PART : 4

CHAPTER : VII

LITHOFACIES

INTRODUCTION :

The Khadir Formation in Kutch comprising eight members as discussed earlier is further divided into ten facies associations each composed of genetically related sediments. This descrimination is based on the area of occurrence, lithofacies geometry, stratigraphic position, lithological features, physical and biogenic sedimentary structures, and on the patterns of vertical sequence confirmed by the author in the field. All these representative lithofacies are shown in the Figs. 9, 10, 15 and 29 to 33. It is, however, important to note that many of these lithofacies are repeated in their vertical extent and also integrate with each other in their lateral extent. The vertical sequence of facies also varies from outcrop to outcrop and not all facies are repeated at all localities. The limited occurrences and poor areal distribution of exposures, however limits the establishment of detailed regional facies trends. As a result the present study is focused mainly on vertical facies relationship exhibited at each outcrop. The inferred vertical relationship based on the characteristic biogenic structures in each facies is further discussed in detail in Chapters VIII to X.

Another important factor to be noted is that most of the sediment types in all the above facies associations are mixtures of siliciclastic and carbonate material both of intra and extra basinal in origin are found to have been involved in various proportions in making up the rocks.

As largely agreed blending of descriptive cum genetic criteria for the classification of such rocks is problematic, and has almost rendered confusion in the classification systems developed by a number of workers.

As noted by Pettijohn [1975], it is hard to impose a single classification system on diverse type of sediment because of their polygenetic nature. Questions of compositional and textural maturity are difficult to assess equally between siliciclastic and carbonate sediments, primarily because : [1] carbonate clasts are derived both intrabasinally and extrabasinally, [2] siliciclastic and carbonate sediment respond differently to hydraulic transport, and [3] their diagenetic history is usually quite different. Despite these differences in origin as argued by Jeffrey Mount [1985], the siliciclastic and carbonate sediments do mix and they form rocks that are not readily accommodated in the most commonly used classification systems. As further quoted by him, the level of understanding of mixed sediments is commonly in a juvenile stage and it is inappropriate to derive a scheme that brings genetic interpretation into the classification of the sediments. He has therefore preferred a simplistic view and advocated a first-order classification intended for descriptive purposes and general categorisation of mixed sediments. This newly introduced scheme by Jeffrey Mount, has an advantage for its simplicity towards recognising four components of mixed sediments : [1] siliciclastic sand [sand size quartz, felspar etc.]; [2] Mud [Mixture of silt and clay; [3] Allochem [carbonate grains such as pelloids, ooids, bioclasts and intraclast greater than 20 MM in size]; and [4] carbonate mud or micrite [less than 20 MM in size]. Jeffrey Mount's [1985] classification is advantageously used by the author for the description of lithofacies recognised by him for the region of

Khadir Island.

DETAILS OF FACIES ASSOCIATION

[1] FACIES 'A' : CLAST - SUPPORTED POLYMICTIC BRECCIO CONGLOMERATE [PBC] FACIES :

This facies association is reported only in and around Chhariya Bet. It is characterised by clast-supported extrabasinal polymictic conglomerate [Plate : 1]. The clast composition is varied but consists predominantly of granite, felsite, rhyollite, trachyte and syenite in subarkosic sandy matrix. The conglomerate lithofacies is apperantly spread over the entire Chhariya Bet region. The clast size differs between and within the units but is often covered by the pebble to cobble size clasts with occasional boulder size material. The maximum long axis in such a extraformational clast recorded by the author is 18 cm. The average pebble and cobble material which is more dominant [Plate : 1] has an average size of 6 cm. Most of the clasts are angular to subangular having rhomb-shapes but some low sphericity clasts are also observed [Plate : 1]. The concentration of clasts is highly variable and clast/matrix ratio varies bet 80 to 20 maximum and 75 to 25 minimum. In some beds, clasts concentration is seen varying both vertically and laterally.

Internally, the conglomerate beds are disorganised with the clasts randomly oriented. Some preferred orientation of rhomb-shaped clast is seen in the lower parts of some beds especially adjoining the prominant cross-cutting joint surfaces oriented in the NE-SW and NW-SE direction [Plate : 2]. In addition to the extraformational clast, rare occurrence of intraformational bodies of medium to coarse grained arkosic sandstone upto 0.75 m are found incorporated in some conglomerates [Plate : 2]. No major sandstone packages, however are developed in most of the unoriented successions of the polymictic conglomerate bodies. It is further observed that these clast supported extrabasinal conglomerate are not usually observed with major sandstone packages but tend to be isolated in haphazardly.

Interpretation :

The clast-rich polymictic breccio-conglomerate form complex to highly scoured amalgamated sequences. Invariably such beds are laterally discontinuous and accurate subdivision of amalgamated sections into depositional units is rather difficult. Classifying the conglomerate on the basis of presence or absence of grading [inverse or normal] and the stratification allows subdivisions into three subfacies - ungradded, inversely to normally gradded, and multiple gradded. These group of subfacies are similar to those developed by Walker [1975, 1977], and Surlyk [1978] for the comparable resedimented conglomerates. Although such a scheme of classification form a useful framework a discussion of transport mechanism and depositional processes in the Khadir Polymictic conglomerate based largely on a vertical sections and their lateral variables does not fully reflect, the range of processes operating in individual flows. Furthermore, for the concealment of sediments by the vast exposure of Rann material, the vertical contact between the surfaces of various beds are difficult to be observed in the field.

The internally chaotic, ungradded and non-stratified nature of the clast-supported conglomerate invites comparison with the debris flow deposit as discerned by Jhonson [1970] and Pierson [1981]. The absence of mud indicates a non-cohesive mechanism. The overall evidences on the basis of broad definition of Lowe [1971] indicates that, the deposition of polymictic conglomerate could have been taken place from debris flow or more accurately from lamellar high cohesive less flows.

The inverse grading reflects predominant flows of depositional processes, commonly within traction carpet at the base of high energy, high concentration turbulent flow. The overlying normally gradded intervals reflect setting of clast out of a tractional suspension. The presence of minor occurrence of sandstone packages supports the suggestion by Lowe [1982] that sedimentation of sand although unlikely within the hydrodynamic condition necessary to develop such a high energy traction carpet, sand-grade detritus would be fully supported within overriding turbidity current and would bypass the area of gravel sedimentation.

The multiple grading and absence of sharp erosional contact between conglomerate layers suggests that these conglomerate are the deposits of individual surging flows other than an amalgamated sequence of flow deposits. Such a surging flow style reflects retrogressive slope failure or internal hetrogenetics with a sinusus confined flow.

The overall evidences of Facies Association [A], thus display features, analogous to a modern flow deposits from subaerial environment. Many of the features of the debris flow described by Thourton [1984], such as inverse grading and random orientation of clasts confirm such a view. Clasts composition suggest that material was mainly derived from Meruda Takkar Hill [NE of Chhariya Bet], Kalinjar Hill [Nagar Parker - Further NE of Chhariya Bet - now in Pakistan], and Erinpura Granite [Rajasthan]. It is possible that coarse material was deposited at the mountain front in fan-delta environment and was further redeposited in deeper water by the debris flow incorporating large volume of sediments. As suggested by Davis [1983] the accumulation of fan-shaped wedge of sediment typically develops at the base of rather steep mountain slope where there is an abrupt change to a flat or only slightly slopping area. Such fans are particularly numerous in tectonic regions where long fault block produce an extensive scarp.

[2] FACIES 'B' : SANDY ALLOCHEMIC LIMESTONE [SAL] :

The 'SAL' facies as a whole is developed at many places throughout the Khadir Island region and good exposure can be found in Hadibhadang Dungar Member, Hadibhadang Pir Member, Chamwa Wandh Limestone Member, Gadhada Sandstone Member, Ganeshpur Calcareous

Sandstone Member and Bambanka Member. The maximum development of this facies is found in Hadibhadang Pir Member with a thickness of 17 mt.

The nomenclature of this facies is based on the proposed classification of mixed siliciclastic and carbonate sediments by Jeffrey Mount [1985]. The characteristic feature of SAL facies association is that, it contains abundance of fossil material and their skeletal fragments in shelly - sandy - calcareous matrix. The concentration of carbonate sediments is greater than siliciclastic sand and roughly varies between 70% to 80%. The occurrence of different sand/limemud ratio and other subordinate lithological differences permit subdivision of this facies into two subfacies viz. [1] sandy intraformational limestone conglomerate subfacies [SILC], and [2] shelly sandy limestone subfacies [SSL].

Sub-Facies 'B-1' : Sandy Intra-formational Limestone Conglomerate [SILC] :

This subfacies can be found SE of Chhariya Bet, adjacent the escarpment face of Khadir Island. It occurs as an intrabasinal conglomerate with a typical grey to buff colour and a slumping appearance. Its maximum thickness is about 4 m. The bioclast include shells predominantly of brachiopod, more or less of the same average size [3 cms]. The brachiopod shells are usually subjected to greater amount of wear and tear and are usually defaced in their external appearance. This renders difficulty in identifying and ascribing them a proper geological age. Very often the cavities left over by the removal of such shells are found, filled by secondary ferruginous material.

As noted in the field, the 'silc' subfacies has a very limited occurrence and is restricted to only one single outcrop, perhaps disconformably overlying the Chhariya Bet Polymictic Conglomerate. The next stratigraphic unit consisting of shelly sandy limestone subfacies [ssl] is found flanking the lensoid of this facies and also gradually overlying it. Furthermore, the facies appears to be a deposit formed by penecontemporaneous fragmentation and redeposition but with a minor interlued in the deposition with clast mostly consisting of local origin having undergone practically very little or no transportation. Following Pettijohn [1975] and Jeffrey Mount [1985], the author has preferred to call it a sandy intraformational limestone conglomerate.

Interpretation :

The large average size of the bioclast and the small grain size of matrix reflect depositional environment with predominantly high energy condition. Small scale alteration of coarser and somewhat fine-grained lamellies, however indicate minor fluctuation in energy levels. The lack of mechanical compaction indicate thorough and effective sedimentation. It is possible that during the period of increased erosion unlithified surface material overlying the cemented surface layers were removed [e.g. Brachiopod shells, leaving the clasts or getting defaced]. Such an erosion and reworking must have taken place at the sediment-water interface. Detrital, medium to coarse grained, angular to subangular polycrystalline cum monocrystalline quartz showing undulose extinction indicate igneous and metamorphic origin of the grains. Sutured nature observed in some of the quartz grains highlights sheared quartz or stretched metamorphic quartz. The undulose extnction seen in some of the quartz could be a result of strain in their parent rock body. The angular and subangular nature of quartz further indicate nearness of their provenance to the depositional site. All the above observations present strong evidences of this sub-facies being deposited in a shoreface environment. Most of the sediments alongwith their bioclast were probably deposited during sporadic high energy such as storms.

Sub-Facies 'B-2' : Shelly Sandy Limestone Subfacies [ssl] :

This subfacies comprise bioclasts 1 to 5 cms in size associated with fine to medium grained detrital quartz sand embedded in a micritic matrix. The sub-facies is well represented in the following members viz. Hadibhadang Dungar Member, Hadibhadang Pir Member, Chamwa Wandh Fossiliferous Limestone Member, Gadhada Sandstone Member and Bambanka Member. The predominant body fossils include, pelecypod - chiefly **Corbula lyrata** and **Gervillia sp.**, oysters, **pholadomya** and gastropods. Rare occurrences of ammonoidal shells are also observed in Chamwa Wandh Fossiliferous Limestone Member and Bambanka Member.

On the basis of predominance of the fossil forms, this sub-facies is further subdivided into four units namely, [1] Corbula-bearing Limestone Unit [SSL Cg], [2] Oyster-bearing Sandy Limestone Unit [SSL Oy], [3] Pholadomya-bearing Sandy Limestone Unit [SSL Ph], and [4] Ammonoidal Sandy Limestone Unit [SSL Am]. Some of these units contain microfossials of foraminifera such as species of **Lenticulina, Robulus, Palmula** and **Texularia.** All these evidences indicate Bathonian age of the rocks. Total cummulative thickness of the sub-facies is 6.2 m.

Sub-Facies 'B-2.1' : Corbula Bearing Limestone [SSL Cg]

This subunit of the shelly sandy limestone subfacies is dominated with the occurrence of the pelecypod genera - **Corbula lyrata** and **Gervillia sp.** About 5.2 m. cummulative thickness of such thinly-bedded limestone beds are very easily recognised in the field. Good exposures can be located on the lowermost levels along the E-W escarpment face of Khadir Island and near the damsite NE of Gadhada.

The SSL Cg subunit is characterized by yellowish brown to reddish brown, hard compact limestones very often studded with shell fragments of pelecypods, corals and gastropods. At NE of Gadhada [near damsite] both the valves of **Corbula lyrata** are often found intact with inner portions diagenetically calcified. This can be very well confirmed in thin sections where the presence of crystalline calcite is very significant.

Cox [1940], on the basis of occurrence of **Corbula lyrata** and **Gervillia sp.** bearing beds, assigned Bathonian age to these rocks. Thin section study reveals that medium to coarse grained, angular to subangular detrital quartz, embedded in micritic cum crystalline calcite groundmass characterize the rocks. Alongwith quartz grains two to three grains of microcline were also identified. Some quartz grains with more or less straight boundary facies showing grooved embayments reveal their volcanic origin. Besides, skeletal fragments pelecypods are also abundantly found. Quartz grains often are surrounding the long platy slightly curved shell fragments and some of them are found even replacing part of shell fragments.

Sub-Facies 'B-2.2' : Oyster-bearing Sandy Limestone [SSL Oy] :

This unit comprises yellowish brown, hard compact, fine-grained fossiliferous limestone. It is characterized by large development of oyster shells. Some detrital quartz in calcareous matrix is always the ingradient of this rock unit and hence termed as oyster-bearing sandy limestone unit following Jeffrey Mount's [1985] classification. Alongwith oyster, the other shelly ingredients include fragments of coral, brachiopod and pelecypod. Maximum development of the unit is recorded in Hadibhadang Pir Member. Here, the unit is underlain by yellowish brown polymictic conglomerate and overlain by ferrugenous sandy limestone. The concentration of carbonate material dominates over the detrital siliciclastic sediments in this unit.

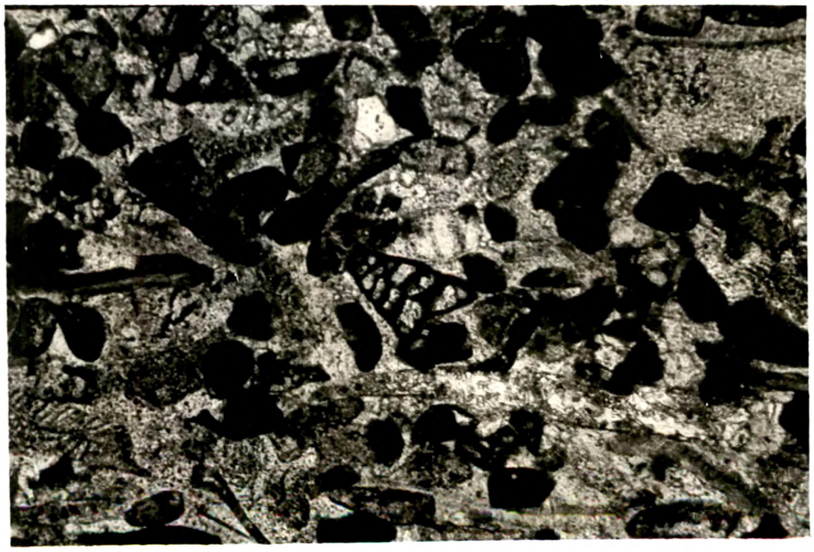
Thin section study reveal that the sediments in the unit contain abundance of skeletal fragments especially of oysters, brachiopod [rhynchonelloids] and other bivalve associated with variety of corals, echinoids, and bryozoa. A distinction between skeletal brachiopod and oyster with pelecypod [Mollusks] in thin section was possible from typical thin parallel layers of calcite normally having a wavy banded appearance against parallel extinction of pelecypod observed in the slides. It is further observed that some thin sections of the rock include rounded, subrounded to oblong shaped Oolites and Pellets, embedded in the micritic material. Subangular to angular detrital quartz grains are often found replacing parts of skeletal fragment-boundary and indicate replacement of micritic bearing bioclast [biomicrite] by quartz during later phase of silicification. In some cases, the periphery of skeletal fragment as observed is coated with hematitic material and indicate replacement of calcareous material by hematite during late diagenetic process.

Foraminifers such as **Lenticulina, Robulus Sp., Palmula** and **Texularia** observed [Plate : 4] confirm a Middle Jurassic age of this unit.

Sub-Facies 'B-2.3' : Pholadomya-bearing Sandy Limestone [SSL Ph] :

This unit is 3.0 m. in thickness, with its maximum development in Chamwa Wandh. In its field appearance, it exhibits yellowish brown to reddish brown colour and thinly developed beds of sandy limestone containing predominance of Pholadomya bivalves. The

[a] Photomicrograph showing occurrence of foraminifer and skeletal fragments in Shelly Sandy Limestone



[b] Photomicrograph showing occurrence of foraminifer [Texularia] associated with bioclast in Shelly Sandy Limestone

pholadomya shells are subovate, equivalve, gaping posteriorly, anterior side rounded and short. Surface display radiating ribs crossed by concentric striae with prominant umbo and external ligament, adductor scars are feable. Most of the bivalves are haphazardly distributed and have no clear pattern of their orientation. At times tiny gastropods alongwith hollow cylindrical tubes possibly representing echinoderm spines are found associated with the rock.

In the bottom layers the SSL Ph. unit is invariably yellow to yellowish brown in colour becoming dull red and ferruginous at the top. Acid treatment which response with effervences in the lower part is almost rendered ineffective in the reddish portion. It is possible that the calcareous portion of this unit is practically replaced by ferrous elements during the process of diagenesis from the top.

The unit overlies ammonoidal sandy limestone [SSL.Am.] and underlies corbula-bearing sandy limestone unit. This relationship is clearly observed in NE of Gadhada in Chamwa Wandh Fossiliferous Limestone Member.

Thin section studies exhibit abundance of skeletal fragments of pholadomya type pelecypod bivlaves embedded in micritic matrix. Very often the hollows in the fragmental shell fraction filled with micritic material are found to have been replaced by crystalline calcite. In other cases angular to subangular fine to medium grained detrital quartz are found to have been occupying the spaces between the shell fragments.

The overall appearance of this unit renders its similarity to sandy bioclastic packstone.

Sub-Facies 'B-2.4' : Ammonoidal Sandy Limestone Unit [SSL Am] :

This unit is largely dominated by the presence of large ammonoidal shells and detrital quartz alongwith the calcareous matrix. The overall appearance of the unit is yellowish to brown with no apparent bedding structure formed. Alongwith ammonoids large bivalves - Trigonia, Astarte and Pholadomya in their life position have been located. The pelecypod shells are invariably found to have been bored by different borers. This unit conformably overlies khaki, grey calcareous shale subfacies [D-1] of Micritic Mudstone facies [D] and underlie pholadomya-bearing sandy limestone unit [B-2.4] of shelly sandy limestone subfacies [B-2].

Interpretation :

The association of Corbula-bearing Sandy Limestone [SSL Cg], Oyster-bearing Sandy Limestone [SSL Ph], and Ammonoidal Sandy Limestone [SSL Am] makes up most of the shelly-sandy limestone subfacies in Khadir Island. The large size organic material embedded in the calcareous matrix with a typical grey to brown colouration marks the character of the subfacies. Very often the wearing and tearing of the bioclast show abundant erosional features. The internal cavities of the fossils very often display diagenetic effects in skeletal transformation. All these assemblages described in detail earlier thus represent elements of submarine distributary system influenced with terrestrial components. Furthermore, the large scale lenticular morphology of these sandy bioclastic bodies probably indicate their formation parallel to the basin margin and suggest a localized source of these sediments and perhaps a radially sediment dispersed pattern from the landward margin as indicated by the extrabasinal mixtures of detrital quartz of metamorphic cum plutonic origin. The association of the subfacies in a larger context can be interpreted as inner channel deposits in the region of a coarse gradually submarine fan.

[3] FACIES 'C' : SUBARKOSIC MICRITIC SANDSTONE [SMS] :

The facies association [SMS] comprises a thick 125 m. massive deposit of subarkosic micritic sandstone. It is well represented in Hadibhadang Dungar Member, Ratnasar Calcareous Sandstone Member, and Ganeshpur Calcareous Sandstone Member. The rocks are pinkish to purplish white or buff coloured, slightly friable medium to coarse grained [at places gritty] sub-arkosic micritic sandstones. Good exposures of the facies are observed along the vertical section of escarpment face of Khadir Island facing north, and in the Shobharel River section [a ruined archaeological site], situated NE of Chanpar.

The term 'sub-arkose' referred here implies a transitional class of arenities with subordinate felspar and with few or no rock particles. The SMS lithological unit is thus characterized predominantly by the existence of more than 80% angular to subangular detritus terrigenous quartz grains derived from pre-existing rock and 5% to 10% felspar [microcline] grains embedded in comparatively low micritic material, hence termed by the author subarkosic micritic sandstone [SMS].

The facies SMS which lie over sandy allochemic linestone facies-B or within alternation of facies-D is almost devoid of any body fossil or fossil remains. Maximum development of the facies is seen in the Hadibhadang Dungar Member [HDM]. Another characteristic aspect of this facies is the slumping of beds which is predominantly observed in HDM where varieties of slump folds are located [Phate : 5].

Microscopically the rocks of SMS reveal predominance of medium to coarse-grained, angular to subangular, polycrystalline cum monocrystalline detrital quartz alongwith 5 to 10% felspar. The felspar is dominantly of K-feldspar, usually microcline in nature. The feldspar grains are either fresh or weakened or mixture of both fresh and weakened are rather common. Different felspar grain also show varying degree of replacement by Kaolinitic clays. Their boundaries are often corroded. Large flakes of detrital mica are also observed in the matrix. No skeletal fragments or microfossils have been located in thin section studies.

