CHAPTER 6

ICHNOANALYSIS: TRACE FOSSIL ASSEMBLAGES, ICHNOGUILDS AND ICHNOFACIES

6.1 INTRODUCTION

After a comprehensive description of total 71 ichnospecies in the previous chapter, author has emphasized the concept of Ichnology under the title of Ichnoanalysis in the present chapter. Ichnoanalysis is a general term which has been used to define different aspects of Ichnology which includes ethology; ichnoassemblage; ichnoguild and ichnofacies. Author prefers to use the term 'ichnoassemblages' in place of 'ichnocoenosis' because ichnocoenosis term has been problematic (Bromley 1990). Dorjes and Hertweck (1975) clearly identified ichnocoenosis as covering 'an association of traces that can be related to one definite biocoenose (benthic-endobenthic community)' or 'assemblage of traces produced in one definite environment by members of given biocoenose'. Thus, the term is strictly confined to the Neoichnologic realm, though some of the workers have used it in fossil context and have modified as 'an ecologically pure assemblage of traces and trace fossils, deriving from the work of a single endobenthic community' (Ekdale et al, 1984 and Bromley, 1990). Because of the prevailing confusion in the usage of the term ichnocoenosis, the author has used ichnoassemblages- an association of traces that can be related to one definite stratigraphic level (i.e. bed). On the whole, on the basis of ichnoanalysis author has derived specific paleoenvironment and paleoecological conditions at the time of deposition of the sediments of the Jhura hill area.

6.2 ETHOLOGY

The word Ethology derives from ethos, means characteristic spirit of community, people or system. It is a science of character, formation and behavior. In the perspective of Ichnoanalysis, Ethology means behavioral classification of trace-fossils. The simplest behavioral or ethological, classifications of traces derive directly from elementary descriptive-genetic concepts-the designation of given structures as tracks, trails, burrows, borings and so on. Ethology has the advantage of grouping similar assemblages of traces /

lebensspuren according to the life habits or behavioral patterns of an animal. Due to its easy application, this system has proved useful for fossils and trace-fossils. Seilacher (1953, 1964); Frey and Seilacher (1980) have proposed a classification based on ethological principles and consequently six groups (Cubichnia - Resting Traces; Repichnia - Crawling Traces; Pascichnia - grazing Traces; Fodinichnia - Feeding Structures; Domichnia - Dwelling Structures and Fugichnia - Escape structures) were suggested. Afterwards, Ekdale et al. (1984) recognized seven basic categories of behaviour, in which farming system – agrichnia was added to the earlier groups proposed by Seilacher. Ekdale (1985a, b) added one more predation traces – praedichnia and Frey and Pemberton (1985) emphasized the importance of equilibria – fugichnia to all other behavioral patterns. All the identified ichnospecies are summarized in the Table 6.1 on the basis of their ethological groups corresponding to the lithofacies. Author has found only five behavioral categories among all the trace fossils observed in the study area.

Table 6.1 Ethological distribution of the trace fossils in the different lithofacies

Lithofacies	Cubichnia Resting traces	Repichnia Crawling traces	Pascichnia Grazing traces	Fodinichnia Feeding structures	Domichnia Dwelling structures
DOs			*Gyrochorte comosa;*	*Chondrites intricatus; C. patulus; C. isp. ; Thalassinoides horizontalis ; T. paradoxicus ; T. suevicus ; Rhizocorallium irregulare; Zoophycos brianteus; Z. Caudagalli; Z. circinnatus; Z. insignis; Z. laminatus; Z.* villae; *Z. TypeA; Z. TypeB; Z. TypeC; Z. TypeD; Z. TypeE;*	*Palaeophycus annulatus; P. tubularis; Skolithos verticalis*
RMCSSL	*Bergaueria* isp.;	*Ancorichnus ancorichnus; Gordia marina;*	*Gyrochorte comosa; Pilichnus dichotomus;*	*Biformites isp. ; Gyrolithes polonicus; Planolites annularis; Pl. beverleyensis; Pl. montanus; Pl. isp. ; Sabularia ramose; Chondrites intricatus; C. patulus; C.*	*Margaritichnus reptilis; Calycraterion samsonowiczi; C. isp.; Monocraterion* isp.; *Laevicyclus mongraensis;*

				recurvus; C. targionii ; Thalassinoides horizontalis; Phycodes circinnatum; Ph. Palmatum; Phymatoderma isp. ; Rhizocorallium irregulare; Parahentzschelinia ardelia; Gyrolithes polonicus;	*Palaeophycus annulatus; P. heberti; P. striatus; P. tubularis; Skolithos linearis; Arenicolites carbonarius; Ophiomorpha nodosa; Diplocraterion habichi;*
NWWLs	*Lockeia ornate; Lockeia siliquaria;*	*Ancorichnus ancorichnus; Scolicia strozzii; Didymaulichnus* isp, ; *Cochlichnus anguineus ; Protovirgularia dichotoma ;*	*Keckia annulata; Cosmorhaphe carpathica;*	*Planolites annularis ; Pl. beverleyensis; Pl. montanus; Chondrites intricatus; C. patulus ;Thalassinoides horizontalis; T. paradoxicus; T. suevicus ; Beaconites antarcticus; B. coronus; Taenidium cameronensis; Phoebichnus trochoides ;*	*Palaeophycus ; annulatus; P. heberti ; P. striatus ; P. tubularis; Skolithos verticalis*
GOs	*Calycraterion isp.;*	*Ancorichnus ancorichnus; Didymaulichnus* isp.;	*Keckia annulata; Gyrochorte comosa;*	*Planolites annularis ; Pl. beverleyensis; Pl. montanus; Sabularia ramose ; Chondrites*	*Margaritichnus reptilis; Calycraterion samsonowiczi;*

		Gordia marina ; Protovirgularia dichotoma;		*intricatus ; C. patulus ; C. recurvus ; C. targionii ; C. isp. ; Pilichnus dichotomus ; Thalassinoides horizontalis ; T. paradoxicus ; T. suevicus ; T. foedus ; Phycodes circinnatum ; Ph. Curvipalmatum ; Ph. Palmatum; Ph. Pedum; Phymatoderma* isp. ; *Beaconites coronus; Taenidium cameronensis; T. satanassi; T. serpentinum; Rhizocorallium irregulare;*	*Palaeophycus annulatus; P. heberti; P. striatus; P. tubularis; Monocraterion* isp.; *Skolithos linearis; S. verticalis; Arenicolites carbonarius ; Ophiomorpha nodosa ; O. recta ; Diplocraterion habichi;*
CSSL	Bergaueria isp.	*Scolicia strozzii; Didymaulichnus* isp.; *Cochlichnus anguineus;*	*Gyrochorte comosa; Urohelminthoida dertonensis; Pilichnus dichotomus ;*	*Biformites isp.; Planolites annularis; Pl. beverleyensis; Pl. montanus; Pl. isp. ; Sabularia ramose ; Chondrites recurvus ;C. targionii ; Thalassinoides foedus ; Phycodes circinnatum ;*	*Margaritichnus reptilis; Calycraterion samsonowiczi; C. isp. ; Monocraterion* isp.; *Laevicyclus mongraensis; Skolithos linearis ;*

				Phymatoderma isp. ; Rhizocorallium irregulare ; R. jenense ; R. uraliense ; Gyrolithes polonicus ;	*Palaeophycus annulatus; P. heberti; P. striatus; P. tubularis;* Arenicolites carbonarius ; *Diplocraterion habichi;*
BLs	*Lockeia ornate; Lockeia siliquaria;*	*Scolicia prisica; Protovirgularia isp.*	*Beaconites coronus; Urohelminthoida dertonensis*	*Thalassinoides horizontalis ; T. paradoxicus; T. suevicus ; Rhizocorallium irregulare; Zoophycos brianteus; Z. circinnatus*	*Ophiomorpha nodosa*

6.3 ICHNOASSEMBLAGES

As mentioned in the introduction, this is the basic collective term, all the trace fossils occurring within a single unit of rock. Trace fossils of an assemblage may have been emplaced simultaneously as a single ecologically related group or they may represent several overprinted events of bioturbation (Bromley 1990). Table 6.2 demonstrates categorically (rare, common and abundant) the presence of different ichnospecies against different lithofacies.

