithos*

Tiering: Shallow to medium tiers

Ichnofacies: *Cruziana* and *Skolithos*

8.2.3 Upper Offshore to Lower Offshore

The offshore zone is regarded to lie below FWWB and above SWWB. The offshore is commonly subdivided into lower and upper subzones. Howard and Frey (1984) subdivided the offshore into lower, middle and upper offshore subzones. The upper offshore to lower offshore, as defined here, comprises of calcareous khaki colored silty shale of CSSL, generally thoroughly heterogenised by biogenic reworking. Fine to very fine silty sandstone beds are present and predominantly intensely bioturbated, although rarely showing undulatory parallel lamination, suggesting a distal storm-generated origin. The ichnological assemblage may be regarded as a *Cruziana* with rarely developed distal *Skolithos* ichnofacies incorporating a relatively high diversity of both deposit feeding and grazing structures. Common ichnogenera include, *Rhizocorallium, Pilichnus, Planolite, Chondrites, Palaeophycus, Scolicia, Phymatoderma, Thalassinoides, and Urohelminthoida* (Table 8.2). Distal *Skolithos* ichnofacies include rare presence of *Diplocraterion, Arenicolites,* and *Skolithos*.

Ichnological Parameters of Upper Offshore to Lower Offshore Environment

Intensity of bioturbation: Zero to medium

Ichnodiversity: High

Important ichnotaxa: *Rhizocorallium, Pilichnus, Planolite, Palaeophycus* and *Chondrites*