Development of distinct slump structure in Subarkosic Micritic Sandstone facies of Hadibhadang Dungar Member

Interpretation :

The subarkosic micritic sandstone facies association is probably deposited in inner shelf to nearshore carbonate terrigeneous setting. This assumptions is based on the presence of sand-size quartz grains and K-felspar [probably from Plutonic (granite) and metamorphic (gneissic) origin]; development of cross-bedded structures; and clay-drapes. The necessary condition for the product of subarkosic sand as revealed by Pettijohn et al [1973] is low relief of the landforms with more stable slopes. Significant subarkosic sandstone accumulation, as further suggested by him are expected when sharp uplift bring - a granitic or gneissic basement up into zone of erosion. This is likely to result vast amount of accumulation of sub-arkosic material in the basinal areas when subjected to regional subsidence and then to acqueous transportation. Such a process as suggested by Pettijhon [1973] is envisized by the author to have taken place during deposition of SMS around the Khadir Island. The overall accumulation of subarkosic micritic sandstone facies with its intraclasts, therefore points high energy environment with active sediment transporting.

The non-development of trace fossils on any of the bedding plane further supports such a view.

Deformations associated with this facies probably must have resulted from submarine slumps and slides which occur in areas of unstable slopes more likely associated with but not restricted in regional and steeper fan gradient. Ideal locations of such sites are levy and confining wall [Normark, 1974], local depression within the levy into channel, transition zone when gradients gradually decreased towards the channel.

[4] FACIES 'D' : MICRITIC MUDSTONES [MM] :

Following Jeffrey Mount [1985], this facies is defined on the basis of predominance of micritic material over the siliciclastic components. The facies is found to have been well developed in the following members viz. Hadibhadang Dungar Member [HDM], Ratnasar Calcareous Sandstone Member [RCSM], Chamwa Wandh Fossiliferous Limestone Member [CWFLM], Gadhada Sandstone Member [GSM], Ganeshpur Calcareous Sandstone Member [GCSM], and Bambanka Member [BM]. Most conspicuous development, however is found in Hadibhadang Dungar Member, Ratnasar Calcareous Sandstone Member, with maximum thickness of 17.5 m. Rocks of this facies are thinly bedded to massive, occasionally non-laminated calcareous shales. The facies is often associated with the micritic sandstone facies [MS] and rarely with the shelly sandy limestone [SSL] subfacies. On the basis of presence or absence of gypsum, the micritic mudstones facies is further grouped into two subunits viz. [1] Khaki, grey calcareous shale [kgCS], and [2] gypseous calcareous shale [GS] subfacies, respectively.

Sub-Facies 'D-1' : Khaki, Grey Calcareous Shale [kgCS] :

Most of such shaley beds are typically parallel and thinly laminated. On their top they are either current-rippled or capped by symmetrical interference ripples or by oscillatory influence ripples. Shale is composed of silt-size quartz grains with mica flakes and clay material in calcareous matrix. It is difficult to know whether colour to these shales is assigned from the weathering in the source areas, developed through insitu oxidation and reduction at the time of deposition or as a result of diagenetic or weathering process after burial. This facies ['D'] is often associated with and interbeds with facies respectively.

Interpretation :

The deposition MM indicates very slow setting of suspended fine hemipelagic material in a very low energy environment marked almost by the absence of coarse-grained sands. It is possible that the detritus representing this facies was probably placed in suspension by current or wave velocity in an adjacent high energy environment. The sedimentary structures like current ripple are indicative of migrating current-ripples under influence of moderate straight currents. The presence of Khaki colour of the shales is consistant with the rapid alteration between oxic and anoxic conditions below the sedimentary surface as proposed by Burner [1981].

[5] [FACIES - E] : SANDY INTRAFORMATIONAL CONGLOMERATIC LIMESTONE [SIC] :

The Sandy Intraformational Conglomeratic Limestone facies is characterized by coarse to very coarse grained, pebbly conglomerate having, either, intensive development along the entire Khadir Island region [sub facies SIPC] or having a localized development as exhibited by sub facies [SOPC]. Parallel stratification is commonly found to have developed in the upper parts of the gradded conglomerates of this stratification unit. This unit is further defined and distinguished on the basis of its clasts/matrix ratio which often exceeds 30.70% with lower limits of 20.80%. The facies can be found in Hadibhadang Pir Member [HPM] and Bambanka Member [BM]. On the basis of the variation of clasts, it is divisible into two sub-facies viz. [i] Sandy Intraformational Polymictic Conglomerate [SIPC] and [ii] Sandy Intraformational Oligomictic Conglomerate [SIOC].

Sub-Facies 'E.1' : Sandy Intraformational Polymictic Conglomerate [Sipc] :

This poorly sorted matrix supported ungradded conglomerate consists mainly of angular clasts of rhomb-shaped felsite, granite, iron stone, and gravel sized cherty quartz embedded in sandy and calcareous matrix. The size of the clast varies from 2 cm to 5 cm. No preferred orientation of the clasts is observed in the rocks of Sipc sub-facies. The overall appearance of the rock indicate the material to have been deposited in a very unorganised manner. Some fibrous structures of unidentified vertebrate bones are found associated with the sediments of the facies [Phate : 6]. The grains are poorly sorted, usually angular to subangular, at times surrounded, deposited in the calcareous matrix. No mega fossils

Brick-red coloured vertebrate-bone-fibrous structures developed in Sandy Conglomerate Limestone Subfacies of Hadibhadang Pir Member are visible except small fragmented belemnites. Concentration and the size of clasts is found decreasing laterally from East to West and also from North to South. This sub-facies over lies the hard, compact sandy micritic sub facies [SM] [micritic sandstone (MS)] and underlie the Oyster-bearing sandy limestone unit [SSLOy].

In thin section, the matrix in the conglomeratic rock display sub angular to subrounded quartz grains embedded in micritic material. Alongwith the quartz some shell fragments are also seen partly filled with crystalline calcite. Typical floating texture of quartz grains embedded in micritic ground mass is also observed.

Sub-Facies 'E.2' : Sandy Intraformational Oligomictic Conglomerate :

This sub facies incorporates oligomictic clasts of different size from the underlying sub facies F.1 [facies micritic sandstone (F)]. The clasts vary in size from 2 cm to 3 cm. The overall arrangement of the clasts renders a chaotic appearance to the rock where no development of bedding structure is observed. Rarely broken burrow tubes and scattered flat pieces of ferruginous clay stones are seen embedded in the rock matrix which happens to be invariably calcareous. The sub facies is locally developed and can be observed only in the ENE of Umrapur Village and at NE of Bambanka Village.

Interpretation :

The clastic material of the sandy intraformational conglomerate matrix rich facies is compositionally and texturally very immature.

Compositionally the conglomerates contain high proportion of fragments of rocks in addition to variously gradded cherty material. The overall description of the 'Sic' facies match the decription of "slurry sandstone" of "Hiscott and Middleton" [1979]. Such sandstone are interpreted by the above authors to have been deposited by sandy debris flow. Thus, the ungradded and unstratified Sipc facies can be interpreted to represent deposition from noncohesive sediment gravity flows, transitional between sandy debris flow and density modified grain flow. The sandy, medium to coarse grained material probably deposited from turbulent to suspension that accompanied the densal flow.

[6] [FACIES - F] : MICRITIC SANDSTONE FACIES [MS] :

This facies association is by far the most predominent in the whole of the Khadir Island region. It can be observed in Hadibhadang Dungar Member [HDM], Hadibhadang Pir Member [HPM], Ratnasar Calcareous Sandstone Member, Gadhada Sandstone Member, Ganeshpur Calcareous Sandstone Member and Bambanka Member. Its maximum development is found in RCSM, GSM and GCSM. Distinction of this facies is made on the basis of abundance of siliciclastic and carbonate allochems and the sandy material. The matrix incorporates greyish yellow to pinkish white, medium to coarse grained terrigeneous sandstone grains intercalated with calcareous mudstone. The facies often displays tabular cross-bedding. The facies once again is extremely rich in various types of trace fossils including **Ophiomorpha**, **Skolithos**, **Gyrochorte**, **Arenicolites** etc. This facies is further divisible into three sub facies namely Sandy Micrite [SM], Ferruginous Sandy Micrite [FSM], and Cross-bedded Micritic Sandstone [CMS] sub facies.

Sub-Facies 'F.1' : Sandy Micrite [SM] :

It consists of yellowish, fine grained calcareous sandstone with symmetrical ripple marks. Good exposures of this sub facies can be found in Hadibhadang Dungar Member [HDM], Hadibhadang Pir Member [HPM], Ratnasar Calcareous Sandstone Member [RCSM], Gadhada Sandstone Member [GSM], Ganeshpur Calcareous Sandstone Member [GCSM] and Bambanka Member [BM]. The sub facies is variously overlain and underlain by CMS, SMS, KGCS, CRMSS, WRSAL, AS at different localities.

In thin section, subangular to subrounded quartz grains of metamorphic and igneous origin are found to have embedded in micritic material. Some thin sections also display skeletal fragments. No microfossils are observed. Occurrence of rhomb-shaped dolomite in micritic matrix is another characteristic observed in thin section studies [Phate : 7]. The rhomb-shaped dolomite often display conspicuous zonning which is lined with brownish red coloured hematite. Some thin section show high-iron-rich dolomite, which may indicate diagenetic process which probably altered, the previously existing micritic or crystalline calcite material.

Sub-Facies 'F.2' : Ferruginous Sandy Micrite [FSM] :

This sub facies is characterized by thinly-bedded ferruginous or

Photomicrograph of sandy micrite exhibiting well-developed rhombic texture of dolomite red to brick red coloured micritic sandstone and with the predominance of **Skolithos** burrows. The range of bioturbation by such vertical burrows very often is found to be disturbing bedding laminae giving bulky appearance to the entire rock. This sub facies overlies gypseous and yellow shales [Fig.30] and is underlain by cross-bedded sandstone sub facies [F.3] or with fossiliferous limestone [Fig.30].

Thin section of the rocks indicate subangular to subrounded, fine to medium grained detrital quartz embedded in reddish brown opaque hematitic ground mass. Alongwith micritic some small grains of crystalline calcite are also seen.

Sub-Facies 'F.3' : Cross-bedded Micritic Sandstone [CMS] :

This sub facies consist mainly of whitish to greyish, very fine to fine grained medium to thick bedded trough cross-bedded sandstone. It is very well observed in the exposures of Ratnasar Calcareous Sandstone Member [Fig.30], Gadhada Sandstone Member [Fig.31] and Ganeshpur Calcareous Sandstone Member [Fig.32] where large scale cross-bedding can be seen. The cross-bedding in most of the areas show S35°W to West paleocurrent directions. The rocks of the sub facies are found to overly ferroginous sandstone [F.2] and underlie greyish white siltstone of facies [G].

Thin section study shows the rock fabric as that of a typical calc arenaceous sandstone. Most of the rock is supported by angular to subangular quartz grains of plutonic cum volcanic origin embedded in micritic matrix. Grains are moderately to well sorted. Besides quartz grains, K-felspar i.e. microcline is also found. The grains are cemented in micrite, dolomite, calcite and hematitic material. No skeletal fragments are seen.

Process of calcification appears to have responsible for the formation of dolomitic rhombic texture developed in the rock.

Interpretation :

The depositional processes dominating the micritic sandstone facies association appears to be sandy non-cohesive debris flow and low density turbidity currents. Evidences of bioturbation is wide spread in most of these rocks, which suggest low rate of sedimentation and oxygenated bottom currents. The bedding structures developed in the rocks indicate there existance of channels. It is proposed that the association of the facies may represent sediment deposition at the base of slope, that funneled scoured into the basin. The reddish, fine-grained variation in this facies perhaps indicate facies of fine-grained, flood plain deposits by vertical aggradation and perhaps is an important paleoclimatic indicator. Following McBride [1974], the reddish colouration can be interpreted to have been formed by the decomposition of iron-rich minerals to iron-hydroxides during pedogenesis, a process that is better developed in semi-arid high temperature environment. However, such an interpretation of red colouration is not widely accepted and a late biogenetic origin regardless of the original environment can also be proposed. The overall evidences in the deposition of this facies association is indicative of debris aprons typically developed in small basin along carbonate platform or at the base of the continental slopes as indicated by Nelson [1983].

[7] [FACIES - G] : ALLOCHEMIC SILTSTONE [AS] :

This facies comprises buff coloured, very fine to fine grained silt-size detrital quartz with minor grains of felspar and flakes of mica, embedded in micritic matrix. It is found overlying the cross-bedded micritic sandstone sub facies of facies [MS] and underlying the iron-rich subarkosic micritic sandstone [Fig.30]. It is very well developed in Gadhada Sandstone Member [GSM] and found in alternating sequence with burrowed calcareous sandstone. The [AS] facies in GSM displays development of excellent **Skolithos** burrows [Phate :]. Besides GSM, development of AS is also found in Ganeshpur Calcareous Sandstone Member [Fig.32] with overlying and underlying beds of calcareous sandstone and fossiliferous calcareous sandstone respectively. No sedimentary structures are observed in the rocks of this facies.

Thin section study shows that no other minerals are incorporated in the sediments except dominently silt-size detrital quartz with minor amount of felspar and mica flakes with micrite within the matrix. Occurrence of silt-size detrital quartz angular to subangular in nature generally is originated as by chipping of particles from large-quartz grains.

Interpretation :

A few generalizations towards interpretations can be made for this facies. Allochemic siltstone sequences capped by bioturbation zones are most likely developed by dilute turbidity currents. During periods of quiecence and extrabasinal fine-grained sedimentation, which punctuated times of deposition, burrowing organisms most likely occupied the uppermost layers. This is indicated by the vertical burrows of **Skolithos.**

The process of formation of silt is generally attributed to wind action in desert. Besides this the delta of large river or eolian actions are also responsible.

[8] [FACIES - H] : MICRITIC CLAY STONE [MCL] :

The facies MCL is scattered through only in one member i.e. Chamwa Wandh Fossiliferous Limestone Member [CWFLM]. It comprises clay-size quartz particles embedded in micritic matrix. The facies lacks fine laminations or fissility. It's cummulative thickness is 2.4 m. The facies is underlain by ammonioidal sandy limestone [B-2.4] of sandy allochemic limestone [Facies B] and overlain by Khaki grey calcareous shale.

The micritic claystone is composed chiefly of clay-size detrital quartz with less proportion of felspar and Kaoline grains. The quartz grains are angular to subangular embedded in micritic matrix. The sediments are thus immature in their origin with source not far away from the sites of the deposition. The mineral grains could have been removed from the older sediments and some could have been derived from their original Precambrian terrains situated in the NE mountain belts from their multiple source rock units.

Interpretation :

The deposition of this facies from the lack of bedding and lamination structure and limited extent appears to be somewhat problematic. Its deposition as compared to the previously deposited iron-rich sandstone imply considerably slower sedimentation, and may represents a continuous event in the depositional phase with sharp lithological and textural changes. Some changes represent episode indicating change in the sedimentary feature without much time lapse. The variegated colours of the facies suggest slightly reducing environment and their red colour domination probably represents for the longer exposed periods.

[9] [FACIES - I] : CURRENT-RIPPLED MICRITIC SANDSTONE/SHALE [CRMSS] :

This facies is recognised as a discrete lithostratigraphic unit in only two members - The Gadhada Sandstone Member [GSM] and Ganeshpur Calcareous Sandstone Member [GCSM]. It is characterized by the combination of interbedded micritic sandstone/shale, sequence.

Current ripples are although very common, intensive weathering at places commonly disguishes these primary sedimentary structures. Grain size variation is very minor and is restricted to the sandstone, containing fine-grained detrital quartz embedded in micritic matrix. Basal calcareous sandstone contacts are sharp with the underlying beds, while upper contacts are gradational or abrupt with the overlying shale and micritic sandstone. Bedding thickness usually does not exceed 2.5 m. Biosedimentary structures are practically absent in sandstone layers, while in contrast are predominently developed in the shaly parts. Moreover, the shale portion is almost noncalcareous in nature.

Interpretation :

The current ripple micritic sandstone/shale facies are probably deposited to some near shore carbonate-terrigenous settings. Following the work of Walker [1967], the wide variation in sands and sandstone/shale ratio of the facies, their bedding thickness [2.5 m] can be explained by judging the facies proximity to individual distributary channels.

[10] [FACIES - J] : WAVE-RIPPLED SANDY ALLOCHEMIC LIMESTONE [WRSAL] :

The wave-rippled sandy allochemic limestone facies is very well observed in Gadhada Sandstone Member and Ganeshpur Calcareous Sandstone Member. The characteristic feature of this facies is its association with hummocky cross-stratification and underlying bioturbated beds. It also contains skeletal fragments of organic shells in shelly-sandy calcareous matrix. The lower micritic bed is highly bioturbated by **Ophiomorpha** and **Skolithos** burrows. Stacking of randomly oriented closely packed shell fragments are conspicuous in mega-wave-rippled medium to coarse grained sandy allochemic limestone beds [Plate : 8]. The curve-crested mega ripples have wave length 3 cm with amplitude of 9 cm indicating their possible large-scale wave origin.

Interpretation :

The association of hummocky cross-stratification with wave-rippled sandy allochemic limestone suggest its formation because of strong surges generated through large storm wave action in fair weather conditions as suggested by Walker [1967, 1975]. As further claimed by Dott and Bourgeois [1983], Walker et al [1982] and Swift et al [1983], formation of such large scale ripples is often the result of a combination of waning storm-generated unidirectional flows with superimposed oscillatory storm wave action. In this regard the closely stacked shell beds suggesting transport by oscillatory currents are very significant. The movements of the upward oscillatory currents resulting in hummocky cross-stratification further confirms the dominant influence. It is apparent that the generation of thicker and medium to coarse-grained allochemic limestone bed in associated with high depositional rates and hummocky cross-stratification infer highest intensity of currents both oscillatory and unidirectional.

Plate : 8

Development of wave ripple [mega-ripple] in wave-rippled shelly allochemic limestone facies

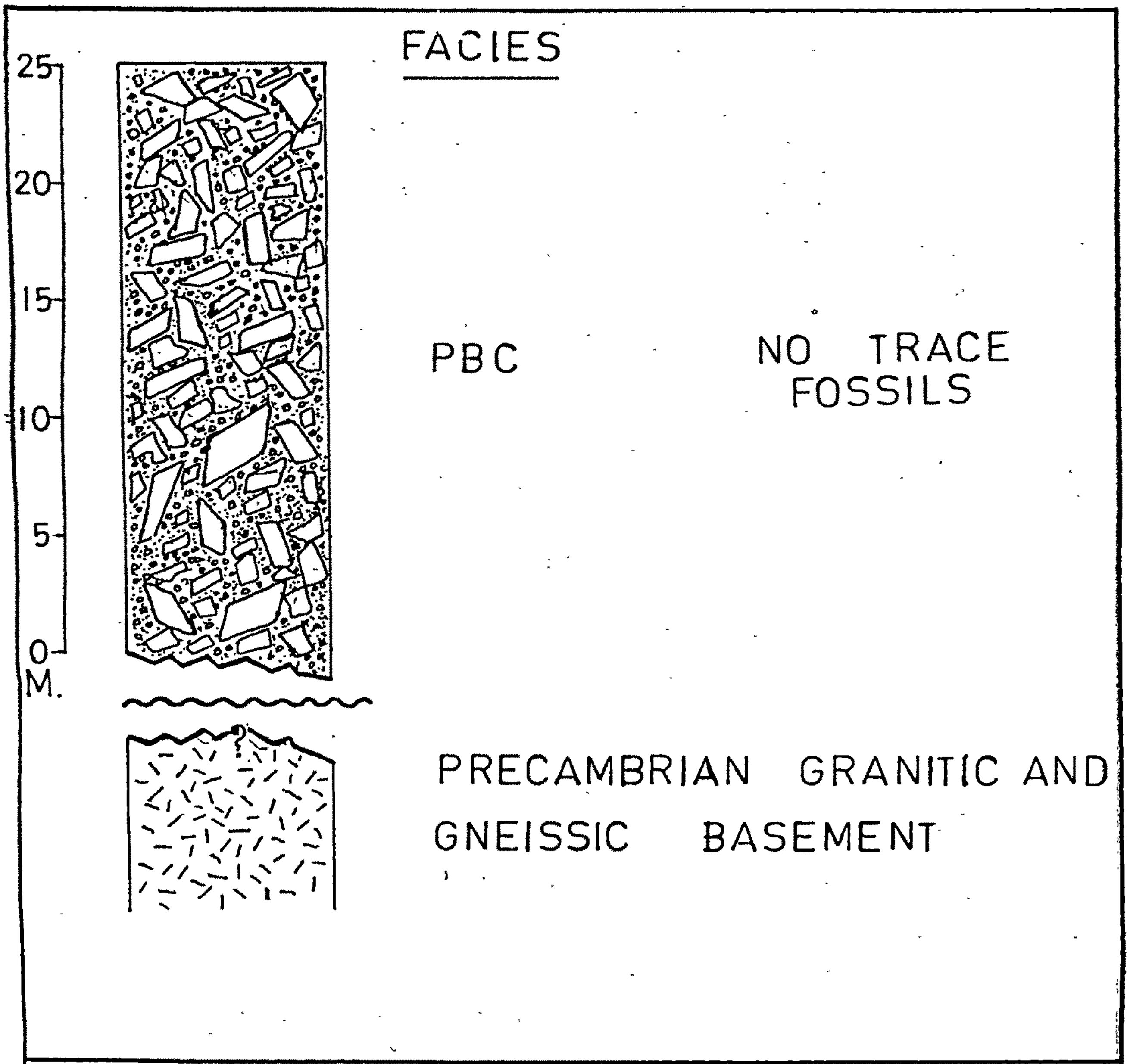


FIG 9 CHHARIYA BET BRECCIO-CONGLOMERATE MEMBER (COMPOSITE SECTION)