6.3.1 *Protovirgularia – Lockeia – Thalassinoides – Phoebichnus – Cochlichnus - Cosmorhaphe* assemblage

This assemblage (Fig. 6.1) is associated with NWWLs of Jhurio formation. *Protovirgularia* is the most abundant trace fossil, and it occurs mainly in association with *Lockeia*. Lockeia is typical resting trace (cubichnia) of bivalves, associated with *Protovirgularia and Cochlichnus* giving a clear representation of deposit feeding bivalves that are living in the calm and stable conditions. Including *Thalassinoides* and *Cosmorhaphe* as a feeding as well as dwelling and feeding traces of *Phoebichnus* provides good oxygenated environment at the time of deposition. They are mid-tier deposit feeder structures indicating good oxygen availability; nutrient supply and comparatively low energy level. As a whole, *Protovirgularia – Lockeia – Cochlichnus - Cosmorhaphe* represents shallow-tier and *Thalassinoides – Phoebichnus* signify to mid-tier traces. BLs facies of Jhurio Formation has also replicated this assemblage to a certain extent.

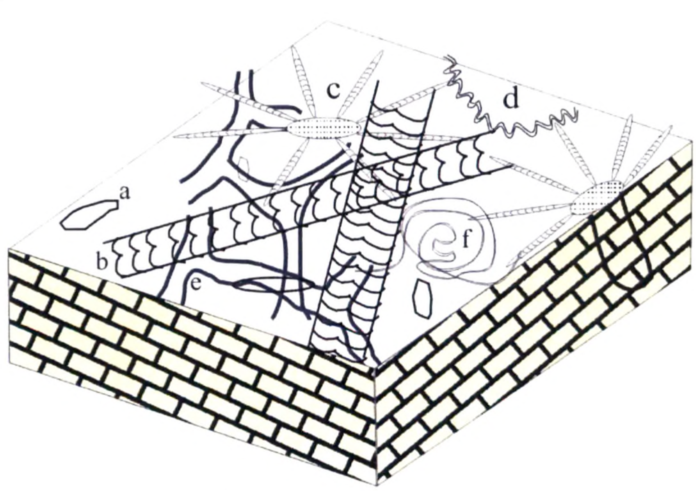

Fig. 6.1 Schematic representation of *Protovirgularia-Lockeia* ichnoassemblage: a*) Lockeia;* b) *Protovirgularia;* c*)Phoebichnus;* d*) Cochlichnus*; e*)Thalassinoides* and f*) Cosmorhaphe.*

6.3.2 *Zoophycos – Chondrites* assemblage

A very unique and typical assemblage is associated with DOs of Jumara formation and partially developed in BLs of Jhurio formation. Both *Zoophycos* and *Chondrites* represent feeding activity at deeper tiers (Fig. 6.2) and are associated with *Thalassinoides, Rhizocorallium, Palaeophycus* and *Gyrochorte* at shallow-tier. It indicates opportunist's assemblage of deeper tier cutting across the shallower tiers. Bromley (1990) considers *Zoophycos* in low resource, inhospitable, oxygen depleted environments. These specimens most probably represent offshore shoals and bars, where the assemblage, as it occupies deepest levels in the sediments constituting depleted zone of the substrate, has been characterised as representing oxygen depleted sea floor. But, there may be other structures in upper levels which could have been eroded, leaving *Zoophycos* assemblage alone. This postulation is based on the occurrence of *Thalassinoides, Rhizocorallium, Gyrochorte* and *Palaeophycus* at the same horizon.

In general, the trophic and behavioral characteristics of the assemblage indicate a gradient in bottom water agitation. The deposit feeding *Rhizocorallium* and *Thalassinoides* assemblage reflect progressively lower energy conditions. On the other hand *Chondrites* and *Zoophycos* assemblage are characterized by extremely low energy conditions, where slow deposition and less erosion prevailed. Finally, the trophic diversity of trace fossil data reflect different types of substrate conditions, varying rates of sedimentation, salinity differences and different degrees of wave agitation. Many of these factors, individually or collectively, must have been responsible for the overall distribution of the animal communities in sedimentary units of study area.

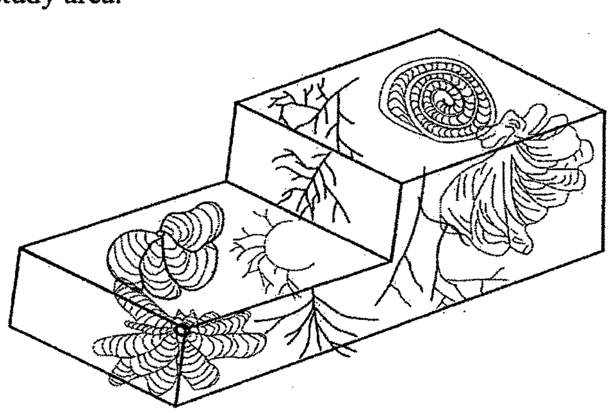

Fig. 6.2 Schematic representation of Zoophycos-Chondrites ichnoassemblage: a) Zoophycos and b) Chondrites.

6.3.3 *Rhizocorallium* – *Pilichnus* – *Palaeophycus* – *Planolites* – *Chondrites* - *Diplocraterion* assemblage

Numerous *Rhizocorallium* in association with *Pilichnus*, *Palaeophycus*, *Diplocraterion, Chondrites* and *Planolites* were distinctively observed in the clastic deposits of CSSL of Jhurio and Jumara formations (Fig. 6.3). All are shallow to mid-tier deposit-feeder structures. Buckman (1990) interpreted that *Rhizocorallium* indicates shallow marine conditions and also sediment feeding mode of life. High degree of bioturbation at shallow tier specifies good oxygenated conditions with high nutrient supply at a low sedimentation rate and presence of *Chondrites* indicates deep tier relatively deeper upper offshore to lower offshore to shelf environment.

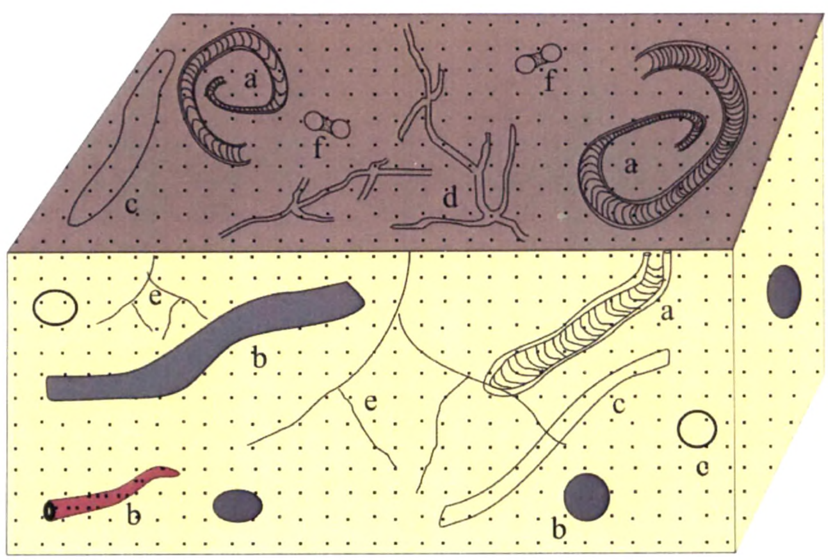

Fig. 6.3 Schematic representation of *Rhizocorallium-Pilichnus* ichnoassemblage: a) *Rhizocorallium*; b) *Planolite*; c) *Palaeophycus*; d) *Pilichnus*; e) *Chondrites* and f) *Diplocraterion.*

6.3.4 *Ophiomorpha* – *Arenicolites* - *Diplocraterion*– *Skolithos* – *Calycraterion* – *Parahentzscheliana* – *Margaritichnus* - *Monocraterion* assemblage

Stationary, deep suspension-feeder and dwelling structures at shallow to mid tier; mainly associated with GOs of Jhurio formation and RMCSSL of Jumara formation (Fig. 6.4). The assemblage is of unstable sand substrates in hydrodynamically energetic environments

(Bromley 1990). In this setting the high energy and frequent turbulence inhibited the biogenic activity that was reduced to a few ichnotaxa typical of shifting substrates in energetic environments, supported by presence of Oolitic lithofacies. The low ichno-diversity and moderate density of ichnospecies suggests abundance of opportunistic suspension feeding community. Considering the above facts it is postulated that the depositional environments varied from foreshore to middle shoreface under moderate to relatively high energy conditions. Such conditions normally are formed in slightly muddy to clean, well sorted, shifting sediment subjected to abrupt erosion or deposition.

