Chapter - 8

ICHNOCOENOSES, PALAEOECOLOGY AND PALAEOECOLOGICAL CONSIDERATIONS

VIII. 1. INTRODUCTION:

`Ichnocoenoses' (ichna-traces, coenosi-community) is defined by Dorges and Hertweck (1975; p.468-9) as `an association of traces that can be related to one definite `biocoenose', or as `covering an Assemblage of ecologically coherent traces produced in one definite environment by members of a given biocoenose'. According to them, it is an association of trace fossils that can be recognised and determined individually reflecting life activities of members (individuals) of a biocoenoses, i.e. a community of organisms on or in the substratum. As per the above definition, the association of lebensspuren (trace fossils) is related to one definite biocoenose, that means the term `ichnocoenose' is conformable with the term `biocoenose'. The members of such a community of traces can thus be recognised as described individually. The lebensspuren to be incorporated may be surface traces, dwelling structures, or other internal traces of a contemporary animal community, as well as preserved trace fossils originated by previous or emigrated community/ies.The individual ichnofossil of an ichnocoenose further reflect ethological and ecological responses of the trace making organisms of a palaeobiocoenose, to the substratum. Additionally, in case of uncertain systematics and taxonomic position of the organisms, the functional morphology of trace making organisms may be advantageously reconstructed.

Many geologists have used the word ichnocoenoses to describe fossil equivalents, i.e. assemblage of trace fossils that appears to be the work of a single community (e.g. Bromley and Asgaard, 1979; Bottjer et al, 1986). Bromley (1990) suggests that the term palaeoichnocoenoses would be more appropriate to pair with palaeobiocoenoses, and its equivalent life assemblages. But in case of geological sequences, the term becomes unnecessarily prefixed and lengthy. As far author is concerned, the term ichnocoenoses is used by him in the meaning to denote palaeoichnocoenoses.

The first recognization of Palaeoichnocoenoses was made by Seilacher (1967) who noted that in marine environments many parameters which govern the abundance and distribution of trace makers (such as temperature, food supply and intensity of wave and current agitation) tend to change progressively with water depth. Further, as suggested by him, it is important to define the physical environment of an ichnocoenose and its depositional set ups. The physical environment of an ichnocoenose or a characteristic lebensspuren has therefore to be defined by its particular sedimentological characters such as composition and grain size, content of organic matter, aeration, compaction, and oceanographic factors such as water depth, salinity, water circulation and many others; while depositional conditions can be postulated by sedimentary structures which are indicators of current and wave action, rate of sedimentation or erosion and reworking. Moreover, characteristic ichnofossils are usually not the only bioturbation structures in an ichnocoenose. Associated lebensspuren also provide representative frequencies and abundances of trace making organisms.

Different ichnofacies have been recognised by Seilacher (1964, 1967) and Frey (1975) as important pelaeoenvironmental indicators depicting the behavioral responses of the distinct depth controlled organisms in relation to the energy conditions at the sediment water interface, substrate types and nutrient distribution regimes. But, there has been an argument by Crimes (1970), Fray and Howard (1970) and Fursich (1975), that even though the depth related ichnofacies concept of Seilacher (1964, 1967) is a useful hypothesis, it has been over simplified because other environmental parameters also control the trace fossil distribution. Crimes (1973) and Frey (1975) have argued that the distribution and abundance of trace making organisms is controlled by dynamic environmental factors which are not necessarily directly related to bathymetric concept of Seilacher (1967). The general gradation of trace fossil assemblages in relation to some of these factors in increasing depth of water is once again given by Rhoads (1975, fig 9.1) following the initially proposed scheme of Seilacher (1964, 1967). Kern and Warme (1974) have commented that ichnofacies or individual ichnotaxa, as previously employed by Seilacher (1964, 1967) may not always be reliable palaeoenvironmental indicators and that interpretations must be made considering the total available ichnocoenoses.

In ichnological explorations, the main way to determine characteristic lebensspuren according to Frey (1975), is to investigate profiles (or other quantitative sampling arrangements) consisting of a considerable number of representative samples from different environments. Then by comparing ichnocoenoses related to different substrate one can evaluate biogenic features which are common to several or to a single environment along the profile. The individual trace fossil thus then reflect ethological and ecological response of the trace making organism in a specific environmental condition.

The idealized ichnofacies succession works well in most 'normal' situations as argued by Frey and Pemberton, (1984, fig. 5); yet according to them one should not be surprised to find nearshore assemblages in offshore sediments, and vice-versa, if these accumulated under conditions otherwise like those referred by the trace making organisms (Frey, 1971). The basic consideration rests not with such inanimate back drops as water depth or distance from shore, or some particular tectonic or physiographic setting, but rather with such innate, 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 prowess of trace makers themselves (e.g. Vossler and

Pemberton, 1988). Resulting ichnocoenoses are related to bathymetry only where particular combinations of environmental parameters are related to bathymetry.

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 some times 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 on set of favourable conditions.

Despite the rarity of physical redeposition, there are certain factors that readily cause trace fossil assemblages to be ecologically impure groupings. The most threatening factor is the rapid succession of communities that can develop on an aquatic floor. Time averaging by relatively slow depositional rates ensures that the structures produced by each successive community are super imposed in the same rock unit. Care has been taken against this, whenever required, by checking cross cutting relationships. The opposite problem is that ecological tiring may spread the work of different members of an endobenthic community over several units more than a meter apart. One of the most fundamental tenets of ichnocoenoses analysis is that all available evidences - physical, chemical or biological - could be integrated and utilized in interpretations. For bathymetric assessments, these collective observations can be placed in the context of proximality trends, whether emphasized from a sedimentological view point or an ichnological one. Association between, and configuration of biogenic and physiogenic sedimentary structures become powerful combinations in the reconstruction of environmental gradients (Moslow and Pemberton, 1988; Frey and Wheatcroft, 1989); they are especially useful where otherwise prevalent trends have been modified by episodic events or other environmental fluctuations. Even, integrated quantitative approaches can not replace common sense evaluations.

Thus biogenic structures in the Mesozoic sequence studied by the author contain a rich and varied trace fossil fauna, that demonstrate wide range of animal behaviors and can be interpreted in terms of ecology, strategy of adaptations and biological parameters directly related to physical aspects of the palaeoenvironments. Their use in palaeoecology could also be made to draw information on the fossil community distribution and on their feeding habits by probing structures. The present author has used such associations of traces advantageously.

The main purpose in the ichnocoenoses description by the author, therefore, will to demonstrate the significance of the trace fossils in their `community-', `palaeoecology-' and `environmental-' reconstructions. It is further important to acertain in the above context that the distribution of trace fossils in different stratigraphic sections of central mainland Kutch exhibit a distinct non-random pattern of its distribution. As confirmed earlier, out of nine Members in the Mesozoic sequence, two are poor in trace fossil contents. Maximum trace fossils are concentrated in rhythmic or intercalated sequence of shale, siltstone and sandstone. Some trace fossils are seen occurring together recurrently, where as the others are never found, even at the same level. These relationships are easily recognisable in the field. The Tapkeshwari Member of Umia Formation comprises predominance of a variety of trace fossils within a few (5.0-7.0) meter thick part of its sequence. While JWM of Chari Formation and MDM and JM of Katrol Formation stood on second position in exhibiting several varieties of trace fossils. Differences in trace fossil assemblages among the various facies can also be attributed to the preservational factors that are related to parameters (e.g. grain size) of the original sediments.

Naming the individual ichnocoenose is necessary for their identification as recurring entities. The simplest method is to identify the ichnocoenose by its characteristic dominating ichnogenus. The eponymous form does not necessarily need to be abundant in every occurrence of its ichnocoenose, and still, it might also appear on other ichnocoenoses.

The group of trace fossils occurring together (as recognised by the author) constitute eleven ichnocoenoses (fig-11). Each ichnocoenose thus recognised is named after its most abundant trace fossil form in general. Detailed description and significance of each of these ichnocoenose is dealt in the following paragraphs, and their distributions in the study area is given in fig-11.

VIII. 2. ICHNOCOENOSES:

VIII.2.1. ASTERIACITES ICHNOCOENOSE :

The ichnocoenose is dominated by various resting traces like *Asteriacites*, Calycraterion, *Bergaueria* with few dwelling (*Skolithos*, *Diplocraterion*, *Palaeophycus*), feeding (*Palaeobullia*, *Gyrochorte*, *Crossopodia*) traces. It is observed in red to brown or yellowish coloured, thinly intercalated RFSSS facies of TM near observatory, and in a nala section north of Bharapar village. The possible palaeo- environmental interpretation for the *Asteriacites* assemblage following Pemberton et. al. (1988), the *Asteriacites* ichnocoenose represents a thixotropic muddy sandy substrate of a lower tidal, infratidal regime, where fluctuations in the water level caused the animals to be stranded on the muddy sands substrate). Markings of the movement of arms in *Asteriacites* demonstrates some kind of activity of the organism which may be predatory on its prey (plate-19).

VIII.2.2. CHONDRITE ICHNOCOENOSE:

This association is characterise by *Chondrites* alongwith frequent occurrence of *Planolites* and infrequent occurrence of *Zoophycos* (only in OL facies of DOM). The ichnocoenose has been observed in LM (in SS, LSS and in exhumed pebbles present in the IC facies), DOM (in OL facies), MDM (in LSS facies),

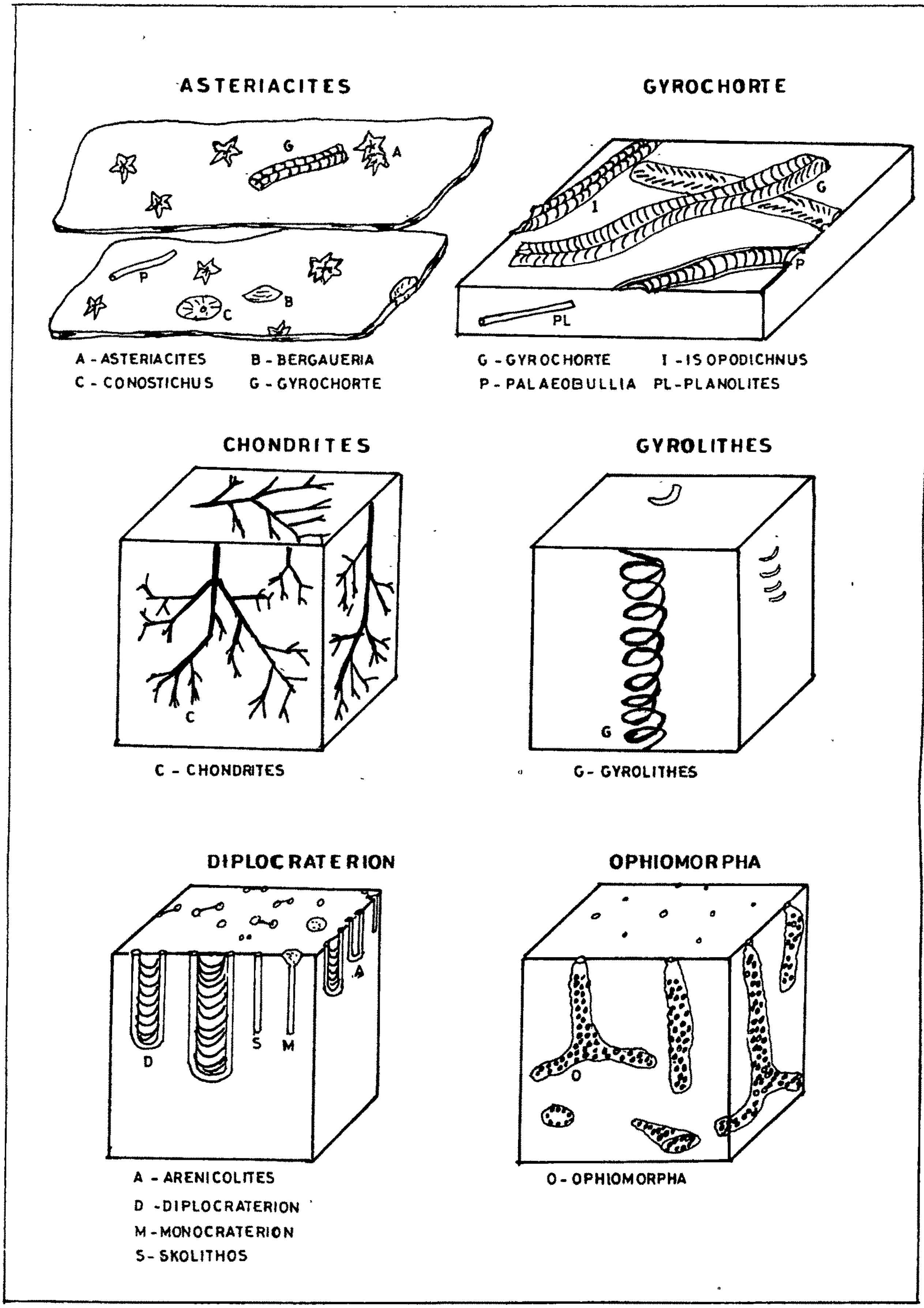

FIG. 11 a. DISTRIBUTION OF ICHNOCOENOSES IN THE STUD
AREA

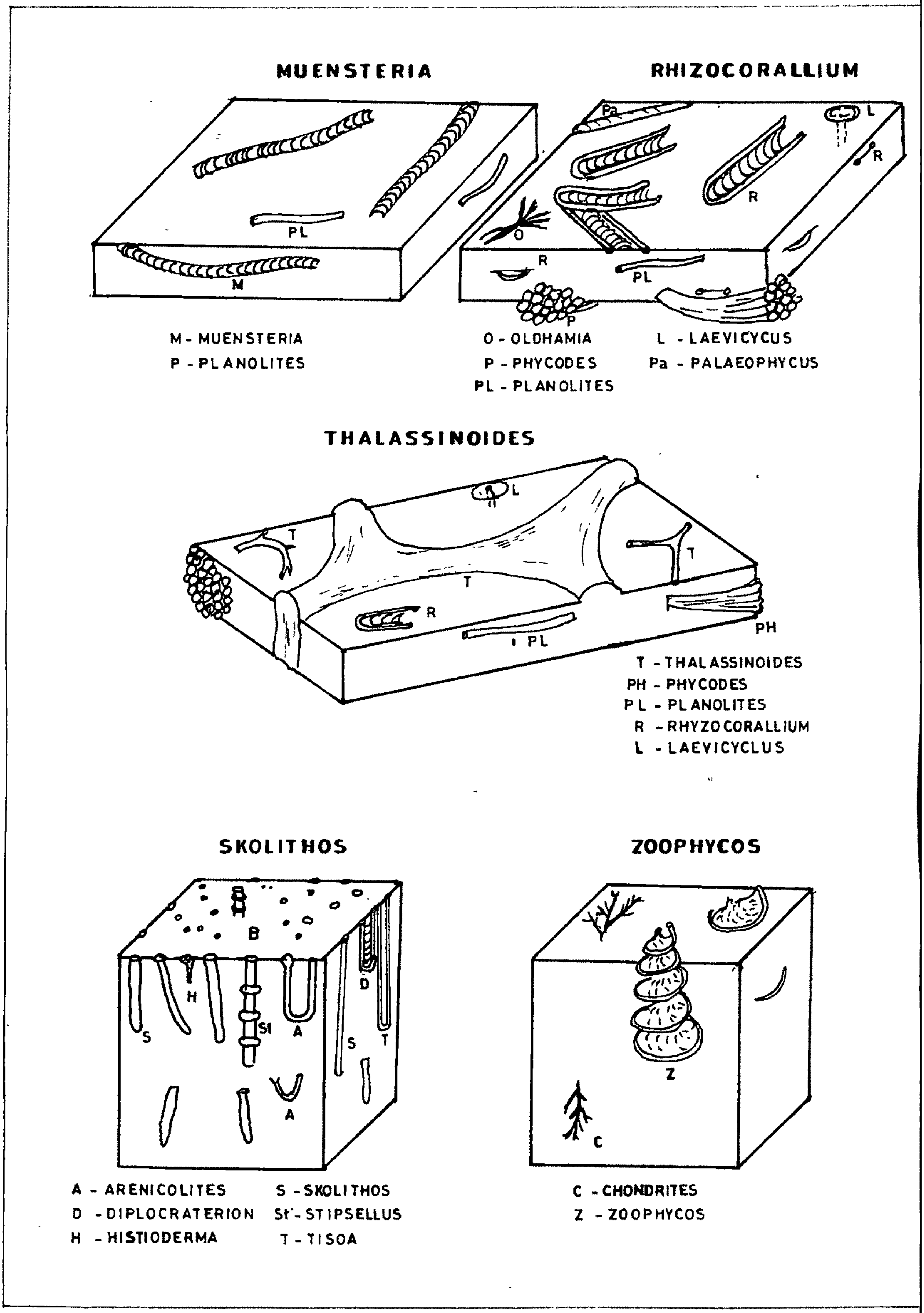

FIG. 11 b. DISTRIBUTION OF ICHNOCOENOSES IN THE STU
AREA

JM (in SS facies) and in TM (in LSS facies). The assemblage represents regularly branching burrow system constructed by endobenthic deposit feeding organisms of unknown taxonomic affinity, where the burrows are emplaced well below the water sediment interface, i.e. found deeply in the sediments. The nature of such burrow in the field indicates that the burrow was kept open by its inhabitant and had lateron filled passively by sediment 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* postulates 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 a low energy regime quiet water conditions. According to Frey, Pemberton and Saunders (1990), the ichnocoenose develops in circa-tidal to bathyal conditions or protected intracoastal to epeiric sites with poor water circulation. It typically occurs in mud or muddy sands rich in organic matter but some what deficient in oxygen. Off shore sites are below storm wave base to deep water, in areas free of turbidity flows or significant bottom currents. Intracoastal to epeiric sites include features such as silled basins and restricted lagoons.

Ekdale (1985; p. 71) 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, 1988). Wightman et.al. (1987; fig. 33) have found *Chondrites* in brackish water situations.