FIG.10 HADIBHADANG DUNGAR MEMBER

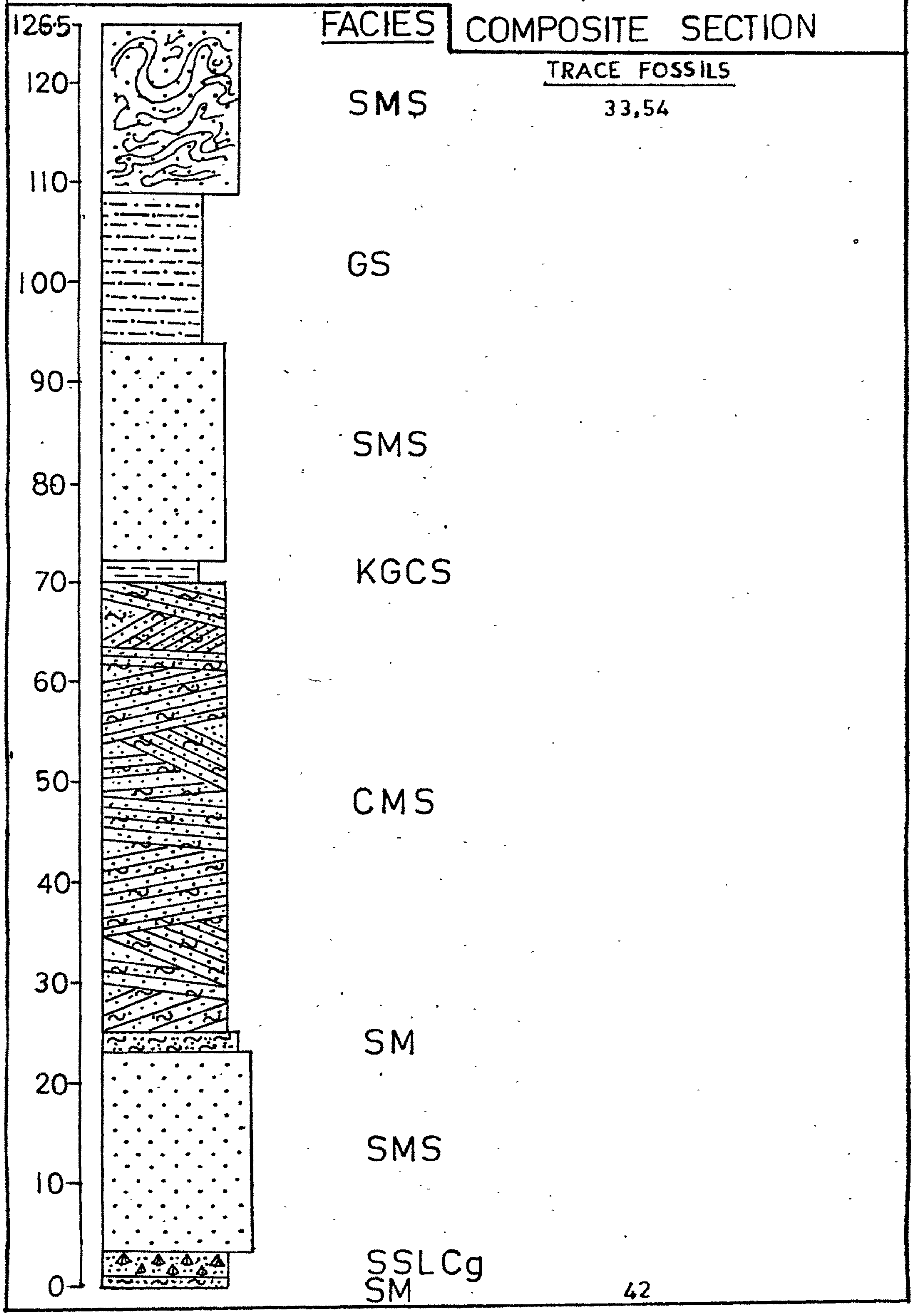


FIG.11 MEASURED SECTION NORTH OF HADIBHADANG PIR.

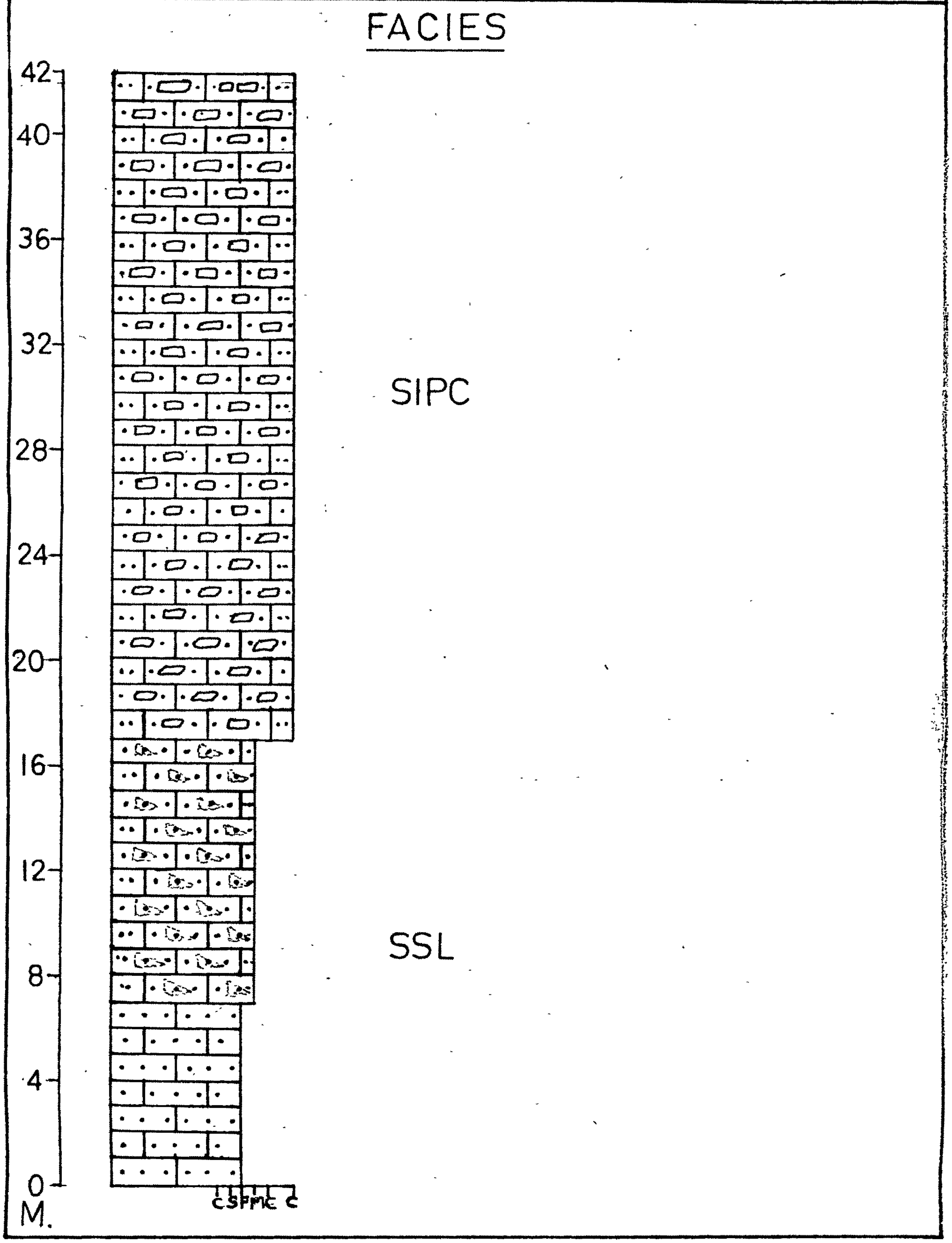


FIG.12 MEASURED SECTION, ENE OF UMRAPUR

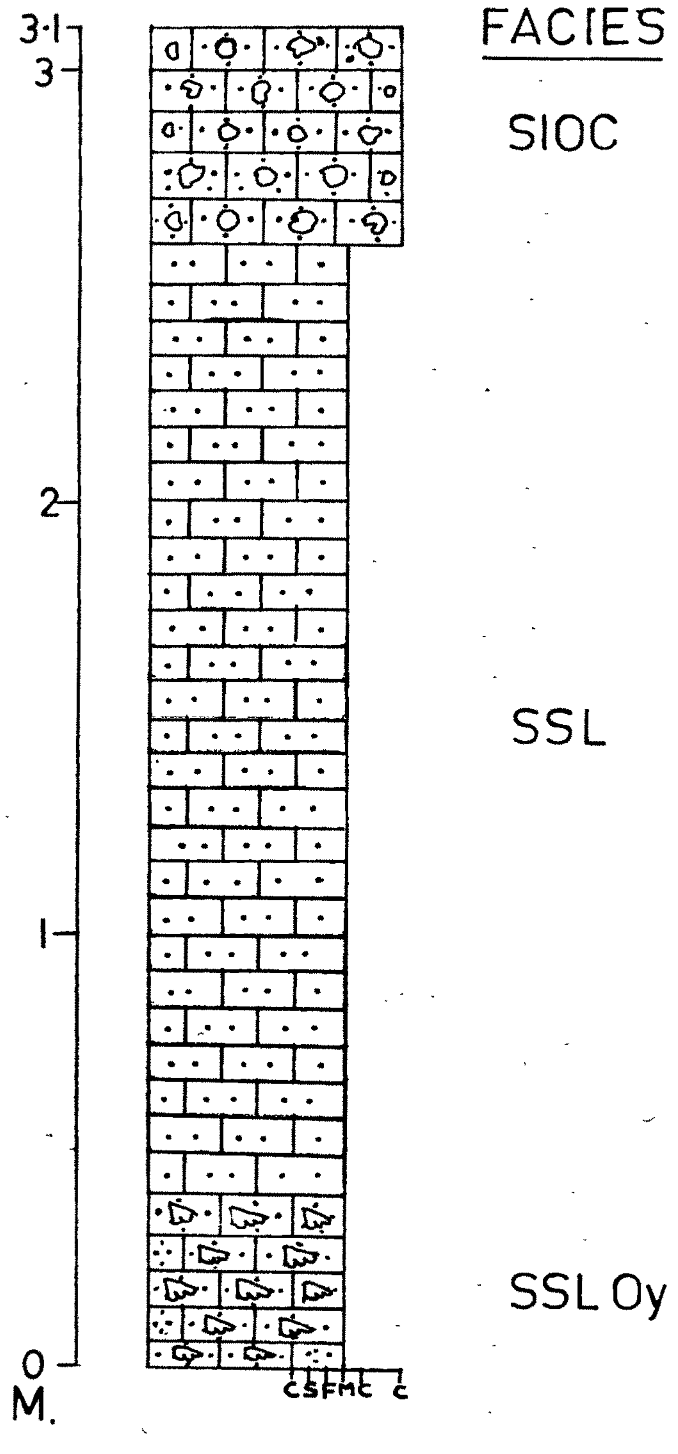


FIG.13 MEASURED SECTION WNW OF UMRAPUR

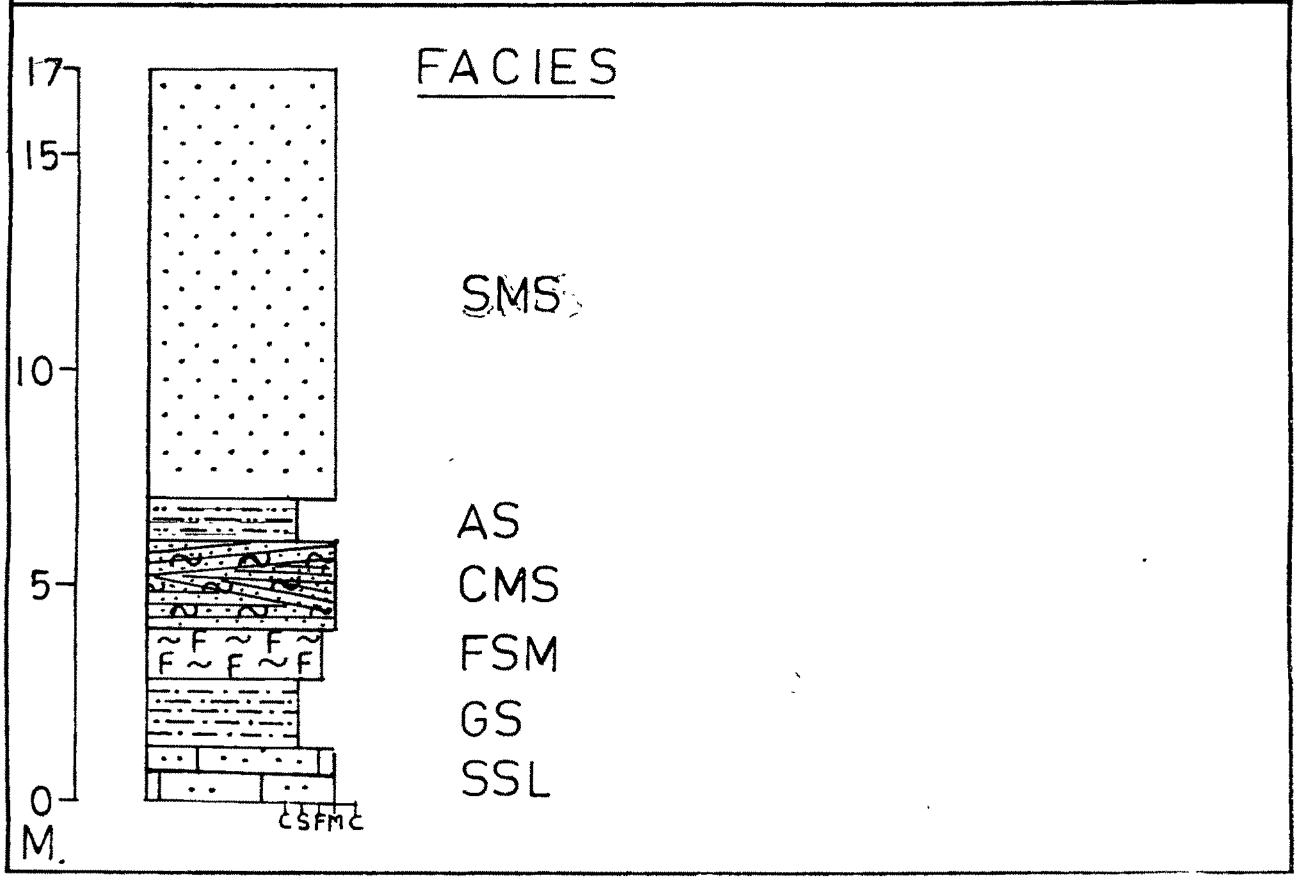


FIG.14 MEASURED SECTION SW OF RATNASAR T.

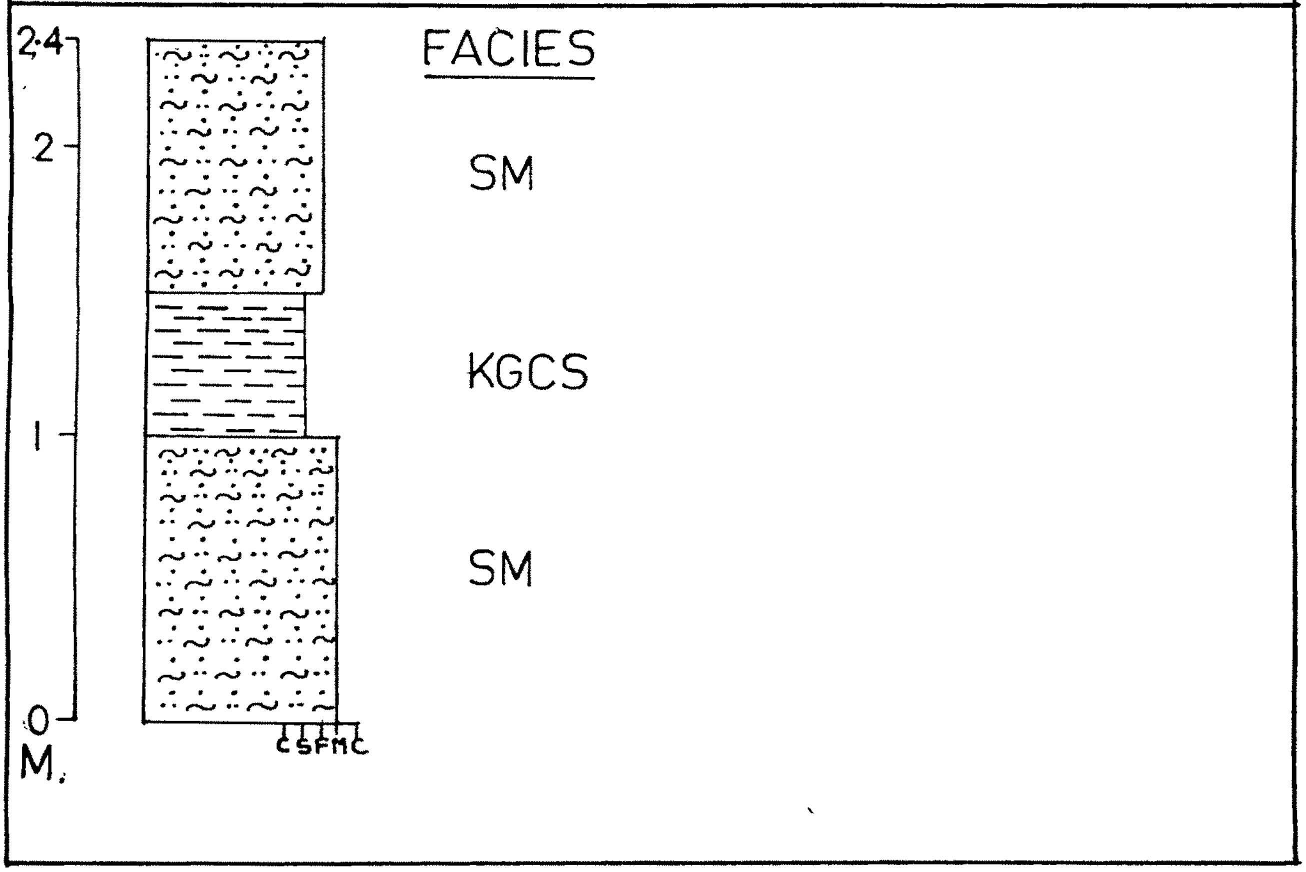


FIG.15 CHAMWA WANDH FOSSILIFEROUS LIMESTONE MEMBER

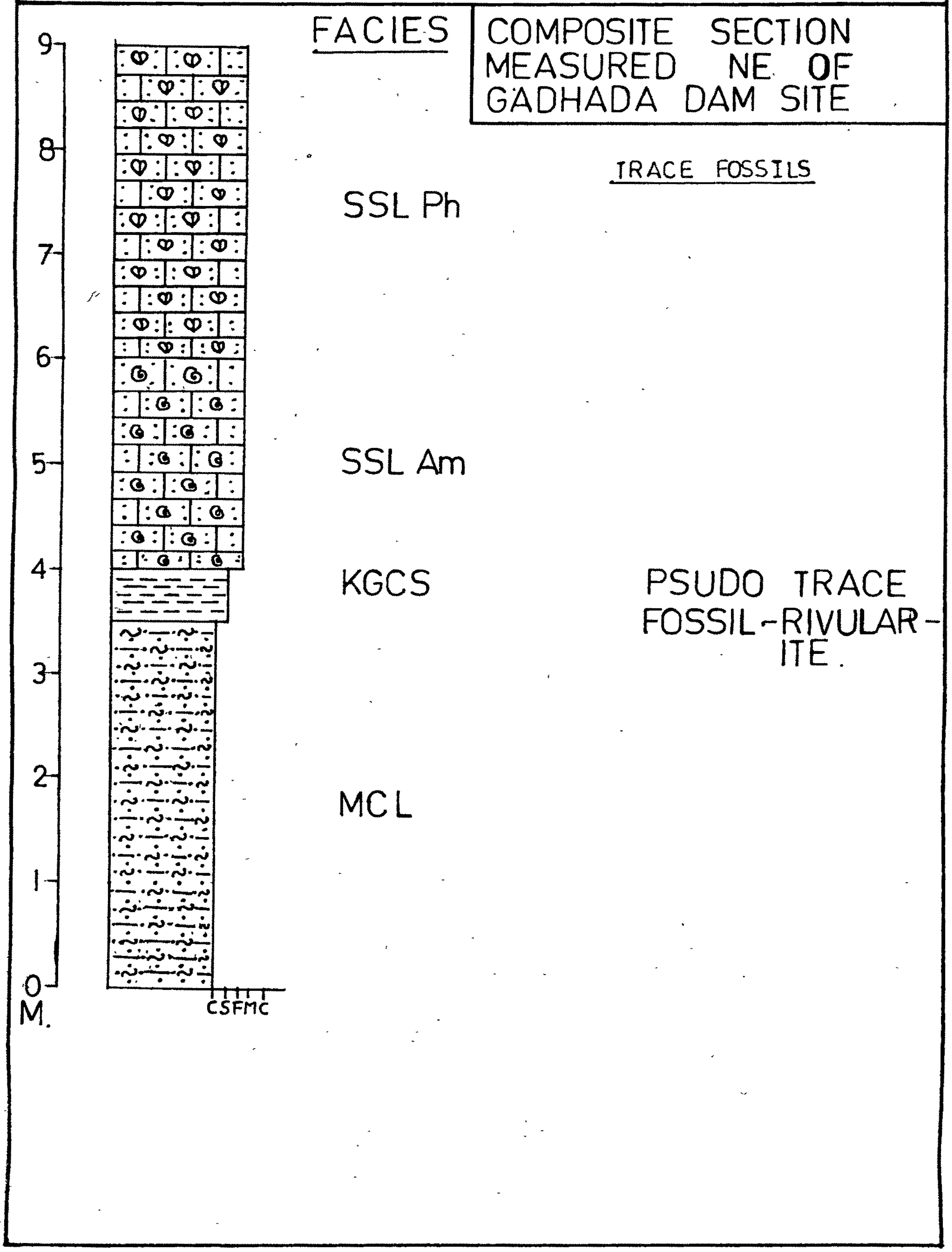


FIG.16 MEASURED SECTION: NW OF RATANPUR (NEAR VAVDI)