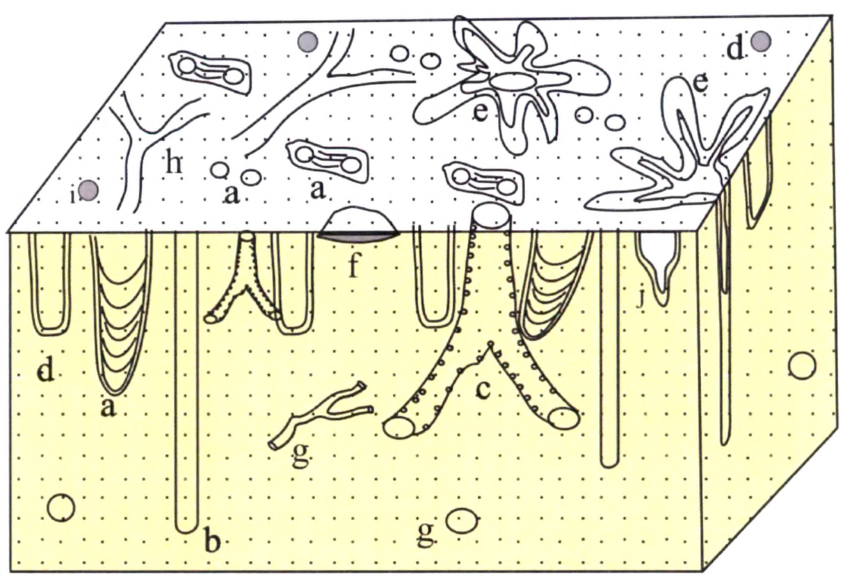

Fig. 6.4 Schematic representation of *Ophiomorpha-Arenicolites* ichnoassemblage: a) *Diplocraterion*; b) *Skolithos*; c) *Ophiomorpha*; d) *Arenicolites*; e) *Parahentzscheliana*; f) *Bergaueria*; g) *Palaeophycus* ; h) *Thalassinoides* ; i) *Margaritichnus* and j) *Calycraterion*

6.3.5 *Thalassinoides – Taenidium – keckia assemblage*

This assemblage (Fig. 6.5) is present in the GOs of Jhurio formation. These show active back-filled feeding activity structures at mid to deep tier. Ripple marks; cross stratification; Oolitic nature of the lithofacies along with mid to deep tier feeding activity will indicate moderate to high energy conditions between middle shoreface to upper offshore depositional environment.

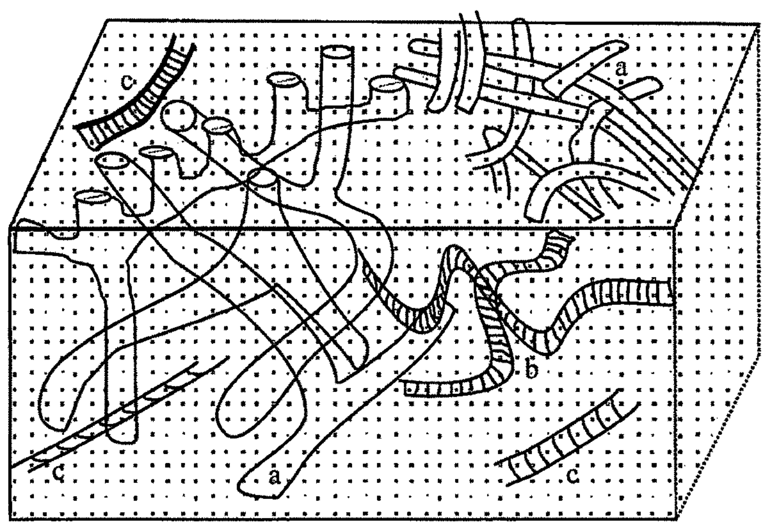

Fig. 6.5 Schematic representation of *Taenidium-Keckia* ichnoassemblage: a) *Thalassinoides*; b) *Taenidium* and c) *Keckia*.

6.3.6 *Palaeophycus – Thalassinoides - Planolites – Phycodes* assemblage

This assemblage is characterized by the presence of shallow tier, subsurface deposit feeders. It occurs in both, the clastic and non-clastic sequences of the Jhura dome, central Mainland Kachchh and is observed in CSSL, GOs, and RMCSSL. Occurrence of this assemblage (Fig. 6.6) is in a wide range of substrates. The predominant occurrence of the horizontal structures and fine grained nature of the sediments indicates low wave and current energy. Furthermore, association with different ichnogenera at different stratigraphic levels indicates that it is formed in lower shoreface to upper offshore environmental conditions, irrespective of the normal wave base or storm wave base, but it is formed in quiet-water conditions, so that finer food particles were deposited on the sea floor. All the individual ichnotaxa commonly occur in shallow water marine environment.

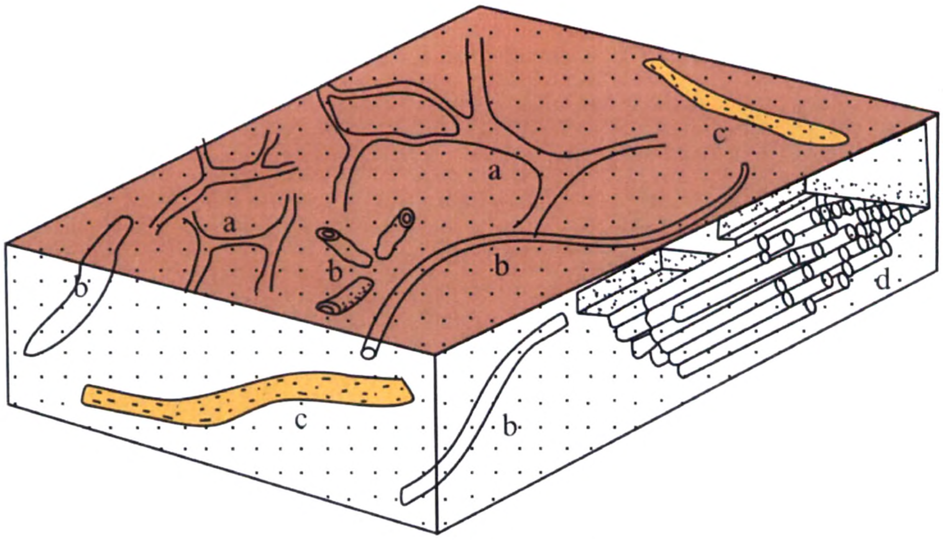

Fig. 6.6 Schematic representation of *Thalassinoides-Palaeophycus* ichnoassemblage: a) *Thalassinoides*; b) *Palaeophycus*; c) *Planolite* and d) *Phycodes*.

6.4 ICHNOGUILD

Ichnoguild is a group of ichnospecies that express a similar sort of behaviour, belong to the same trophic group (term embracing species having similar feeding behaviour) and occupy a similar tier or location within the substrate (Bromley 1990). Ichnoassemblages may provide a starting point for the definition and identification of distinctive ichnoguilds. The easiest way to identify guild is by its characteristic ichnogenus. Bambach (1983) has defined the guild as covering three major aspects of species groups (1) Structural plan of the body (bauplan) (2) Food source and (3) Space utilization.

6.4.1 *Arenicolites* Ichnoguild

This guild has vertical U-shaped burrow, lacking spreite (*Arenicolites)* and occurs in CSSL of Jhurio Formation and RMCSSL of Jumara Formation as domichnia. This is probably formed by annelids or crustaceans producing permanent domiciles at distinct stratigraphic levels suggesting an opportunistic behaviour showing tube-dwelling suspension-feeding polychaetes (Dam, 1990). They represent low diversity assemblage of single species that adapted itself to a well-aerated high-energy environment of great physical instability and abundant food supply in suspension. *Skolithos, Diplocraterion, Ophiomorpha, Calycraterion, Bergaueria* and *Monocraterion* are also found in this Ichnoguild. These represent shallow to deep tier suspension feeding, argillaceous to sandy shifting substrate behaviour organisms in foreshore to upper shoreface environment. This ichnoguild can be considered to be a part of both *Skolithos* and *Cruziana* ichnofacies (Gerard and Bromley, 2008).

6.4.2 *Calycraterion* Ichnoguild

This includes stationary, mid to deep tier suspension feeding structure same as *Arenicolites* Ichnoguild. This guild has shown moderate diversity with the presence of two species (*Calycraterion Samsonowiczi* and *Calycraterion isp.*). Their presence in RMCSSL together with *Arenicolites, Margaritichnus* and *Ophiomorpha* Ichnoguilds suggest their opportunistic suspension as well as dwelling burrows in foreshore to upper shoreface high-energy depositional environment.