Bromley (1990) described the ichnocoenose as non-vagile, deep deposit feeder structures. As it is an ichnocoenose 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 Kutch association, whenever occurs in LSS facies appears to be related to sediments deposited below subtidal region, below storm wave base, in areas free from significant bottom currents or turbidity flows, while in case of SS and OL facies, It seems to be in association with the sediments accumulated in protected intracoastal and epeiric parts to lagoon or restricted near shore areas, lagoons and even subtidal restricted parts of beach extension & barriers.

There, the structures inhabit deeper levels within then unconsolidated to semi-consolidated sediments. The structures mostly occurs in fine argillaceous silty rocks where circulation is poor and in sandstones but prefers rocks with carbonate cement (originally lime mud - micrite) which is product of reducing conditions.

VIII.2.3. DIPLOCRATERION ICHNOCOENOSE:

Characteristic members of this ichnocoenose are *Diplocraterion* parallelum and *Diplocraterion* Sp. The *Diplocraterion* ichnocoenose constitute association of different types of dwelling tubes of considerable lengths. It occurs in JWM, GM, LM, TM and BM. In JWM it occurs in SS facies in association with *Laevicyclus*, *Bifungites*, *Ophiomorpha*, *Planolites*, *Palaeophycus*, *Tisoa* etc. In GM the ichnocoenose is found in MS and HS facies mainly alongwith *Asteriacites*, *Skolithos*, *Monocraterion* etc. In LM, the ichnocoenose occurs in LSS facies and mainly consisting of *Skolithos*, *Ophiomorpha*, *Tisoa*, *Planolites* etc. In TM, the RFSSS, MS and HS lithofacies contains *Diplocraterion* ichnocoenose, where the associated members are *Arenicolites*, *Monocraterion*, *Skolithos*, *Ophiomorpha*, *Enteropneusta burrows*, *Spirophyton*, *Stipsellus*, *Laevicyclus*, *Bergaueria* etc. While in BM, the assemblage occurs in

BTS facies in association with *Arenicolites*, *Monocraterion*, *Stipsellus*, *Skolithos*, *Rosselia*, *Enteropneusta burrows*, *Corophioides*, *Ophiomorpha* etc. Here, in BM, at places (as on Tapkeshwari hill top) the eponymous form is dominant-monodominant, and in BM only, the ichnocoenose shows high density, in other Members the density is low to moderate.

The *Diplocraterion* ichnocoenose thus represents a community dominated by suspension feeding (domichnia) organisms, which inhabited calcareous, ferruginous to felspathic arenaceous substrates during the deposition of JWM, GM, LM, TM and BM.

The *Diplocraterion* ichnocoenose can further be interpreted as of a relatively high energy environment, with moderate to insufficient sedimentation of fine grained particles to support deposit feeders. Thus suspension feeding seems to have predominant, during this ichnocoenose. Physical reworking appears to be frequent, as indicated by presence of tapering against erosional surfaces in numerous horizons of BTS facies of BM, and MS facies of GM (plate-31, 32). it is probable that the long tubes could have served as a protective shelter against unstable conditions on the sea floor depicting agitating water conditions with low rate of sedimentation.

The low ichno-diversity and moderate to high density of ichnocoenose suggest abundance of opportunistic ichnotaxa. Sedimentological data (sedimentary structures, erosional and reactivation surfaces, in BM and other Members) indicate 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 uneven sedimentation rates and merely newly deposited substrate.

Considering the above facts it is postulated that the depositional environments, varied from lower tidal to infratidal and tidal flats 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. Increased energy conditions enhanced physical reworking and obliterated the biogenic sedimentary structures, leaving behind low to moderate density of the ichnocoenose. Episodic erosion and deposition could have resulted in producing alternately protrusive and retrusive spreiten structures.

VIII.2.4. GYROCHORTE ICHNOCOENOSE:

The ichnocoenose is characterised by dominance of the ichnospecies *Gyrochorte* comosa in association with other trails. The assemblage occurs in JWM, GM, LM, MDM, JM and TM. In JWM, the ichnocoenose occurs in LSS, DSSS and SS facies, where the main associates are *Didymaulichnus*, *Isopodichnus*, *Cochlichnus*, *Bolonia*, *Planolites* etc. In GM the ichnocoenose has been observed in MS facies represented by *Gyrochorte*, *Isopodichnus* and bilobe and *Crustacean* trails. In LM, it is found in BS and LSS facies, where it occurs in association with *Bolonia*, *Scolicia* and *Planolites*. In MDM, it has been seen in LSS facies with *Cochlichnus* and echinoid trails. In JM, again it occurs in LSS facies where assemblage constitutes *Gyrochorte*, *Didymaulichnus*, *Isopodichnus*, *Cochlichnus*, *Scolicia* etc. In TM, the association of *Gyrochorte*, *Isopodichnus*, *Scolicia*, *Crossopodia*, occurs in RFSSS and monodominant occurrence of *Gyrochorte* in MS and SS facies. The ichnocoenose generally shows a high degree of bioturbation indicating relatively slow sedimentation and little physical reworking. The small scale ripple laminated sandstones with *Gyrochorte* assemblage very often found in the Observatory, Sanatorium, Jadura nana, SES hill and Jamaywadi nala sections indicate small scale sediment transport, but not necessarily increase of sediment influx.

The *Gyrochorte* ichnocoenose represents the activity of crawling which is similar to amphipod trails. The very good preservation of crawling trails mostly in form of epirelief and intrastratal suggest low energy conditions, with almost nil sedimentation at the time of omission and early diagenesis or hardening. The ichnocoenose occurs in shelf sequences, commonly infratidal to shallow circatidal substrates 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 ichnocoenoses. It normally occurs in well sorted silts and sands to interbedded muddy and clean sands, and moderate to intensely bioturbated, and depicts negligible sedimentation. Very common type of depositional environments involve shelves and epeiric slopes, tidal to subtidal parts of estuaries, lagoons, bays and tidal flats. Howard and Reineck (1981) have observed common storm deposition in which this assemblage is found, producing repeated laminated to scrambled units bioturbated at top.

In Kutch, the ichnocoenose occurs in silts and sands to interbedded muddy and clean sands mostly containing ripple marks with moderate bioturbation. It occurs in tidal flats to lagoonal subtidal and shallow shelf deposits, and represents a community of opportunists to intermediate in between opportunists and equilibrium trace fossils to produce a post-depositional ichnocoenoses.

VIII.2.5. GYROLITHES ICHNOCOENOSE:

The ichnocoenose occurs monodominantly in MS facies of JM of Katrol Formation. The assemblage constitutes high density of vertically oriented spiral burrows of *Gyrolithes* showing combined deposit feeding and dwelling activity. The low ichno-diversity and high density (monodominance) of the burrows place it in an opportunistic category. The structures show some degree of permanence and morphology reflects exploitation of substrate for food. These are semi- vagile and vagile, middle level (mid tier) deposit feeder structures; present in oxygenated substrates, commonly leading to high degree of bioturbation.

As per Frey, Pemberton and Saunders (1990), the assemblage occurs in distal regions to the shoreline and records continuous slow deposition and bioturbation. It indicates quiet but oxygenated waters and stable and slowly accreting substrates. In shelf sequence, it is located in the fine grained sandstones indicating dominance of deposit feeding activity, the interpretation is supported by the fine grained nature of the enclosing sediments.

The Kutch assemblages are post-depositional structures and have been observed in subtidal shelf part. Their low ichno-diversity is suggestive of community under continuous slow deposition and bioturbation, yielding complex bioturbate textures.

VIII.2.6. MUENSTERIA ICHNOCOENOSE:

The ichnocoenose is dominated by various back fill tunnels (*Muensteria* sensu lato). The ichnocoenose is monodominant in SS facies of JWM of Chari Formation alongwith *Planolites*, *Helminthopsis*, Protopalaeodictyon, and *Bolonia* and in RFSSS facies of TM alongwith *Circulichnus*, *Helminthopsis*, *Megagrapton*, *Planolites*. All traces are interpreted as traces of deposit feeders. The ichnocoenose occurs in the fine grained sandstones and shales indicating dominance of deposit feeders that lived in a low energy environment, an interpretation supported by the fine grained nature of the enclosing sediments.

As per Frey, Pemberton and Saunders (1990), the assemblage occurs in more distal regions and records continuous slow deposition and bioturbation yielding complex bioturbate textures. It also indicates quiet but oxygenated waters, and stable and slowly accreting substrates, as further postulated by Frey, Pemberton and Saunders (1990).

Based on Wetzel's (1983a, fig. 6, 1984, fig. 6) work and samples, Bromley (1990) suggest that there are no grounds for considering the Nereites assemblage to represent deeper water than the *Zoophycos* association, as Nereites association and *Zoophycos* assemblage have been observed in the same box core.

Zoophycos perhaps produced about 1.0 m below water sediment interface, it displaces upward up to 20.0 to 30.0 cm by Nereites community. This suggests that the original endobenthic communities, modify temporarily by the presence of sand substrate, probably differ little in present day environments, where as the palaeoichnocoenoses are widely different, may be largely as a result of differing taphonomic histories. And hence one demonstrates its well oxygenated upper parts within the sediments (tiers), the other only its oxygen starved lower parts (tiers). Moreover, Frey et al., (1990) suggest that *Zoophycos* ichnocoenose may occur at intracoastal to epeiric sites, and so Kutch association of *Muensteria* demonstrates infratidal to circa tidal depositional environments. Ekdale, Bromley and Pemberton (1984), Frey and Bromley (1985), Bromley and Ekdale (1986) have considered such an assemblage as vagile, deep deposit feeder structures. They have observed them in many situations, the deeper tiers of the ichnocoenoses cutting deeper than *Thalassinoides* ichnocoenose but less deeper than *Zoophycos* assemblages. The ichnocoenose constitutes climax trace fossils under equilibrium environments.

VIII.2.7. OPHIOMORPHA ICHNOCOENOSE:

The *Ophiomorpha* ichnocoenose consists of monodominant *Ophiomorpha* burrows in a given bed and can be observed in JWM (LSS and SS subfacies), LM (LSS subfacies), MDM (LSS subfacies), JM (LSS subfacies), TM (RFSSS and MS subfacies) and BM (CBCGS facies).

Density of *Ophiomorpha* burrows varies in different Members and Lithofacies, but maximum population can be observed in BM (CBCGS facies) near Chakar and can be interpreted to indicate conditions of moderate of 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 burrow individuals at the same time. Periodic additions of new layer of sediments causing successive upward extensions of the shafts as suggested by Howard, Valentine and Warme (1971) seems to be a reasonable explanation.

It is considered as ichnocoenose of unstable sand substrates in hydrodynamically energetic environments which mainly found in form of shafts (Bromley 1990). Such burrows are present in BM. Irregularly inclined to horizontal structures in JWM, LM, MDM and JM depict moderate to relatively low energy conditions below daily wave base (but not storm wave base).

The *Ophiomorpha* ichnocoenose in Kutch thus represents suspension feeders and occurs in well sorted silts to interbedded muddy and clean sands. The common types of depositional environments include estuaries, bays, lagoons, tidal flats, as well as continental shelves and epeiric slopes.

VIII.2.8. RHIZOCORALLIUM ICHNOCOENOSE:

The ichnocoenose constitutes primarily of *Rhizocorallium jenense*, *Rhizocorallium* irregularie and *Rhizocorallium* Sp. with other characteristic elements variably present in different Members. The association occurs in JWM, LM, DOM, MDM, JM and TM. In the JWM, the trace fossils present in the association are *Rhizocorallium*, *Laevicyclus*, *Palaeophycus*, *Phycodes*, *Planolites*, *Granularia* etc. In LM, it occurs in LSS, where assemblage is *Planolites*, *Palaeophycus* and *Chondrites*. In DOM, the ichnocoenose have been observed with bilobate trail in LSS facies. In MDM, the assemblage of *Phycodes*, *Rosselia*, *Laevicyclus*, *Granularia* etc., have been observed. In JM, it occurs in association with *Oldhamia*, *Laevicyclus*, *Phycodes*, *Cylindricum* etc. While, in TM, the assemblage mainly occurs in RFSSS subfacies alongwith *Keckia*, *Laevicyclus*, *Taenidium*, *Spirophyton*, *Rosselia*, *Oldhamia*, *Gyrophyllites* etc.

Most elements of this association are shallow, burrowing deposit feeders, found in fine to medium grained sandstone-siltstone alternations of Chari, Katrol, and Umia Formations. Sediments in these Formations, wherever the *Rhizocorallium* ichnocoenose is located do not exhibit any sedimentary structures except ripple marks, which in turn indicate very low rate of deposition. It has been recently shown by Buckman (1990) that in some cases R. *jenense* may indicate marginal marine conditions and also possibly a sediment feeding mode of life. *Rhizocorallium* ichnocoenose in Kutch as compared with these observations seems to be indicative of low energy lower tidal - subtidal areas, less protected with intermittent currents sweeping the sea floor.

The Kutch assemblages occur variedly from lower tidal to subtidal substrates of lagoons, tidal flats and shelves.

VIII.2.9. SKOLITHOS ICHNOCOENOSE:

The *Skolithos* ichnocoenose consists primarily of *Skolithos* linearis and *Skolithos* Sp. with other characteristic elements including mainly dwelling burrows. This ichnocoenose is developed in GM, LM, MDM, JM, TM and BM. In GM, the ichnocoenose occurs in MS and HS facies in association with *Arenicolites*, *Diplocraterion*, and *Monocraterion*. In LM, it is found in LSS in association with *Diplocraterion*, *Ophiomorpha*, *Tisoa*, *Palaeophycus* and *Planolites*. In MDM, the *Skolithos* have been observed alongwith *Histioderma*, *Ophiomorpha*, *Monocraterion* and *Cylindricum*. In JM, it occurs in SS lithofacies in association with *Cylindricum*, *Monocraterion* and *Planolites*. In TM, it has been observed in association with *Diplocraterion*, *Monocraterion*, *Ophiomorpha*, *Arenicolites* and *Enteropneusta burrows*. In BM, the ichnocoenose occurs in association with *Stipsellus*, *Diplocraterion*, *Monocraterion*, *Corophioides*, *Ophiomorpha* and *Enteropneusta burrows*.

In majority of the cases, the traces are thinly populated and generally show low to moderate degree of bioturbation, except in BTS facies in BM, where it indicates high degree of bioturbation. (the rate of biogenic reworking exceeding than that of the sedimentation). The *Skolithos* ichnocoenose as claimed by Bromley (1990) chiefly represent 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 ichnocoenose are commonly heavily dominated by *Skolithos* linearis. As per Frey, Pemberton and Saunders (1990), the ichnocoenose generally corresponds to the beach, fore shore, and shore face but numerous other settings of comparable energy levels may be represented including estuarine point bars, tidal deltas and deep sea sand fans.

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 the 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* ichnocoenose have the low ichno-diversity, low to moderate density, vertical orientation and deep burrowing of suspension feeders, and are dominated by *Skolithos*, *Arenicolites*, *Stipsellus* and *Diplocraterion*. High density has developed as a result of repeated reworking of upper part of sands and slow deposition. The upper parts of these structures, are only exceptionally become preserved. The ichnodiversity certainly does not convey much idea of the species diversity of organisms and biomass of the endobenthos community that might had inhabit the shifting sands

Following the above discussion, it could be inferred that the *Skolithos* ichnocoenose in the study area of Kutch represents low to moderate bioturbation and relatively high (high degree of bioturbation) energy conditions in lower tidal to sub-tidal environments.

VIII.2.10. THALASSINOIDES ICHNOCOENOSE:

Thalassinoides ichnocoenose is widely distributed stratigraphically and frequently observed in the Mesozoic sequence of the study area. The ichnocoenose occurs in JWM, GM, LM, GRM, MDM, TM and BM.

In JWM, it is observed in LSS and SS facies in association with *Phycodes*, *Rhizocorallium*, *Granularia* etc. In GM, it occurs in MS facies, which shows low degree of bioturbation and almost monodominant. In LM, it has been found in LSS facies (in BS and IC in form of exhumed burrow fragments) with *Rhizocorallium*, *Planolites* etc. In GRM, it is more or less monodominant in OBS facies. In MDM, again it occurs in LSS litho-facies in association with *Phycodes*, *Rhizocorallium*, *Planolites*, *Rosselia*, *Laevicyclus*, *Granularia* etc. In TM, it is found in association with *Gyrophyllites*, *Keckia*, *Laevicyclus*, *Phycodes*, *Rhizocorallium* etc., mainly in RFSSS and infrequently in MS facies. While in BM, it occurs occasionally in BTS in association with *Planolites*.

It is usually found with interbedded sandstones and shales. In thick sandstones also, it has been observed but in low density. The large, semipermanent, 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 alongwith the sediments. This ichnocoenose probably represents the lowest energy levels (Fursich and Heinburg, 1983).

The ichnocoenose occurs in shelf sequences in infra-tidal to shallow circa-tidal substrates normally below daily wave base but not storm wave base, to some what quieter conditions offshore. A very common type of depositional environment, including not only shelves and epeiric slopes but also tidal to sub-tidal parts of estuaries, lagoons, bays and tidal flats. The ichnocoenose mostly occurs in well sorted silts and sands to interbedded muddy and clean sands, moderate to intensely bioturbated. Commonly occurs in negligible to appreciable, though not necessarily rapid, sedimentation areas. Substrate unconsolidated. 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 presence of characteristic originators.

Bromley (1990) considered it as semivagile and vagile, middle level deposit feeder structures, present in oxygenated situations, which are intermediate to equilibrium or climax trace fossils.

The Kutch forms can be attributed to similar conditions.