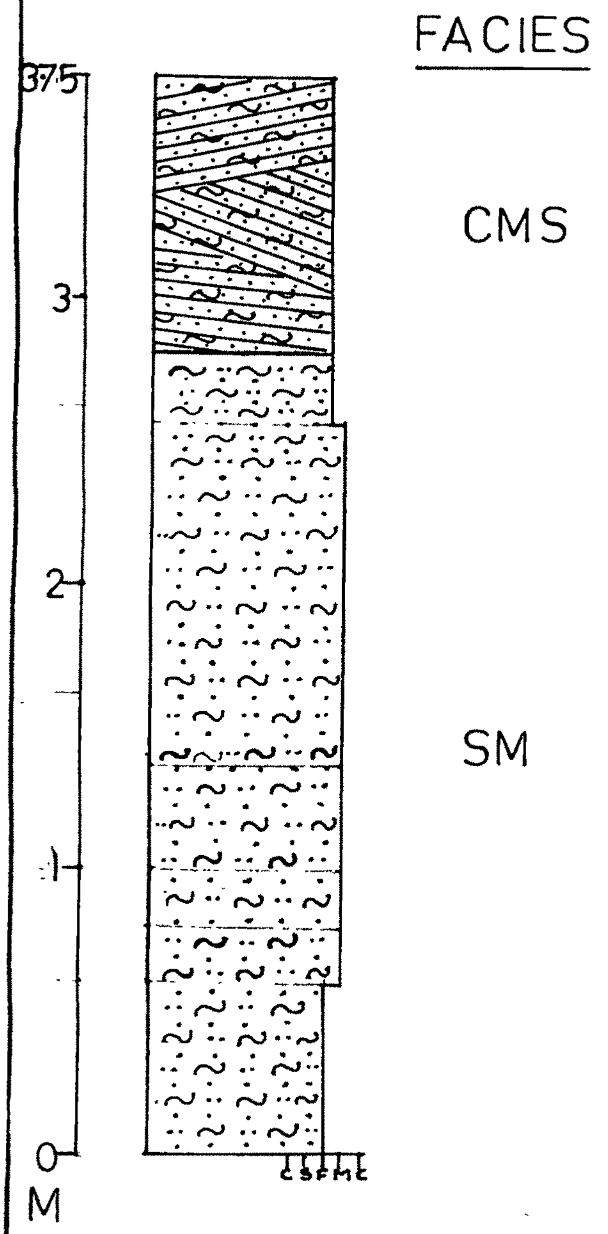


FIG.17 MEASURED SECTION: JHINJU RIVER SE OF GADHADA

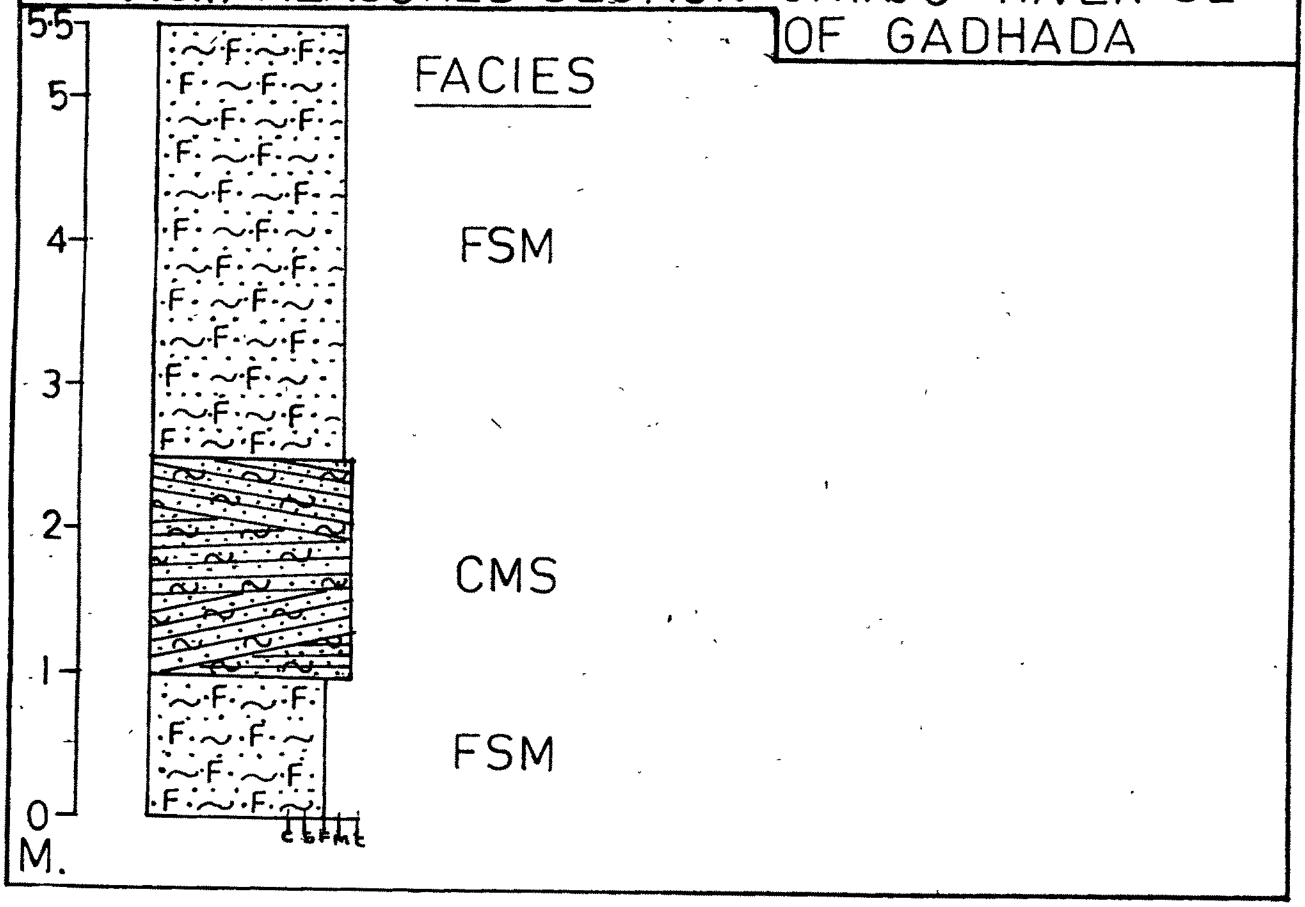


FIG. 18 MEASURED SECTION: SE OF GADHADA

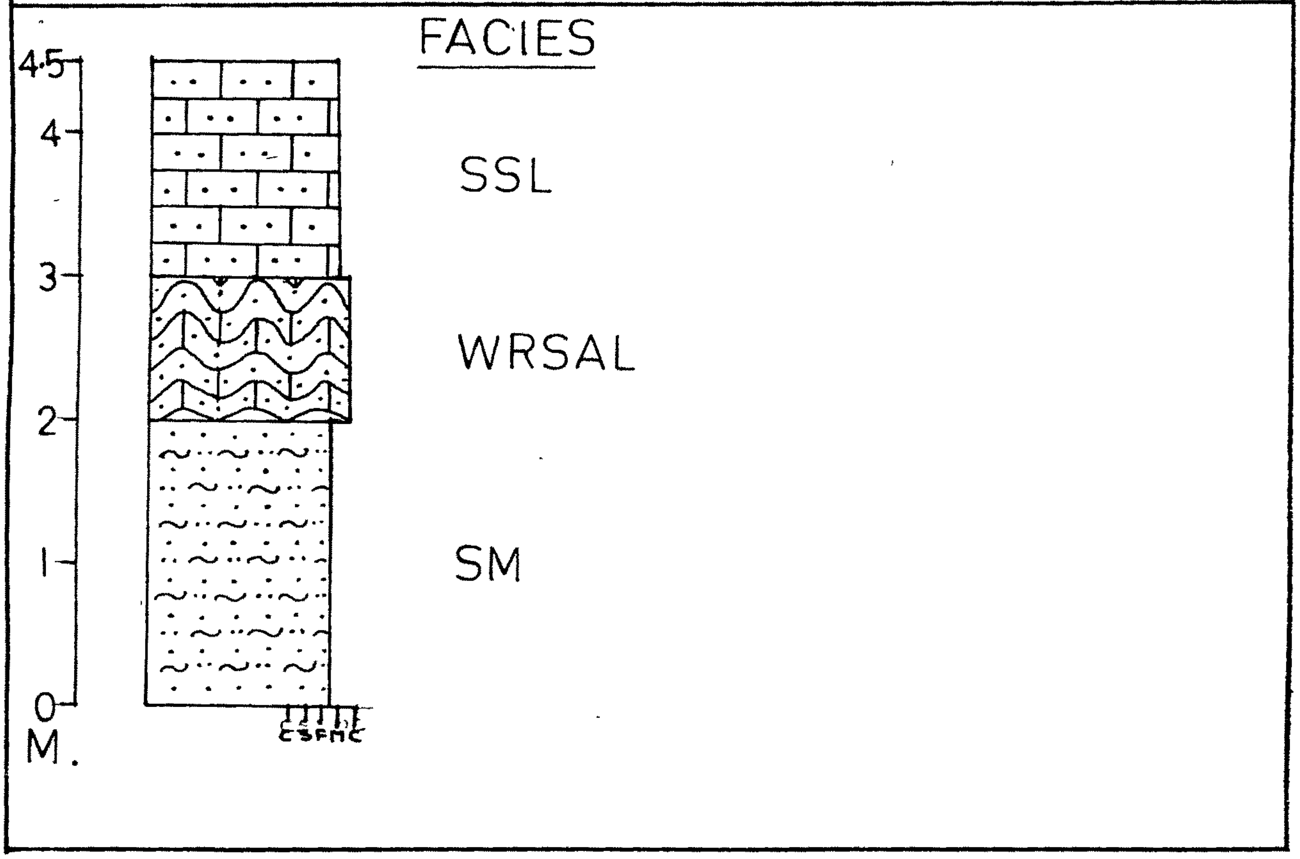


FIG.19 MEASURED, JANAN-GADHADA EAST-WEST ROAD CUTTING SECTION

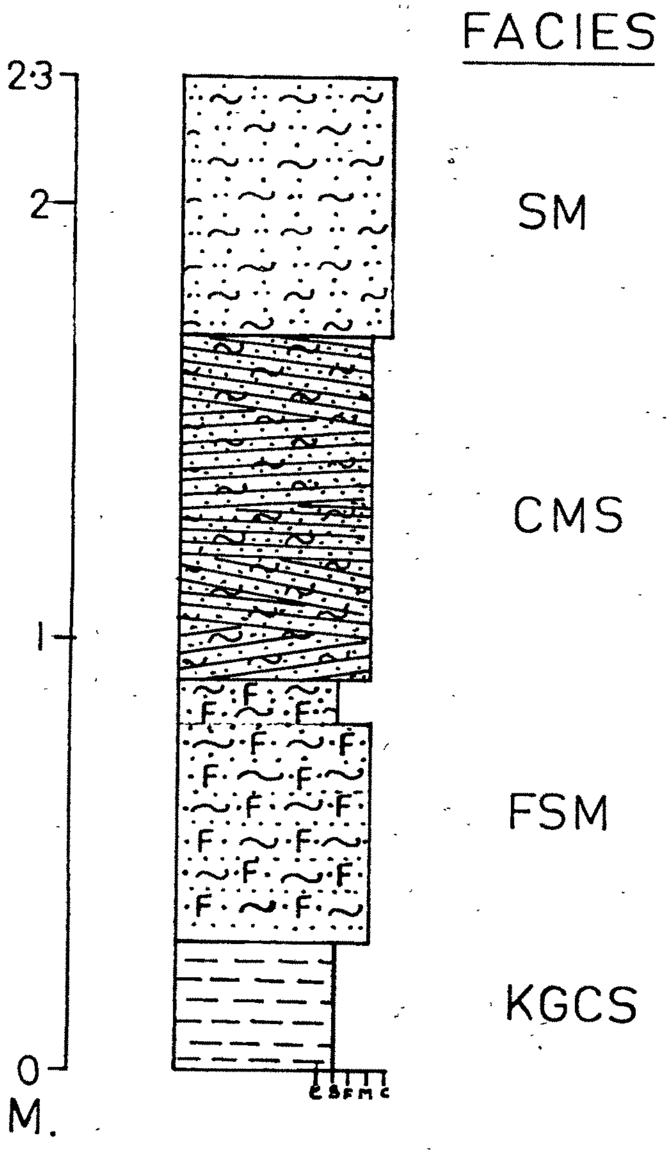
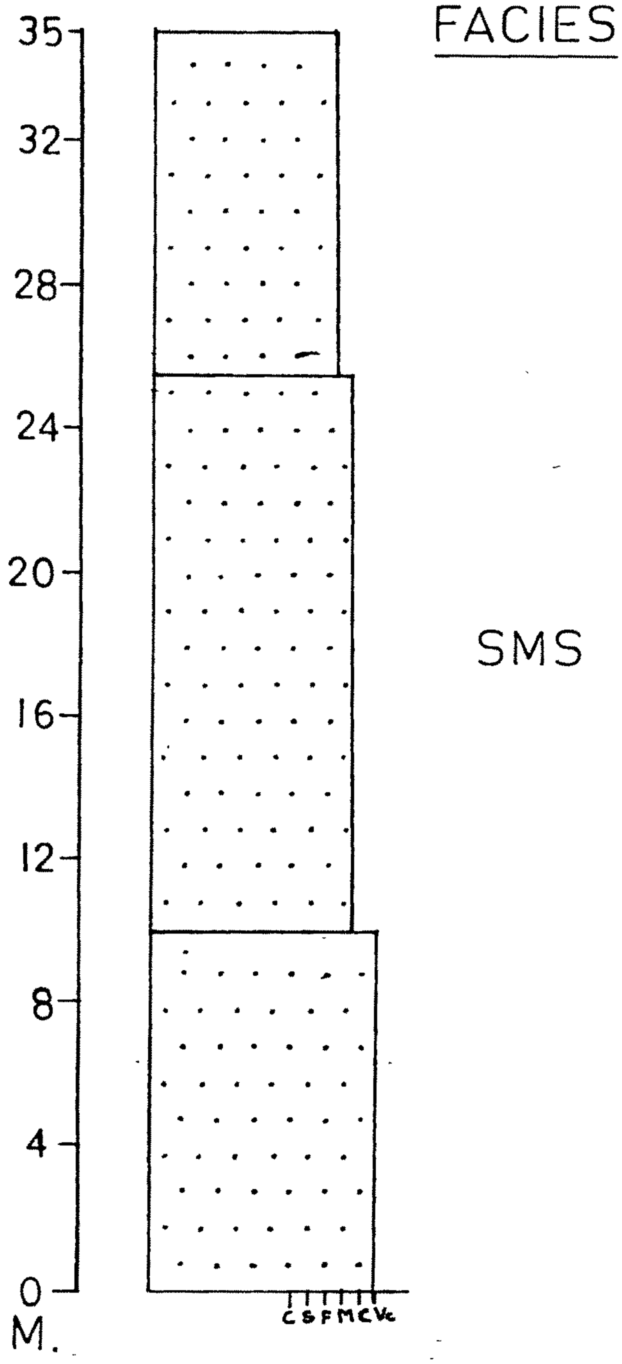