6.4.3 *Chondrites* Ichnoguild

This ichnoguild has very high diversity characterised by different ichnospecies of *Chondrites* (*C. intricatus C. patulus, C. recurvus, C. targonii* and *C. isp.)* along with frequent occurrences of *Planolites, Palaeophycus, Pilichnus* and *Zoophycos*. This ichnoguild has been observed in BLs, DOs, CSSL, RMCSSL and GOs. The assemblage represents vertical shaft branching into oblique and horizontal burrows, regular branches are lateral y-shaped never dichotomous, at deep tier, constructed by endobenthic deposit feeding organisms of unknown taxonomic affinity, where the burrows are emplaced well below the water sediment interface, i.e. found deep in the sediments. The nature of such burrows in the field indicates that the burrow was kept open by its inhabitant and had later on become filled passively by sediments from above. The occurrence of *Chondrites* in a deposit, according to Bromley and Ekdale (1984), indicates very low oxygen levels in the interstitial waters within the sediment, at the site and time of' burrow emplacement. Thus, oxygen deficient conditions influence the distribution of *Chondrites,* keeping the organisms to a much more significant degree. In short, *Chondrites* suggest an environmental tolerance of oxygen level; lower than any other ichnogenus. Its occurrence is related to chemically reducing conditions deep within the sediment and is only indirectly dependent on sea floor conditions. Further, it represents fully marine, low energy regime, quiet water conditions. According to Frey et al., (1990), the association develops in upper offshore to shelf conditions with poor water circulation. It typically occurs in mud or muddy sands rich in organic matter but somewhat deficient in oxygen. Off shore sites are below storm wave base to deep water, in areas free of turbidity flows or significant bottom currents. Ekdale (1985a) considered *Chondrites* as an opportunist, where its strategy reveals opportunism in severely oxygen depleted environments, in which it may occur alone (Bromley and Ekdale, 1984a; Vossler and Pemberton, 1988a). This guild is associated with other ichnogenus like *Zoophycos, Planolites, Palaeophycus, Pilichnus, Ophiomorpha, Rhizocorallium and Thalassinoides.*

Bromley (1990) described the ichnoguild as non-vagile, deep deposit feeder structures. As it is an ichnoassemblages of opportunists, precariously colonizing inhospitable zones at very fringe of habitability, minor fluctuations in the general environment or ecological environment may affect the availability of such niche to the community.

The *Chondrites* species occur in BLs and DOs facies of Jhurio and Jumara Formations respectively and appear to be related to sediments deposited below lower shoreface region or below storm wave base, in areas free from significant bottom currents or turbidity flows. While in case of GOs (Jhurio FM.), CSSL (Jhurio FM.) and RMCSSL (Jumara FM.) facies, it seems to be in association with the sediments, deposited in upper shoreface to lower shoreface conditions up to daily wave base, because these sediments infrequently consist of cross-bedding and different types of ripple marks including mega (wave) ripples. There, the structures inhabit deeper levels within than in unconsolidated to semi-consolidated sediments. The structures mostly occur in fine argillaceous silty rocks where circulation is poor and in sandstones but preferred rock is with carbonate cement (originally lime mud - micrite) which is a product of reducing conditions. The *Chondrites* ichnoguild has replicate *Cruziana, Zoophycos* as well as *Nereites* ichnofacies (Gerard and Bromley, 2008).

6.4.4 *Diplocraterion* Ichnoguild

This ichnoguild is observed in the RMCSSL facies of the Jumara Formations; GOs and CSSL of Jhurio Formation. Characteristically it consists of mono-dominant species of *Diplocraterion habichi.* This ichnoguild is characterized by the presence of shallow to moderately deep tier of suspension feeders. *Diplocraterion* consists of either two parallel tubes or is represented by two circular tubes joined by grooves (retrusive spreite) on the bedding plane surface. The *Diplocraterion* ichnoguild thus represents a community dominated by suspension feeding (domichnia) organisms, which inhabited calcareous, ferruginous to felspathic, arenaceous substrates during the deposition of bedded silty sandstone of the Jhurio and Jumara Formations.

The *Diplocraterion* ichnoguild can further be interpreted as of a relatively high energy environment, with moderate to low rate of sedimentation of fine grained particles to support deposit feeders. Physical reworking appears to be frequent, as indicated by the presence of tapering against erosional surfaces in numerous horizons of RMCSSL. The low ichno-diversity and moderate to high density of ichnospecies suggests abundance of opportunistic ichnotaxa. Sedimentological data (sedimentary structures, erosional and reactivation surfaces) indicates that the burrows were produced over a short period of time and also that the depositional environment was inhospitable to most life forms due to high rate of sedimentation and shifting substrate.

Considering the above facts it is postulated that the depositional environments varied from upper shoreface to lower shoreface under moderate to relatively high energy conditions. Such conditions normally are formed in slightly muddy to clean, well sorted, shifting sediment subjected to abrupt erosion or deposition. Episodic erosion and deposition could have resulted in producing spreiten structures.

6.4.5 *Gyrochorte* Ichnoguild

This ichnoguild is characterized by dominance of horizontal, crawling and feeding structures such as *Gyrochorte comosa*. It also consists of *Planolites, Thalassinoides* etc. This ichnoguild is also characterized by the presence of shallow to mid tiers of deposit feeders, observed in only DOs facies of Jumara Formation. The guild generally shows a high degree of bioturbation indicating relatively slow sedimentation and little physical reworking.

The very good preservation of crawling trails, mostly in the form of epirelief and intrastratal preservation suggests low energy conditions, with moderate rate of sedimentation. The guild occurs in lower offshore, below daily wave base but not storm wave base, to somewhat quieter conditions offshore. From a taphonomic point of view, this situation profoundly increases the preservational potential of the guild. It normally occurs in well sorted sands which are moderate to intensely bioturbated and depicts slow rate of sedimentation. Other ichnotaxa like *Planolites*, *Palaeophycus* and *Thalassinoides* are observed in association with *Gyrochorte* Ichnoguild.

6.4.6 *Keckia* Ichnoguild

This ichnoguild is characterized by active back-filled structures of middle to deep tier, subsurface deposits and suspension feeder structures. The guild has low diversity, presence of single species *Keckia annulata* within the NWWLs and GOs of Jhurio Formation. These indicate relatively energetic environment of protected upper offshore to lower offshore zone where both types of the food particles (deposit and suspension) were available. The major associated ichnogenus are *Taenidium, Planolite, Palaeophycus, Protovirgularia, Phoebichnus* and *Chondrites*.

6.4.7 *Margaritichnus* Ichnoguild

Margaritichnus Ichnoguild is a domichnia of a soft-bodied organism. A vertical plugged, slightly inclined to the bedding and shows high density. These represent shallow to mid tier mainly associated with *Thalassinoides*, *Laevicyclus* and *Skolithos* in CSSL of Jhurio Formation. It normally occurs in silty shale and correspond to relatively moderate energy upper shoreface to lower shoreface depositional environment.

6.4.8 *Ophiomorpha* Ichnoguild

The suspension-feeding-dwelling structure *Ophiomorpha* ichnoguild was observed in the BLs, NWWLs, GOs of Jhurio Formation and RMCSSL of Jumara Formation. This ichnoguild is characterized by stationary, deep tier, suspension feeder structures of mobile, opportunistic organisms, exploring the substrate for dwelling purpose. Moreover, they showed that sedimentation was periodic, causing a successive upward extension of shafts. This is an ichnoguild of unstable sandy and oolitic substrate in hydrodynamically energetic environment. Ichnotaxa represented are *Arenicolites, Skolithos, Calycraterion, Parahentzscheliana, Margaritichnus* and *Monocraterion*. This ichnoguild is characteristically found co-occurring with coarse-medium grained sandstones of RMCSSL, Golden oolitic limestone and Badi limestone subfacies.

Density of *Ophiomorpha* burrows varies in different lithofacies, but maximum population can be observed in RMCSSL and GOs, which can be interpreted to indicate conditions of mostly clean send but also muddy sand, moderate to instantaneously high sediment influx. It is further suggested that a low rate of reworking seems to be a precondition for the construction of structures since the delicate clay ball lined walls in *Ophiomorpha* are wholly preserved. On the other hand, the regular nature of the tube swellings along certain bedding planes reveals that these were brought by some events affecting all the burrowing individuals at the same time. It is considered as ichnoguild of unstable sandy, oolitic substrates (RMCSSL and GOs) in foreshore to upper shoreface hydrodynamically energetic environments which are mainly found in the form of shafts (Bromley 1990). The occurrence of Ophiomorpha alone in amalgamated sandstones indicates physically unstable high storm frequency conditions which favour opportunistic behaviour (Frey at el., 1978; Rhoads et al., 1985; Vossler and Pemberton, 1988b).

6.4.9 *Palaeophycus* Ichnoguild

This ichnoguild is characterized by the presence of shallow tier, subsurface deposit feeders. It occurs in both, the clastic and nonclastic sequences and is observed in GOs, DOs, RMCSSL, CSSL and BLs. This ichnoguild is represented by different species of *Palaeophycus (P. heberti, P. annulatus, P. striatus* and *P. tubularis)* with other forms which include *Anchorichnus, Chondrites, Cochlichnus, Pilichnus, Rhizocorallium, Taenidium, Thalassinoides,* and Planolites are very commonly found in most of the lithofacies.