Tiering: Medium to deep tiers

Ichnofacies: *Cruziana*

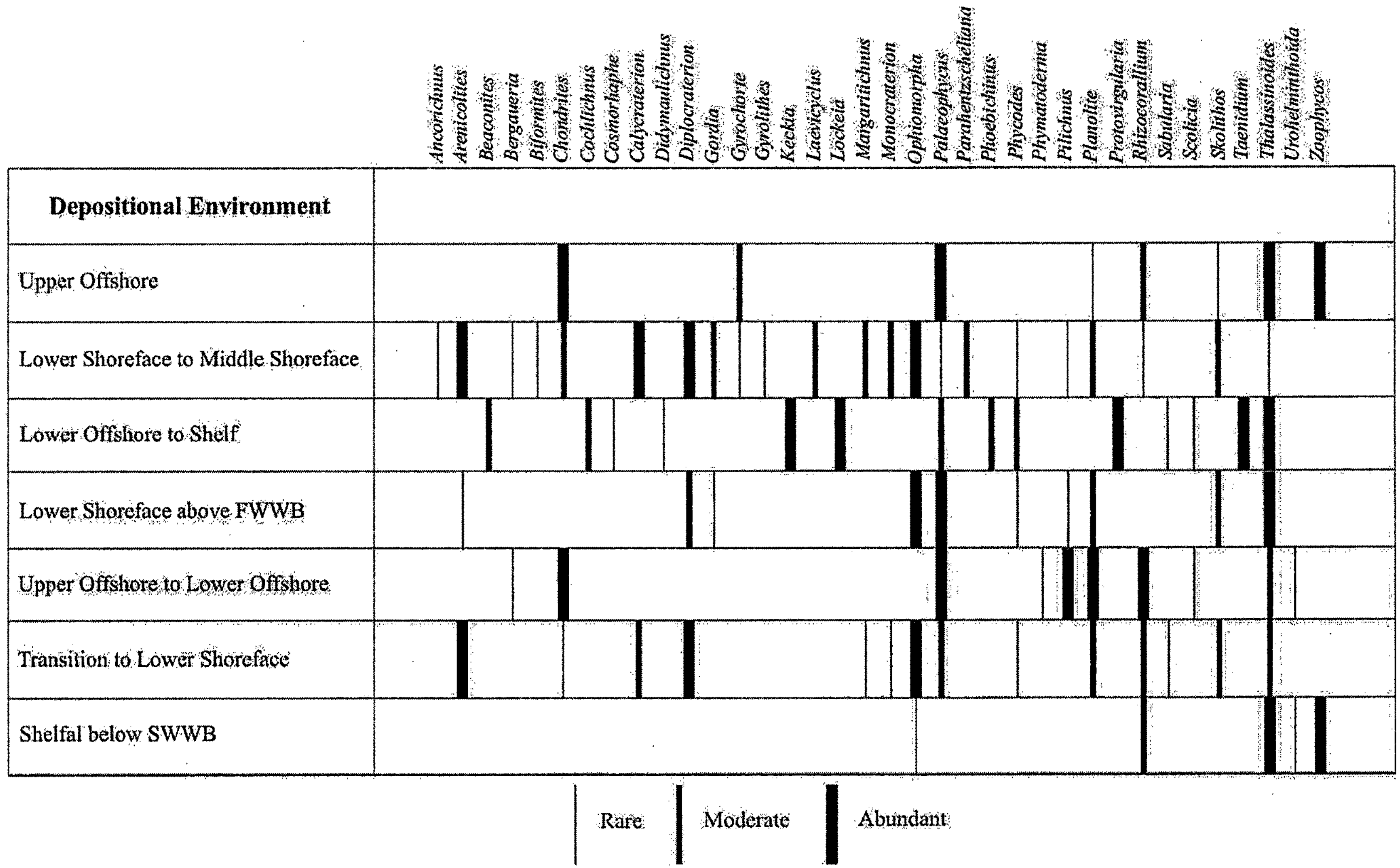

Table 8.2 Environmental distribution of Trace-fossils and their abundance.

8.2.4 Lower Shoreface above FWWB

The lower shoreface above FWWB is defined here as thick, bedded, massive, mega-rippled, cross-stratified, oolitic facies (GOs) showing fairly coarsening upward sequence. Ichnologically, the environment corresponds to the dominance of suspension feeding behavior of *Skolithos* ichnofacies over deposit feeding behaviour of *Cruziana* ichnofacies. The bulk assemblage consists of *Ophiomorpha* (vertical), *Diplocraterion, Skolithos, Arenicolites, Planolites, Pilichnus, Palaeophycus, Phycodes, Gordia* and *Thalassinoides* (Table 8.2). Pemberton and Frey (1984); Howard and Frey (1984); Frey (1990) have noted that *Ophiomorpha* systems tend to shift from horizontal to vertical in orientation as energy level increases. As the storm effects become more uncertain, diversity of deposit feeding structures increase markedly and the character of transition to offshore prevails and subsequently ichnofacies of *Cruziana* (*Taenidium, Keckia, Gordia, Phycodes, Palaeophycus* and *Sabularia*) trace makers are formed.

Ichnological Parameters of Lower Shoreface above FWWB Environment

Intensity of bioturbation: High
Ichnodiversity: Commonly High
Important ichnotaxa: *Taenidium, Keckia, Ophiomorpha, Thalassinoides, Palaeophycus* and *Skolithos*
Tiering: Shallow to mid tiers
Ichnofacies: *Cruziana* and *Skolithos*

8.2.5 Lower Offshore to Shelf

The lower offshore to shelf is situated in low energy zone, at this juncture, is represented by thick well bedded, parallel-laminated, white colored, limestone (NWWLs) and intercalated oolitic facies (GOs) at the bottom suggests transgressive phase simultaneously decrease in siliciclastic input as increase in bathymetry. Except, parallel-lamination; transgressive-lag deposit; and a flooding surface consisting conglomeratic nature; the entire sequence has shown a gradation from siliciclastic oolitic facies to carbonate well bedded limestone facies without any unconformity surface. The dominance of ichnotaxa like *Protovirgularia, Lockeia, Cochlichnus, Thalassinoides, Cosmorhaphe, Phoebichnus, Beaconites* and *Scolicia* towards top indicate deeper shelfal environment. On the other hand, lower oolitic facies intercalated with bedded limestone facies comprising deposit feeding structures i.e. *Taenidium, Planolite, Keckia, Gordia, Didymaulichnus Phycodes, Palaeophycus, Asterosoma* and *Sabularia* (Table 8.2) suggest comparatively shallow lower offshore environment.