FIG.20 MEASURED SECTION: AT SHOBHAREL RIVER NE OF CHANPAR



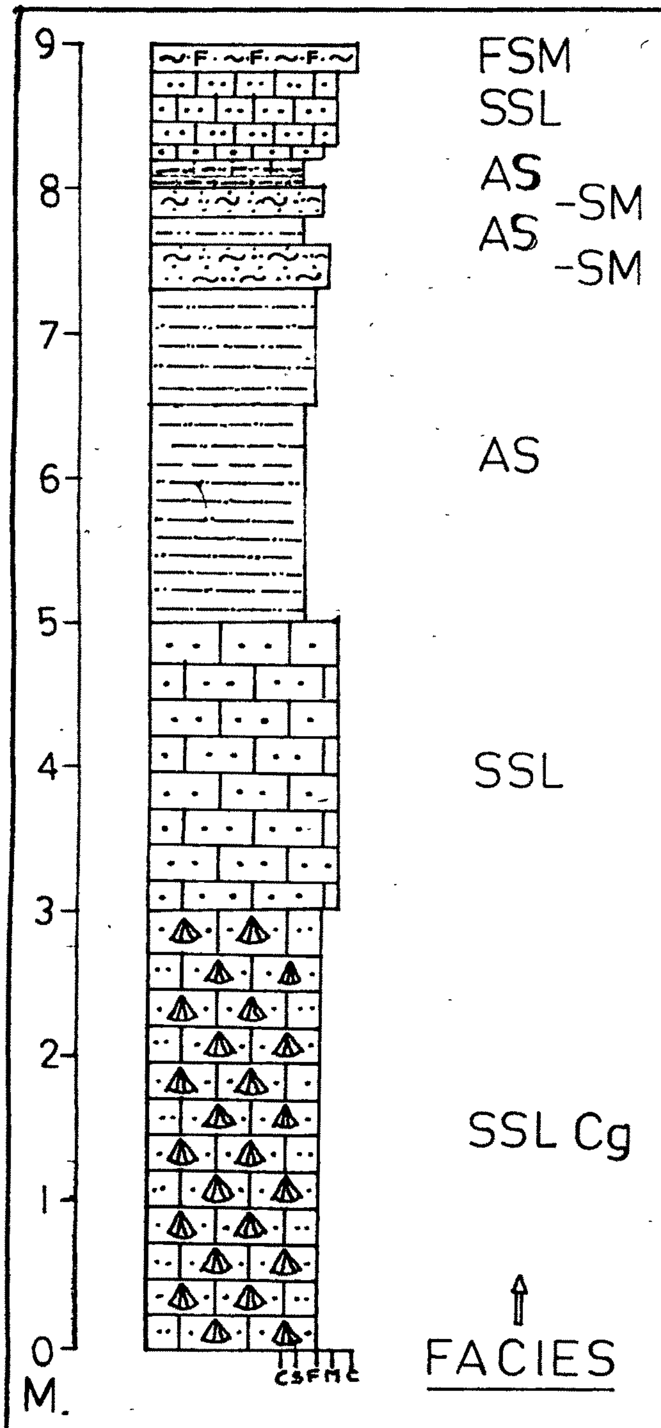


FIG.21 MEASURED SECTION: SE OF RATNASAR TALAO

FIG.22 MEASURED SECTION AT VAVDI

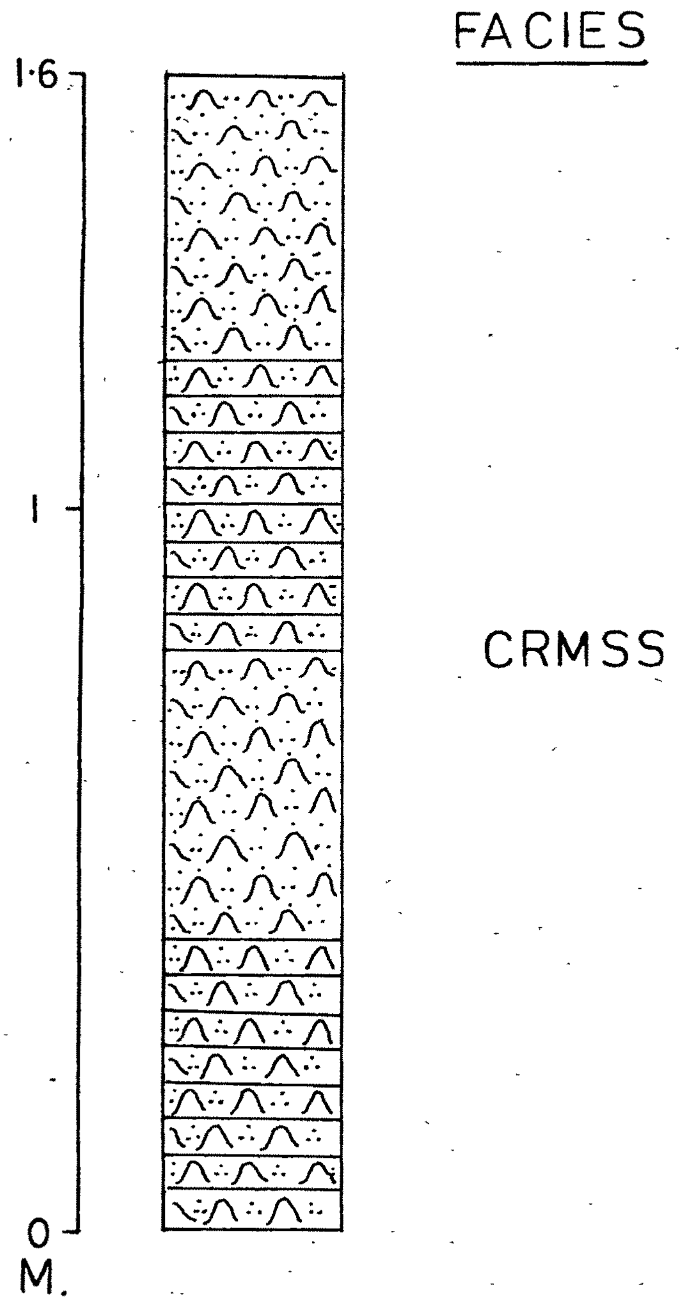


FIG.23 MEASURED SECTION : N 70°W OF GANESHPUR

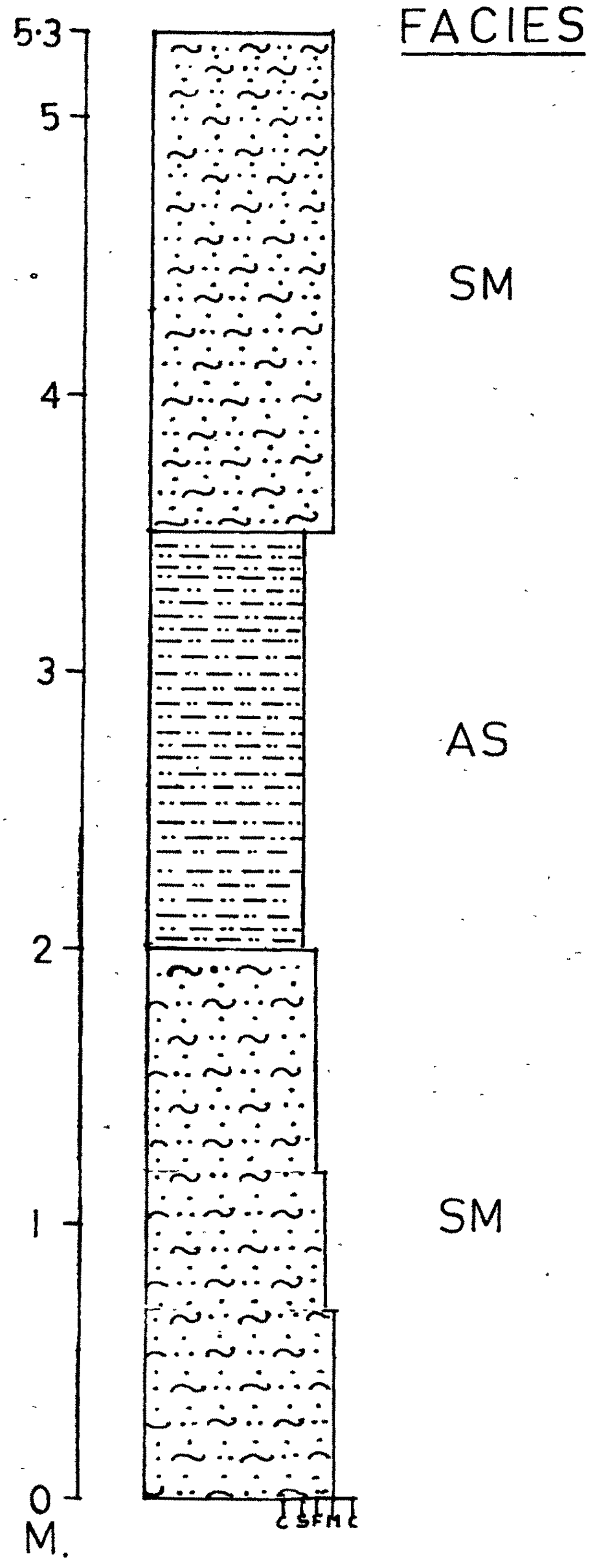


FIG.24 MEASURED SECTION: W. OF GANESHPUR

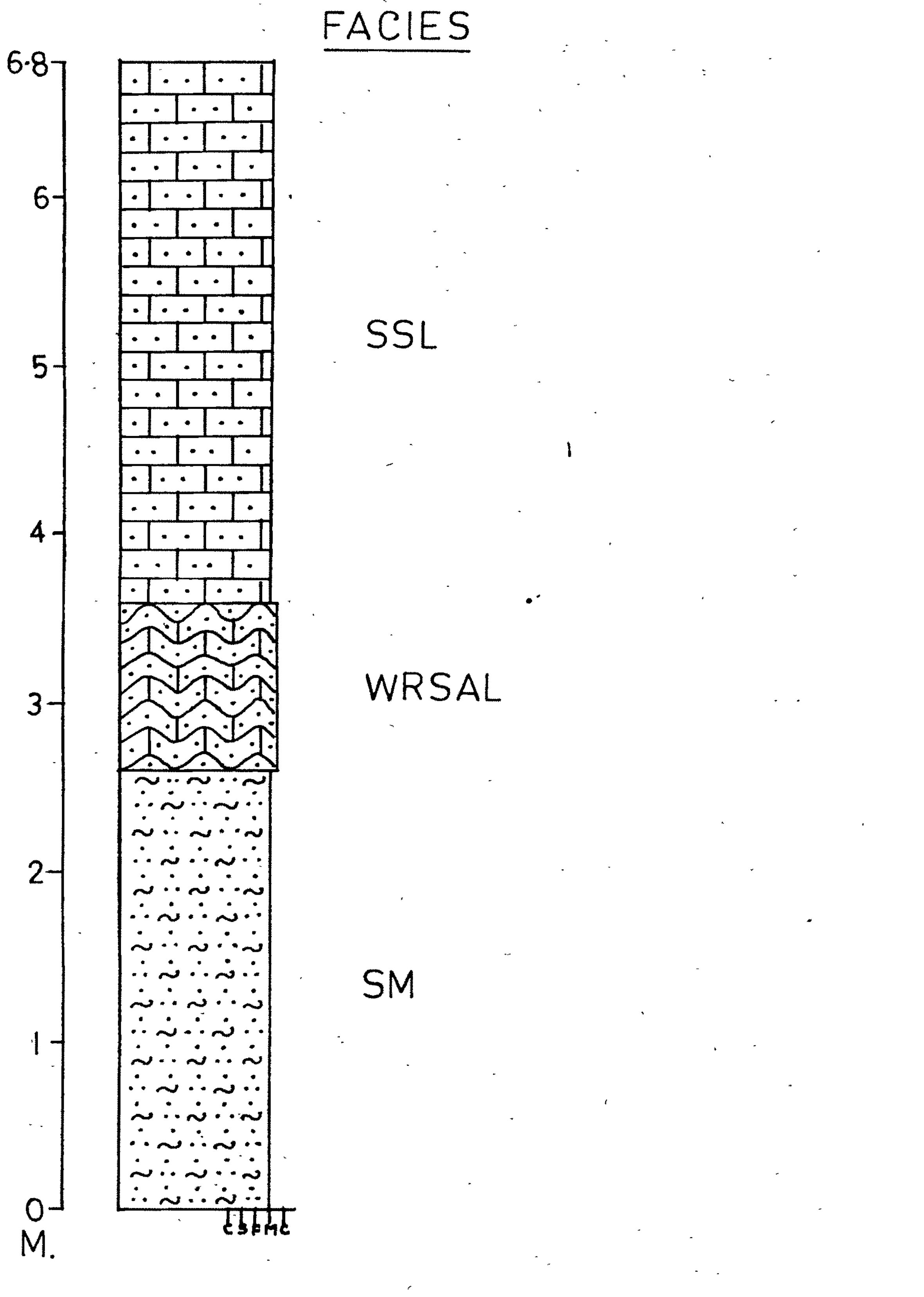


FIG.25 MEASURED SECTION: SW OF GANESHPUR

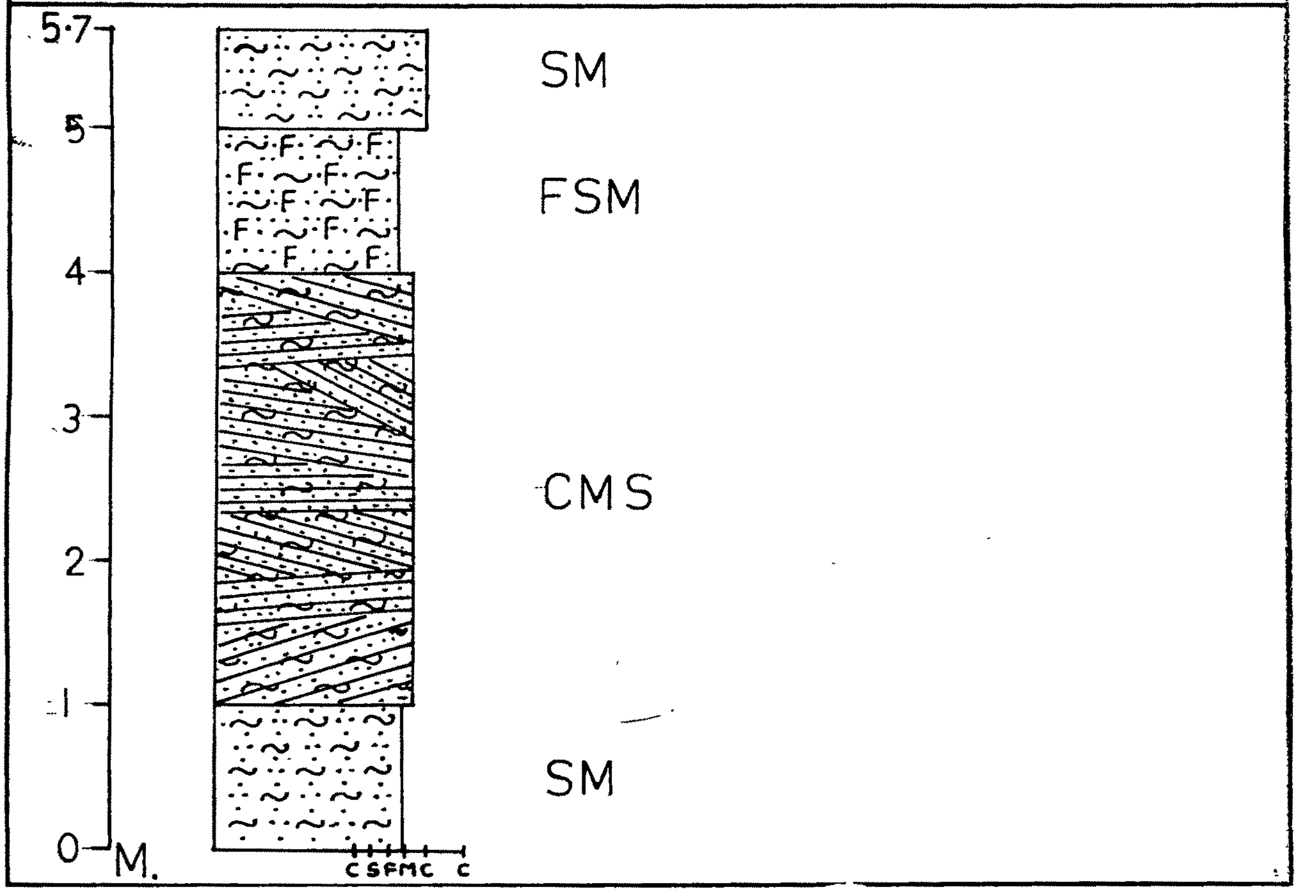


FIG26 MEASURED SECTION: AT GANESHPUR

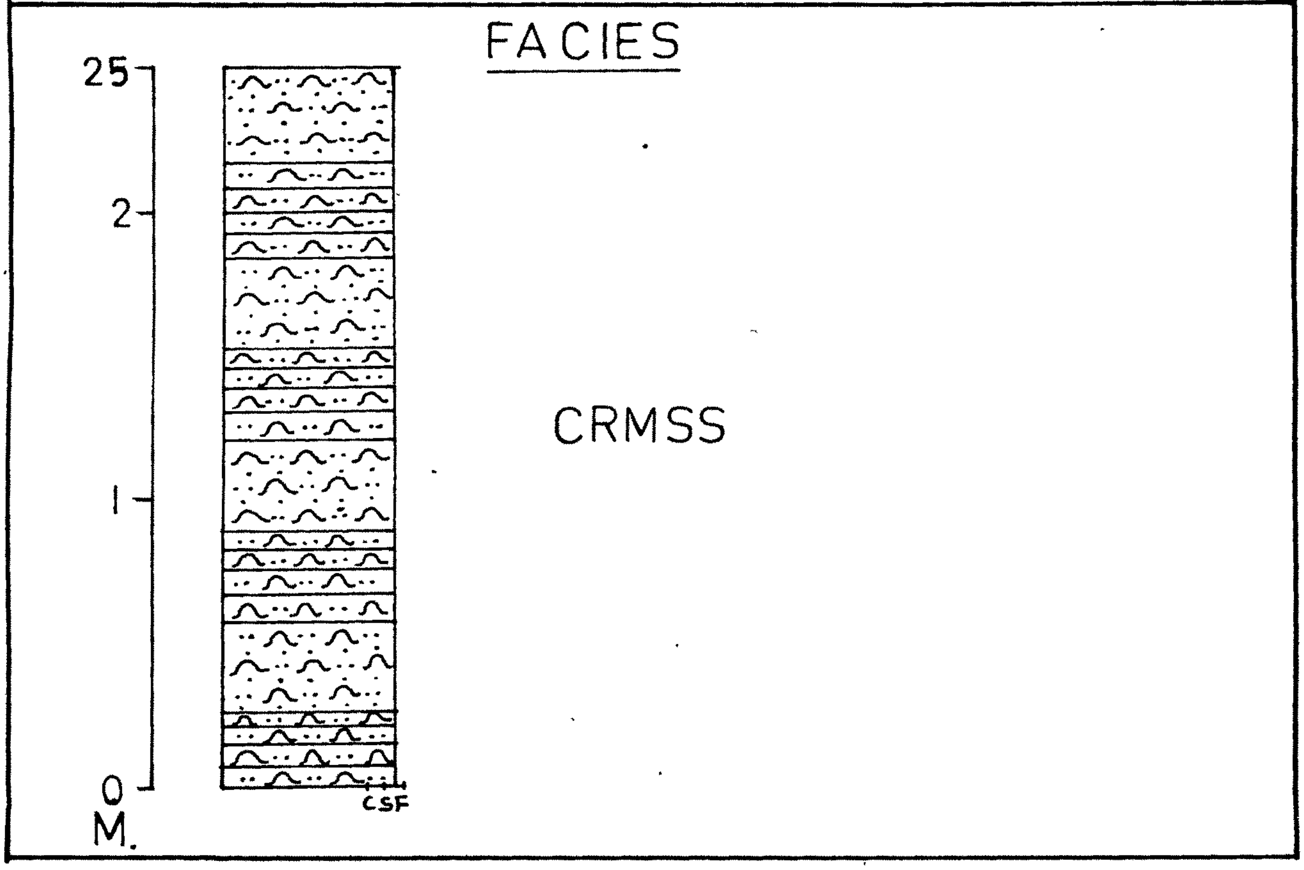


FIG.27 MEASURED SECTION: AT BAMBANKA

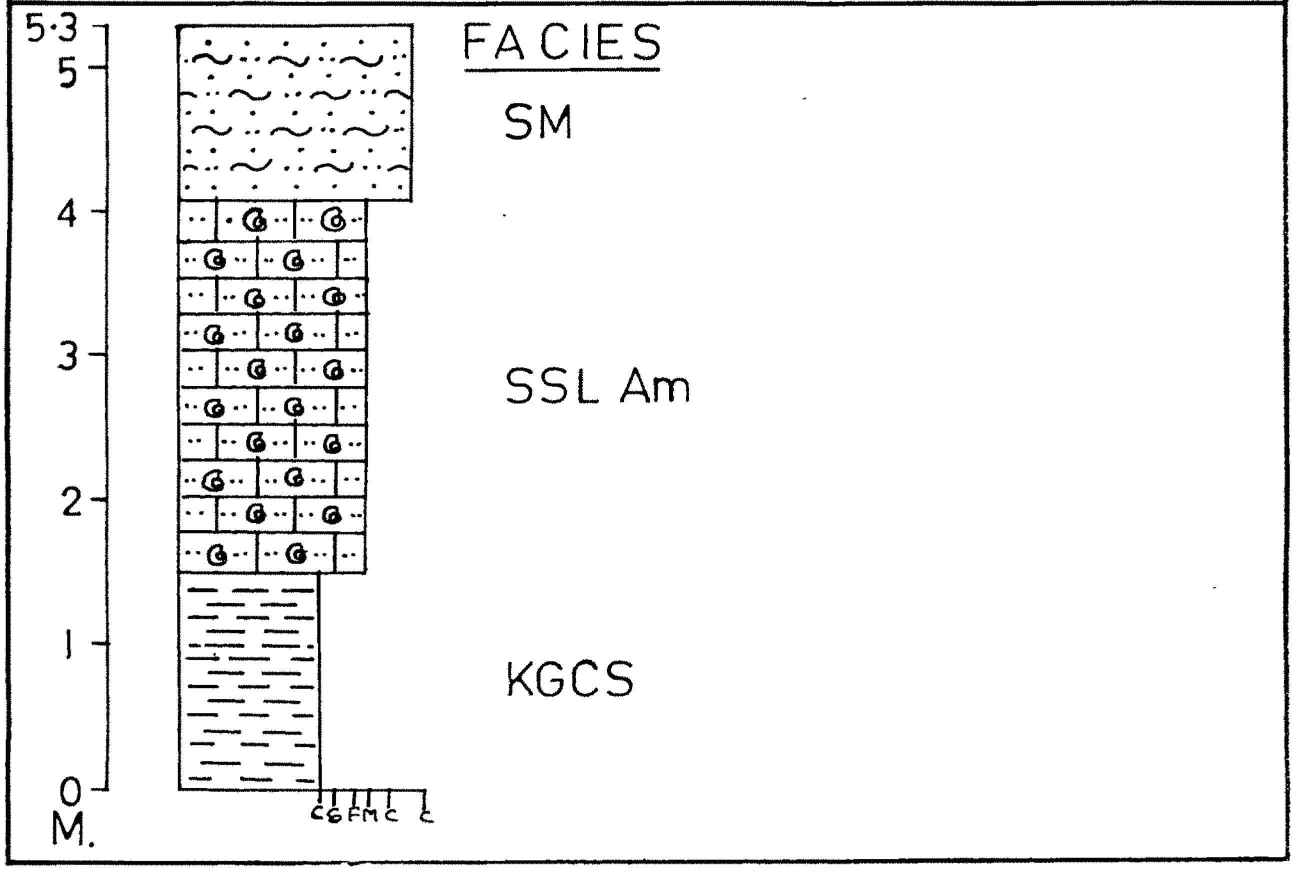


FIG.28 MEASURED SECTION: NE OF BAMBANKA

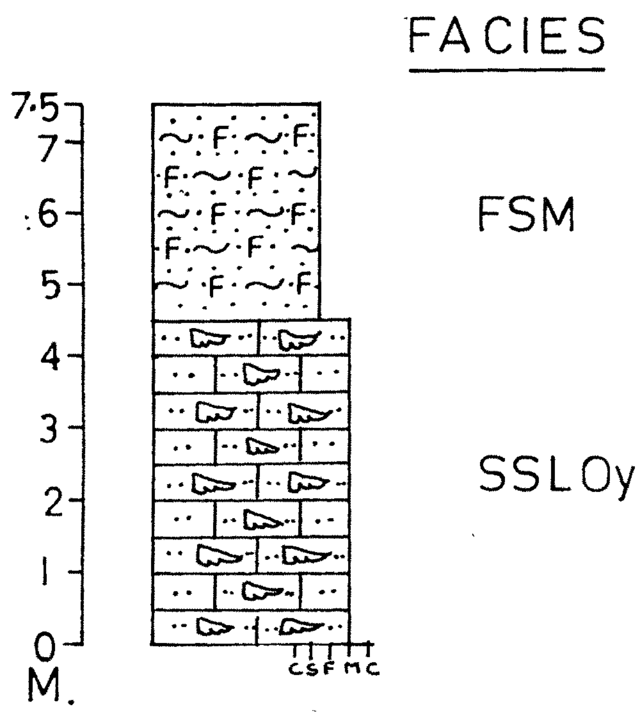


FIG.29 HADIBHADANG PIR MEMBER: COMPOSITE SECTION

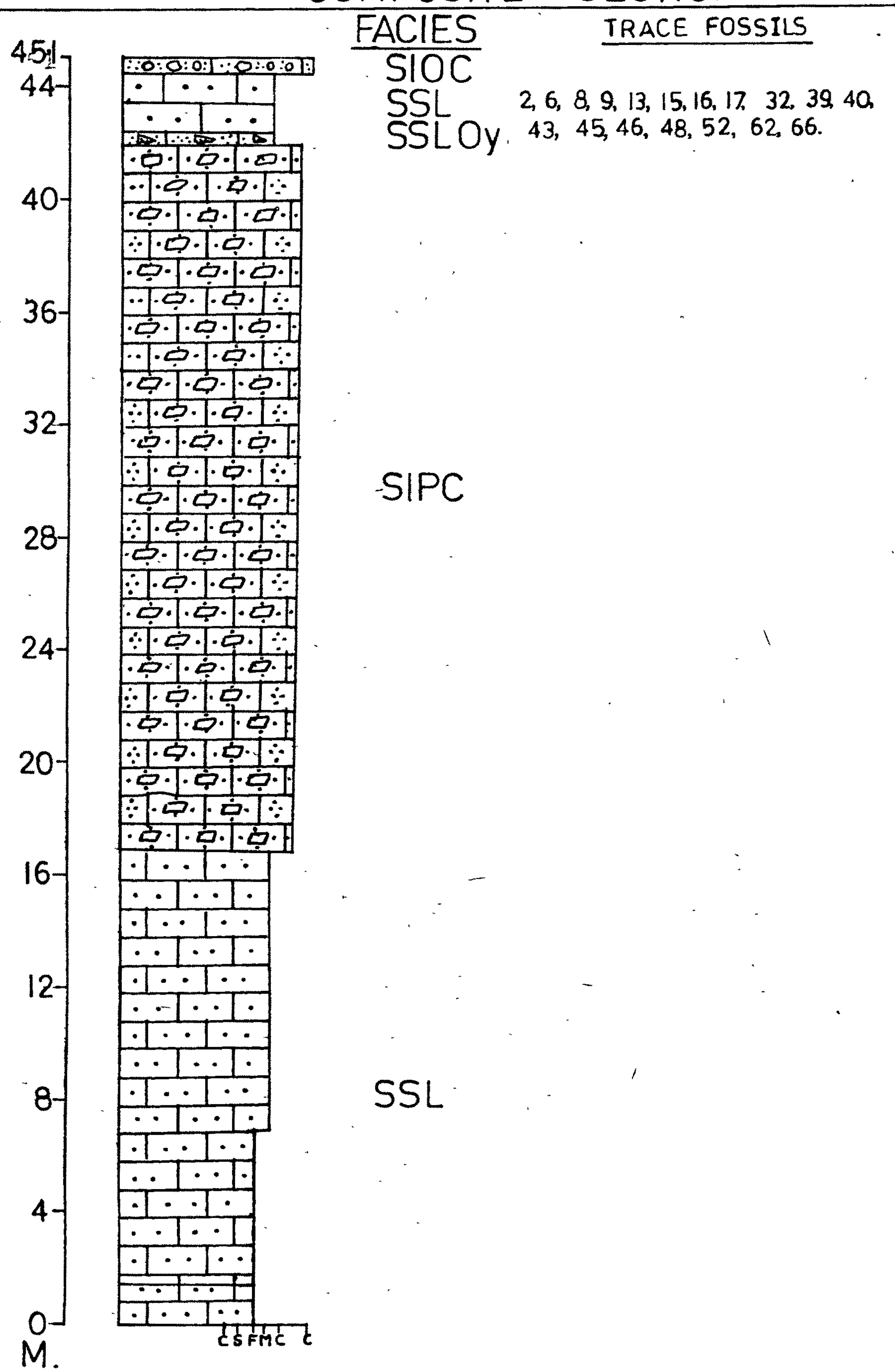
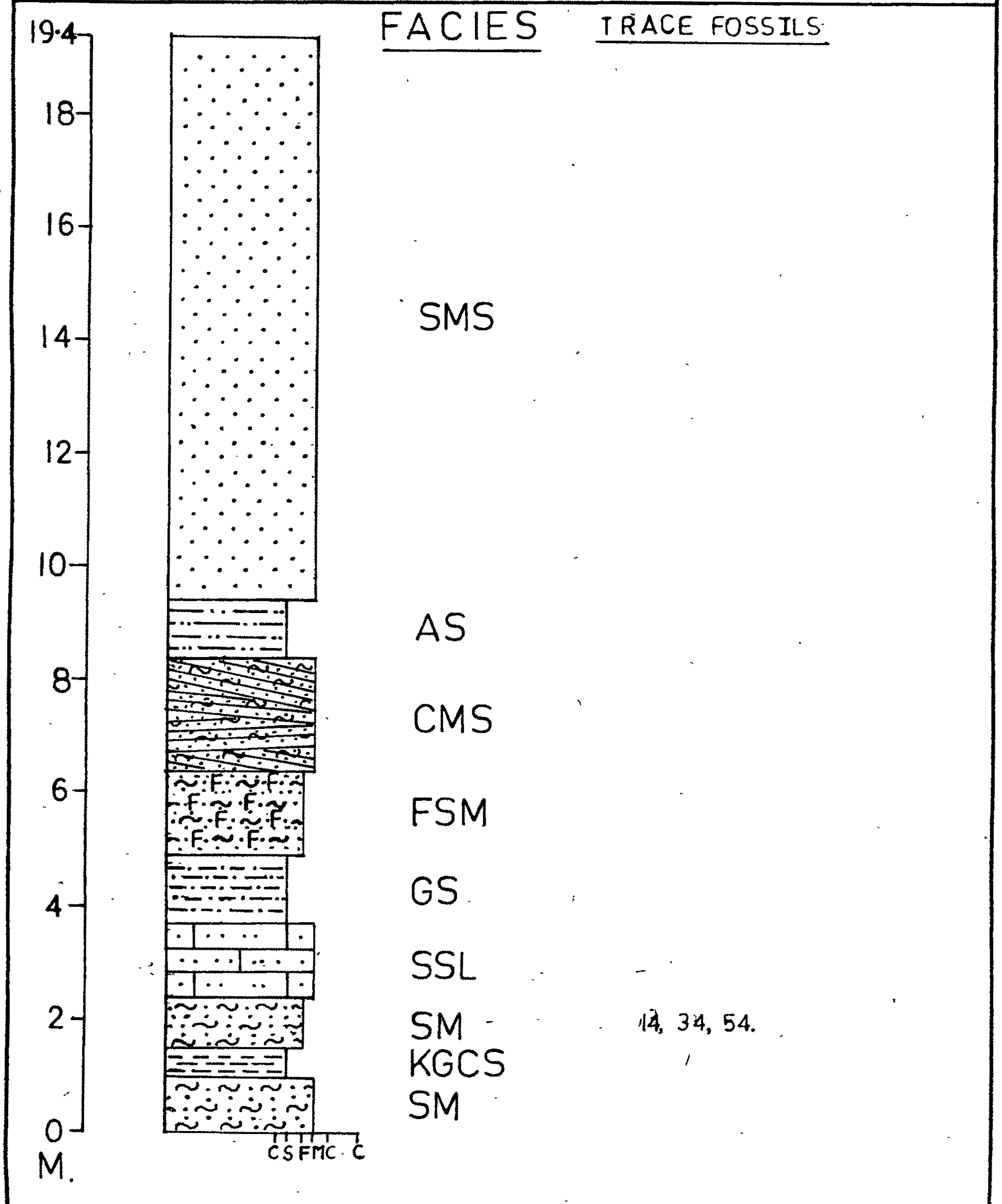


FIG.30 RATNASAR CALCAREOUS SANDSTONE MEMBER



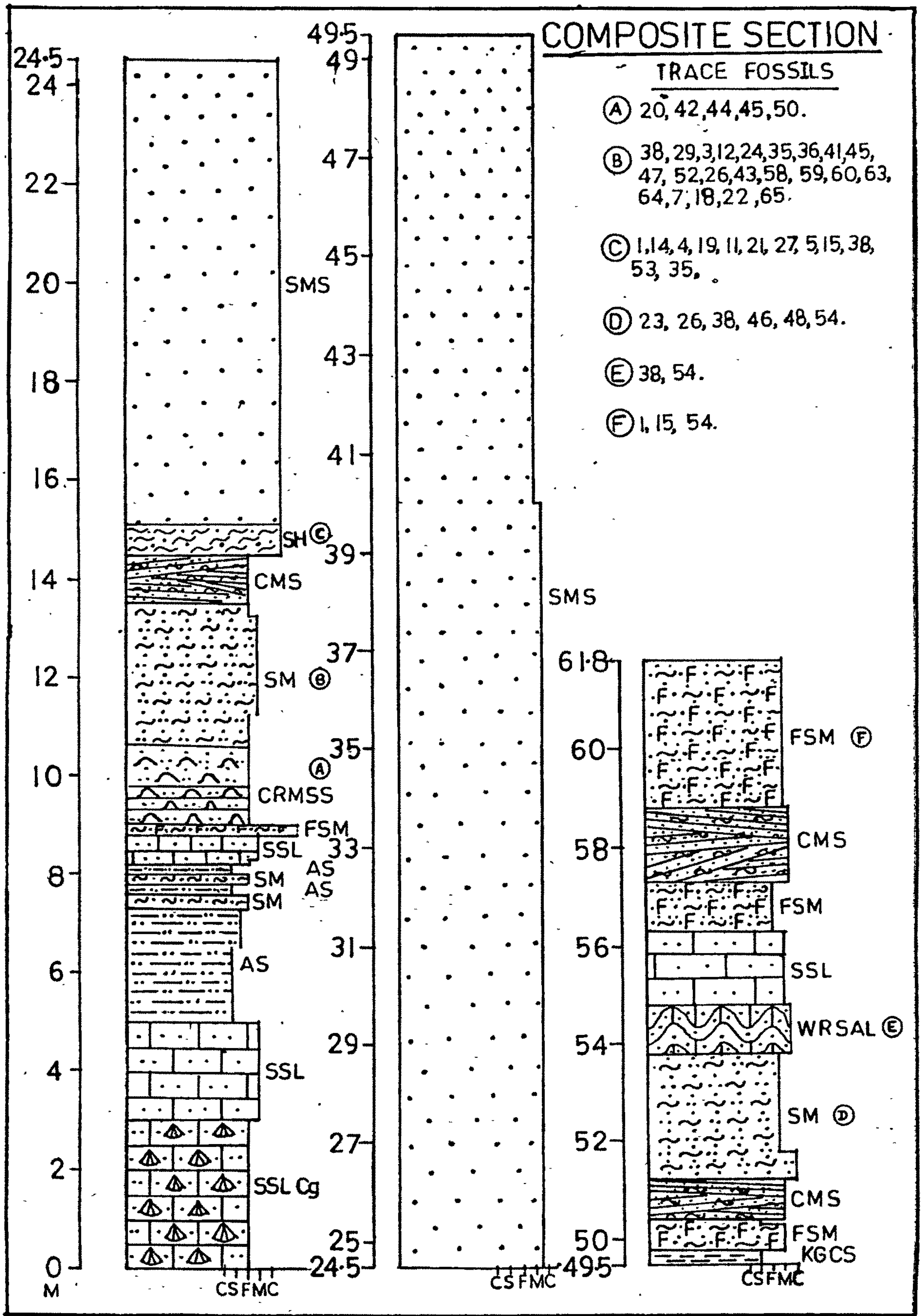


FIG.31 GADHADA SANDSTONE MEMBER

FIG.32 GANESHPUR CALCAREOUS SANDSTONE MEMBER: COMPOSITE SECTION

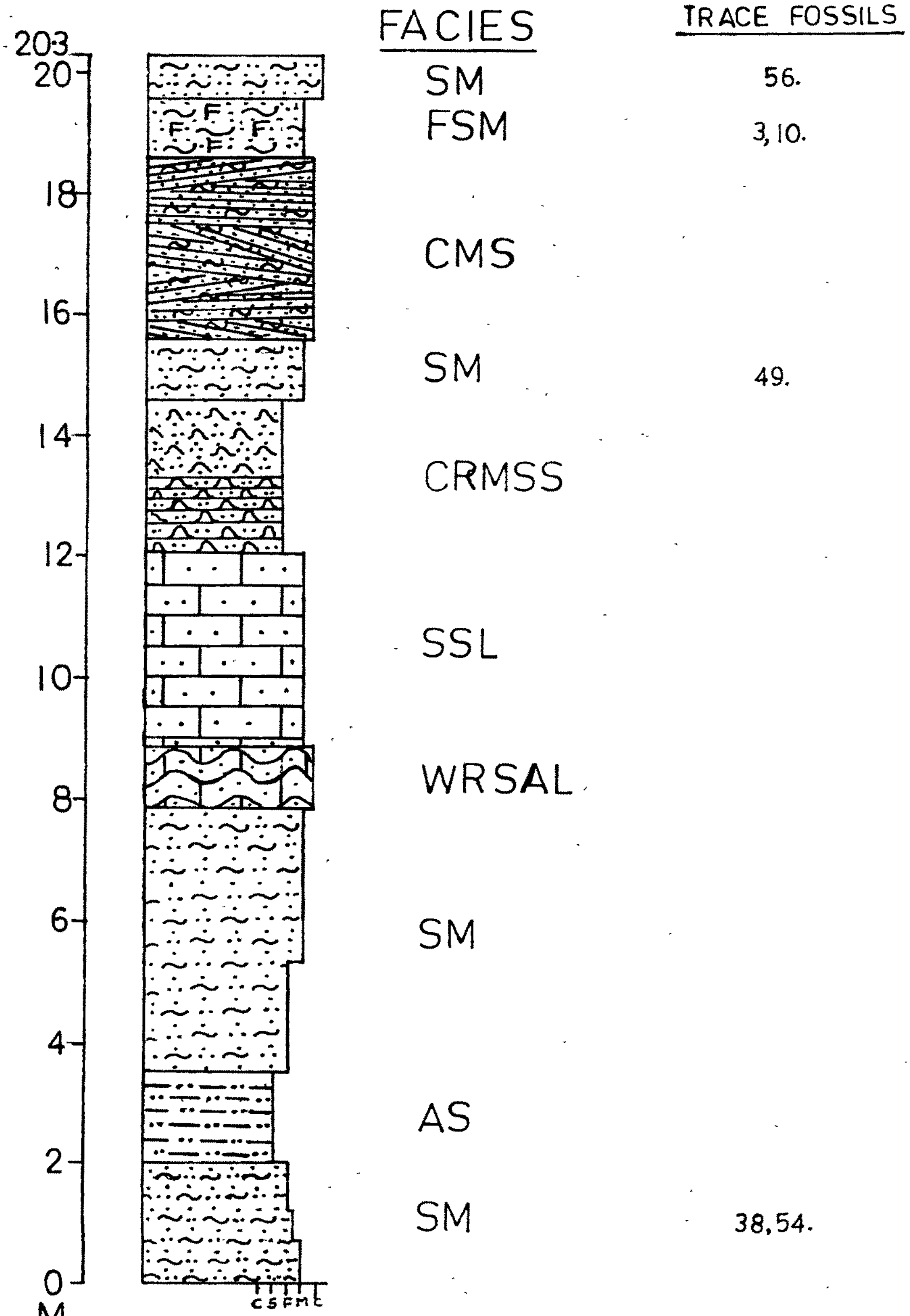
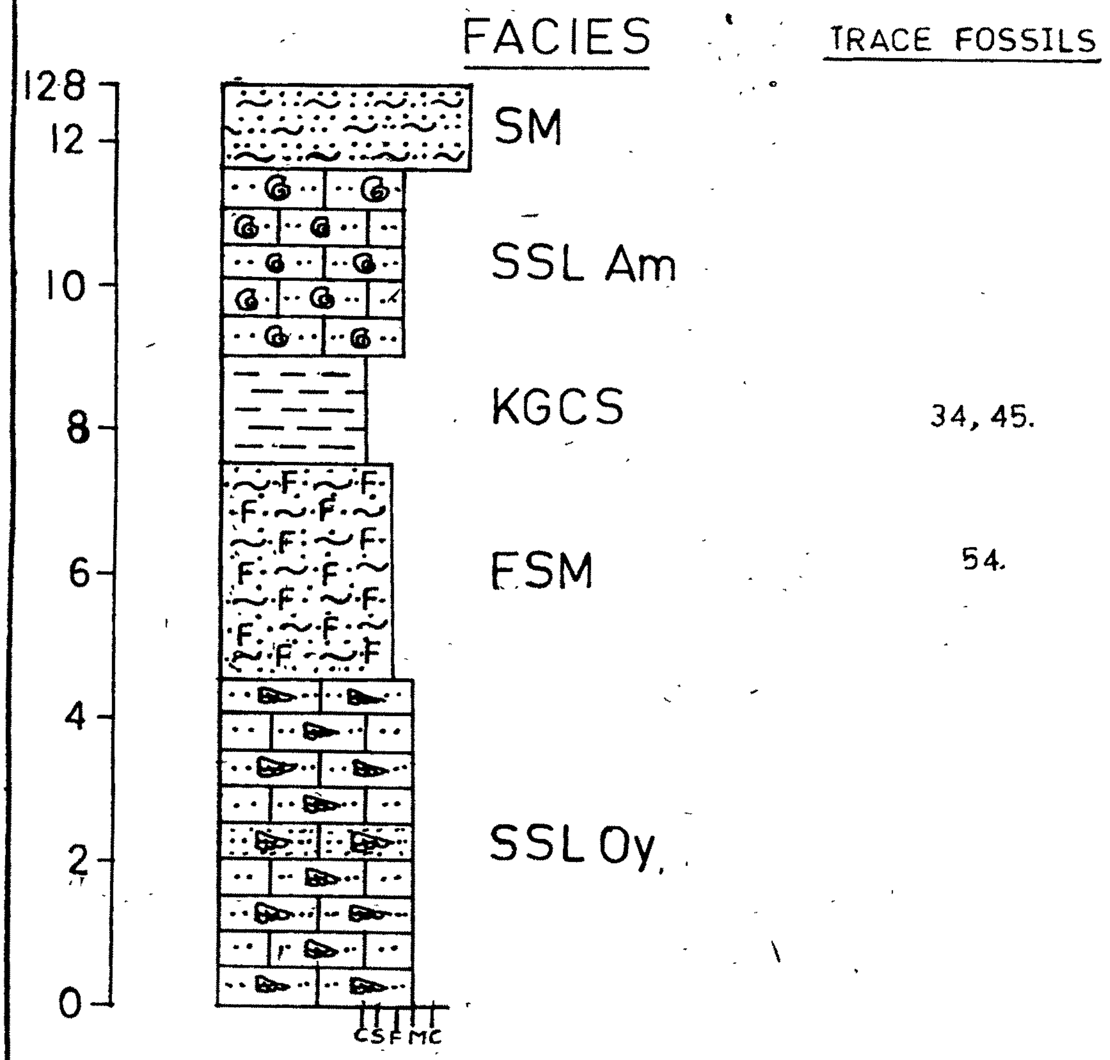


FIG.33 BAMBANKA MEMBER
COMPOSITE SECTION



CHAPTER : VIII

DESCRIPTION OF ICHNOFOSSIL

Organisms of one sort or another today inhabit virtually every sedimentary environment on the Earth, and rock record tells us that this has been the case through the greater part of our planet's history. Furthermore organisms leave their marking in most sedimentary settings either directly in the form of body fossils or indirectly as biogenic structures [trace fossils].

An increased significance is being attached recently to the trace fossils in environment and diagenetic interpretations of rock units and in the reconstructions of ancient life and benthic behavioral patterns. To satisfy such diverse interests a consistent workable system of classification and nomenclature is necessary. However, difficulties frequently arise in assessing present taxonomic concepts and in assigning ichnogeneric and ichnospecific names. The terms genera and ichnogenera and species and ichnospecies are intermixed through out most of available literature. This is because of the ruling of the International Commission on the Zoological Nomenclature that recognize tracks, trails and burrows named before 1931 as valid genera and species, but does not recognize those named later.

In the present studies ichnogenera and ichnospecies are named according to I.C.Z.N. rules using the binomial system of nomenclature. Descriptive and informal classification terms are used as in Chamberlain [1971, 1977], Fursich [1974], Hantzschal [1962], and Seilacher [1953]. Stratonomic Seilacher [1953a] is considered equal to preservational Seilacher [1964], phylogenetic, equal to taxonomic Seilacher [1953a] and this inturn equal to behavioral Seilacher [1964]. All these classifications have been applied to the present studies separately or in combination.