Occurrence of this ichnoguild is in a wide range of substrates (clastic and nonclastic). So, it is difficult to interpret the environmental conditions on that basis, even though predominant occurrence of the horizontal structures and fine grained nature of the sediments indicates low wave and current energy. Furthermore, association with different ichnogenera at different stratigraphic levels indicates that it is formed in shallow water upper shoreface to inner shelf environmental conditions, irrespective of the normal wave base or storm wave base, but it is formed in quiet-water conditions, so that finer food particles were deposited on the sea floor.

This ichnoguild is characterized by the palaeo-community of mobile, shallow to mid-tier, subsurface deposit feeders. This ichnoguild is interpreted to be the work of complex behaviour of deposit feeders seeking food as well as shelters. All the individual ichnotaxa commonly occur in marginal to fully marine middle to lower shoreface and offshore environment.

6.4.10 *Parahentzscheliana* Ichnoguild

This ichnoguild is characterized by the presence of mid to deep tier, subsurface, deposit / suspension feeders and is observed in the RMCSSL of Jumara Formation. This ichnoguild also contains *Arenicolites, Skolithos, Calycraterion, Margaritichnus, Monocraterion* and *Ophiomorpha*. The radiating inclined burrows originating from vertically to obliquely central shaft indicates that the structures were made in the shifting substrate. It is considered as ichnoguild of unstable sandy substrates of RMCSSL in hydrodynamically moderate energetic environments which are mainly found in the form of shafts with inclined radiating tubes. Presence of such structures in sandy facies indicates moderate to high sedimentation rate in between physically unstable high energy conditions above and below. Overall, it signifies upper shoreface to middle shoreface depositional environment.

6.4.11 *Phoebichnus* Ichnoguild

This ichnoguild is characterized by complex burrow *Phoebichnus trochoides,* which occur in moderate density in NWWLs facies of Jhurio Formation. This fodinichnia trace was produced by an in-faunal deposit feeder, systematically mining the sediment for food in one particular place (Bromley and Asgaard, 1972). This ichnoguild generally shows a moderate degree of bioturbation indicating slow rate of sedimentation and physical reworking. The occurrence of an exclusively deposit feeding organism, is indicative of a very quiet environment in which organic material was deposited (Heinberg and Birkelund, 1984). Low diversity and moderate density of this ichnoguild suggests abundance of life under low to moderate energy conditions. The presence of *Protovirgularia – Lockeia – Cochlichnus – Thalassinoides* association supports the views. This type of stationary fodinichnia guild probably exemplifies an oxygen-limited environment that was exploited thoroughly by a population of opportunistic organisms (Ekdale and Mason, 1988).

6.4.12 *Planolites* Ichnoguild

This ichnoguild embraces different specie of *Planolite* like *P. annularis*; *P. beverleyensis*; *P. montanus* and *P. isp.* representing deposit feeding activity at shallow to mid tier. They were produced by in-faunal organisms combining the activity of deposit-feeder and locomotion, thus producing endostratal pascichnia burrows (Dam, 1990). They are occurring in most of the lithofacies i.e. BLs, GOs and CSSL of Jhurio, and Dos, and RMCSSL facies of Jumara Formations. As mentioned in the *Palaeophycus* ichnoguild, due to wide range of occurrence window through lithofacies it is very difficult to identify particular depositional environment for the *Planolite* ichnoguild. The low diversity in the BLs facies suggests a limitation of oxygen and nutrient supply within the sediment (Ekdale and Mason, 1988). The guild has associated ichnogenus like *Palaeophycus, Pilichnus, Thalassinoides, Rhizocorallium, Ophiomorpha* and *Keckia* suggests middle shoreface to lower offshore environment of deposition.

6.4.13 *Protovirgularia* Ichnoguild

This ichnoguild is observed only in NWWLs of Jhurio Formation. It contains semi-vagile to vagile, shallow to mid-tier deposit feeder structures. The large sized, semi-permanent, mainly horizontal structures, show deposit feeding traces having very low diversity. This ichnoguild chiefly consists of infaunal traces of keel-like trail- *Protovirgularia* and associated resting structures-*Lockeia*; feeding structure- *Phoebichnus* and *Thalassinoides*. Other ichnotaxa are *Cochlichnus* and *Palaeophycus* are also present but in low abundance.

It is usually found with interbedded sequences of shale and limestone. This indicates extremely quiet water condition with little physical reworking, where organic matter was being deposited along with the sediments. Sedimentary characteristics and other physical and ichnological parameters suggest that these sequences were formed in upper offshore to shelf environment well below the storm wave base.

6.4.14 *Rhizocorallium* Ichnoguild

The ichnoguild characteristically consists of abundant species of *Rhizocorallium* (*R. jenense, R. irregulare* and *R. uraliense*). It is characterized by horizontal to oblique U-burrow with an active back-filled spreite surface feeding structures. This occurs in large number of CSSL of Jumara Formation. It also occurs in BLs, GOs, and CSSL of Jhurio and RMCSSL and DOs of Jumara Formation. The other feeding structures of shallow tier are also observed which include *Palaeophycus, Pilichnus, Planolites* and *Thalassinoides*. Most elements of this association are shallow burrowing, deposit feeders, found in thinly bedded calcareous silty shale/limestone of the Jhurio Formation. Sediments in the CSSL, wherever the *Rhizocorallium* ichnoguild is located, are fine grained and do not exhibit any sedimentary structures, which in turn indicates very low rate of deposition. *Rhizocorallium irregulare, R. jenense,* and *R. uraliense,* indicates marine conditions and also possibly a sediment feeding mode of life in the well light (clear water, photic) zone of the lower offshore or shelf. In contrast, presence of *Arenicolites* ichnoguild in CSSL of Jhurio Formation suggests organic detritus in suspension and moderate energy conditions at lower shoreface to upper offshore. Overall, this guild has exposed high energy shoreface depositional environment with colonize transgressive and omission surfaces.

6.4.15 *Skolithos* Ichnoguild

It includes stationary, shallow and mid tier suspension feeding structures. The *Skolithos* ichnoguild consists primarily of *Skolithos linearis* and *Skolithos verticalis* with other characteristic elements including mainly dwelling burrows. This ichnoguild is developed in GOs of Jhurio Formation and RMCSSL and DOs facies of Jumara Formation. This is the ichnoguild of opportunistic trace fossils found in unstable sandy and oolitic substrates, in hydrodynamically energetic environments.

The *Skolithos* ichnoguild, as claimed by Bromley (1990), chiefly represents suspension feeding organisms living in high energy hydrodynamic setting and shifting substrate, subject to abrupt erosion and deposition. According to Vosslar and Pemberton (1988), opportunistic ichnotaxa are commonly heavily dominated by *Skolithos linearis*. As per Frey et al., (1990), the ichnoguild generally corresponds to high energy levels of the beach, foreshore and shoreface settings.

As per Bromley (1990), slow suspension feeders that inhabit the shifting sand environment seek security through burrowing deeply and remaining stationary for longer periods. These have a good chance of preservation. In rapidly accreting sands such as migrating sand waves or ripples, there may be no erosional loss of upper parts, yet the ichnological result is the same - low density *Skolithos* assemblages. In such cases, rapidity of burial may inhibit maturation of communities allowing only temporary colonization by a stressed pioneer community.

Thus, the structures typical of the *Skolithos* ichnoguild have low ichno-diversity, low to moderate density, vertical orientation and shallow to mid burrowing of suspension feeders indicates high energy conditions at middle shoreface to upper offshore.

6.4.16 *Taenidium* Ichnoguild

Straight or sinuous, dominantly horizontal meniscate backfilled burrow occurs as shallow to mid tier, crawling - feeding structures. This ichnoguild consists of various ichnospecies of *Taenidium (T. cameronensis, T. satanassi* and *T. serpentinum*) and has shown moderate diversity and density in GOs facies of Jhurio Formation. The occurrence of *T. cameronensis* and *T. serpentinum* in the GOs indicates its presence being restricted to the shelf during the Jurassic times (Keighley and Pickerill, 1994) but other sedimentary features like cross-stratification, mega ripples and oolitic facies indicates relatively energetic environment of protected lower shoreface to upper offshore zone where both types of the food particles (deposit and suspension) were available.