VIII.2.11. ZOOPHYCOS ICHNOCOENOSE:

The ichnocoenose is observed only in OL facies of DOM in Chari Formation in association with *Chondrites*. *Zoophycos* mainly consist of 'U' and 'J' shape nets, former related to oxygen deficiencies and latter may indicate a respiratory connection with oxygenated bottom waters. The structures are efficiently executed feeding traces, with spreiten typically planar to gently inclined, distributed in delicate sheets, ribbons or spirals. Animals virtually all deposit feeders. Normally shows low diversity, and given structures may be abundant.

Zoophycos has an extremely broad bathymetric range and depositional gradients. The ichnocoenose occurs in circalittoral to bathyal, quiet water conditions, or protected intracoastal to epeiric sites 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 storm wave base to deep water, in areas free of turbidity flows or significant bottom currents. Some times water saturated surfacial sediments are difficult to exploit by epibenthos, resulting in low diversity and low abundance and poor preservation of epistratal traces. In some cases, relict or palimpset substrates are present where bottom slopes are swept by shelf edge or deeper contour currents, this ichnocoenose may be omitted in the transition from infratidal to abyssal environments. Intracoastal to epeiric sites include such features as silled basins and restricted lagoons.

Bromley (1990) considers *Zoophycos* an opportunistic, 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 lacks the intrinsic characteristics of an opportunist form.

Bromley (1990), further considered the ichnocoenose as non-vagile, deep deposit feeder structures, which comprises the deepest tier structure. Minor variations in the general environment or ecological condition may affect the availability of such structures.

Zoophycos ichnocoenose is thus characterised by low ichnodiversity, and since *Chondrites* is labeled as a facies breaking form (Seilacher, 1978; fig. 6) whereas *Zoophycos* is not, *Zoophycos* is stated to be the only characteristic ichnotaxon.

The Kutch specimens most probably represent offshore shoals and bars, where ichnocoenose, 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*, *Arenicolites* & *Palaeophycus* at the same horizon.

In general, the trophic and behavioral characteristics of the ichnocoenoses indicate a gradient in bottom water agitation. The suspension feeding *Skolithos*, *Diplocraterion* and *Ophiomorpha* ichnocoenoses represent the highest energy levels, followed by trophically diverse *Asteriacites* ichnocoenose. The deposit feeding *Rhizocorallium*, *Thalassinoides* and *Gyrolithes* ichnocoenoses reflect progressively lower energy conditions. On the other hand *Chondrites*, *Gyrochorte*, *Muensteria* and *Zoophycos* ichnocoenoses are characterised 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.

VIII. 3. ETHOLOGICAL GROUPING OF THE TRACE FOSSILS:

The trace fossils of the study area comprise a number of well defined ichnogenera and ichnospecies as well as some less distinct forms (fig-12, A to I). These have been interpreted in terms of origin and behaviour of their producers in chapter - VII. Their resulting ethological groups are summarized in table. 10 These trace fossils demonstrates tangible evidence of the behaviour of animals, and the most natural way to classify them is assigned to their behavioral patterns based on trace fossil morphology. The ethological classification deduced by Seilacher (1953a, 1964) fulfills this purpose and is in general used in trace fossil description and interpretation. In this context the author has classified the trace fossil in to five ethological groups. It is given in table: 10. Brief description of the ethological groups is given below.

It must be emphasized once more that there is a natural overlap between compartments. This merely reflects the intergradations inherent in nature.

VIII.3.1. CUBICHNIA [RESTING TRACES]:

These are shallow depressions made by animals that temporarily settle on to, or dig in to the substrate. Emphasis is up on reclusion. Actually these are structures made by vagile benthos digging down for a period and then departing by the same route. These structures are found isolated, but some times intergrade with crawling traces or escape structures. Few trace makers can be considered actually to 'rest', and the production of cubichnia more usually represents concealment, or traces of animals that feed stationarily but shift their position at intervals. Some predators such as star fish, some times produce cubichnia in order to capture buried prey. The resting traces investigated in the study area are mostly represented by conical - circular, radiating or almond shape structures and includes *Asteriacites*, *Bergaueria*, *Conostichus*, etc.

VIII.3.2. REPICHNIA [CRAWLING TRACES]:

Repichnia are track ways and epistratal or intrastratal trails made by organisms traveling from one place to another, and reflect direct locomotion rather than any other activity. Most typically these traces follow bedding planes. Certainly the animals may have been feeding as