Ichnological Parameters of Lower Offshore to Shelf Environment

Intensity of bioturbation: Medium to high
Ichnodiversity: Medium
Important ichnotaxa: *Protovirgularia, Lockeia, Thalassinoides, Phoebichnus* and *Cochlichnus*
Tiering: Shallow tiers
Ichnofacies: *Cruziana*

8.2.6 Lower Shoreface to Middle Shoreface

The thickest facies (RMCSSL) of the study area were deposited in this lower shoreface to middle shoreface environment as calcareous silty sandstone comprising of mega ripple surface along with cross-stratification and graded lamination and marked coarsening upward sequence and forming pebbly intraformational conglomerate. It is characterized by highstand regressive facies followed by Transgressive system tract – I. The middle shoreface dominant *Skolithos* ichnofacies essentially embrace *Diplocraterion, Arenicolites, Ophiomorpha* (horizontal), *Monocraterion, Margaritichnus, Laevicyclus, Calycraterion, Planolite, Chondrites, Bergaueria, Gyrolithes, Biformites, Rhizocorallium* and *Parahentzscheliana* (Table 8.2). Horizontal nature of *Ophiomorpha* along with other dwelling and suspension feeding burrows indicates that the lower shoreface to middle shoreface conditions were prevailing during the deposition of RMCSSL.

Ichnological Parameters of Lower Shoreface to Middle Shoreface Environment

Intensity of bioturbation: Commonly high
Ichnodiversity: Medium
Important ichnotaxa: *Ophiomorpha, Diplocraterion, Parahentzscheliana, Arenicolites* and *Chondrites*

Tiering: Shallow to mid tiers
Ichnofacies: *Skolithos*

8.2.7 Upper Offshore

Followed by highstand regressive facies, transgressive soft, very fine grained gypseous shale, in lower part of the DOs, can be defined as upper offshore suite. With the increasing bathymetry, mixed oolitic-siliciclastic sedimentation started and terminated with the maximum flooding surface represented by distal *Cruziana* ichnofacies is indicative of an upper offshore environment. The dominant ichnogenera are *Zoophycos, Chondrites, Palaeophycus, Planolites, Phycodes, Thalassinoides, Gyrochorte* and *Rhizocorallium* (Table 8.2).

<u>Ichnological Parameters of Upper Offshore Environment</u>

Intensity of bioturbation: Zero to high
Ichnodiversity: Medium to high
Important ichnotaxa: *Zoophycos, Chondrites, Palaeophycus, Planolites, Phycodes,* and *Thalassinoides*
Tiering: Medium to deep tiers
Ichnofacies: *Cruziana*

Overall, the entire sequence of the Jhura dome has revealed a cyclic sedimentation through typical Transgressive – Regressive cycles with siliciclastic as well as mix carbonate-siliciclastic sedimentation. In the process of such cyclic sedimentation, accommodation space; tectonic and sediment influx rate played a major role.

8.3 ICHNO-SEDIMENTOLOGICAL MODEL

The overall data can be synthesized very well and compared with the transgressive and regressive phases of sedimentation model of the shallow marine environments. Carbonates are regionally extensive of shallow, shelf to shoreface sedimentation and retrogradation of shoreface, producing deepening upward sequences is the dominant depositional process (Tucker, 1985). The shallow marine carbonate rocks of the Jhura dome shows the variation in facies and evolutionary patterns. There have been significant variation in composition of carbonate rocks which consist of micrites, sparites, and various kinds of bioclasts, ooids, syn-sedimentary cements and other physical parameters reflecting fluctuations in sea levels. Major phenomenon in sedimentation of nonclastic materials are the regressive (coarsening upward sequence) sequences reflecting major shifting of facies in a given environment. The typical environments resulting from such interaction are shoreface, transition, offshore and shallow shelf setups in the depositional regime. Such settings are characterized by complex ecological conditions reflecting in their physical and biological structures. The schematic three dimensional diagram (Fig. 8.2) showing the deposition of mixed clastic-nonclastic sequences of shallow marine environment of the Jhura dome of Middle Jurassic sediments of north Central Mainland Kachchh can now be explained as under:-

The lithological, paleontological and ichnological evidences from the earlier studies have revealed that the sedimentation continued in the area from Bathonian to Callovian and Oxfordian time, depositing a total thickness of sediments of around ~500 meter. This has been classified under two stratigraphic units viz., Jhurio Formation and Jumara Formation comprising thickness of 230 meter and 260 meter of stratified deposits respectively. The entire Middle Jurassic depositional phase is marked by four major transgressive and three regressive episodes including storm generated events. Many of these events are controlled by the eustatic sea level changes, regional tectonic movements, and physiographic and biologic responses.