The main purpose of this Chapter being description of the trace fossil morphology and their behavioral characteristics. The aspects of taxonomy, preservation and behavior of the ichnofossils are clearly separated by the author wherever possible in their systematic descriptions. A summary of the stratonomic, phylogenetic and ethologic classification applied to these fossils is separately given at the end of the Chapter.

Trace fossils are described alphabatically and divided into five different categories as listed in Table : 5.

ICHNOFOSSIL STUDY :

ICHNOGENUS

Arenicolites SALTER 1857

Diagnosis : Simple U-tube without spreite, perpendicular to bedding.

ICHNOSPECIES

Arenicolites Variabilis FURSICH 1974

Plate 9.a

Diagnosis : Simple, smooth walled, very thinly lined, essentially vertical U-shaped burrows lacking spreiten, limbs of 'U' somewhat variable in symmetry and configuration.

TABLE : 5

ETHOLOGICAL CLASSIFICATION OF TRACES FOUND IN KHADIR

DOMICHNIA [DWELLING STRUCTURE]	FODINICHNIA [FEEDING TRACE]	PASCICHNIA [GRAZING TRACE]	REPICHNIA [CRAWLING TRACE]	CUBICHNIA [RESTING TRACE]
Arenicolites	Chondrites	Circulichnus	Beaconichnus	Berguaeria
Cylindrichnus	Ctenopholeus	Cochlichnus	Bolonia	Calycraterion
Cylindricum	Dactylophycus	Compaginatichnus	Crosspododia	Conostichnus
Diplocraterion	Gyrolithus	Dendrotichnium	Curvolithus	Lockeia
Lanicoidichna	Keckia	Fustiglyphus	Didymaulichnus	Mammillichnis
Monocraterion	Muensteria	Halopoa	Gyrochorte	Pelecypodichnus
Ophiomorpha	Phoebichnus	Helminthopsis	Isopodichnus	
Palaeophycus	Phycodes	Megagrapton	Kouphichnium	
Scalarituba	Rhizocorallium	Paleodictyon	Merostomichnites	
Siphonites	Rosselia	Planolites	Mesichnium	
Skolithos	Saportia	Rhabdoglyphus	Neonereites	
Spongeliomorpha	Spirophycus	Taphrhelminthopsis	Nereites	
	Spirophyton		Palmichnium	
	Steigerwaldichnum		Psammichnites	
	Susterigichnus		Scolicia	
	Taenidium		Tylichnus	
	Thalassinoides			
	Treptychnus			
	Volkichnium			
	Zoophycos			

Description : In the Kutch specimen of Arenicolites variabilis both limbs are parallel and occur in a single vertical plane, but the limbs in adjoining burrows were either nearly vertical or gently or steeply inclined within that plane. Opening of the tube rarely with funnel shape. Burrow walls are smooth and lack the spreiten structure. Burrow diameter differ in the same species and dimensions vary in different burrow population. Maximum observed length is 27.0 cm and diameter 4.0 cm in left tube and 2.0 cm in right tube. Both the limbs are 13.0 cm apart from one another in the photographed burrow. Unfilled structures are very common. Activity of the organism is clearly indicated by the laminations, that move down in left tube while move up in right tube.

Discussion and Interpretation : Specimens described by Fursich [1974] are more thickly lined than those from Kutch. The tracemaker seem to represent suspension feeding activities.

Preservation : Full relief, unfilled burrows are common.

Facies : Micritic Sandstone and Sub-arkosic Sandstone.

Stratigraphic Distribution : Occurs in the Gadhada Sandstone Member, Hadibhadang Pir Member and Ganeshpur Calcareous Sandstone Member of Khadir Formation.

Association : Cylindrichnus, Cylindricum, Skolithos, Monocraterion

ICHNOSPECIES

Arenicolites Statheri BATHER 1925

Plate 9.b

Diagnosis : Straight symmetrical U-tube without spreite.