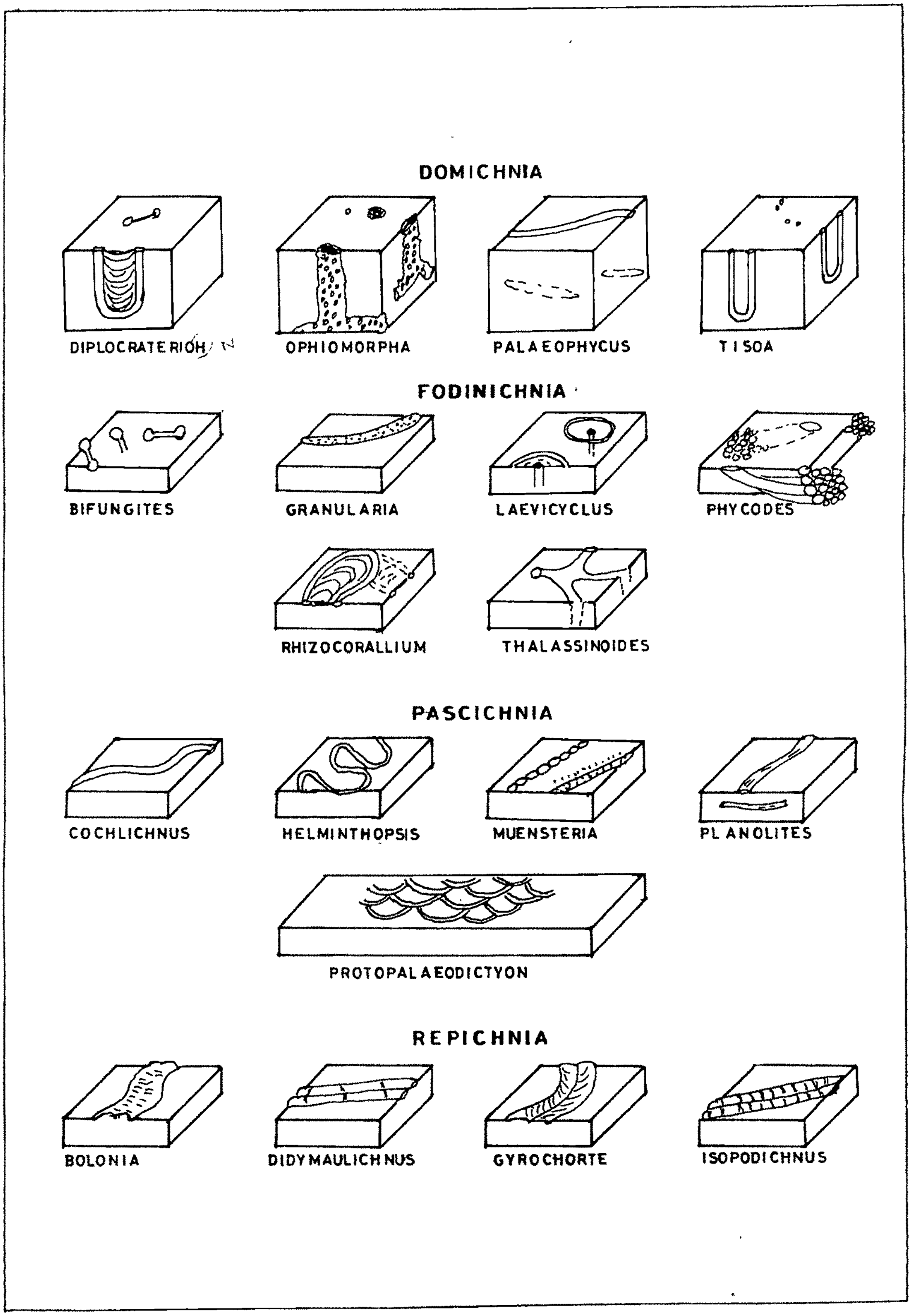

FIG. 12a. FEEDING TYPES IN JAMAYWADI MEMBER

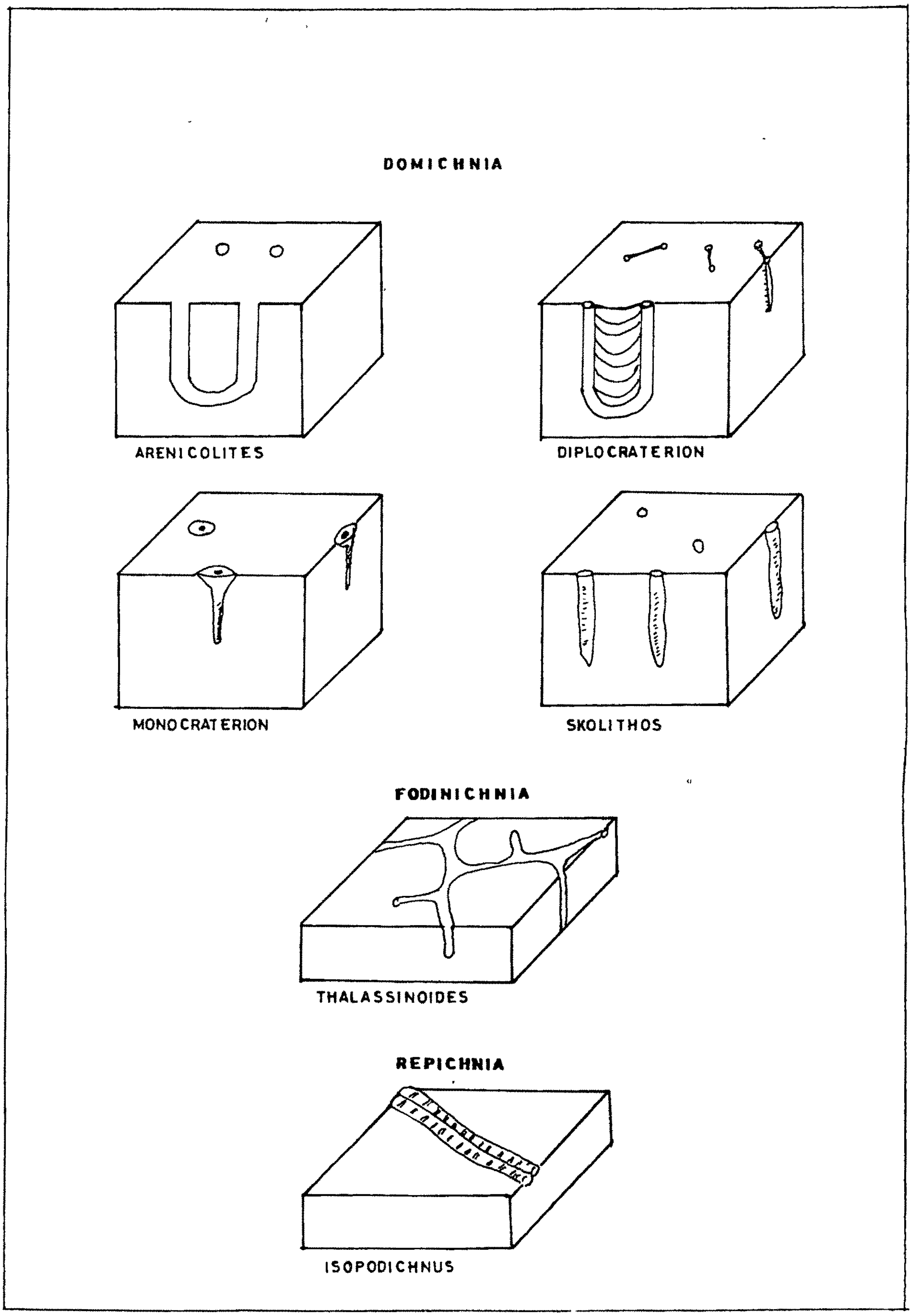

FIG. 12 b. FEEDING TYPES IN GANGESHWAR MEMBER

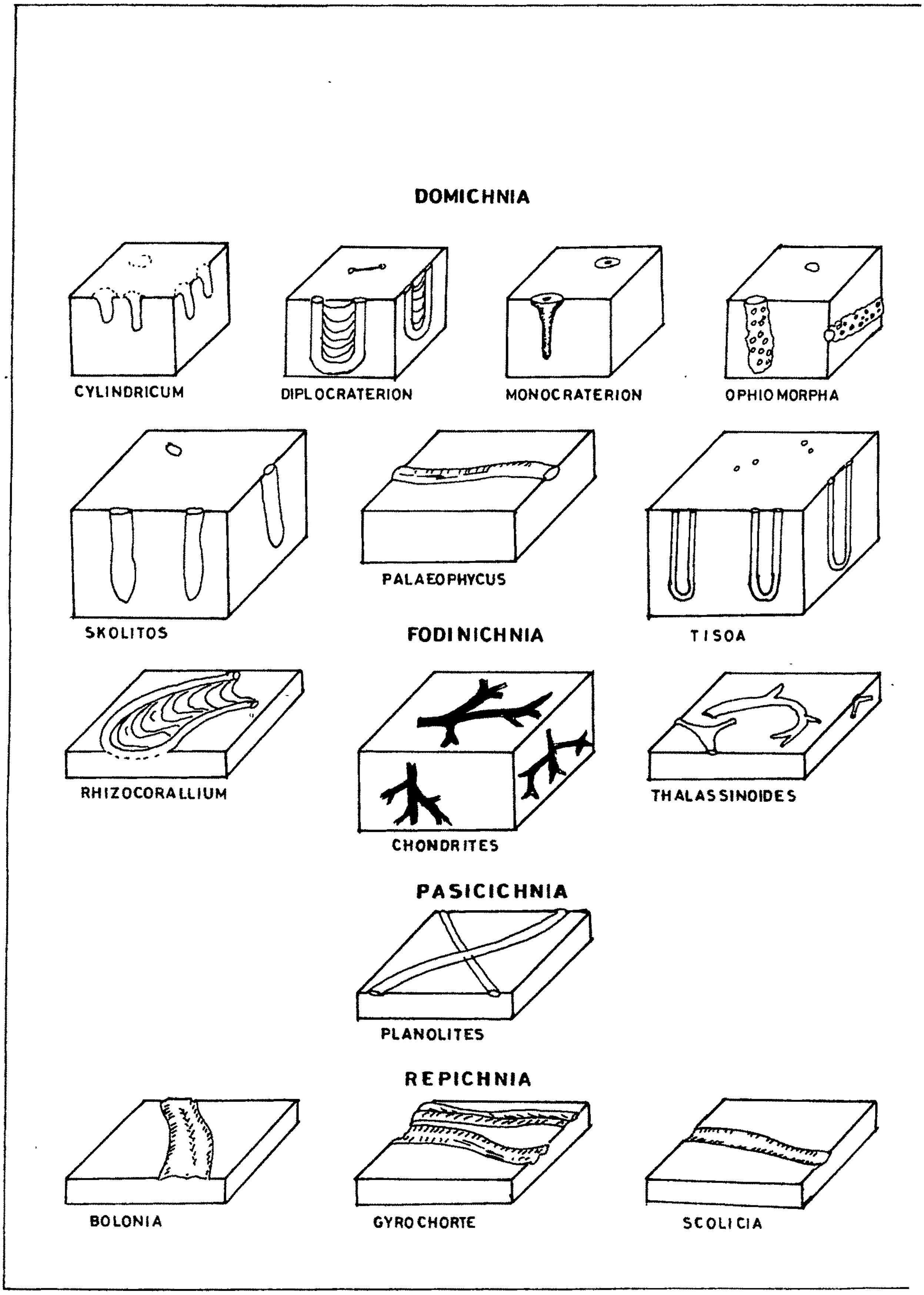

FIG. 12 c. FEEDING TYPES IN LER MEMBER

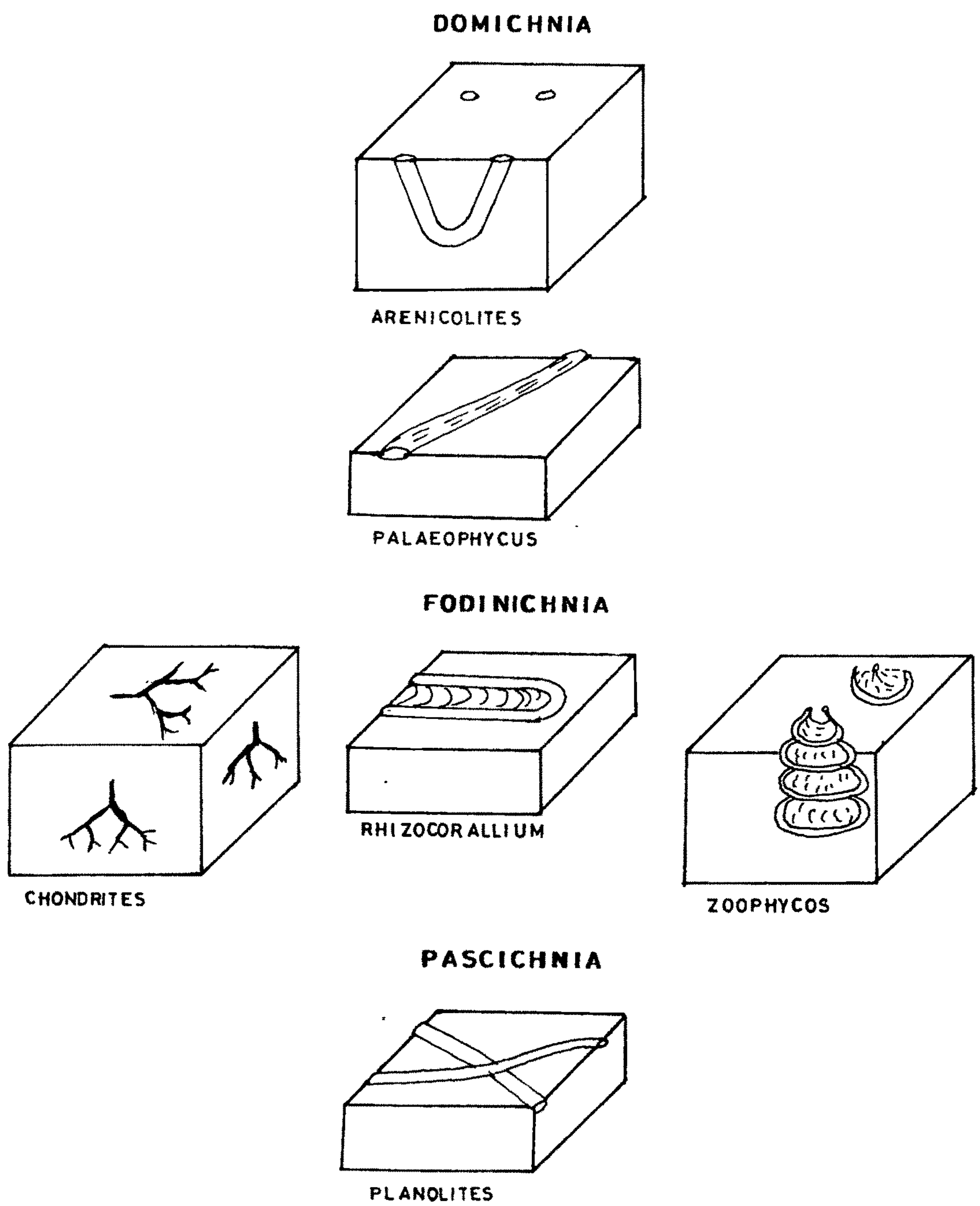

FIG. 12 d. FEEDING TYPES IN DHOSAOOLITE MEMBER

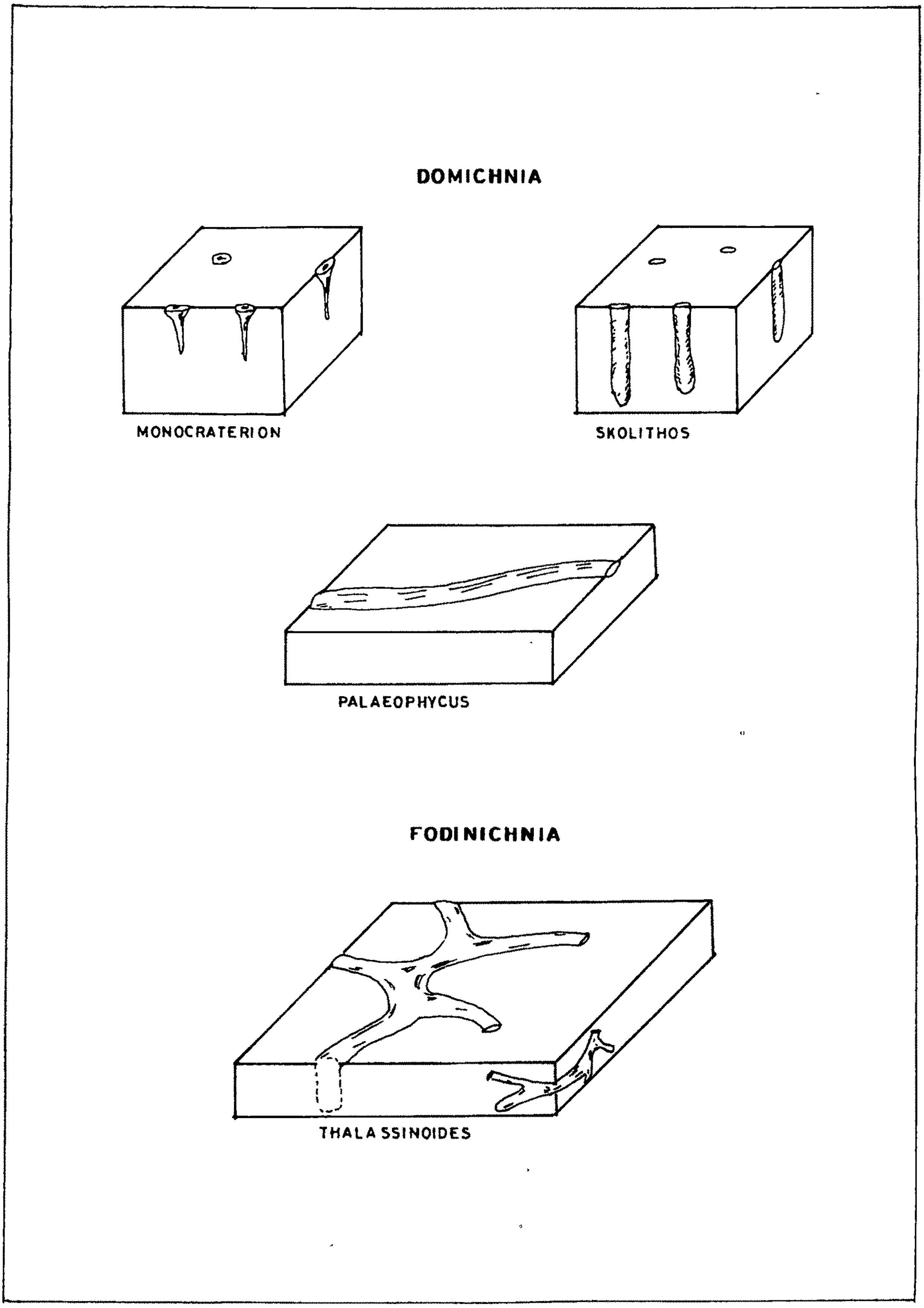

FIG. 12e. FEEDING TYPES IN GUNAWARI RIVER MEMBER

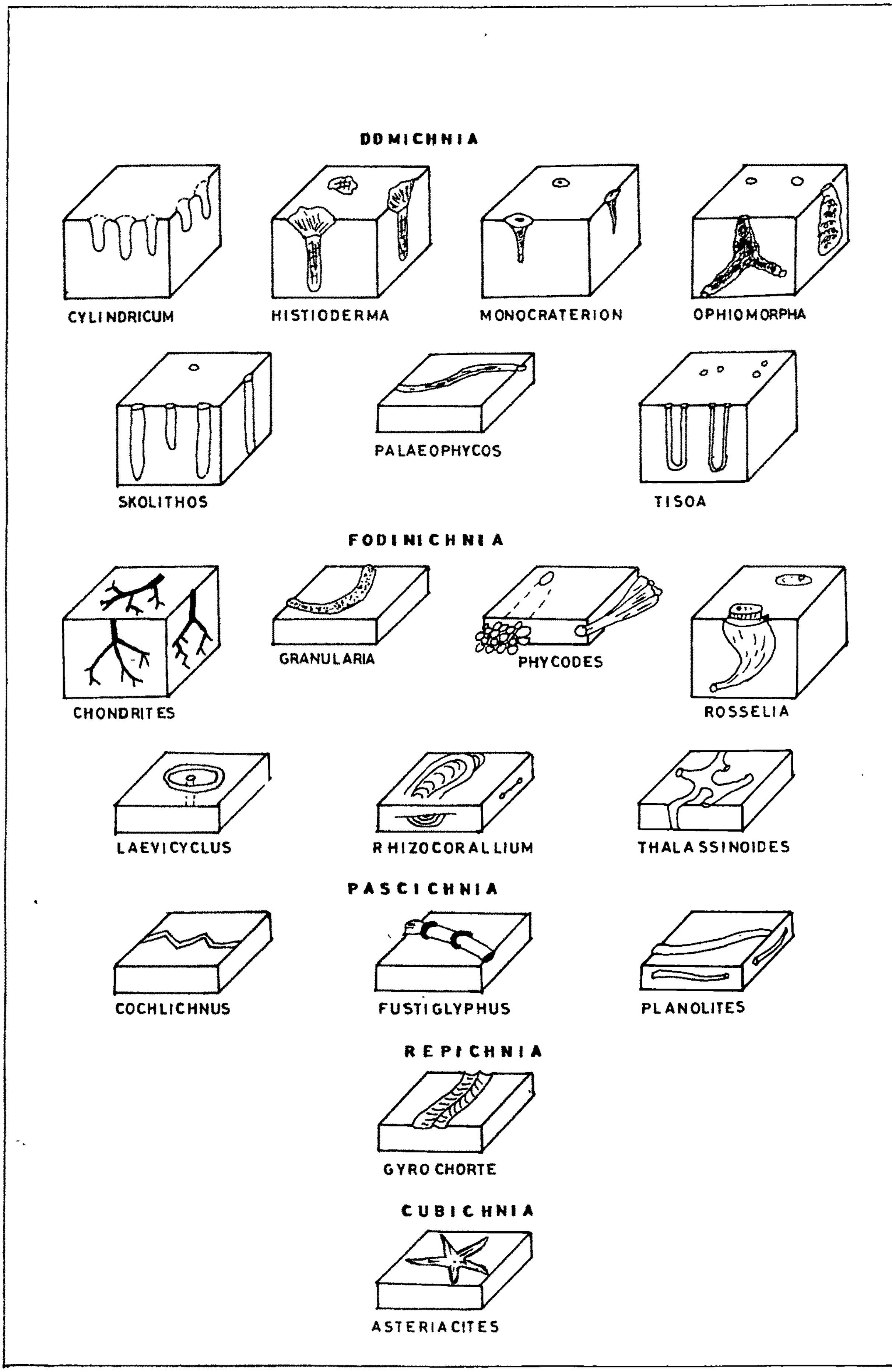

FIG. 12 f. FEEDING TYPES IN MARUTONK DUNGAR MEMBER

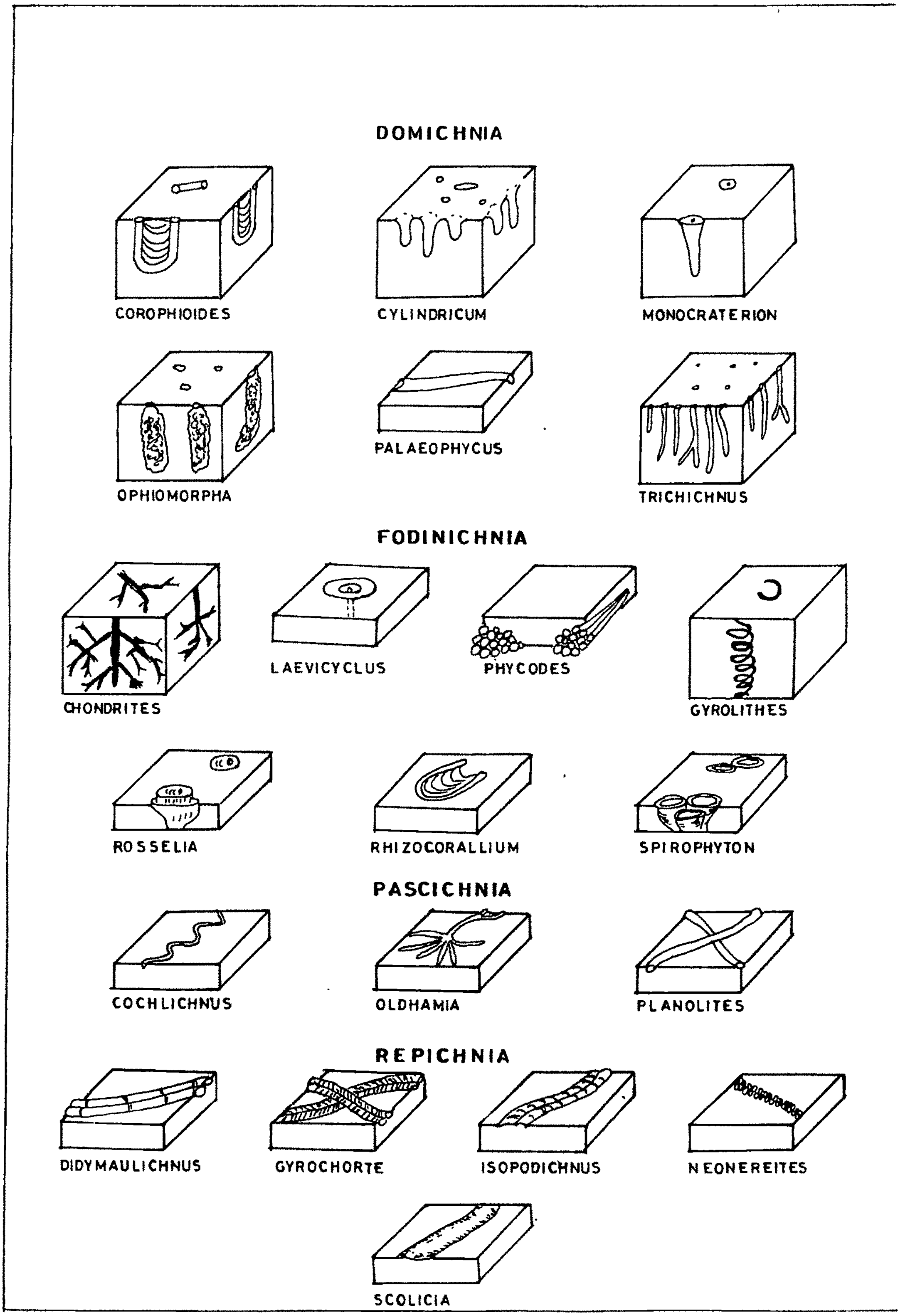

FIG. 12 g. FEEDING TYPES IN JADURA MEMBER

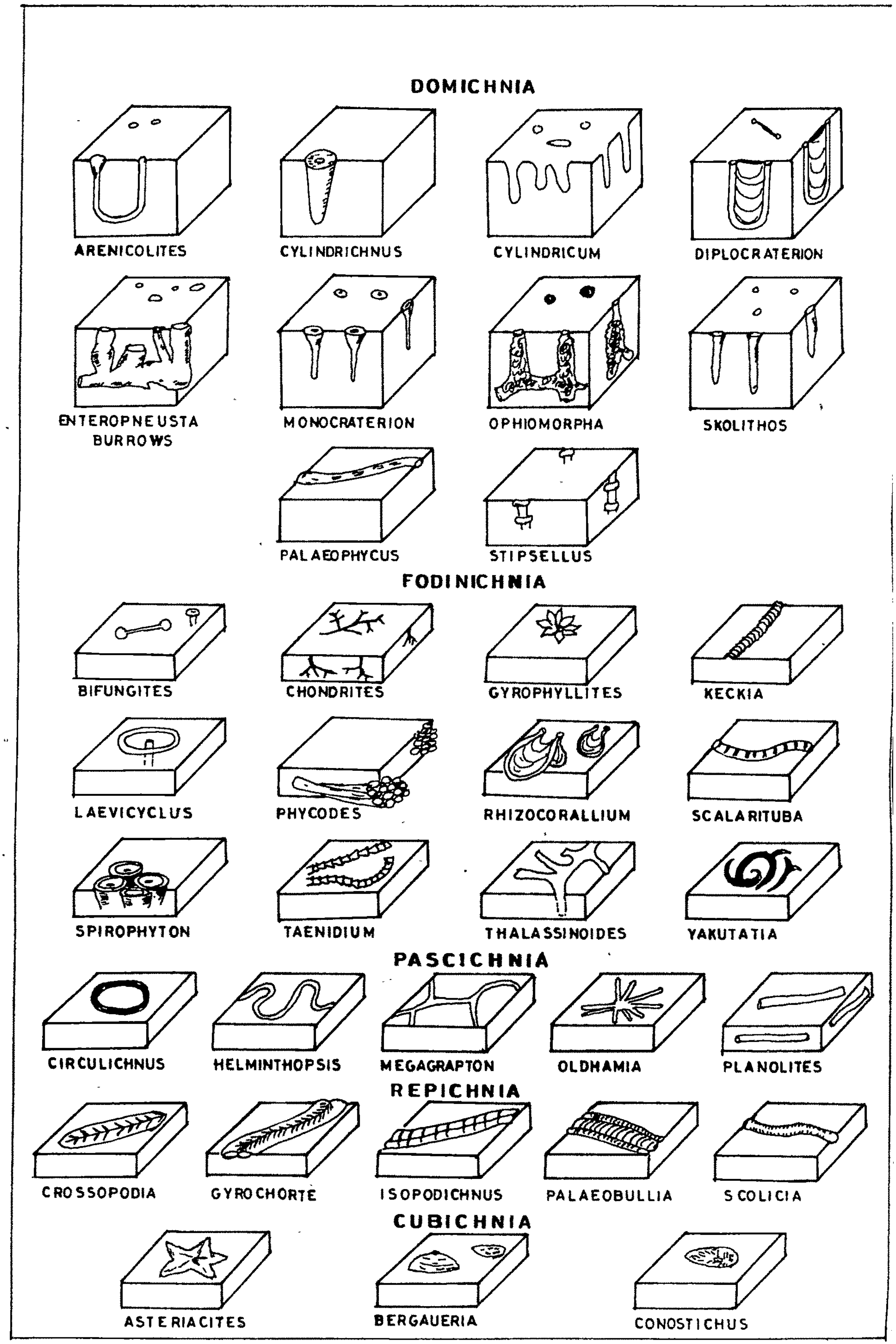

FIG. 12h. FEEDING TYPES IN TAPKESHWARI MEMBER

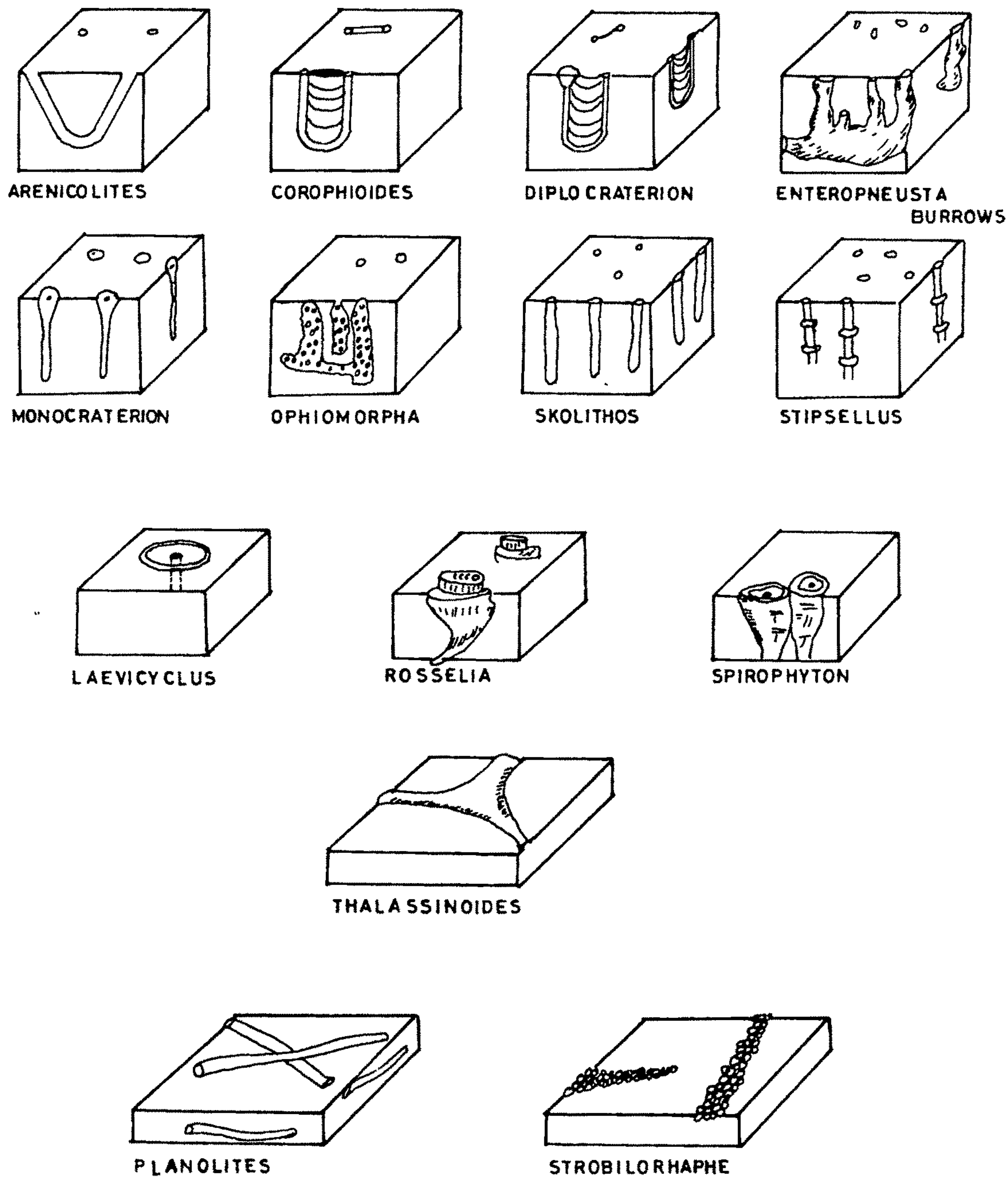

FIG. 12i. FEEDING TYPES IN BHARAPAR MEMBER

it progressed, but this activity is not directly registered in the morphology of the trace fossil. Repichnia traces are found in the sediments of Chari, Katrol, Umia and Bhuj Formations represented by linear or sinuous structures, some of which show branching. These varied structures include *Bolonia*, *Cochlichnus*, *Crossopodia*, *Didymaulichnus*, *Gyrochorte*, *Isopodichnus*, *Neonereites*, *Palaeobullia*, *Scolicia* etc.

VIII.3.3. PASCICHNIA [GRAZING TRACES]:

These are the grooves, pits and furrows, many of them discontinuous made by mobile deposit feeders or algal grazers at or near the substrate surface, where a track way or locomotion trace follows a meandering or spiral course. It is clear that an animal has exploited a particular area or region of the substrate for food. Elegant grazing traces are common on the ocean floor today but most fossil occurrences derived from similar behaviour at a level beneath the sea floor. Emphasis is up on feeding behaviour analogous to 'strip mining'. Most grazing traces are parallel to the sea floor.

The Kutch grazing trails are mostly unbranching, non-overlapping, curved or slightly coiled patterns, reflecting maximum utilization of surfacial area containing food available to the animal. Many complete forms are found well preserved which are *Circulichnus*, *Fustiglyphus*, *Helminthopsis*, *Megagrapton*, *Muensteria*, *Planolites*, protopalaeodictyon etc.

VIII.3.4. FODINICHNIA [FEEDING STRUCTURES]:

These category is characterised by the combined function of deposit feeding and dwelling. Hence, Fodinichnia are more or less temporary burrows constructed by deposit feeders. Thus, the structure has some degree of permanence, and yet its morphology reflects exploitation of the substrate for food. The Kutch representatives include single, branched or unbranched, cylindrical to sinuous shafts or U-shaped burrows, a complex parallel to concentric burrow repetitions (spreiten structures). Burrows are found oriented at various angles with respect to bedding plane. Emphasis is on feeding behaviour analogous to 'underground mining'. Commonly burrow walls of these traces are not lined. Many complete forms of these traces are found preserved, which include *Chondrites*, *Granularia*, *Gyrolithes*, *Gyrophyllites*, *Keckia*, *Laevicyclus*, *Muensteria*, *Phycodes*, *Rhizocorallium*, *Rosselia*, *Spirophyton*, *Taenidium*, *Thalassinoides*, *Zoophycos*, etc.

VIII.3.5. DOMICHNIA [DWELLING STRUCTURES]:

These are burrows, borings or dwelling tubes providing more or less permanent domiciles. The trace maker may be a sessile suspension feeder, or acting carnivores waiting in ambush, or a warm feeding on the surrounding detritus, but the trace fossil emphasizes the stationary dwelling and not the trophic group, i.e. thrust is up on habitation. The dwelling structures investigated by the author in Kutch are mostly represented by simple, bifurcating or U-shape structures perpendicular or inclined at various angles to bedding or branched burrows having vertical or horizontal components at different sedimentation level. Walls of these structures are typically lined. Complete forms are very often found preserved.

Dwelling burrows are found in all the Members of Mesozoic sedimentary sequence of the study area, which incorporates *Arenicolites*, *Corophioides*, *Cylindrichnus*, *Cylindricum*, *Diplocraterion*, *Monocraterion*, *Ophiomorpha*, *Palaeophycus*, *Scalarituba*, *Skolithos*, *Stipsellus*, *Tisoa*, *Trichichnus*, etc.

VIII. 4. TRACE FOSSIL DISTRIBUTION AND PALAEOECOLOGICAL CONSIDERATIONS:

Trace fossils have significant palaeoecological utility because they are (1) wide spread in space and time, (2) found insitu without reworking (3) reflects largely the record of animal behaviour and response, making them ideal indicators of environmental conditions.

In the present day ecological research, it is a general trend to express distribution of benthic forms in terms of 'taxonomic diversity', 'faunal diversity', and 'trophic diversity'. 'Taxonomic diversity' is a fundamental ecologic parameter in recent benthic research, which denotes the number of individuals per taxon per unit of sea floor. This parameter is usually expressed as a diversity index and is used to characterised the taxonomic structure and temporal stability of a benthic community (Rhoads, 1975).

'Faunal diversity' means absolute abundance of traces or body fossils, in terms of the abundance of living organisms at any particular time. This is, however, elusive so far trace fossils are considered. For this reason, measures of biotic density - number of individuals per taxon - are usually not calculated for fossil assemblages. However, relative abundances can be used to estimate common and rare species during life of the assemblage (Rhoads, 1975). Studies by Rhoads (1967), also indicate that the rate of bioturbation is generally poorly correlated with faunal density but is closely related to the mobility of the burrowing or grazing organisms. According to Levinton and Bambach (1975), opportunistic species tend to dominate the fossil record because birth and death rates are high.

However, the density of traces, like body fossils, is a function of both, turnover rate of the population and sedimentation rate.

'Trophic diversity' is another important ecologic parameter in the benthic work and is the proportionating of feeding types amongst the constituent species (Walker, 1972; Rhoads et al., 1972; Walker and Bambach, 1974). According to these authors the distribution of herbivores, carnivores or scavengers, especially suspension feeding and deposit feeding benthos provide useful information about the feeding resources, relative sedimentation rates, water turbidity and sea floor stability (Rhoads et al., 1972).

As regards the rocks of study area are concerned, they contain a variety of lithofacies and as such several factors which operated differently in each sub-environment seems to have exerted control on the preservation of trace fossils in the rocks. Although, preservation biases do affect the body fossils, such effects are especially marked with trace fossils, which are merely arrangements of sedimentary particles that comprise the host lithology. Bearing all these points in mind, the distribution of various ethological groups and genera of trace found in different Formations has been plotted in histograms (fig-13).