6.4.17 *Thalassinoides* Ichnoguild

Thalassinoides ichnoguild is Y- and T- shaped unlined burrows with passive fill dwelling and feeding structure produced by decapod crustaceans. They are widely distributed stratigraphically and frequently observed in the Mesozoic sequence of the study area. Bromley (1990) considered it as semivagile and vagile, middle level deposit feeder structures which are intermediate to equilibrium or climax trace fossils, present in oxygenated situations. Except their abundance presence in BLs, NWWLs, CSSL, GOs and DOs facies, the guild occurs in all the identified lithofacies. This ichnoguild is commonly in association with active and passive back filled horizontal feeding structures, which include *Ancorichnus, Keckia, Taenidium, Phycodes, Rhizocorallium, Planolites, Palaeophycus, Pilichnus, Protovirgularia, Lockeia, Cochlichnus* and *Chondrites* etc.

It is usually found with interbedded limestones and shales. It has been observed in thick sandstones also, but in low density. The large, semi permanent, mainly horizontal tunnel system - exhibiting exclusively deposit feeding traces and their very low diversity, is indicative of extremely quiet water conditions with little reworking where organic matter was being deposited along with the sediments. This guild probably represents the lowest energy levels (Fursich and Heinburg, 1983).

The guild occurs in lower shoreface to lower offshore substrates normally below daily wave base but not storm wave base, to somewhat quieter conditions offshore. It commonly occurs in negligible to appreciable, though not necessarily rapid, sedimentation areas. Because of lower energy level, less abrupt shifting of sediments and also less abrupt change in temperature and salinity - the bioturbation structures are mainly characterised by feeding and grazing traces, marking the presence of characteristic originators. They are commonly associated with upper shoreface to offshore depositional environment.

6.4.18 *Zoophycos* Ichnoguild

The ichnoguild is observed only in BLs and DOs facies of Jhurio and Jumara Formations respectively, in association with *Chondrites, Rhizocorallium, Thalassinoides, Taenidium, Skolithos, Ophiomorpha, Urohelminthoida, Gyrochorte* and *Palaeophycus* etc. *Zoophycos* mainly consists of 'U' and 'J' shaped burrows which are efficiently executed feeding traces, with spreiten typically planar to gently inclined, distributed in delicate sheets, ribbons or spirals. Animals virtually are all deposit feeders, normally showing low diversity and the structures are plentiful.

Bromley (1990) considers *Zoophycos* as an opportunistic trace, which can appear together with *Chondrites* in opportunistic situation - in low resource, inhospitable, oxygen depleted environments. However, *Zoophycos* is a once in a life time structure, the epitome of slow, stable and specialized reworking of sediment for food, lacking the intrinsic characteristics of an opportunist form. Bromley (1990) further considered it as a non-vagile, deep deposit-feeder structure, which comprises the deepest tier structure. The *Zoophycos* of the DOs is characterized by horizontal lobate structures indicate low to moderate energy conditions in shallow water marine environments. The abundance of *Zoophycos* in oolitic limestone bands indicates well aereated zone which are thoroughly bioturbated by infaunal elements. This

postulation is based on abundance presence of abundance traces of shallow to deep tier structures like *Thalassinoides, Phycodes* and *Palaeophycus* at the same horizon.
In general, the trophic and behavioural characteristics of the guild indicate a gradient in bottom water agitation. The suspension feeding *Skolithos* ichnospecies represents the highest energy levels and the deposit feeding *Chondrites, Rhizocorallium, Thalassinoides, Palaeophycus, Planolites etc.* reflect progressively lower energy conditions, where slow deposition and less erosion prevailed.

Finally, the trophic diversity of trace fossil data reflects different types of substrate conditions, oxygen availability, nutrient supply, varying rates of sedimentation, salinity differences and different degrees of wave agitation. Many of these factors, individually or collectively, must have been responsible for the overall distribution of the animal communities in sedimentary units of the study area. *Zoophycos* has an extremely broad bathymetric range and depositional gradient. The presence of other ichnospecies with this ichnoguild indicates upper offshore, quiet water conditions, with poor water circulation, typified by nearly thixotropic muds or muddy sands rich in organic matter but somewhat deficient in oxygen. Offshore sites are characterised by area below the wave base, in areas free of significant bottom currents.

6.5 ICHNOFACIES

Seilacher (1964, 1967) introduced the term ichnofacies for recurring associations of trace fossils through the Phanerozoic on a global scale. The associations were related to both sedimentary facies and depositional environment. As per Frey and Pemberton (1984), Ichnofacies means associations of traces are recurrent through space and time, wherever the requisite set of environment conditions occurs. Perhaps the single most significant environment concept derived from modern Ichnology is the grouping of characteristic ichnofossils in recurring ichnofacies. Marine sediments of different ages are characterized by peculiar assemblages of trace fossils. Each such assemblage belongs to a particular marine environment and is composed of specific associations of trace fossils, constituting an ichnofacies. Therefore, many trace fossils are good facies indicators.

Originally, Adolf Seilacher (1967) has recognized six ichnofacies (*Skolithos, Cruziana, Zoophycos, Nereites, Glossifungites* and *Scoyenia*) recurrent in time and space, that reflects environmental conditions like bathymetry, salinity, substrate consistency, food supply, oxygen level and temperature, named according to characteristic ichnogenera. In which *Glossifungites* ichnofacies reflects firm to hard substrates (unlithified-omission surfaces) where as *Scoyenia* ichnofacies characterized nonmarine substrate. *Skolithos, Cruziana, Zoophycos* and *Nereites* ichnofacies were clearly based on bathymetry indicate marine softgrounds. Subsequently, three more ichnofacies have been defined on the basis of substrate consistency: the *Trypanites* ichnofacies for rockgrounds and clasts (lithic substrate) (Frey and Seilacher 1980); the *Teredolites* ichnofacies for woody substrate (Bromley et al. 1984). Today, these ichnofacies remain valuable in environmental reconstructions, but paleobathymetry is only on aspect of the modern ichnofacies concept (Frey et al. 1990).

The idealized ichnofacies succession (Fig. 6.7) works well in most 'normal' situations as argued by Frey and Pemberton (1984). Yet according to them one should not be surprised to find near shore assemblages in offshore sediments, and vice-versa, if these accumulated under conditions other than those referred by the trace making organisms (Frey, 1971). The basic consideration rests not with such inanimate backdrops as water depth or distance from shore, or some particular tectonic or physiographic setting, but rather with such native, dynamic controlling factors as substrate consistency, hydraulic energy, rate of deposition, turbidity, oxygen and salinity levels, toxic substances, quality and quantity of available food, and the ecologic and ichnologic ability of the trace makers themselves (e.g. Vossler and Pemberton, 1988a).

It is, however, important to note that the near shore environments are generally highly variable than the deeper water and are subjected to more rapid, more regular and sometimes abrupt changes. Consequently, animals which inhabit the shallow water zones must be tolerant to a wide range of conditions than their deeper water counterparts and must be able to relocate readily, following onset of favourable conditions. This can be observed in different lithofacies at various levels in the Mesozoic sequence of the Jhura hill.

Trace fossils of the Mesozoic sediments of the Jhura hill show environmentally controlled sedimentary facies and are therefore useful in understanding the palaeoecological parameters. Each of the formation consists of abundant and diverse groups of trace fossils, which show a wide range of behavioural patterns– crawling, grazing, feeding, and dwelling, of the marine benthic organisms. Trace fossils were also found in environments ranging from upper shore face high energy and storm-wave influenced ramp to basinal setting beyond storm influence. Their distribution pattern exhibits a clear relationship to the hydrodynamic conditions and secondarily, to bathymetry and follows the classic ichnofacies concept of Seilacher (1967) and Bromley (1996). Analysis of trace fossils in different lithofacies exhibits the recurrent patterns of trace fossil associations which show bathymetric controls and display three different ichnofacies in the study area; (i) *Skolithos* Ichnofacies indicating high wave and current energy, (ii) *Cruziana* Ichnofacies - medium energy conditions and iii). *Zoophycos,* ichnofacies – free from turbidity currents.

6.5.1 *Skolithos* Ichnofacies

This ichnofacies is indicative of relatively high levels of wave and current energy and is typically developed in clean, well-sorted, loose or shifting particulate substrate. Abrupt changes in rates of deposition, erosion and physical reworking of sediments are frequent. Such conditions are commonly occurring on the upper shoreface and bar environment (Fig. 6.7); associated energy levels are represented by fine, parallel to sub-parallel, gently seaward dipping sedimentary laminae, large and small scale trough cross beds. Most common ichnogenera of such conditions especially include *Skolithos* and *Ophiomorpha* with *Parahaentzscheliana, Arenicolites, Diplocraterion, Monocraterion* and *Rhizocorallium* with resting traces.