The oldest sedimentary unit in the area of investigation is the Jhurio Formation with an approximate thickness of 250 m and represents Bathonian age. In the basin, the lithological characteristics indicate that the initial phase of sedimentation takes place in shallow shelf deposition in a slowly transgressive sea under relatively stable conditions. The presence of BLs, CSSL, GOs, and NWWLs facies indicates the occurrence of both transgressive and regressive cycles, frequently interrupted by waves, storms and calm conditions and are well documented in the sedimentary record and sequential trace fossil evidences. The shallow shelf sedimentation was such that, it developed intercalations of bedded limestone and calcareous siltstones. On the other hand, lower shoreface to offshore sedimentation has been inferred for the development of the cross-bedded golden oolitic limestone with mega wave ripples surface and intrabasinal conglomerate. These episodes were typical characterized by typical body and trace fossils.

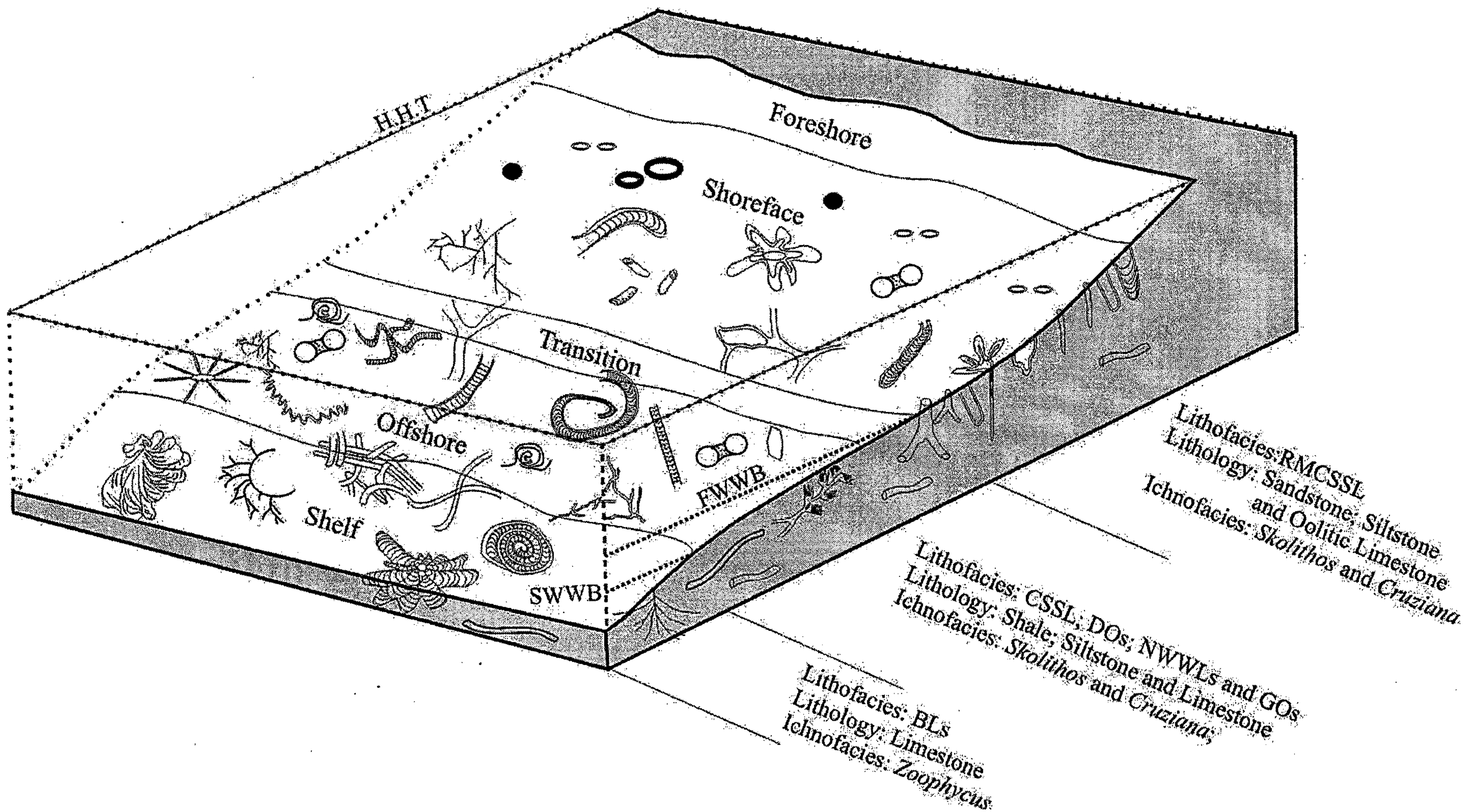

Fig. 8.2 A schematic three dimensional model showing depositional environments and distribution of Trace-fossils