As seen from these diagrams, the diversity and abundance of ichnogenera appears to be variable in different Formations except in the Umia Formation where it is maximum. This is probably due to the suitability of various sediment types to the suspension feeders and deposit feeders both.

The average percentage of each ethological group were calculated for the entire Mesozoic sequence of the study area and for various Formations. To obtain percentage of ethological group, number of ichnogenera present in each group were multiplied by hundred and divided by the total number of ichnogenera present. These frequency diagrams show that the feeding structures predominates, followed by dwelling, grazing, crawling and resting traces. Here, the overall picture indicates that the Mesozoic sequence was chiefly populated by deposit feeders and less abundance of crawlers and carnivores. These show that, feeding structures are predominant, followed by dwelling, grazing, crawling and resting traces

As seen from the frequency diagram of ethological groups (fig-13) present in various Formations, the diversity of genera seems to be quite different through the Mesozoic cycles.

The figures show that the feeding structures dominated in Chari, Katrol and Umia Formation rocks alongwith dwelling burrows, but in Bhuj Formation, the latter out rights all other type of activities. The various types of behavioral structures present in the Formations are given below in their order of decreasing abundance - Chari Formation· Feeding and Dwelling structures, Grazing and Crawling traces; Katrol Formation. Feeding and Dwelling structures, Crawling structures, Grazing traces; Umia Formation: Feeding structures, Dwelling structures, Grazing and Crawling traces, Resting traces; Bhuj Formation: Dwelling Burrows, Feeding traces, Grazing structures. Frequency diagrams, however, show no clear preference by these organisms to any particular substrate type.

To obtain more information about substrate preference by the trace makers, the abundance of structures produced by them were observed by recording in each unit, presence or absence of the biogenic structures and classifying them according to their occurrences in to four groups as (1) abundant, (2) common, (3) sparse, and (4) rare (Table-12 & 13).

The abundance of individual trace fossils in various substrate type also does not give a clear picture. Many forms including *Arenicolites*, *Planolites*, *Palaeophycus*, *Thalassinoides* are found in variety of sediments. Abundance of *Asteriacites*, *Gyrochorte*, *Rhizocorallium* is especially found in Rippled Ferruginous Sandstone Siltstone Shale facies sediments While abundance of *Diplocraterion*, *Skolithos*, *Stipsellus* is found in Bioturbated Sandstone

TABLE - 13: ETHOLOGICAL DISTRIBUTION OF TRACE FOSSILS IN DIFFERENT MEMBERS AND THEIR RELATIVE ABUNDANCE.

ICHNOGENERA	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Arenicolites		+		+				+	+	S	+				
Asteriacites						+		+		A-S					+
Bergaueria								+		A-C					+
Bifungites	+							+		S		+			
Bolonia	+		+							S				+	
Chondrites			+	+		+	+	+		C-S		+			
Circulichnus								+		R			+		
Cochlichnus	+					+	+			S-R			+		
Conostichus								+		S					+
Corophioides							+		+	A	+				
Crossopodia								+		S				+	
Cylindrichnus								+		R	+				
Cylindricum			+			+	+	+		C-R	+				
Didymaulichnus	+						+			C-S				+	
Diplocraterion	+	+	+					+	+	A-S	+				
Enteropneusta burrows								+	+	C	+				
Fustiglyphus						+				R			+		
Granularia	+					+				S-R		+			
Gyrochorte	+		+			+	+	+		A-C				+	
Gyrolithes							+			A-C		+			
Gyrophyllites								+		R		+			
Helminthopsis	+							+		S-R			+		
Histioderma						+				C-S	+				
Isopodichnus	+	+					+	+		S				+	
Keckia								+		C-S		+			
Laevicyclus	+					+	+	+	+	S-R		+			
Megagrapton								+		R			+		
Monocraterion		+	+		+	+	+	+	+	S	+				
Muensteria	+									C			+		
Neonereites							+			R				+	
Oldhamia							+	+		S			+		
Ophiomorpha	+		+			+	+	+	+	A-S	+				
Palaeobullia								+		R				+	
Palaeophycus	+		+	+	+	+	+	+		C-S	+				
Phycodes	+					+	+	+		C-S		+			
Planolites	+		+	+		+	+	+	+	C			+		
Protopaleodictyon	+									R			+		
Rhizocorallium	+		+	+			+	+		A-C		+			
Rosselia						+	+		+	R		+			
Scalarituba								+		R		+			
Scolicia			+				+	+		R				+	
Skolithos		+	+		+	+		+	+	A-C	+				
Spirophyton							+	+	+	S-R		+			
Stipsellus								+	+	C-S	+				
Strobilorhaphe									+	C			+		
Taenidium								+		R		+			
Thalassinoides	+	+	+		+	+		+	+	C-R		+			
Tisoa	+		+			+				S-R	+				
Trichichnus							+			A	+				
Yakutatia								+		R		+			
Zoophycos				+						R		+			

1 = JAMAYWADI MEMBER
2 = GANGESHWAR MEMBER
3 = LER MEMBER
4 = DHOSA OOLITE MEMBER
5 = GUNAWARI RIVER MEMBER
6 = MARUTONK DUNGAR MEMBER
7 = JADURA MEMBER
8 = TAPKESHWARI MEMBER
9 = BHARAPAR MEMBER

10 - A = ABUNDANT
C = COMMON
S = SPARSE
R = RARE
11 = DOMICHNIA
12 = FODINICHNIA
13 = PASCICHNIA
14 = REPICHNIA
15 = CUBICHNIA

lithofacies. On the other hand *Gyrochorte*, *Neonereites*, *Trichichnus*, *Oldhamia*, *Phycodes* and *Didymaulichnus* are well preserved in the Laminated Shale Siltstone sub-facies. While *Zoophycos*, *Gyrolithes* and *Strobilorhaphe* are found only in the OL facies, MS sub-facies and CBCGS facies respectively.

In general, results obtained from table-12 suggest that most of the Mesozoic trace fossils of Kutch mainland are related to the substrates only in a very limited way. This indicates that, there are too many other factors that influence the distribution of trace fossils in study area sediments and no clear picture could be obtained when only one of such factors (substrate) was considered by the author in the above studies.

Fig. 14 drawn after Fursich (1974), illustrates in a simplified way the relationship between trace fossils and their environment. The diagram indicates that their substrate is only one factor besides distribution of available food below or above the depositional interface, whilst both in turn depend mainly on the hydrodynamic condition and food production. The hydrodynamic conditions are ultimately governed by depth and palaeogeographic setting.

Interpretation of sediments in terms of lithofacies some times indicate relationships between the trace fossils and the environments.

Diplocraterion and *Skolithos* burrows, for example are found associated with trough cross bedding, rippled to mega rippled surface and coarse sandstones of BM indicate a high energy environment. *Planolites*, *Palaeophycus*, *Phycodes*, *Rhizocorallium*, *Thalassinoides*, *Gyrochorte* etc. occurring in TM, JM, MDM and JWM in RFSSS or LSS or DSSS lithofacies in low to moderate energy environments. As confirmed earlier, the suspension feeders as expected show higher diversity in the finer sediments also reflect the energy conditions. In

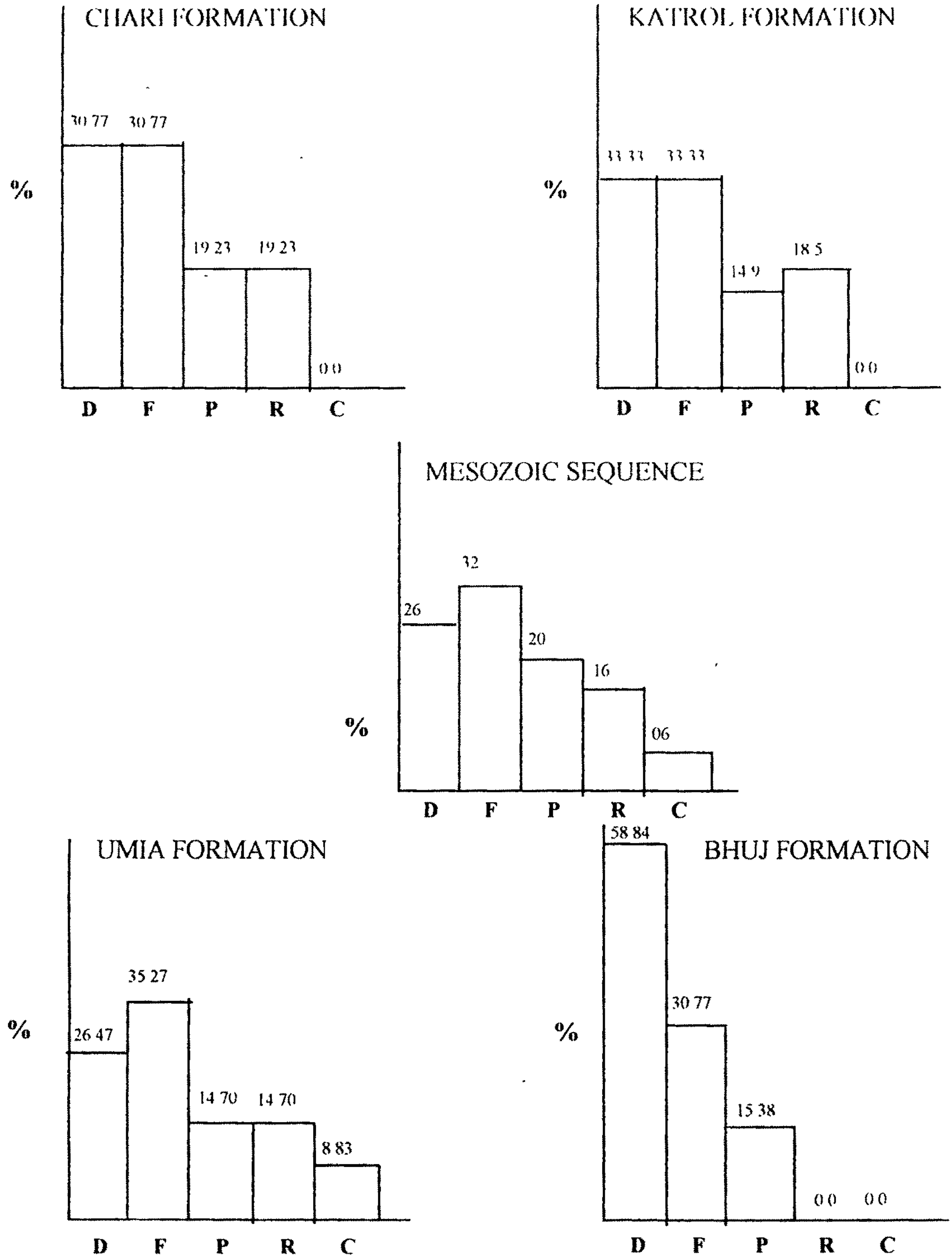

FIGURE - 13: FREQUENCY DIAGRAM SHOWING AVERAGE RELATIVE ABUNDANCE OF THE ETHOLOGICAL GROUPS IN THE STUDY AREA.