Skolithos ichnofacies is very well developed in RMCSSL of Jumara Formation and moderately developed in GOs of Jhurio Formation and consists of different trace fossils genera in various proportions. Wave ripples in GOs and RMCSSL and large size cross-bedding in RMCSSL indicates high wave and current energy in the shallow marine environment, above the fair whether wave base. Mostly suspension feeding animals were abundant and they constructed deeply penetrating, more or less permanent domicile structures, like *Ophiomorpha* and *Skolithos* and unusual large burrow systems of *Thalassinoides*.. Conglomeratic nature and high fossil content towards top suggests storm events and subsequent rapid transgression will give intercalated siltstones. GOs has shown mega ripple surfaces; low angle cross and trough stratification, graded bedding with abundant *Skolithos* and *Ophiomorpha* which indicates upper shoreface to lower shoreface environment.. The presence of vertical and U-shaped burrows indicates high energy conditions and an unconsolidated shifting sandy substrate located in the shoreface zone.

Skolithos ichnofacies also appears in the slightly to substantially deeper water deposits like NWLS, where energy levels, food supplies and hydrographical and substrate characteristic were suitable.

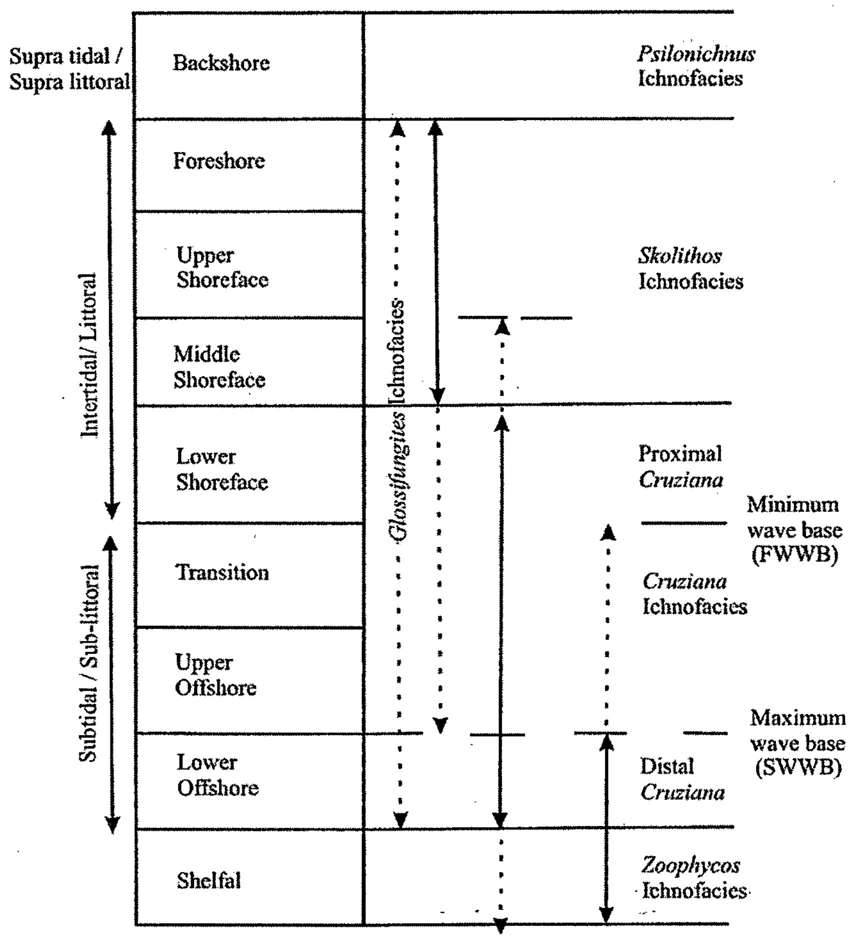

Fig. 6.7 Idealized shoreface model of ichnofacies (modified after Pemberton et al. 1992)

6.5.2 *Cruziana* Ichnofacies

The Cruziana ichnofacies is typically associated with poorly sorted, unconsolidated, marine substrates lying below minimum wave base and above maximum wave base (Fig. 6.7) littoral to sublittoral depositional environment. The ichnofacies is typically associated with vertical, inclined and horizontal structures. The traces have high diversity and abundance; mostly feeding and grazing structures constructed by deposit feeders, except where crawling traces are predominant constructed by mobile organisms.

This ichnofacies is observed in the storm-influenced ramp and also represents classical gradation from *Skolithos* to *Cruziana* in many different types of substrates as indicated either by change in hydrodynamic conditions, depositional dip or bathymetry in the basin (Fursich 1974 b and d; Frey and Howard, 1985). This ichnofacies recurs through the exposed sequence of the Jhura Dome and found in all the lithofacies includes BLs, NWWLs, CSSL, GOs and DOs and consists of abundant horizontal structures. Diversity of the trace fossils is appreciable, but the population density differs in different lithofacies. However, mixed *Skolithos* – Cruziana associations do occur at various stratigraphic levels. It mainly consists of *Rhizocorallium, Chondrites, Beaconites, Gordia, Didymaulichnus, Megagrapton, Phymatoderma, Phycodes, Planolites, Palaeophycus, Pilichnus Protovergularia, Thalassinoides, Taenidium* and *Zoophycos*. The BLs, CSSL, GOs and NWWLs of Jhurio Formation has shown well developed *Cruziana* ichnofacies, while at some extent RMCSSL and DOs has also exposed a development of such ichnofacies along with *Skolithos* ichnofacies. A most conspicuous trace fossil such as *Zoophycos* occurs abundantly in the DOs of the Jumara Formation and is characteristically found associated with *Cruziana*.

Abundance of horizontal structures in the *Cruziana* ichnofacies indicates low energy environment of deposition on an unconsolidated substrate and repeated appearance of *Skolithos* ichnofacies in the stratigraphic record, indicating either shallowing of the basin or high energy conditions, as found in the subtidal zones above the storm wave base. Change in energy levels and allied parameters during the deposition of RMCSSL, the temporary excursion of *Skolithos*–type conditions into a *Cruziana* –type setting is also seen. This indicates sub-tidal to poorly sorted sediments and typically forms in either moderate energy condition in shallow waters below the fair weather wave base and above storm wave base, to low energy levels in the deeper, quiet waters.

In the DOs sudden change in environmental condition is noticed where temporary excursion of large sized and morphologically conspicuous burrows of *Zoophycos* species were appeared and altered the sediments into a *Cruziana* type setting. Overall bedding style association is *Cruziana* type and also consists of abundant burrows of *Thalassinoides, Phycodes, Planolites, Palaeophycus, Rhizocorallium* and *Taenidium*, which are the members of the *Cruziana* ichnofacies.

Overall, the lithofacies of the Jhura dome area consist of poorly sorted, fine grained sediments indicating low to moderate energy conditions and contain both suspended and deposited food components. The grazing, feeding and dwelling activities of the animals characteristically indicates both suspension and deposit feeders, as well as mobile carnivores and scavengers were abundant. Because of lowered energy and abrupt shifts in temperature and salinity, burrow structures tend to construct horizontally rather than vertically (Pemberton et al., 2001).

6.5.3 *Zoophycos* Ichnofacies

Frey and Pemberton (1985); Frey and Seilacher (1980) characterized the environment as circalittoral to bathyal, quiet-water conditions, more or less deficient in oxygen; offshore sites are below storm wave base to fairly deep water for *Zoophycos* ichnofacies. The exact environment implications of the *Zoophycos* ichnofacies and its variant have not yet been determined. Rocks of *Zoophycos* ichnofacies usually show total bioturbation. The quiet accumulation of mud allows climax communities to develop, spread over many levels, the *Zoophycos-Chondrites* ichnoguild occupying the deepest tier (Bromley 1990). Apart from *Zoophycos,* ichnologist have found difficulty in assigning any characteristic ichnotaxa to the *Zoophycos* ichnofacies. The ichnogenus *Zoophycos* may also be abundant in the *Cruziana* and Nereites ichnofacies under normal oxygen levels. In popular bathymetric schemes (Fig. 6.8), the *Zoophycos* ichnofacies typically is represent as an intermediary between the *Cruziana* and *Nereites*. *Zoophycos* ichnofacies is interpreted as oxygen-poor settings relatively simple to moderately complex, efficiently executed grazing traces and shallow feeding structures; spreiten typically planar to gently inclined, distributed in delicate sheets, ribbons, lobes or spirals (Walker and James, 1992; Pemberton and MacEachern, 1995).

This ichnofacies occurs in the BLs of Jhurio Formation and is characterized by two species of *Zoophycos* (*Z. circinnatus,* and *Z. brianteus*). The diversity of the trace fossils are insignificant but isolated form also occurs such as *Thalassinoides, Urohelminthoida* and *Rhizocorallium*. The fine grained nature of the sediments indicate low rate of sedimentation in shallow water marine environments. The presence of *Zoophycos* association indicates thixotropic conditions, low oxygen content and low nutrient supply which give rise to deepest tier. The sudden appearance of elements of *Cruziana* association indicates changes in environmental condition from lower offshore to upper offshore conditions during the deposition of sediments of the BLs.