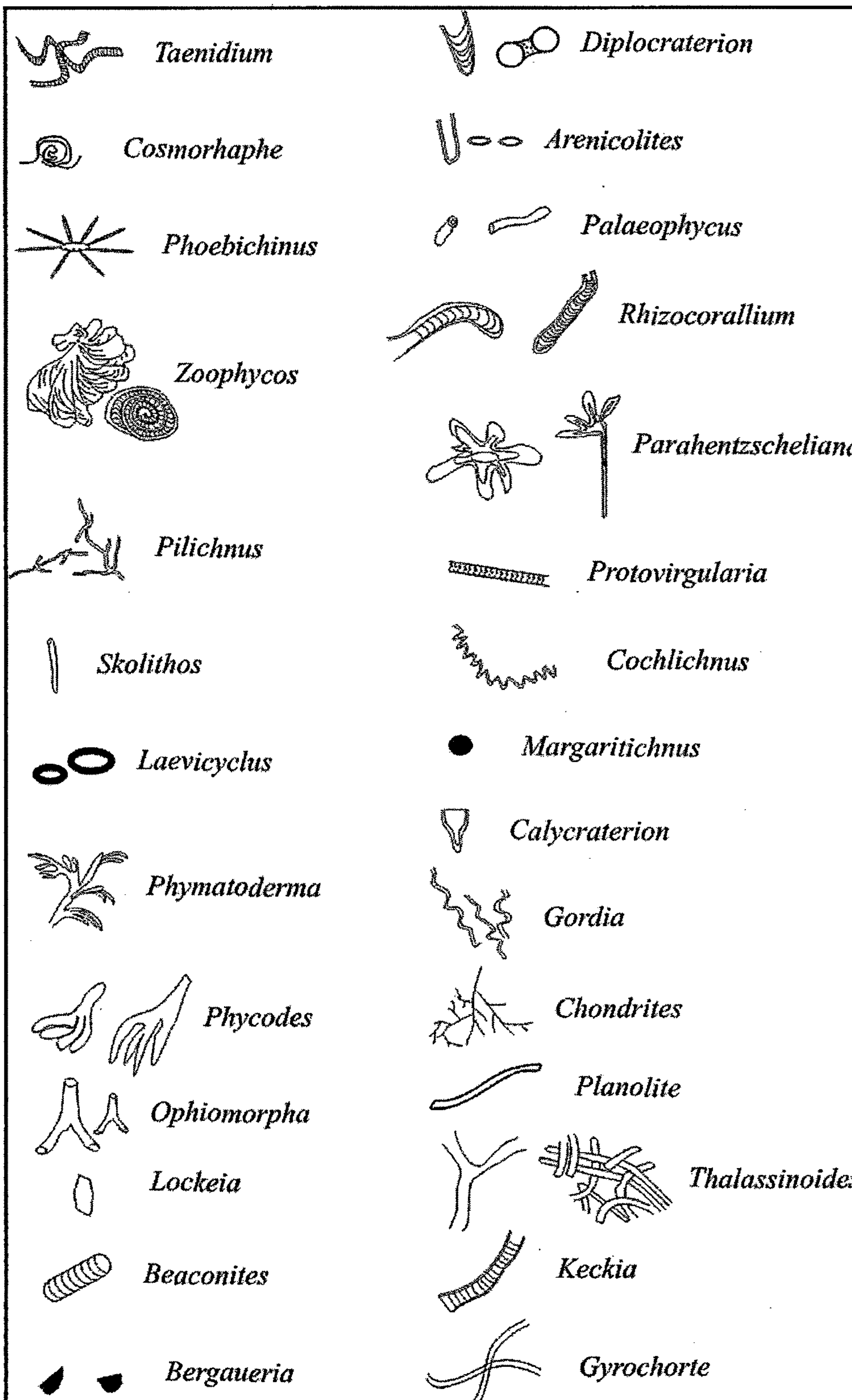

Fig. 8.3 Legend for Fig. 8.2

The lower shoreface to offshore conditions were continued during the deposition of the Lower Jumara Formation and the basin was filled by the intercalated finer mixed clastic and nonclastic sediments. The basin was, in all possibilities, shallowing with finer clastics and gradually being shifting towards coarser clastic sequence to form either barriers or blanket sand bodies. The overall conditions were constructive creating net sedimentation in the basin. This shoreface sedimentation by far was such that it developed quick intercalations of shales, siltstones and sandstones, with or without ripple marks but always finely laminated. Such an episode was characterized by typical trace fossil assemblages and scattered remains of marine fossil forms indicate regressive-retrograding sequences.

The formation of shoreface environment as pointed earlier is mixed siliciclastic-carbonate rocks dominated and characterized by lateral extension of individual beds with more or less uniform thickness, and showing massive to horizontal stratification with cross bedding structures. The calm condition in the shoreface environments was distinguished by intercalations of siltstones/shales in the RMCSSL and lower part of the DOs. In this case ripple marks, cross bedding and ripple laminations are very distinctive. The fluctuating sediment supply of argillaceous and arenaceous material has been recorded in the quick alternation of RMCSSL facies in a shoreface environment.

The renewed sedimentation in many cases is resumed by development of shoreface conditions where primary environment was set on to the offshore-transition in RMCSSL facies. This was immediately encroached by regressive sea and the shoreface sediments were mostly settled in upper-middle shoreface conditions in form of reworked, relict to palimpsest deposits. Such fluctuating conditions remained established for a prolonged time to give rise to thick sequence of ridge sandstones of Jumara Formation. The sedimentary structures often indicate wave dominated shoreline conditions, while the trace fossil associations indicate high energy conditions.

The bands of DOs shows much less terrigenous sediment supply and generation of basinal authigenic sediments and development of *Cruziana* ichnofacies in transition-offshore conditions have resulted to produce deepening upward Oolitic Limestone deposits.