D - DOMICHNIA, F - FODINICHNIA, P - PASCICHNIA, R - REPICHNIA, C - CUBICHNIA

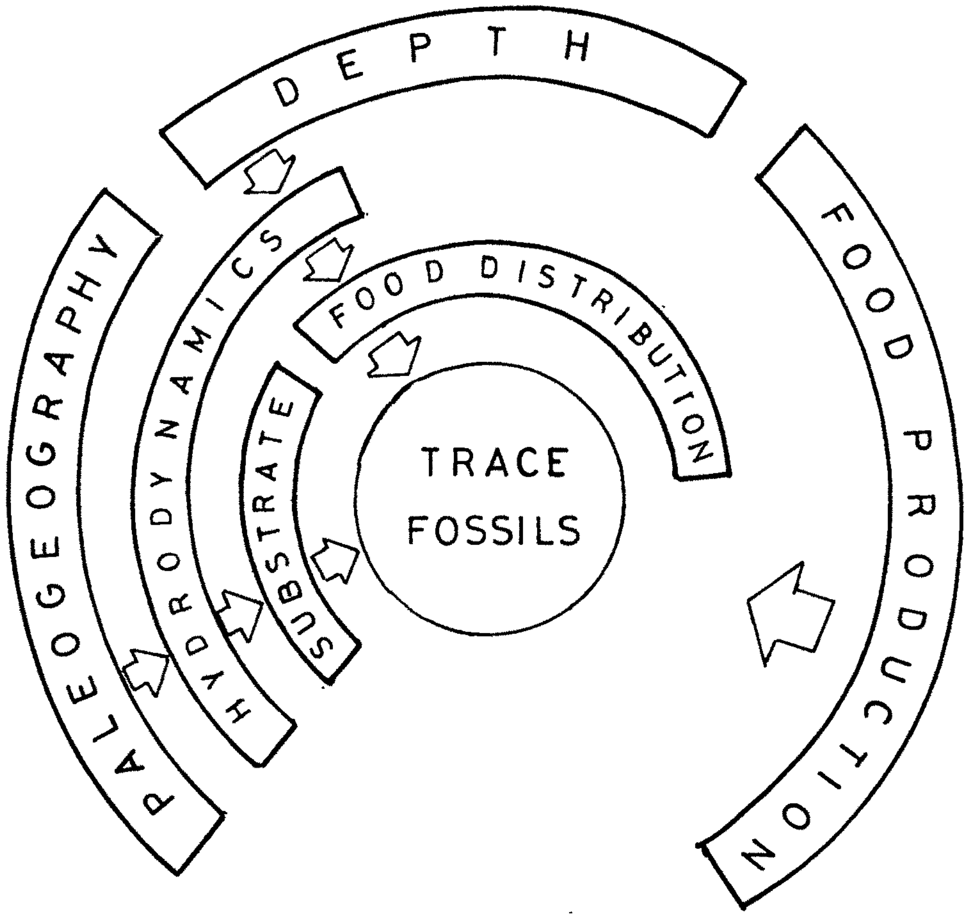

FIG. 14. SIMPLIFIED MODEL OF THE RELATIONSHIP AMONG TRACE FOSSILS AND THEIR ENVIRONMENTS - MORE IMPORTANT RELATIONS ARE INDICATED BY ARROW

(After Fursich, 1974)

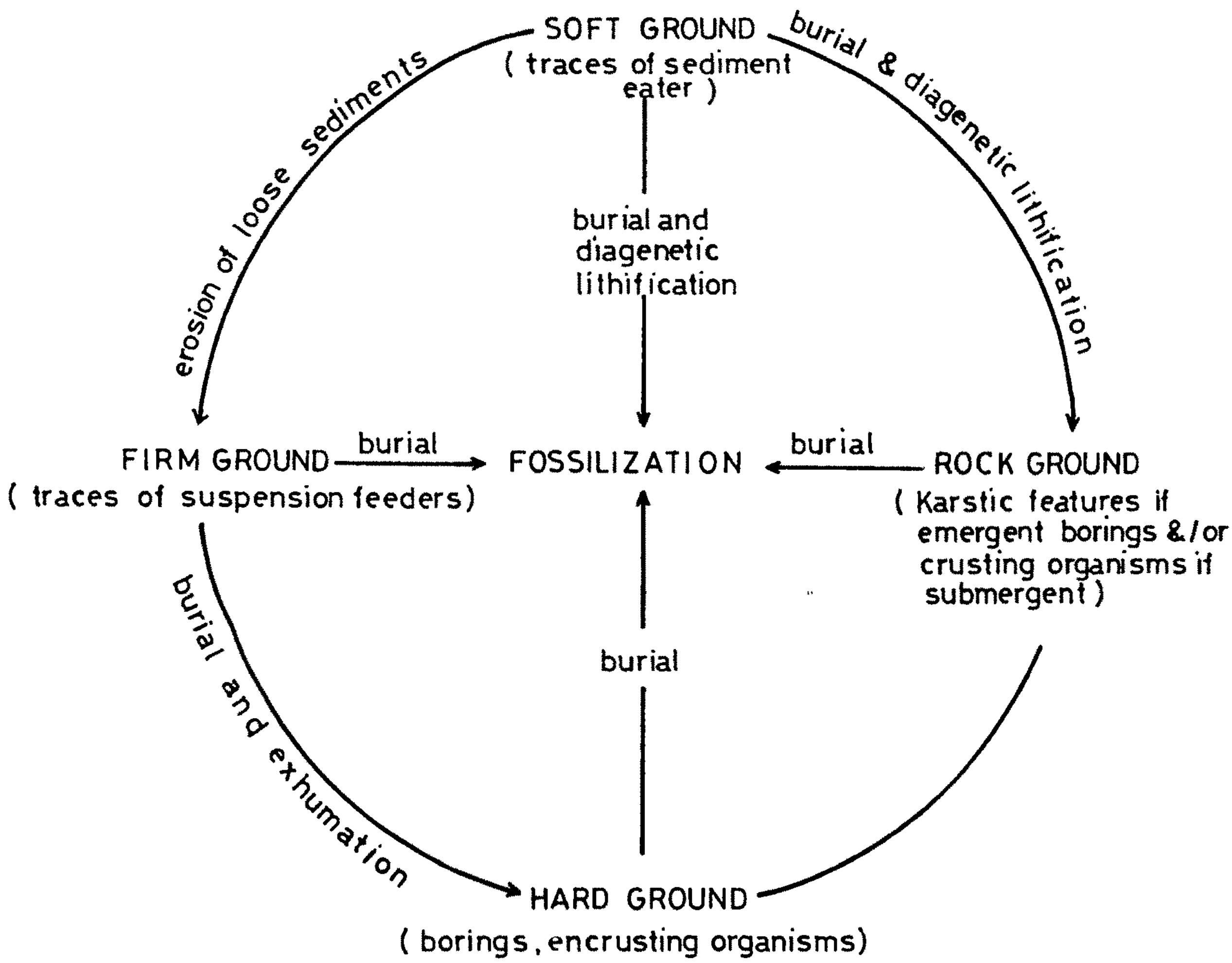

FIG. 15. SIMPLIFIED MODEL OF SUBSTRATE CLASSIFICATION
(After Lewis, 1984)

the higher energy conditions food particles are held in suspension and are, therefore, more easily available for suspension feeders. Whilst, in low energy environments food particles tend to accumulate within the sediment which can be exploited by the deposit feeders. In general, the comparison of the abundance of the two feeding types represented by Domichnia and Fodinichnia indicate that there is a decrease of suspension feeders in low energy environment and a particular increase of deposit feeders. Some deposit feeders present in all sediments and environments seems to have found equally suitable conditions every where, while suspension feeders are found strongly dependent on turbulence or current for their food intake.

It can, therefore, be concluded that the hydrodynamic conditions together governed by depth and palaeogeography played the most important role in the distribution of the trace fossils in the investigated area. High energy environments favoured deep burrowing suspension feeding and low energy environments, shallow burrowing and deposit feeding organisms.

Figure 15 drawn and modified after Lewis (1984), shows substrate classification. Here, the physical characters of sediments and overall diversity of trace fossil forms indicate physical parameters of depositional environments. Absence or limited appearance of some forms in such a substrate may result from drastic changes in the environmental conditions, viz. hyper-saline waters, anoxic bottom conditions, mobility of bottom materials,.excess of suspended

sediments, or too rapid sedimentation and biological variability in original environments. For example, RFSSS lithofacies is characterised mainly by dwelling and feeding structures and thus indicates soft and firm but unconsolidated sediments favourable to suspension feeding and deposit feeding animals. LSS, DSSS and OL lithofacies are characterised by feeding and grazing trails indicating soft ground, favourable for sediment eaters.

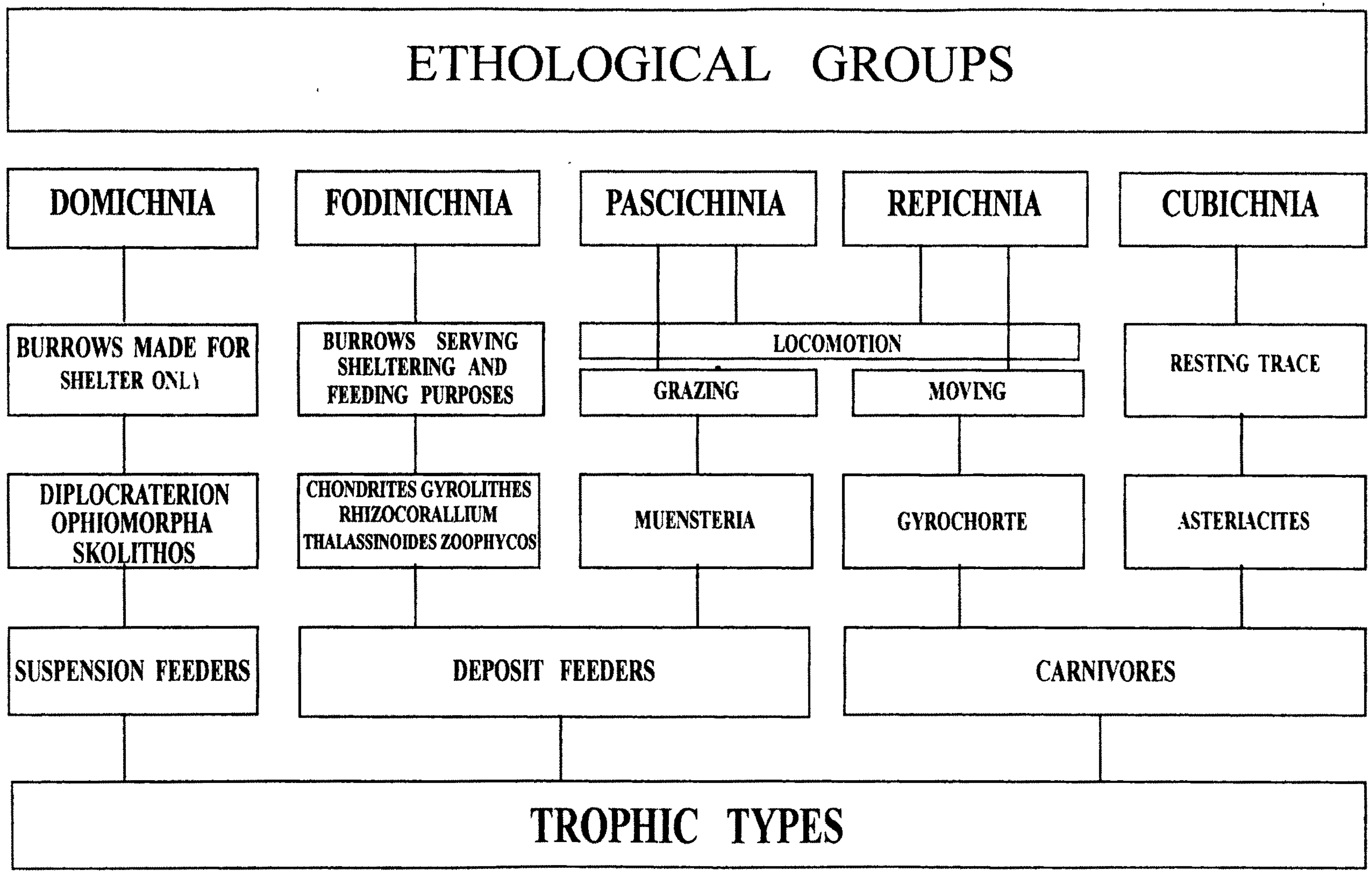

FIGURE -- 16 : CHART SHOWING RELATION AMONG THE ETHOLOGICAL GROUPS, TRACE FOSSIL ASSEMBLAGES [ICHNOCOENOSES] AND TROPHIC STRUCTURES.

Relation among the ethological groups, trace fossil assemblages and trophic structures is illustrated in fig-16.

V III. 5. I CHNOLOGICAL EVENTS DEPICTED IN DIFFERENT STRATIGRAPHIC UNITS AND THEIR SIGNIFICANCE:

In chapter - V, the author has fully described the Chari, Katrol, Umia and the Bhuj Formations with their nine Members. The constituents of these units are characterised by fine to medium clastic sediments that exhibit an extremely diverse and abundant trace fossil community. These ichnofossils are variously distributed throughout most of the stratigraphic columns. However, the Dhosa Oolite Member and the Marutonk Dungar Member are found poor in trace fossil contents, and hence denote little information on ichnocoenoses concepts. On the other hand, the bioturbated surface layers of the background sediment, occupied by bottom dwelling organisms are normally found to slowly migrate upward with the sediment surface, which are either episodically truncated or replaced by an event deposit. Recolonization of such an event layer is achieved by specially adopted fauna burrowing from the new surface downward. Furthermore, the nearshore environmental conditions are generally highly variable than deep water and are subjected to more rapid and more regular changes. Consequently, animals which inhabit these shallow water zones are tolerant to a wider range of conditions than their deeper water counter parts and are able to relocate readily following outset of unfavourable conditions. These environmental zonations, entirely based on trace fossil distributions on the above aspects as suggested by Rhoads (1975), the author feels may not be a very straight forward task when applied to the sedimentary rocks having complex shallow water environmental patterns studied by him. Despite some of these difficulties, an attempt has been made here to use trace fossil evidences to reconstruct the possible Mesozoic depositional environments and events prevailed in the main land Kutch.

The different ichnocoenoses and their associated common trace fossils as depicted in different Members are given in the figure no: 11. Detailed stratigraphic significance of all these ichnocoenoses is suggested in the following paragraphs.

VIII.5.1. Jamaywadi Member:

The JWM is characterised by various types of feeding, grazing structures and crawling trails, which denote typical marine influence in low to moderate energy conditions. The Member is represented by grayish and yellowish shales and yellow, red, gray, buff, brown sandstone intercalations. Here, *Gyrochorte*, *Ophiomorpha*, *Muensteria*, *Rhizocorallium* and *Thalassinoides* and very low density of *Diplocraterion* ichnocoenoses, appear to be intimately associated with the lithological units. Normally, it has been observed that *Ophiomorpha* and *Thalassinoides* ichnocoenose does not appear in the same bed. Borings Podichnus some times occurs in this Member.

The biogenic sedimentary structures of the JWM show wide range of behavioral habits which include feeding and grazing structures, crawling trails and resting traces of deposit feeding animals. Some of these live in the burrows, live as mud ingesters, and develop locomotion structures and resting traces respectively. Their biogenic structures are mostly produced by *Worm*, *Polychaete*, *Annelids*, *Crustaceans*, *Gasteropods*, *Apalcophore*, *arthropods*, *holothurian* etc. As a whole, the dominant ichnocoenoses represent a zone densely populated by deposit feeders, grazers or mud ingesters, predators and scavengers. The associated sandstones very often demonstrates development of low angle cross stratification, interference ripple marks, parting lineations, tongue or wedge shape shales and slump structures as well as tidal gully or channel structures. The entire sequence is coarsening upward suggest shallowing of the basin while intermingling of shale dominated bed and sandstone indicate fluctuating conditions clearly reflect trace fossil community in much less density and diversity.