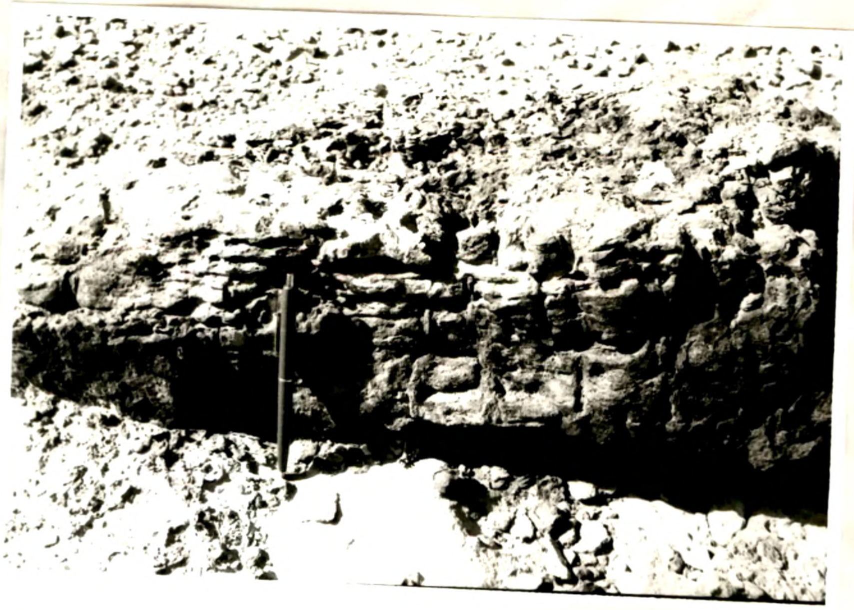
Description : Simple U-shaped burrows without spreite, oriented perpendicular to bedding plane. Burrows preserved as full relief but also seen at their intersection with bedding plane, where it appears as paired circular opening. The depth at the burrow upto 7.0 cm, diameter various from 0.3 to 0.5 cm and the distance between the arms varies from 4.0 to 7.8 cm. Among some specimens the upper parts of burrow limbs tend to be slightly enlarged and terminates in funnel or oval shaped depression.

Preservation : Full relief, fill identical with the matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : Occurs in Gadhada Sandstone Member, Hadibhadang Pir Member and Ganeshpur Calcareous Sandstone Member.

Association : Cylindricum, Skolithos



[a] Arenicolites variabilis Location : Gadhada

[b] [i] Arenicolites statheri Location : Gadhada
[ii] Paleophycus Sp.

ICHNOGENUS

Beaconichnus GEVERS 1973, P.1002

ICHNOSPECIES

Type Species : Beaconichnus darwinum GEVERS 1973

Diagnosis : Two narrow parallel grooves, 9 to 18 mm apart, absolutely linear or only slightly curving, length upto more than 1 m.

Remarks : There are four recognized ichnospecies of Beaconichnus namely,

[1] B. antarcticum, characterized by regularly arranged 3 sets of short parallel rows of foot imprints [upto 3 cm wide], 30.0 cm wide, and consisting central median line representing telson drag marking,

[2] B. giganteum, represented by irregular pattern of foot print in each trend line,

[3] B. darwinum is characterized by two narrow parallel grooves, and

[4] B. gouldi [Gevers 1971]. Two parallel rows of commonly very closely spaced footprints. Foot imprints appearing as small circular pits.

When compared with the above four different ichnospecies of Beaconichnus, the better preserved Kutch specimens and could be assigned to B. darwinum Gevers [1973] an ichnospecies characterized by its full narrow parallel groove with slightly curving.

ICHNOSPECIES

Beaconichnus darwinum GEVERS 1973

Plate 10

Description : Straight to gently curved, ribbon-like horizontal trails, characterized by two narrow parallel grooves, 2.0 cm apart from each other, Median ridge broad [1.8 cm width] and flat, traces flat in cross-section. Maximum observed length of 30.0 cm.

Preservation : Concave hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : Occurs in the Hadibhadang Pir Member of Khadir Formation.

Association : *Scolicia*, *Bolonia*, *Psammichnites*

[i] Beaconichnus darwinium
[ii] Planolites Sp.
[iii] Palaeophycus heberti

Locality : East of Umrapur

ICHNOGENUS

Bergaueria PRANTL 1946

Diagnosis : Bergaueria are cylindrical protrusive burrows with smooth walls. Length and diameter of such burrows is subequal, lower ends rounded, with shallow depression which is sometimes subrounded by 6 to 8 very short radially arranged tubercles. Some species display biradially symmetrical impressions on ventral surface.

Remarks : Bergaueria PRANTL, 1946, contains seven ichnospecies that makes it difficult to determine in synonymy. However, recently Pemberton et al [1988] described four ichnospecies on the characteristic of the distal termination and wall lining.

1 Distinctly lined, unornamented burrows :

[a] Thick walled burrows - B. langi

[b] Thin wall burrows - B. hemispherica

2 Very thin lined, distally ornamented burrows :

[a] Radiating ridges - B. radiata

[b] Ridges faint or lacking - B. perata

ICHNOSPECIES

Bergaueria Sp. PRANTL 1946

Plate 11

Description : Broad vertical cylinders of which lower end is rounded with shallow trough. Diameter of the cylindrical structures 6 to 7 cm, depth 6 to 8 cm, burrow walls smooth without lining.

Discussion and Interpretation : Prantl [1946] as quoted by Fursich [1974] suggested that Bergaueria Sp. might represent the burrows of some anthozoans or allied forms. Whilst Seilacher, regarded them as domichnia of partly burrowed actinians. Hantzschel [1962, 1975] thought it likely that they are resting traces of burrowing actinians. The lack of any lining according to Fursich [1974] suggests that Bergaueria Sp. might belong to the Cubichnia rather than to the Domichnia. The Author is in agreement with Hantzschel [1962, 1975] and interprets his Kutch traces as the resting traces of actinians.

Preservation : Positive hyporelief, fill identical with the overlying sediment.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Ganeshpur Calcareous Sandstone Member of Khadir Formation.

Association : Kouphichnium, Cylindricum.

Bergaueria Sp. Location : West of Ganeshpur

ICHNOGENUS

Bolonia MEUNIER, 1886

ICHNOSPECIES

Bolonia lata MEUNIER, 1886

P.567, Pl.30, Fig.8

Plate 12

Description : Angular meandering furrow preserved as an epirelief with with narrow, rounded lateral compression ridges on both the sides. Traces 1.2 to 2.5 cm wide and 0.2 cm high and 8 to 10 cm in length. Slightly irregular marks across furrow, probably caused by compression during peristaltic motion of animal.

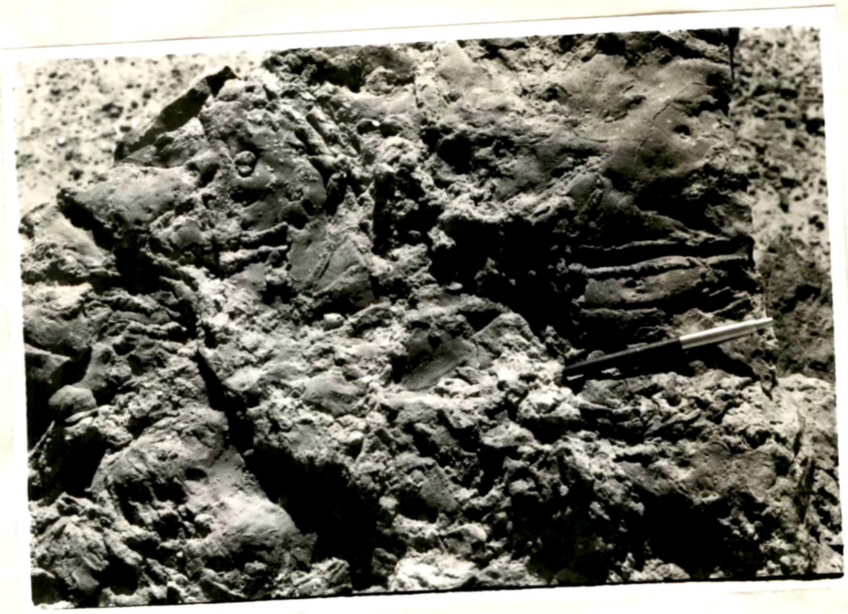
Discussion and Interpretation : Like the type species reported from the upper Jurassic of France where it is associated with _Crossopodia_, the Kutch species of Bolonia also is developed in association with _Crossopodia_ traces.

Preservation : Concave hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhda Sandstone Member of Khadir Formation.

Association : _Scolicia_, _Psammichnites_



Bolonia lata

Location : Vavdi

ICHNOGENUS

<u>Calycraterion</u> KARASZEWSKI 1971 P.104

Types Species : <u>Calycraterion samsonowiczi</u> Karaszewski 1971.

Diagnosis : Regular calyx-shaped depressions, smaller ones similar to impression of lower part of very large hazelnut; inner walls smooth, "Calyx" 15 to 40 mm in diameter, 5 to 15 mm in depth, 2 to 3 small circular depressions on the bottom representing outlets of filled burrows, 2 to 5 mm in diameter.

ICHNOSPECIES

<u>Calycraterion samsonowiczi</u> KARASZEWSKI 1971

Plate 13

Diagnosis : Smooth, calyx-shaped structures, usually asymmetrical, possessing upto three smaller depressions or knobs on the apical end.

Description : Shallow, vertical burrow displaying, smooth, calyx-shaped structures, preserved on soles of calcareous sandstone units. The burrows are circular to slightly elliptical in cross-section, having maximum diameter of 43 cm with height of about 5.6 cm. Sometimes burrow consists smaller depression or knobs on the apical disc and calyx which is vertical to slightly inclined, filled identical to matrix.

Discussion and Interpretation : Calycraterion is distinguished from <u>Bergaueria</u>, <u>Mammillichnus</u> and <u>Margaritichnus</u> by its calyx-shaped structures with smaller depression and lack of low ring-like wall around the tubercles. According to Karaszewski [1971], calycraterion is produced by annelids, with the smaller depressions or knobs representing burrow outlets.

Preservation : Positive hyporelief. Fill identical to matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : Occurs in Gadhda Sandstone Member of Khadir Formation.

Association : Arenicolites, Bergaueria, Gyrochorte

Calycraterion samsonowiczi

Location : Ratanpur

ICHNOGENUS

Chondrites VON STERNBERG 1833 P.25

Type Species : Fucoides lycopodioides BRONGNIART 1828 P.72.

Diagnosis : Plant-like dendritic patterns of small cylindrical ramifying tunnel systems. Individual tunnels neither crossing each other nor interpenetrating. One or few main axes open to the surface; branching tunnels trending downward across bedding and then mostly lying parallel to bedding planes or may branch in regular or irregular patterns, angles of branches may be variable or constant.

Remarks : Chondrites is a well established genus that is generally easily recognized and understood, but that contains so many species that it is difficult to determine its synonymy. More than 170 species of Chondrites have been named [Chamberlain, 1977], and are probably junior synonyms of the few species first named by Brongniart [1823, 1828]. Chondrites is thought to be produced by a variety of organisms such as sipunculids, polychaetes, anthoptiloid sea pens and arthropods [Pickerill et al 1984, P.419].

According to Frey and Howard [1985] identification of the ichnospecies must await monographic restudy of the Chondrites ichnogenus. The material studied by the Author although appears belonging to some new varieties of Chondrites forms, its assignment to different species has not been attempted in this studies. At least two species generalisation are present in the Kutch material, preserved on hypichnia and exhichnia and interpreted as feeding structures.

ICHNOSPECIES

Chondrites Sp. A

Plate 14.a

Description : Dendritic branching structure oriented parallel or subparallel to bedding with no evidence of vertical expression. Burrow wall smooth, slightly irregularly but asymmetrical branched burrow system. Burrow diameter is variable [0.2 to 0.5 cm] in given system, individual tunnels vary in length [0.5 to 2.0 cm], branching frequent and commonly pinnate. Burrow fills commonly are lighter in colour than or otherwise construct with, the enclosing sediments.

Chondrites has been interpreted following Simpson [1956] as the traces of deposit feeding siphunculid worm having a retractable proboscis which allowed the animal to work from a fixed point to mine efficiency the substrate.

Preservation : Preserved mainly as endichnia, occasionally epichnia.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhda Sandstone Member and Ganeshpur Calcareous Sandstone Member of Khadir Formation.

Association : Paleodictyon, Protopaleodictyon, Planolites

[a] Chondrites Sp. A. Location : Gadhada

[b] Chondrites Sp. B. Location : NE of Umrapur

ICHNOSPECIES

Chondrite Sp. B

Plate 14.b

Description : Plant-like dendritic patterns of small cylindrical ramifying tunnel systems. Tunnels are essentially parallel to bedding plane with no evidence of vertical expression. Individual tunnels are neither penetrating nor interconnecting. Branch diameter constant throughout each individual burrow and range from 0.5 to 0.13 cm, system of branching both diachotomous and pinnate, burrow length variable, upto 2.5 cm, though commonly smaller.

Preservation : Preserved mainly as endichnia, epichnia and occasionally exichnia.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Hadibhadang Pir Member.

Association : Paleodictyon, Protopaleodictyon, Compaginatichnus, Planolites, Palaeophycus

ICHNOGENUS

Circulichnus VYALOV 1971 P.91

Type Species : *Circulichnus montanus* VYALOV 1971.

Diagnosis : Ring-shaped trace, almost circular, formed by some cylindrical object.

ICHNOSPECIES

Circulichnus montanus VYALOV 1971 P.91

Pickerill and Keppie 1981 and

McCann and Pickerill 1988 P.334

Plate 15

Diagnosis : Smooth, circular unlined burrow, burrow diameter constant in individual specimens.

Description : A number of species of *C. montanus* are observed in Kutch Burrows are smooth, circular to ellipsoidal in outline and unlined. They are essentially parallel to bedding plane and preserved in concave and convex hyporelief. Peripheral or outer diameter is about 17.3 cm and burrow diameter is about 2.4 cm. Thickness of the individual species are constant throughout. Burrow filled with fine grained particles which is identical to surrounding matrix. Sometimes burrows are completely weathered and unfilled structures are very common.

Preservation : Full relief, convex and concave hyporelief, filled identical to matrix.

Circulichnus montanus

Location : Ratanpur

Facies : Micritic Sandstone.

Stratigraphic Distribution : Occurs in Gadhda Sandstone Member of Khadir Formation.

Association : Bergaueria

ICHNOGENUS

Cochlichnus HITCHCOCK, 1858

Diagnosis : Regularly meandering smooth trails, resembling sine curve.

Remarks : There are three recognized ichnospecies of Cochlichnus, namely C. anguineus Hitchock, 1858. C. Kochi Ludwig, 1968, and C. serpens Webby, 1970, whose definition and differentiation in the literature is confusing and can best be regarded as conspecific. The Kutch specimen probably represent the mould of a burrow, which is identical to Webby, 1970, described. Cochlichnus serpens burrows. According to Eager et al [1985], Cochlichnus are crawling traces and probably feeding structures of small worm or warm-like animal. Cochlichnus has been recorded in sediments of supposed low-salinity Paleoenvironments [Hakes, 1976].

ICHNOSPECIES

Cochlichnus Serpens WEBBY, 1970

Plate 16

Diagnosis : Regular meandering, smooth unbranched sinusoidal unlined burrows.

Description : Sinuous trails preserved as mould of burrows on the upper surface of beds. A single specimen was collected but more material is available at the locality. The collected specimen shows two different trails having maximum length about 35.0 cm, diameter is constant throughout being 1.4 cm. Amplitude of the sine curve is 3.0 to 5.0 cm, wave length of 5.0 to 8.0 cm.

Cochlichnus serpens

Location : West of Umrapur

Preservation : Burrow preserved in convex hyporelief. Sediment filled identical to host rock.

Facies : Micritic sandstone.

Stratigraphic Distribution : It occurs in Hadibhadang Pir Member.

Association : Compaginatichnus, Chondrites, Curvolithus, Scolicia

ICHNOGENUS

Compaginatichnus PICKERILL, 1989, P.913

Diagnosis : Horizontal, unlined, unbranched, straight to curved to meandering burrows which are deeper than wide and possess an upper segmented fill articulated by meniscus-shaped partings and a lower unsegmented fill with densely packed fecal pellets.

ICHNOSPECIES

Compaginatichnus forbesi PICKERILL, 1989

Plate 17

Diagnosis : *Compaginatichnus* with evenly or unevenly spaced menisci of variable thickness, density 6-9 per centimeter, distance between adjacent mensci shorter than burrow width, basal fecal pellets spheroidal to ellipsoidal, of different sizes, upto 1.5 mm in length.

Description : The Kutch specimens *C. forbesi* consists evenly or unevenly spaced menisci of variable thickness with spheroidal to ellipsoidal fecal pellets. The maximum observed length is 30. cm with relatively constant width being 0.9 cm. Burrows upto three times deeper than wide so that their gutter like transverse cross-section similar to that of *Teichichnus*, Seilacher, 1955. Burrow course straight to curved to irregular meandering exhibits regular sinelike meanders similar to those exhibited by *Cochlichnus* Hitchcock, 1858. Burrow walls poorly to well defined and unlined, upper meniscate and intermeniscate segments longer than wide; irregularly spaced, with 3 to 6 menisci per centimeter, menisci of variable

Compaginatichnus forbesi Location : West Umrapur thickness [0.6 to 1.4 mm] both within and between specimens, concave and may possess the same of different radii of curvature, may be symmetric in plane view of asymmetric with respect to mid-line of the burrow. Upper menisci and intermenisci, respectively different and compositionally identical fills to the adjacent host rock.

The morphology of C. forbesi suggests that it was produced through active tunnelling by a vagile deposit feeder [an annelid] at or below the sediment water interface as predicted by Pickerill [1989].

Preservation : Semi-relief, typically on upper surface of the calcareous sandstone.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Hadibhadang Pir Member.

Association : Scolicia, Curvolithus, Keckia, Planolites

ICHNOGENUS

Conostichus LESQUEREUX 1876, P.142

Type Species : Conostichus Ornatus Lesquereux, 1876.

Diagnosis : Conical to subconical, vertical burrows, most of which display a duodecimal symmetry on the apex and sides. Most walls are fluted by transverse constrictions and longitudinal ridges and furrows. Well-developed apical disc and central subcylindrical core may or may not be present. Burrow fills may be structureless or composed of concentric conical or subconical laminae.

Remarks : Conostichus encompasses a virtually complete range of conical forms, from low wide cones having slightly sloping sides to high narrow cones having flat apices and nearly parallel sides [Chamberlain, 1971]. Overall dimensions are variable, but generally the diameter is equal or less than the height. Recently, Pembertan et al [1988] recognized five ichnospecies of Conostichus, on the basis of well developed ornamentation and inclusion of apcial disc, transverse contrictions, and longitudinal ridges, and furrows. The overall geometry of Conostichus and the well developed apical disc and surface ornamentation in Conostichus therefore distinguish it from Bergaueria, Conichnus, and Dolopichnus. The following ichnospecies are described by Pemberton et al [1988] on the basis of primarily on overall burrow geometry and characteristics of the apical disc :

1 Strongly conical burrow form

[a] Narrow, short apical disc - C. broadheadi

2 Conical to subconical burrow form

[a] Broad, planar apical disc having strong septation - C. ornatus

[b] Broad, planar, apical disc having moderate septation - C.typicus

[c] Small, narrow apical disc having weak septation - C. stonti

3 Subcylindrical burrow form

[a] Broad, flat apical disc having weak septation - C. wycherlyi

ICHNOSPECIES

Conostichus wycherlyi KING 1955 P.158

Plate 18

Diagnosis : Subcylindrical conostichians having weakly developed transverse constrictions and longitudinal furrows, broad, planar apical disc having weak septation.

Description : Relatively large, broad, conical structure displaying circular cross-section. Burrow walls are eroded in most of the burrow system, but somewhere preserve, also consist indistinct transverse constrictions and longitudinal furrows. Dimensions of the burrow varies in different burrow population, height upto 9.0 cm. and diameter varies from 6.0 to 13.0 cm. The apical disc is characteristically broad and flat, eroded in most of the traces and appearing as circular opening with diameter of 3.0 to 5.0 cm.

Discussion and Interpretation : Conostichus wycherlyi is distinguished from other ichnospecis of Conostichus by its cylindrical shape and its broad, flat apical disc. Conostichus was originally interpreted as an

Conostichus wycherlyi Location : West of Ganeshpur alga [Lesqureut 1876, 1880, 1883] or a sponge [Lesqureut 1880], its medusoid affinities were recognized early by Fuchs [1895]. Chamberlain [1971] interpreted as dwelling burrows of actinians and feeding cones of Arenicola like worm [Berthel and Barth 1972].

Stratigraphic Distribution : Occurs in Ganeshpur Calcareous Sandstone Member.

Association : Spirophyton

ICHNOGENUS

Crossopodia M'COY 1851, P.395

Diagnosis : Meanderning, curved or straight trails, width about 1 cm. with broad dense fringe on each side, mostly with median furrow.

ICHNOSPECIES

Crossopodia Sp. M'COY 1851

Plate 19

Description : The Kutch specimens identified as crossopodia are distinct, unbranched, straight to gently curved trackways probably of arthropod. Many specimens are found tapering towards both the ends. Traces are covered by the sediment and show poorly preserved median furrow. The traces in the author's collection indicates variable length from 8.0 to 10.0 cm. although some specimen are shorter than 5.0 cm. The overall width of the specimen is also variable and is found ranging between 0.7 to 1.3 cm.

Discussion and Interpretation : The specimens from Kutch are found approaching in their general form and appearance as those described and illustrated by Hattain and Frey [1969].

Preservation : Convex and concave hyporelief, sediments filled identical to the matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Gyrochorte, Didymaulichnus

Plate : 19

Crossopodia Sp.

Location : Gadhada

ICHNOGENUS

Ctenopholeus SEILACHER AND HEMLEBEN 1966

Types Species : Ctenopholeus, kutscheri Seilacher and Hemleben 1966, P.47.