The top most lithofacies of the study area DOs of Jumara Formation comprises the Intraformational conglomerate with abundant large ammonites, belemnites and pebble of limestone clasts indicates wave and current overshadowed by biological reworking and absence of trace fossil. The fluctuations in sea levels and other environmental conditions are reflected in abundance and diversity of biogenic sedimentary structures in various lithofacies in the study area and paucity of trace fossils in shale facies.

The part of the basin is present in the area of study is further claimed to have witnessed cycles in which transgressive events (subsidence rate > sedimentation rate), altered with progradational or regressive events (subsidence rate < sedimentation rate). Such repetition patterns seem to be largely "allocyclic" - resulted from external events like relative sea level fluctuations, tectonic events, and compaction of underlying sediments, or any combination of these parameters. Although the overall sedimentological and ichnological evidences at various localities of the study area support possibilities of both the autocyclic and allocyclic nature of deposition up to certain extent.

In conclusion, the marine sedimentary record of the study area shows a diachronous pattern of deposition that is typical of a 2^{nd} order Transgressive mega-sequence. This essentially corresponds to a number of transgressive - regressive cycles and development of mixed clastic-carbonate and pure carbonate settings in a shallow marine complex. Evidences from trace fossils assemblages definitely indicate relative energy levels, oxygenation and turbidity but provides no absolute limits for depth. It has very well demarcated the response of infaunal benthic communities to numerous aspects of physical environments. The most important of this appears to be the salinity, interstitial oxygen, sediment composition and texture, and hydrodynamic energy of depositional environment in terms of rate of sedimentation, frequency of erosion events and orientation of waves and current. The trace fossil association in the investigated area is, therefore, remarkable in their density; diversity and excellent state of preservation have helped in demarking the various sequence stratigraphic surfaces and disconformities.