The laminated shales-siltstones in the lower part with *Gyrochorte* and *Rhizocorallium* ichnocoenoses and resting traces are indicative of very low energy environment representing subtidal to shallow shelf marine environment commonly below normal wave base to even storm wave base. The ichnocoenoses suggest slow deposition to omission surfaces and almost nil physical reworking, and occurs in well sorted silts to interbedded muddy and clean sands.

The intermingled sandstones mainly contain either *Thalassinoides* or *Ophiomorpha* ichnocoenoses and *Gyrochorte* ichnocoenose. These ichnocoenoses normally indicate moderate to relatively low energy conditions below daily wave base but not storm wave base and quieter near shore shelf conditions respectively. Low rate of reworking is a precondition with moderate sediment influx. Density of the structures is normally low, and found with interbedded sandstones and mudstones. The structures commonly indicate quieter water conditions and deposition of organic material alongwith sediments. It shows unconsolidated substrate.

The shale-sandstone intervening sequence and sandstones in the upper part with physical structures and *Muensteria*, *Thalassinoides*, *Rhizocorallium*, *Ophiomorpha*, *Diplocraterion* ichnocoenoses suggest low to moderate energy conditions in a shallowed basin These indicate tidal to subtidal parts of tidal flats with lagoons - tidal pools, beach and barrier complexes as depositional site with negligible to appreciable, though not necessarily rapid sedimentation areas. Because of moderate to lower energy levels, as the ichnocoenoses suggest, less abrupt changes in temperature, salinity, and less abrupt shifting sediments can be predicted. The ichnocoenoses suggest that changing energy conditions and allied parameters represent a temporary excursion of one type of association in to another type of setting and thus overlapping two or three types of assemblages in a fluctuating or changing environmental conditions. *Muensteria* assemblage suggests development in deeper level of oxygenated sediments in some what distal parts of tidal conditions and continuous slow sedimentation.

As a whole, the entire sequence of traces suggest oxygenated substrate conditions. And the assemblages are mainly of climax trace fossils under equilibrium conditions to intermediate trace fossils in between opportunists and climax trace fossils. The trace fossils are mainly developed in the upper and middle levels in the sediments.

It may thus be concluded that low to moderate energy environments in the basin favoured deposit feeding, grazing, crawling and resting organisms in shallow and intermediate tires of sediments to prevail.

VIII.5.2. Gangeshwar Member:

In contrast to the JWM, the GM is characterised by very low diversity of traces by few suspension feeding, dwelling, deposit feeding and crawling trace making organism. It mainly consist of vertical burrows such as *Arenicolites*, *Diplocraterion*, *Monocraterion*, *Skolithos*, horizontal feeding burrows like *Thalassinoides* and crawling trails like *Isopodichnus*, *Crustacean* trails and bilobe trails These traces clearly display the presence of *Skolithos*, *Diplocraterion*, *Thalassinoides* and *Gyrochorte* ichnocoenoses in the Member.

The depositional conditions of the GM appear to be quite different than the JWM and the changes are well documented in ichnocoenoses, lithology and structures, which are characterised in the sandstone sequence of the GM. In the lower massive to horizontally stratified beds belonging to the MS facies, the presence of *Skolithos* and *Diplocraterion* ichnocoenoses indicate high energy hydrodynamic setting and shifting substrate further subjected to abrupt erosion and deposition, and dominance of opportunistic suspension feeding organisms living in permanent shelters. Low to moderate density and low ichno-diversity clearly suggest low species diversity of organisms and lower amount of biomass. Associated sediments are slightly muddy to clean sands, and occurrence of these structures only in the upper parts of the beds shows fast rate of sedimentation. The occurrence of large ripple marks and cross stratification in the upper part alongwith ichno-assemblage depict onset of lower tidal to subtidal environmental conditions and temporary colonization by a stress pioneer community. The burrows are shallow level structures in the sediments. When depositional environment was inhospitable and substrate was biologically unconditioned, to the settlement of the trace making community.

However, due to shifting of environmental conditions *Thalassinoides* and *Gyrochorte* ichnocoenoses appear superimposed on *Skolithos* & *Diplocraterion* ichnocoenoses in the same sequence. The structures are deposit feeding and crawling traces indicative of extremely quiet water conditions with little reworking where organic matter was being deposited alongwith the sediments

In the upper part of the sequence, development of *Skolithos* and *Diplocraterion* assemblages on topmost part of cross stratified HS facies most probably demonstrates moderate to high energy conditions with shifting sediments, high rate of sedimentation and frequent physical reworking which have obliterated traces and leaving a preserved record of physical stratification only, in the entire sequence except top part. High energy environments had offered vertical burrows to prevail to unconsolidated sediments. The trace making organisms seems to be mainly *Polychaete, Crustacean, Worm, Gasteropod, bivalve, arthropod, Apalcophore* etc.

VIII.5.3. Ler Member:

The Ler Member consist of considerable frequency of traces and requires some critical comments on its ichnocoenoses distribution. The Members as a whole passes through *Skolithos, Diplocraterion, Ophiomorpha, Gyrochorte, Thalassinoides, Chondrites, Rhizocorallium* ichnocoenoses. It contains *Skolithos, Diplocraterion* ichnocoenoses at its base followed by *Rhizocorallium, Ophiomorpha, Thalassinoides* ichnocoenoses in LSS facies; *Chondrites* assemblages in SS facies; then *Thalassinoides* ichnocoenose in BS facies; again followed by *Chondrites, Thalassinoides, Rhizocorallium, Ophiomorpha* ichno-assemblage in LSS facies in alternation with Borings in BL and IC facies followed towards the top by *Skolithos, Diplocraterion, Ophiomorpha, Rhizocorallium* ichnocoenoses in LSS facies in the topmost part of the entire stratigraphic sequence. All these changes appear to be very significant, and the Member is thus characterised by broad range of forms and several behavioral activities including dwelling, feeding, grazing and crawling traces of *Worms, Crustaceans, Polychaete, Callianassid major, Annelid, arthropod, Gasteropod, Apalcophore* etc. Density and diversity are usually low.

The lowermost BS facies with bioclasts, cross stratification and megaripple marks characteristically suggest storm generated origin in which occurrence of *Skolithos* and *Diplocraterion* ichnocoenoses represented by less number of trace fossils with low frequency like *Skolithos*, *Diplocraterion*, *Cylindricum*, *Monocraterion* indicate continuation of moderate to high energy condition after storm event but slow sedimentation and an unconsolidated shifting substrate located in intertidal zone, containing opportunistic suspension feeders where little to negligible organic material deposited.

The next group of ichnocoenoses - *Rhizocorallium, Ophiomorpha, Thalassinoides* which occur in various separate partings of siltstones and shales of LSS facies includes *Palaeophycus, Planolites, Tisoa, Scolicia, Rhizocorallium* horizontal *Ophiomorpha* and *Thalassinoides.* This indicates moderate frequency and diversity. The ichnocoenoses developed in fine grained clastic sediments indicate an event of subtidal conditions with relatively low energy and slow rate of sedimentation below normal wave base. The trace fossils mainly indicate dwelling, feeding, grazing and crawling activities under oxygenated substrate conditions in surfacial upper and middle levels of pile of sediments. The assemblages show little reworking and organic material in suspended form as well as deposited alongwith the sediments.

These assemblages are followed by *Chondrites* association in calcareous siltstone - fine sandstone of SS facies indicating deposit feeding activity of *Worm* like organisms displaying moderate density but low diversity to monodominance and considered to represent quiet oxygen depleted inhospitable conditions with organic matter rich substrate in deeper levels, probably in subtidal distal parts of bars and barriers or alternately in washover fan part of bars and barriers in a lagoon. The ichnocoenose displays quiet water, protected conditions and poor water circulation. This condition makes the *Chondrites* ichnocoenose much more significant. It is considered as an opportunist, non-vagile, deep deposit feeder structure, where its strategy reveals opportunism in severely oxygen depleted 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.

Chondrites ichnocoenose in turn is followed by *Thalassinoides* ichnocoenose (in BS lithofacies). The assemblage contains *Thalassinoides*, bilobe bivalve trails, *Cylindricum* and *Monocraterion*. The assemblage indicates low density and diversity and considered to demonstrate post-depositional activity of opportunistic, and intermediate between opportunistic and climax trace fossils, produced by *Crustaceans, Bivalves, Annelid, Polychaete, and Worm like organisms*, in the storm generated BS facies. The trace fossils are mainly feeding, crawling and dwelling as per ethological grouping. The ichno-assemblage indicates quiet water conditions with little reworking where organic matter was being deposited and suspended after storm event. The ichnocoenose also depicts negligible sedimentation at the time of their inhabitation and considered as semi-vagile to vagile, surface, shallow to middle level structures.

The next assemblages of *Chondrites*, *Thalassinoides*, *Rhizocorallium* and *Ophiomorpha* indicate development of subtidal nearshore marine conditions with relatively low energy and slow rate of sedimentation below normal wave base. The organisms could be *Worm, Crustacean, Callianassid major, Annelid, Holothurian, Gasteropod* etc. The occurrence of *Chondrites* in some of the partings and nodules depicts either deep level oxygen depleting conditions in fine grained unconsolidated sediments without much circulation or oxygen level fluctuating conditions in a protected basin.

The boring found in the IC facies depicts development of hard substrates and post-depositional activity of bivalves etc., when the conditions were at equilibrium.

The topmost part represented by *Skolithos*, *Diplocraterion*, *Ophiomorpha*, *Rhizocorallium* assemblages suggest higher energy conditions and increase in suspended organic rich material. The assemblage of dwelling, suspension feeding and deposit feeding organisms depicts shallowing of basin and development of infratidal conditions above normal wave base, which are reflected by occurrence of oscillation ripple marks, where organic material deposition is also not uncommon (as shown by *Rhizocorallium* ichnoassemblage) with less amount of reworking.

In conclusion, according to the onset of various environmental conditions, different ichnocoenoses occurred together by quick succession preserving in them the typical environmental conditions.

VIII.5.4. Dhosa Oolite Member:

The Member shows significant change in trace fossil occurrences in comparison to other Members of Chari Formation, i.e. JWM, GM and LM. In its lower part, silty shales of LSS facies has revealed very few trace fossils due to its homogeneity, and mainly includes *Rhizocorallium* and bilobate trails. The above assemblage generally indicates slow sedimentation and little physical reworking. It also suggest low energy quieter conditions and subtidal to shallow near shore shelf sequence. As suggested by Fursich (1974), these conditions are prevalent at depths, where the substrate is less protected with intermittent current sweeping the sea floor. As per Buckman (1990), the conditions indicate marginal marine environments and also possibly a sediment feeding mode of life. The possible life forms are *Crustaceans, Annelid, Bivalves and Gasteropods* showing deposit feeding and crawling activities. These are regarded as climax to intermediate communities in equilibrium ecology The assemblage depicts lower and middle level structures in the unconsolidated sediment column.

At the higher level in the sequence of the Member, Oolitic Limestone facies contains *Zoophycos* and *Chondrites* ichnocoenoses alongwith *Planolites* trace fossils. The association indicates deposit feeding and grazing behavior of vagile mud ingesters like *Polychaetes, Annelids, Worms* etc., in Oolitic Limestone lithofacies displaying low density and diversity. Such forms are considered to represent quiet low energy and probably deeper water conditions where rate of sedimentation is rather slow, and is typified by calcareous mud and muddy sands rich in organic matter but somewhat deficient in oxygen

The Kutch assemblage thus represents offshore shoals and bars, where ichnocoenoses occupy deepest levels in the sediments constituting oxygen depleted zones on the substrate. These areas of deposition could be free of turbidity currents and significant bottom currents. But, there may be other structures in the upper levels of the sediments, which could have been eroded leaving deeper tier structures alone. This has been postulated on the basis of occurrence of evidences provided by *Thalassinoides, Planolites* and *Arenicolites* at the same level. It is also possible that water saturated surfacial sediments could have been difficult to exploit by endobenthos, resulting in low diversity, low abundance of fauna, and oxygen depleted conditions in the lower part to leave behind lower level traces. The associations are thus deep deposit feeder structures, emplaced well below the water sediment interface, and comprise the deepest tiers. The structures are also labeled as opportunistic The assemblages could have been resulted in a protected or restricted epeiric or nearshore region

VIII.5.5. Gunawari River Member:

In a similar manner to DOM, the GRM is characterised by very low diversity and low density of traces produced by very few suspension feeding and dwelling organisms. It consist of vertical cylindrical burrows such as *Monocraterion* and *Skolithos* in its distal fine to medium arenaceous part and *Palaeophycus* and *Thalassinoides* in its proximal coarse arenaceous to fine rudaceous parts, with the presence of *Skolithos* and *Thalassinoides* ichnocoenoses The organisms could be *Worms and Crustaceans*. The rocks of lowermost and intermediate LSS facies have characteristically failed to preserve any distinguishable trace fossils. This suggests an event where substrate may be hostile and unconditioned or physical or diagenetic processes have obliterated the life evidences. The second reason is unjustifiable as higher energy conditions or reworking is not reflected in form of physical structures or even reactivation surfaces and as rocks have preserved fine lamination and delicate body fossils.

The *Skolithos* ichnocoenose chiefly represents suspension feeding organisms living in high energy hydrodynamic setting and shifting substrate subjected to abrupt erosion and deposition and depicts temporary colonization by a stress pioneer opportunistic community. In GRM, it represents subtidal part of delta front deposits in a coarsening and thickening upward sequence of beds. The low density of burrows shows appreciable rate of sedimentation without successive erosion than the biogenic reworking. The organisms that feeding on slow suspension and inhabit the shifting sand environment seek security through burrowing deeply and remain stationary for longer period.

The depositional conditions in the upper part of the Member in OS facies appears to be changed by rising of subtidal parts to delta slopes related to the delta front. These changes are well documented in lithology, structures (like planar and trough cross stratification, reactivation surfaces, and megaripples) and fossils The megaripples indicate stormy conditions and substrate above storm wave base at the time of deposition. These conditions are followed by calm time and negligible to almost nil sedimentation during which *Skolithos* and *Thalassinoides* ichnocoenose could have been nested. The ichnocoenose depicts moderate to low energy conditions, with less erosion, well oxygenated substrates and less abrupt shifts in temperature and salinity. The structures reveal deposit feeding and suspension feeding habits of the organisms. During lower energy conditions suspension feeders can survive alongwith deposit feeders on slowly depositing suspended organic material, but in high energy conditions deposit feeders or grazers can hardly strive because of agitating water keeping organic matter in suspension every time allowing much less food to settle on or with the sediments.

The *Thalassinoides* ichnocoenose also indicates less abrupt shifting of sediments. These are also considered as semi- vagile and vagile, shallow and middle level structures present in oxygenated situations, which are intermediate to opportunists and equilibrium trace fossils.

VIII.5.6. Marutonk Dungar Member:

The MDM contains considerable number of trace fossils with moderate to high diversity and moderate density of structures. These traces include deposit feeding, grazing, crawling, dwelling and suspension feeding and resting behavioral impressions. The producers of such traces could be *Crustacean, Annelid, Gasteropod, Callianasa major, Worm, Polychaete, Sipunculids* etc. The main ichnologic assemblages are *Ophiomorpha, Thalassinoides, Rhizocorallium, Gyrochorte, Chondrites* and *Skolithos*.

In the lower part of the sequence, in the DSSS facies, the main ichnocoenoses present are *Skolithos*, *Rhizocorallium*, *Ophiomorpha*, *Chondrites*, *Gyrochorte* and *Thalassinoides*, represented by *Palaeophycus*, *Phycodes*, *Planolites*, *Tisoa*, *Rosselia*, *Cochlichnus*, *Laevicyclus*, *Histioderma*, *Granularia*, echinoid trails etc., where lowest part is marked by *Skolithos* & *Ophiomorpha*, followed by *Rhizocorallium* and *Thalassinoides* and than by *Gyrochorte* & *Chondrites* ichnocoenoses. The above mentioned assemblages progressively shows higher to lower energy regimes as one approach younging sequence.

Occurrence of few trails, *Phycodes* and horizontal *Ophiomorpha* in the *Skolithos* and *Ophiomorpha* assemblages depict some what lower i.e. moderate to low energy regime. It seems that area was inhabited by slow suspension feeding, deposit feeding and crawling trace makers. The traces suggest colonization of a stress pioneer opportunistic and intermediate community. The trace fossil assemblage, absence of ripple marks and other physical structures and lithology suggest deposition under subtidal conditions below normal wave base in protected basin or lagoon. The association shows typical low ichno-diversity.

The *Skolithos* and *Ophiomorpha* assemblages are followed by *Rhizocorallium* and *Thalassinoides* ichnocoenoses. The ichnocoenoses are suggestive of infratidal substrates below daily wave base but not storm wave base in a lagoon. Occurrence of carbonaceous shales support the above conclusion. As per Fursich and Heinberg (1983), such ichnocoenoses represent the lowest energy levels. Characteristic animals mainly include deposit feeders alongwith some suspension feeders. The communities have been regarded as climax to intermediate in equilibrium ecology.

At the next higher level in the sequence *Gyrochorte* ichnocoenose is represented by Ammonite grooves, *Gyrochorte*, *Palaeophycus*, *Planolites*, Teichichnus, *Cochlichnus*, *Granularia* and Echinoid trails are indicative of deposit feeding, grazing and crawling activities of *Apalcophore*, Ammonites, *Worms*, *Crustaceans*, *Annelid* etc. It suggest low energy conditions with almost nil sedimentation in infratidal part of lagoon. It represents a community of opportunistic to intermediate type which produced post depositional structures.

The assemblage also suggests deposition of organic material alongwith sedimentation In various layers, here, where other trace fossils are absent, *Chondrites* is found, depicts oxygen depletion conditions in the protected basin or lagoon. This may be temporary because immediate upper or lower or in some cases even same layer mostly contains traces of *Gyrochorte* assemblage or it may be possible that in upper tiers of sediments oxygenated conditions prevailed at the same time lower tiers of the finer sediments lacking the proper circulation and low oxygen levels in the interstitial waters and became oxygen deficient. Thus, such conditions influence the distribution of *Chondrites* keeping the organisms to a much more significant degree. In short, *Chondrites* postulates an environmental tolerance of oxygen levels lower than any other ichnogenus and sediments rich in organic matter.