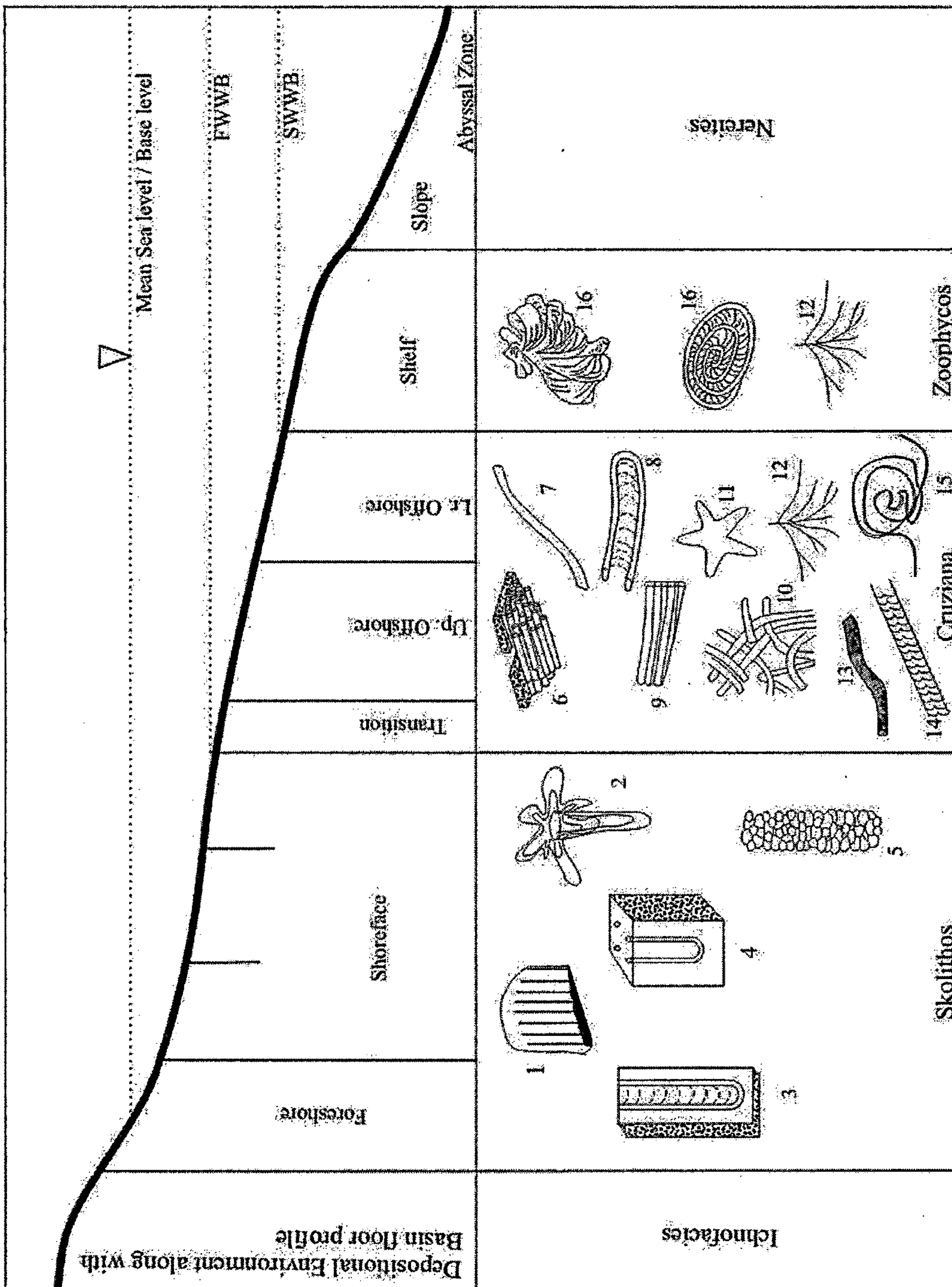

Fig. 6.8 A bathymetry scheme along with Ichnofacies (Modified after Frey and Pemberton 1985) Typical trace fossils include: 1) *Skolithos*, 2) *Parahentzscheliana*, 3) *Diplocraterion*, 4) *Arenicolites*, 5) *Ophiomorpha*, 6) *Phycodes*, 7) *Palaeophycus*, 8) *Rhizocorallium*, 9) Teichichnus, 10) *Thalassinoides*, 11) *Asteriacites*, 12) *Chondrites*, 13) *Planolite*, 14) *Protovirgularia*, 15) *Cosmorhaphe*, 16) *Zoophycos*

Table 6.2 Distribution of trace fossils within Lithofacies

R = rare; C = common, A = abundant.

Trace fossils / Lithofacies	DOs	RMCSSL	NWWLs	GOs	CSSL	BLs
1. Ancorichnus ancorichnus		R	C			
2. Arenicolites carbonarius		A		R	C	
3. Beaconites antarcticus			C			
4. Beaconites coronus			C	R		
5. Bergaueria isp		C			R	
6. Biformites isp		R				
7. *Chondrites* intricatus	C	R	R	C	C	
8. *Chondrites* isp.	C			C		
9. *Chondrites* patulus	R	C	R	R	C	
10. *Chondrites* recurvus		C		A	C	
11. *Chondrites* targionii		C		C	A	
12. Cochlichnus anguineus			C			
13. Cosmorhaphe carpathica			C			
14. Calycraterion isp		C		R	R	
15. Calycraterion Samsonowiczi		C		R	R	
16. Didymaulichnus isp.				R		
17. Diplocraterion habichi		A		R	R	
18. Gordia marina		C		C		
19. Gyrochorte comosa	C	R			R	
20. Gyrolithes polonicus		R				
21. Keckia annulata			C	A		
22. Laevicyclus mongraensis		C			C	
23. Lockeia ornata			A			
24. Lockeia siliquaria			A			
25. Margaritichnus reptilis		R		R	A	
26. Monocraterion tentaculatum		C		C	C	

Lithofacies / **Trace fossils**	**DOs**	**RMCSSL**	**NWWLs**	**GOs**	**CSSL**	**BLs**
27. Ophiomorpha nodosa		A		C		R
28. Ophiomorpha recta		C		A		
29. Palaeophycus annulatus	C	A	C	C	C	
30. Palaeophycus heberti		R	R	A	A	
31. Palaeophycus striatus		R	R	A	A	
32. Palaeophycus tubularis	C	A	C	C	A	
33. Parahentzscheliana ardelia		A				
34. Phoebichnus trochoides			A			
35. Phycodes circinnatum				C	R	
36. Phycodes curvipalmatum				A		
37. Phycodes palmatum		C		C		
38. Phycodes pedum	R			C		
39. Phymatoderma isp.				C		
40. Pilichnus dichotomus		C		A	A	
41. Planolites annularis		A		A	C	
42. Planolites beverleyensis		C		C		
43. Planolite isp.	R	C	R	C	A	
44. Planolites montanus		R		C		
45. Protovirgularia dichotoma			A			
46. *Rhizocorallium* irregulare	C	C		C	C	C
47. *Rhizocorallium* jenense	C				A	
48. *Rhizocorallium* uraliense					A	
49. Sabularia ramosa			R	A	R	
50. Scolicia strozzii			C		C	
51. Skolithos linearis		C		A		
52. Skolithos verticalis	A					
53. Taenidium cameronensis				A		
54. Taenidium satanassi				A		

Trace fossils / Lithofacies	DOs	RMCSSL	NWWLs	GOs	CSSL	BLs
55. Taenidium serpentinum				A		
56. *Thalassinoides* foedus	R	R		A		
57. *Thalassinoides* horizontalis	A	R	A	A		C
58. *Thalassinoides* paradoxicus	R	R		A		C
59. *Thalassinoides* suevicus	R	C	C	R	C	
60. Urohelminthoida dertonensis					C	C
61. *Zoophycos* brianteus	A		R			A
62. *Zoophycos* caudagalli	A					
63. *Zoophycos* circinnatus	A					A
64. *Zoophycos* insignis	A					
65. *Zoophycos* laminatus	A					
66. *Zoophycos* villae	A					
67. *Zoophycos* Type A	A					
68. *Zoophycos* Type B	A					
69. *Zoophycos* Type C	A					
70. *Zoophycos* Type D	A					
71. *Zoophycos* Type E	A					

Table 6.2 Trace fossils and its distribution within Lithofacies

R = rare; C = common, A = abundant.