The next is a diverse group of trace fossils in SS facies, includes *Skolithos*, *Monocraterion*, *Cylindricum*, *Rosselia*, *Fustiglyphus*, *Planolites*, *Palaeophycus*, *Asteriacites* and Teichichnus. The structures show low density and low diversity depicting mainly suspension feeding behavioral activity alongwith few deposit feeding, grazing and resting traces. The ichnoassemblage denotes moderate to relatively high energy conditions most typically associated with clean, well sorted shifting sediments in intertidal - subtidal part of barrier system somewhat away from the shore. This has a base of much thickness and dimensions of DSSS facies formed in lagoons. Here, in rapidly accreting sands such as migrating sandwaves or ripples (preserved on the top part), there is no erosional loss of upper parts, as no truncated structures at different level has found, results in low density *Skolithos* assemblage. This rapidity of burial seems to had inhibit maturation of communities, allowing only temporary colonisation of a stress pioneer opportunistic community. These conditions seems to have changed in the next sequence, and substrate could be rich in organic material which seems to have attracted a different type of community and hence sediments were flourished by deposit feeders and grazers showing systematic mining like Teichichnus, *Planolites*, *Rosselia*, *Fustiglyphus*, *Asteriacites* etc. The assemblage suggests presence of *Annelid*, *Crustaceans*, *Polychaete*, *Ophiuroides* etc., in a shallow shelf sequence below normal wave base, and moderate to relatively low grade hydrodynamic setting, negligible sedimentation and low rate of reworking with quiet but oxygenated waters and stable slowly accreting substrates and less abrupt shifts in temperature and salinity. All these are shallow to middle tier structures, and the conditions persisted in successive sequence and followed by gradual shallowing in the near shore shelf sequence of LSS, as can be observed by *Thalassinoides*, *Gyrochorte*, *Rhizocorallium*, *Ophiomorpha* ichnocoenoses, appearance of ripple marks in the progressively higher partings in the sequence, and several rhythmic intermingling of *Skolithos* ichnocoenose alongwith SS facies at decreasing interval. These suggest fluctuating hydrodynamic conditions most certainly with appropriate depth variations which have been reflected in corresponding ichno-assemblage variations. The uppermost beds of the Member show intertidal-subtidal regime mainly with *Skolithos* ichnocoenose and related trace fossils.

VIII.5.7. Jadura Member:

The JM consist larger frequency of traces in comparison to majority of the Members discussed earlier and as such requires some critical comments on its ichnocoenoses distribution. The Member as a whole passes through *Gyrolithes*, *Gyrochorte*, *Rhizocorallium*, *Ophiomorpha*, *Chondrites* and *Skolithos* ichnocoenoses. The changes projected by the succession of communities appear to be very significant. The broad swings are marked by crawling, feeding, grazing and dwelling structures made by *Apalcophore*, *Gasteropod*, Arthropod, *Annelid*, *Crustacean*, Bivalves, Decapod *Crustacean*, *Worm*, *Polychaete*, Callianassid major, etc.

At its lowermost part, MS facies of JM exposed on Bhuj-Jadura road, contains *Gyrolithes* ichnocoenose, which shows combined deposit feeding dwelling activity. It has monodominance and high density, which makes it an opportunistic trace. In sandstones of MS facies which are unconsolidated relict to palimpset deposits, the structures show some degree of permanence and their morphology reflects exploitation of organic rich substrate for food. The association is considered to be of semi-vagile to vagile middle level traces present in oxygenated waters, and shows post depositional activity under quiet water and highly stable, very slowly accreting substrate, below storm wave base, in subtidal nearshore conditions or alternatively in protected intracoastal to epeiric sites.

At the equivalent level SS and DSSS facies of JM exposures on Bhuj-Mundra road near Satellite Earth Station do not show any trace fossil association. This may be due to unconditioned substrates, unsuitable oxygen and salinity levels, presence of toxic substances etc., reflected in form of carbonaceous shales.

The next progressively higher sequence is that of LSS facies which contains *Gyrochorte* and *Rhizocorallium* ichnocoenoses. The *Gyrochorte* ichno-assemblage with an association of *Didymaulichnus*, *Isopodichnus*, *Neonereites*, *Palaeophycus*, *Planolites*, *Phycodes*, *Oldhamia*, *Cochlichnus*, *Scolicia* etc., has been represented in the lower portion of the facies sequence reflecting crawling, grazing, feeding and rarely dwelling activities of organisms like Arthropod, *Gasteropod*, *Apalcophore*, *Annelid*, Holothurian, Bivalves, *Polychaete*, *Worm*, *Crustacean* etc. Such an assemblage denotes quiet but oxygenated waters in a highly stable, very slowly accreting substrate below normal wave base in a subtidal to nearshore shelf condition. These conditions are reflected in absence of ripple marks and other dynamic sedimentary structures. The record is mainly one of continuous slow deposition and bioturbation in normal temperature and salinity levels, yielding complex bioturbate textures The traces are typically complex horizontal deposit feeding patterns preserved as convex hyporelief. The high diversity of traces and low abundance of specialized form in this Member is typical of a stable but low resource environment. The apparent high number of trace fossils, however, may be because of the long time during which few individuals were successfully able to rework the slowly depositing sediments. The feeding methods employed by the various organisms are generally designed for maximum efficiency, not only with respect to resource utilization, or thorough coverage of space during deposit feeding activity but possibly in response to competition of other biogenic pressures.

In the upper portion of the sequence *Rhizocorallium* ichnocoenose predominates with traces like *Palaeophycus*, *Planolites*, *Phycodes*, *Trichichnus*, *Oldhamia*, *Laevicyclus*, *Ophiomorpha*, *Corophioides*, *Cylindricum*, *Gyrochorte*, bilobe trails etc. The community indicates a broad range of form and behavioral activity including feeding, grazing, dwelling and crawling by *Worm*, *Crustacean*, *Annelid*, *Polychaete*, Callianassid major, *Apalcophore* etc. The assemblage indicates subtidal nearshore conditions, slightly fluctuating above and below normal wave base with relatively low to moderate energy conditions, slow rate of sedimentation and less erosion Higher frequency and diversity of traces indicate unconsolidated well oxygenated substrates with less abrupt shifts in temperature and salinity

Rich organic material seems to be available in suspension. The above inference is further supported by fine grained argillaceous and arenaceous rocks, absence of physical structures except infrequent occurrence of ripple marks etc. The assemblage is regarded as community in equilibrium ecology. The next higher sequence of the Member represented by SS facies shows low frequency and low diversity *Chondrites* ichnocoenose on Reha-Jadura road exposures and *Skolithos* assemblage with *Cylindricum*, *Monocraterion*, *Planolites*, *Palaeophycus*, *Rosselia*, *Spirophyton* etc., trace fossils at other places. The *Chondrites* ichnoassemblage with *Planolites* depicts existence of oxygen deficient hostile conditions in lower tiers of tidal fans off-shooting from a barrier beach regime in subtidal part of a lagoon. The assemblage represents development of quite low energy conditions with improper circulation of pore waters in the sediments.

The *Skolithos* ichnocoenoses on the other hand represents dwelling and deposit feeding activities of *Annelid*, *Polychaete*, *Worm*, *Crustacean* etc. The association suggests development of low to moderate energy conditions with slow sedimentation and unconsolidated slowly shifting substrate in lower intertidal, shallow infratidal to tidal flat zones. The assemblage is more or less opportunistic in shallow level in the oxygenated conditions and most probably with frequent variation in temperature and salinity. The occurrence of funnel shape in a given structure depicts much less erosion.

The absence of trace fossils in DSSS facies which is found between SS facies demonstrates shallow lagoonal to tidal pool conditions, and signifies unsuitable conditions to the presence of organisms and depicts a special kind of ichnological event.

VIII.5.8. Tapkadevi Member:

The TM involves highest frequency and diversity of trace fossils in comparison to any other Members. The unit is characterised by broad range of forms and several behavioral activities including dwelling, feeding, grazing, crawling and resting. The traces are formed by *Worms*, *Crustaceans*, Bivalves, *Gasteropods*, *Annelid*, *Polychaete*, Arthropod, *Apalcophore*, Holothurian, Actinarian sea anemone, Callianassid major etc. It shows classical variation of *Chondrites*, *Gyrochorte*, *Thalassinoides*, *Rhizocorallium*, *Asteriacites*, *Ophiomorpha*, *Diplocraterion*, *Skolithos* type ichnocoenoses and possibly indicates variations in the depositional condition in the basin. All these changes are very significant.

In the lower part of the Member, thick shales of the LSS facies are dominated by *Chondrites* assemblage. The burrows are produced by endobenthic deposit feeding organisms of unknown taxonomic affinity. The burrows are emplaced well below the water sediment interface deeply in the sediments and considered as deepest level structures. Their occurrence indicates very low oxygen levels in the interstitial waters within the sediments rich in organic matter. Occurrence of the ichnocoenose is related to chemically reducing conditions deep within the sediments and only indirectly dependent on sea floor conditions. Similar conditions in TM represents a low energy quiet water condition in a subtidal to nearshore shelf with poor water circulation. It typically occurs in mud, rich in organic matter.

The ichnocoenose thus considered as a non-vagile opportunistic in severely oxygen depleted environments, where *Chondrites* may occur alone. In the progressively higher sequence of SS facies an accumulation of *Thalassinoides*, *Monocraterion*, *Cylindricum*, and *Gyrochorte* has been observed. This association represents dwelling, feeding and crawling activities of organisms in a low to moderate energy region in intertidal - subtidal part of beach and where food could be available in suspension.

The next higher beds consist of maximum number and variety of trace fossils in a thin sequence of RFSSS facies where structures fall in the ichnocoenoses like *Asteriacites*, *Diplocraterion*, *Gyrochorte*, *Ophiomorpha*, *Rhizocorallium*, *Skolithos* and *Thalassinoides*. In the sequence physical structures (like oscillation, symmetrical and interference ripple marks, parting lineation, climbing ripple cross lamination etc.), suggest development of lithofacies in a tidal and related environments. This is further supported by the occurrence of varied ichnogenera showing moderate to high density and diversity. The ichno-diversity is evident by occurrence of following variety of trace fossils: *Asteriacites*, *Bergaueria*, *Bifungites*, *Circulichnus*, *Conostichus*, *Crossopodia*, *Cylindrichnus*, *Cylindricum*, *Diplocraterion*, *Gyrochorte*, *Gyrophyllites*, *Helminthopsis*, *Isopodichnus*, *Keckia*, *Laevicyclus*, *Megagrapton*, *Monocraterion*, *Muensteria*, *Neonereites*, *Ophiomorpha*, *Palaeobullia*, *Palaeophycus*, *Planolites*, *Rhizocorallium*, *Scalarituba*, *Scolicia*, *Spirophyton*, *Taenidium*, *Thalassinoides* *Yakutatia* etc.

The combination of all physical and biogenic structures points to a tidal dominated shore line, where, it could fall in meso-, to macro- tidal region with comparatively larger time duration between the successive tides (episodes). The sea appears to be very calm with much less wave energy. The diversity of various individual ichnogenera is low to moderate. It seems that the dwelling, feeding and resting traces could have developed in accordance with overall low to moderate energy environmental setup in lower intertidal to infratidal substrates above normal wave base in interbedded muddy and well sorted clean silts and sands, showing moderate to intense bioturbation and relatively slow to negligible sedimentation The condition seems to be well oxygenated and ample food availability in deposits and in suspension. Due to lower energy condition less abrupt to negligible erosion and deposition appear to have been prevailed. Deposition could have occurred mainly by slowly accreting shifting substrates. Significant bottom currents which can lead to erosion were absent. The community is a mixture of vagile and nonvagile opportunists and intermediate forms mainly in surface, shallow and middle levels of the sediments. Here, *Asteriacites* assemblages represents development in muddy sandy thixotropic substrates, where tidal fluctuations in the water level caused the animal to be stranded on the existed muddy sands.

The development of specialized systematic feeding, grazing and crawling structures could have been emplaced during much less energy conditions and negligible sedimentation at the time of higher water level in daily, fortnightly or monthly high tide episodes which might have sustained for longer - quarter to half or full days time. It is during this time when finer ferruginous crust appears to deposit on ripple marked top from suspended particles in standstill waters. This seems to have strengthened the delicate ichnostructures by hardening and later on preserved the same at the time of nib tide and surface exposure by dehydration (evidenced by dehydration cracks) process and early diagenesis. Hence ripple marked top with thin ferruginous argillaceous crust and trail depicts omission surfaces and hardening by early diagenesis. The ichnocoenose represents intermediate to climax post depositional community that developed in an equilibrium ecology and oxygenated waters as observed by Bromley, (1990) in his studies. The distribution of assemblages and physical structures indicate very low gradient of basinal slope and hence development of broad tidal flats. The overall conditions therefore suggest less abrupt change in temperature and salinity conditions. Possibly the early diagenesis protected and preserved the intertidal sequence from being reworked in next transgressive cycle. In RFSSS, biogenic structures suggest the behavioral activities by *Ophiuroides*, *Gasteropod*, Bivalve, *Polychaete*, *Annelid*, *Crustacean*, *Worm*, Callianassid major, Arthropod, *Apalcophore*, Actinarian sea anemone, Holothurian etc.

Above this sequence, within MS lithofacies in the top parts *Skolithos*, *Diplocraterion*, and *Ophiomorpha* ichnocoenoses with *Arenicolites*, *Monocraterion*, *Cylindricum*, *Enteropneusta burrows*, *Bergaueria*, *Phycodes*, *Thalassinoides* have been encountered, while in HS lithofacies *Skolithos*, *Diplocraterion* and *Monocraterion* ichnogenus have been observed. This indicates moderate to high energy conditions with shifting substrates and appreciable though not necessarily high rate of sedimentation in lower intertidal to infratidal environments. The biogenic structures are susceptible to abrupt erosion or deposition. The preserved record of physical stratification in MS and HS facies is indicative of higher energy induced physical reworking and obliteration of trace fossils, and hence traces are thinly populated in the top part of the sequence showing low degree of bioturbation. This indicates rate of physical reworking exceeding than that of the sedimentation. The ichnocoenoses chiefly represents suspension feeding, dwelling, deposit feeding and resting behaviors of *Polychaete*, *Annelid*, *Worm*, Callianassid major, *Crustacean*, Actinarian sea anemone etc.

VIII.5.9. Bharapar Member:

The Member is characterized by the maximum density of suspension feeding, dwelling structures. It represents a classical association of *Skolithos*, *Diplocraterion*, *Ophiomorpha*, ichnocoenoses along with other dwelling and feeding structures like *Arenicolites*, *Stipsellus*, *Corophioides*, *Monocraterion*, *Enteropneusta burrows*, *Laevicyclus*, *Spirophyton Rosselia* in BTS lithofacies. The assemblage repeats two times in the vertical sections in the Member alongwith BTS lithofacies, *Ophiomorpha* - monodominant ichnocoenose occurs in the upper part of the sequence, few meters below Deccan Trap Lava flows in CBCGS facies.

While only occurrence of *Strobilorhaphe* observed on the top of CBCGS facies in the exposure near Jamaywadi.

In BM, the diversity of trace fossils is comparatively low and denotes behavioral activities of suspension feeding, dwelling and deposit feeding organisms, such as *Polychaete*, *Crustacean*, bivalve, *Worm*, callianassid major etc. The high frequency of *Skolithos* species represents zone of suspension feeding *Polychaete*. The trace fossils are found in horizontally stratified or ripple marked or wave ripple marked or cross stratified beds. On the basis of both the physical and biogenic sedimentary structures, the stratigraphic sequence of BM can be interpreted as a tidal flat to inter tidal, sub tidal to bar deposit in high to very high energy conditions with low to moderate rate of sedimentation. Coarse to medium clastic sediments and mega ripple marks are also indicative of a high energy environment representing very shallow subtidal to intertidal deposition. This observation is very well in accord with that made by Fursich (1975). Accordingly, it can be said that the high energy environments in the basin favoured deep burrowing and suspension feeding organisms to prevail.

The high degree of bioturbation indicates the rate of biogenic reworking exceeding than that of the sedimentation, i.e. the ichnocoenoses suggest slow rate of deposition and shifting substrate. High density is also as a result of repeated reworking of upper parts of sands and slow sedimentation. The ichnocoenoses represents colonization by a stress pioneer opportunistic community. Repeated reworking is also indicated by tapering of biogenic structures against erosional surfaces. It is probable that long tubes could have served as a protective shelter against unstable conditions on the sea floor depicting agitating water conditions with low rate of sedimentation Prominence of suspension feeders suggest inhospitable depositional environment to most life forms due to uneven sedimentation rates, and newly deposited substrate may be biologically unconditioned Hence, the dense population of trace fossils in this unit is very significant.

In conclusion, it can be said that deep burrowing, high frequency and greater dimension of the traces in BM suggest deposition in moderate to high energy conditions in tidal flat, intertidal to subtidal sediments with thickly populated zone of suspension feeding animals

The dense population of *Ophiomorpha* burrows in CBCGS facies is rather significant The *Ophiomorpha* burrows that terminates progressively higher up in younger bedding planes indicates deposition on erosional bedding plane. The *Ophiomorpha* ichnocoenose in CBCGS facies indicate conditions of moderate to instantaneously high sediment influx in shifting substrate conditions. It is further suggested that a low rate of reworking seems to be a pre-condition for the construction of the biogenic structures since the delicate clay ball lined walls in *Ophiomorpha* are preserved. The *Ophiomorpha* trace fossils has been produced by suspension feeders such as Callianassa major. It is considered as ichnocoenose of unstable sand substrates in hydrodynamically energetic environments. In BM, the monodominant occurrence is found in an estuarine sedimentary environment.