Diagnosis : Long horizontal funnel like burrow, straight or somewhat curved, with vertical shafts rising at equal intervals, burrow only rarely branched horizontally, fragments upto 60 cm. in length.

ICHNOSPECIES

Ctenopholeus Sp. SEILACHER AND HEMLEBEN 1966, P.47

Plate 20

Description : In the Kutch specimens of Ctenopholeus Sp. the vertical shafts are arranged on long horizontal tunnel at more or less equal interval, and opened to the surface in circular hollow ring like structure. The burrow system is 45 cm. long with 4 to 5 vertical shafts. Diameter of burrow varies from 3.0 to 6.0 cm. Burrow unfilled structures are very common, but partly filled burrows are also observed in the field. Burrows are essentially vertical but some tends to incline to the bedding plane surface may indicate current directions.

Preservation : Full relief, unfilled burrow tubes are common.

Facies : Micritic Sandstone.

Plate : 20

Ctenopholeus Sp. Location : WSW of Gadhada

Stratigraphic Distribution : Occurs in Gadhada Sandstone Member.

Association : _Arenicolites_, _Cylindrichnus_, _Cylindricum_, _Diplocraterion_, _Ophiomorpha_, _Skolithos_

ICHNOGENUS

Curvolithus FRITSCH 1908, P.13

Diagnosis : Ribbon-like trails, more or less straight, flat, consisting of 3 parts : broad, usually smooth central stripe [about 0.5 to 2.0 cm. wide] and very narrow lateral ridges [1.0 to 2.0 mm wide].

Remarks : Ribbonlike trails have been diagnosed as Curvolithus by Hantzschel [1962, 1964] and Chamberlain [1971]. According to Heinberg [1973] and Hakes [1976], Curvolithus is commonly thought to be the trail of a gastropod.

ICHNOSPECIES

Curvolithus Sp. FRITSCH 1908

Plate 21

Description : Simple, smooth, straight to gently curved ribbon-like horizontal trails, preserved as half-relief epichnial molds. The trail is broad, flat and consisting of two parallel concave furrow, which divides trails into three parts. The trails are 2.4 cm wide and have a relief of 1.0 to 1.5 mm. Faint oblique annulations observed in places along lateral parts of central lobe.

Preservation : Preserved as half-relief epichnial mold.

Facies : Micritic Sandstone.

[i] Curvolithus Sp.
[ii] Susterigicchnus Sp.

Location : Gadhada

Stratigraphic Distribution : Occurs in the Gadhada Sandstone Member and Hadibhadang Pir Member.

Association : Scolicia, Compaginatichnus, Cylindrichnus, Beaconichnus

ICHNOGENUS

Cylindrichnus TOOTS in HOWARD 1966

Diagnosis : Subconical form, weakly curved, circular to oval in cross-section with diameter of 10 to 20 mm, most commonly 12 to 15 mm, central core 2 to 4 mm, exterior wall composed of concentric layers, preserved in full relief, orientation from nearly horizontal to vertical.

ICHNOSPECIES

Cylindrichnus Sp. TOOTS in HOWARD 1966

Plate 22

Description : Simple cylindrical tube having diameter of 3.4 to 4.9 cm and inclined at various angles to the bedding plane. Simplest forms have a concentric wall structure in which the tube is central, but others may be slightly excentric because wall structures are biased towards very fine material. Interpreted as permanent burrow [domichnia] of filter-feeding organism by Frey and Howard [1970].

Discussion and Interpretation : The species is defined in part on the basis of the presence of internal concentric laminae in cross-section of Cylindrichnus. Such fine scale structure is preserved in purplish to reddish brown of Gadhada Sandstone Member. The general geometry of the genus is considered here to be a reliable taxonomic criteria.

Preservation : Full relief, endichnial burrows, fill of the core either with the matrix or consisting alternating dark and lighter coloured

Cylindrichnus Sp. Location : Gadhada

material.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member and Hadibhadang Pir Member.

Association : Cylindricum, Skolithos, Arenicolites, Ophiomorpha

ICHNOGENUS

<u>Cylindricum</u> LINCK 1949, P.19

Diagnosis : Cylindricum are plug shaped burrows like test tubes, rounded at lower end. Walls of the burrows are smooth. Burrows oriented perpendicular to bedding plane.

ICHNOSPECIES

Cylindrium Sp. LINCK 1949

Plate 23

Description : Simple, straight vertical to steeply inclined, smooth, cylindrical to subcylindrical unbranched burrows and have distinct wall-like structure. It occurs in group or isolated individuals on bedding plane. Mostly circular to elliptical in cross-section. The maximum observed length in field is about 12.0 cm. and diameter varies from 2.8 to 4.3 cm. Burrow filled with identical to surrounding host sediments. Lower end is rounded.

Preservation : Full relief, preserved mainly endichnia, fill identical to matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member and Ganeshpur Calcareous Sandstone Members.

Association : Cylindrichnus, Skolithos, Monocraterion

Cylindricum Sp.

Location : Gadhada

ICHNOGENUS

Dactylophycus MILLER AND DYER 1878, P.1

Diagnosis : Delicately annulated bilobate burrows, small about 15 mm long, 2 to 4 mm; in diameter, radiate or randomly branching, number of branches varying.

ICHNOSPECIES

Dactylophycus Sp. MILLER AND DYER 1878

Plate 24

Description : The Kutch form of Dactylophycus Sp. comprise small, bilobate horizontal burrows, showing delicate annulation and striations which are very common. The burrow radiate from origin and consists of three branches having leaf-like shape. Branches are asymmetrical in outline and also vary in dimension, burrow length variable 10.0 to 16.0 cms; and width of 4.0 to 6.0 cm. Burrow collapse structures are very common. Burrow filled identical to surrounding substrate.

Preservation : Preserved is endichnia, hypichnia or epichnia.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Hadibhadang Pir Member.

Association : Planolites, Palaeophycus, Keckeia

Dactylophycus Sp. Location : West of Umrapur

ICHNOGENUS

Dendrotichnium FARRES 1967, P.30

Type Species : Dendrotichnium llarenai FARRES 1967 P.30

Diagnosis : Treelike trail, 7 to 30 cm long, straight on somewhat curved "main stem" with several "side-branches" on both sides. Their length quite variable, branching of perpendicularly in type species, but obliquely in others.

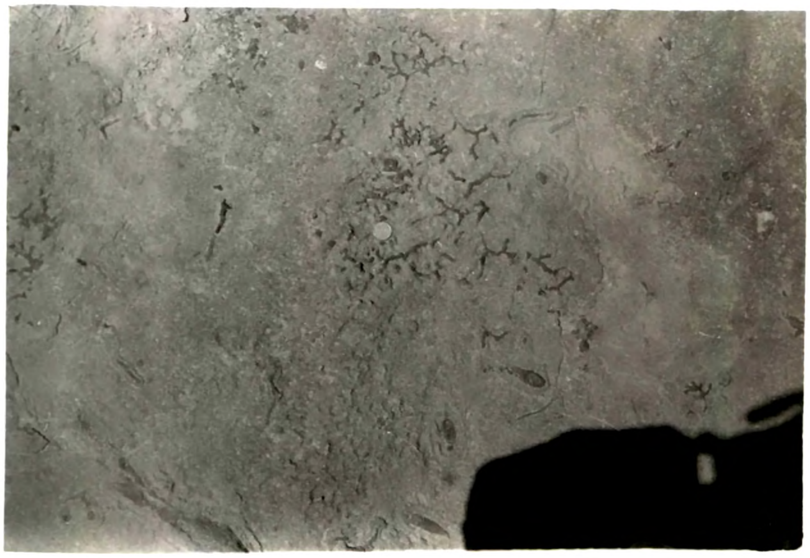
ICHNOSPECIES

Dendrotichnium Sp. FARRES 1967

Plate 25

Description : Meanders smooth, cylindrical and parallel to bedding plane. Main stem is thick and curve [zig-zag shaped] with several small alternating side branches on both side. Branching are perpendicular or oblique to the main stem. The length of the burrow is upto 27.0 cm, amplitude 0.5 cm., wave length 4.0 cm and 0.8 cm. Branches 0.3 to 0.5 cm thick, 3.0 to 5.0 cm long, wave length 2.5 cm with amplitude of 0.25 cm. Burrow preserved as hypichnial ridges and filled identical to matrix.

Remarks : In contrast to truly dendroid burrow systems, such as Chondrites, the side branches alternate regularly and near show any secondary branching.



Dendrotichnium Sp. Location : North of Umrapur

Preservation : Convex and concave hyporelief, sediments filled surrounding the matrix.

Facies : Shelly Sandy Limestone.

Stratigraphic Distribution : Occurs in Hadibhadang Pir Member.

Association : Bolonia, Chondrites, Cochlichnus

ICHNOGENUS

Didymaulichnus YOUNG 1972

Diagnosis : Smooth, straight and gently curving burrows consisting of two lobes separated centrally by distinct furrow and flanked laterally by bevels which are not continuous. Traces commonly crossing and occurring in profusion on bedding planes.

ICHNOSPECIES

Didymaulichnus Lyelli ROUAULT 1870

Plate 26

Description : Simple, smooth gently curving bilobate trails preserved in convex hyporelief, parallel to bedding. Lobes separated by distinct burrow, may have and asymmetric "marginal bevels". Trail at places overlap and truncate over one another.

Description : Long, straight to gently curved trail consisting of two distinct lobes separated centrally by very narrow median furrow. Surfaces of lobes are smooth to slightly undulatory and parallel to bedding plane. The trace is 1.8 cm wide, 0.4 cm high and extends for over 30.0 cm. In some specimens traces commonly crossing and occurring in profusion on bedding planes. Didymaulichnus is generally regarded as a surface trail probably of a Mullusc [Hakes 1976].

Preservation : Full relief, positive hyporelief.

Didymaulichnus Lyelli   Location : Ratanpur

Facies : Micritic Sandstone.

Stratigraphic Distribution : Occurs in the Gadhada Sandstone Member.

Association : Gyrochorte, Crossopodia, Curvolithus, Planolites

ICHNOGENUS

Diplocraterion TORELL 1870

Type Species : Diplocraterion parallel Richter 1926, P.213.

Diagnosis : U-shaped burrow with spreite, vertical to bedding plane, limbs of U-parallel, both limbs of successive U-tube confluent with limbs of preceding U-tube, opening of tubes mostly funnel-shaped, commonly protrusive, but also retrusive forms observed, bottom of burrow semicircular, rarely straight, horizontal cross-section on bedding planes dumb-bell-shaped, diameter of tubes 5 to 15 mm; distance between limbs 1 to 7 cm. depth of burrow 2 to 15 cm.

ICHNOSPECIES

Diplocraterion Parallel RICHTER 1926 P.213

Plate 27.a

Diagnosis : Vertical U-shaped spreite burrows in which burrow walls are parallel and spreite unidirectional.

Description : Fairly straight U-tubes, the arms of which are more or less parallel, oriented perpendicular to bedding, containing spreite and with funnel shaped apertures. The burrows are circular in cross-section. The diameter of tubes is 1.8 cm and 5.0 cm apart from each other. The U-tubes have poorly-developed spreite and are found to penentrate the rock down to 6.0 cm. Burrow collapse structure are very common.

Discussion and Interpretation : Vertical spreiten-burrows are usually regarded as the domichnia of suspension feeders [Richter 1926, Goldring 1962, 1964, Seilacher 1963, 1967]. The spreite being the result of the animal's intension to keep its burrow at a constant depth than the result of mining the sediment for food. The divergence of the arms in Diplocraterion Sp., offers an additional argument for its interpretations as the dwelling burrow of a suspension feeding animals [Fursich 1974]. The increasing distance between the two apertures of the U-tubes as suggested by the above worker guarantees a better separation of inhalent and exhalent currents.

Arkell [1939] and Howell [1957] regarded Diplocraterion as the burrow of a polychaete. Hertwek [1970] figures bioturbation structures produced by the Recent Echiurus echiurus from the German Bay, which are very similar to bioturbation structure of Diplocraterion. Again, burrows of present Corophium are very similar except for their small size [Schafur 1952]. According to Fursich [1974], it may not be justified to exclude either polychaete or crustacean as possible procedures of Diplocraterion, though the absence of scratch marks in tube-walls may fever a polychaete origin. Moreover, there is no doubt that Diplocraterion has been produced by a variety of forms [Seilacher 1957]. It is, however, very important that the Diplocraterion represents burrow made by suspension feeders.

Preservation : Full relief, endogenic, fill identical with the surrounding substrate. Domichnias of suspension feeders.

Facies : Micritic Sandstone.

[a] Diplocraterion Parallel Location : Ratnasar

[b] Diplocraterion habichi Location : Gadhada

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Arenicolites, Cylindrichnus, Monocraterion, Skolithos, Planolites, Palaeophycus, Spongiliomorpha

ICHNOSPECIES

Diplocraterion habichi LISSON 1904

Plate 27.b

Diagnosis : Diplocraterion in which arms of the U-tube diverge-upwards.

Description : U-shaped burrows, oriented perpendicular to bedding, containing spreite and with funnel-shaped apertures, commonly protrusive. The burrows are circular in cross-section. The burrow diameter varies from 2.2 to 3.1 cm and 4.0 to 7.0 cm apart from each other. The burrows are usually only seen at their intersections with bedding planes where they appear as dumb-bell shapes with paired circular openings joined by a slit-shaped area of sediment corresponding to the spreite.

Preservation : Hyporelief fill identical with the matrix. The raised rim of the openings probably represents early cementation of the sediments in the vicinity of the U-tube. This could have caused by organic-rich mucus with which inhabitants lined its burrow [Fursich 1974].

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Arenicolites, Cylindrichnus, Ophiomorpha, Skolithos

ICHNOGENUS

Fustiglyphus VYALOV 1971, P.90

ICHNOSPECIES

Fustiglyphus Sp. VYALOV 1971

Plate 28

Diagnosis : Straight strings or narrow cylinders of varying length encircled by ring-like 'Knots' or well-defined swelling at regular or varying intervals, rosary like.

Remarks : Initially Vassoevich [1951] described Rhabdoglyphus, but an adequate description of this genus had not been provided. The Rhabdoglyphus is subsequently been described by Boucek and Elias [1962]. Boucek and Elias seem to have only expanded the description of Rhabdoglyphus Vassoevich and complicated matters by figuring specimens much different from the material described by Vassoevich originally. This has been pointed out by Ksiazkiewicz [1970, P.286-287]. As a result, the figured specimens of Boucek and Elias have been mistakely considered Rhabdoglyphus by Hantzschel [1965, P.75, 1966 P.15] and Osgood [1970, P.369].

Vyalov [1971, P.90] finally clarified matters by introducing the new name Fustiglyphus for the material by Boucek and Elias.

Description : The Kutch form is essentially horizontal, straight to gently armed cylindrical burrows consisting of varying length encircled by double ring-like Knots. The length of the burrow is about 5.5 cm, diameter 0.8

Fustiglyphus Sp. Location : Vavdi

cm, knots are 0.4 cm wide and 1.7 cm apart from one another. Burrow fill identical to host sediments.

Preservation : Positive hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Phycodes, Planolites, Palaeophycus, Muensteria, Keckeia

ICHNOGENUS

Gyrochorte HEER 1865, P.142

Diagnosis : Trace upto 5 mm wide in epirelief preserved as plaited ridges with biserially arranged, obliquely aligned pods of sediment, in hyporelief preserved as smooth biserial grooves separated by median ridges; course strongly winding and direction changing sharply, trace may intersect itself or other traces, ridges and their grooves may be separated by vertical distance of 1 cm; usually preserved in clastic sediments.

ICHNOSPECIES

Gyrochorte Comosa HEER 1865

Plate 29

Diagnosis : Ridges on bedding planes with biserially arranged, obliquely aligned transverse pods, both series separated by median furrow.

Description : The trace includes long winding ridges on the upper surface of the bedding plane, with the width of ridges 0.3 to 0.5 cm and maximum observed length is about 53.0 cm. The height of the relief is usually less than 0.1 cm. Trails usually consist two lobes separated by median furrow. The each lobe consists an uniformly developed pads. The angle between the pods and the median furrow varies from 45° to 55°. The ridges at places end abruptly. Crossing over occurs frequently in such a way that the earlier formed ridges are not destroyed.

Discussion and Interpretation : After early interpretations - such as

Plate : 29

Gyrochorte comosa

Location : Gadhada

impressions of Ophiurids [Quenstedt 1858] or egg strings of Mollusca [Heer 1865] as in [Fursich, 1974], Gyrochorte was later thought to represent tunnel structure, made by amphipads. Weiss [1940, 1941] and Seilacher [1955 however, interpreted Gyrochorte as produced by a polychaete or wormlike animal moving obliquely through the sediment. Hallam [1980] discussed the origin of Gyrochorte at some length and concluded that the previous interpretation, i.e. the ridges as the product of tunneling amphipads seems to be more likely than Weiss' Model. Recently Heinberg [1973] was able to show in a detailed study, based on excellently preserved material from East greenland, that Weiss' interpretation was correct and that Gyrochorte in fact produced by an elongate organism moving obliquely through the sediment in search of food.

Preservation : Endogenic scour cast.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Crossopodia, Didymaulichnus, Psammichnites, Scolicia, Pelecypodichnus, Rhizocorallium, Thalassinoides, Phycodes

ICHNOGENUS

Gyrolithes DE SAPORTA 1884, P.27

Type Species : Siphodendron girardoti DE SAPORTA 1884.

Diagnosis : Dextrally or sinistrally coiled burrows upto several cm., in diameter, sometimes with rounded or elongate process which may be branching near upper end, diameter of whorls mostly uniform, vertically oriented, upto several decimeters high.

ICHNOSPECIES

Gyrolithes polonicus FEDONKIN 1980

Plate 30

Diagnosis : Dextrally or sinistrally coiled burrows, upright in deposit, surface with rounded or elongated processes.

Description : The Kutch specimen is sinistrally coiled, filled with host sediment, occurs on sole of the bedding plane consisting of a burrow forming an almost complete circle. The diameter of burrow is about 2.3 cm; and diameter of complete trace is about 7.0 cm. Diameter of whole system is more or less constant.

Preservation : Full relief, endichnial burrows filled identical to surrounding substrate.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Hadibhadang Pir Member.

Association : Dactylophcus, Planolites, Palaeophycus, Chondrites

[i] Gyrolithes polonicus
[ii] Keckia annulata

Location : Ratanpur

ICHNOGENUS

Halopoa TORELL 1870, P.7

Diagnosis : Long, slightly curved trails dug along surface, surface of trail with typical imbricate or lycopodiciceous structure, diameter of burrows about 0.5 to 1.0 cm.

ICHNOSPECIES

Halopoa imbricata MARTINSSON 1965

Plate 31

Description : Long branched, straight, gently curved to winding flat bilobed trail with fine narrow poorly preserved median furrow, parallel to bedding plane. The trail composed typical imbricate structure in better preserved specimens. Trail vary in size, length upto 27.0 cm and 0.6 to 0.8 cm wide.

Discussion and Interpretatation : Torell [1870] established the ichnogenus Halopoa for the curved trails dug along surface. Such trails are illustrated by Hantzschel [1975, W67, Fig.41, 5] and figured and described by Martinsson [1965], who grouped Halopoans with Gyrochorte Heer 1865, although they show no typical plate-like structures. According to Hantzschel [1975] it is probably produced by epipsammouts.

Preservation : Preserved in convex and concave hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Planolites, Palaeophycus, Muensteria

Halopoa imbricata Location : Palanpur [WE of Gadhada]

ICHNOGENUS

Helminthopsis HEER 1877, P.116

Diagnosis : Simple meandering smooth trails. Not as strictly developed as Helminthoida in parts with marginal ridges.

ICHNOSPECIES

Helminthopsis abeli KSIAZKIEWICS 1877

Plate 32.a

Diagnosis : Smooth unbranched, gently meandering more typically loose winding trails, burrow constant throughout, low relief.

Description : The Kutch specimens of Helminthopsis Sp. are smooth, unbranched, horizontal trails, filled with fine grain sand size particles and preserved on upper as well as lower bedding surfaces. Burrow diameter is constant throughout and filled identical to host rock. Maximum observed length is about 55.0 cm with diameter of 0.8 cm.

Discussion and Interpretation : These traces closely resemble Helminthoida illustrated by Chamberlain [1970, Fig.118]. However, the specimens from Kutch are placed in ichnogenus Helminthopsis because they lack the regular, tight meandering pattern of Helminthoida. Helminthopsis has been as an endogenic feeding trail of a worm [Chamberlain, 1971]. It has been described from marine to intertidal facies by Miller and Knox [1985].

Preservation : Convex hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It is found in the Gadhada Sandstone Member.

Association : Planolites, Palaeophycus, Didymaulichnus, Gyrochorte, Crossopdia

ICHNOSPECIES

Helminthopsis hieroglyphica HEER in MAILLARD 1877

Plate 32.b

Diagnosis : Smooth unbranched, irregularly winding burrows, typically alternating between winding and straight course.

Description : Variably preserved, smooth, unbranched straight to irregular winding burrows. Burrow diameter 0.4 cm, constant along length, typically short, maximum observed length is about 13.0 cm, burrow fill same as enclosing sediment.

Discussion and Interpretation : H. abeli [Ksiazkiewisz, 1977] is gently meandering, while H. heiroglyphica [Maillard, 1884] is irregularly winding burrow, with typically alternating winding and straight course.

Helminthopsis is a very simple burrow system ranging in age from late Precambrian [Webby, 1970] to Holocene [Swinbunks and Murray, 1981] and is a eurybathic form. Helminthopsis ichnospecies are differentiated on simple parameters such as burrow diameter, presence or absence of

[a] [i] Helminthopsis abeli Location : Vavdi
[ii] Nereites Sp.
[iii] Planolites Sp.

[b] Helminthopsis hieroglyphica Location : ENE of Vavdi

surface ornamentation and style and dimensions of winding and/or meanders [Ksiazkiewicz, 1977].

Preservation : Preserved in convex and concave epirelief and convex hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs on Gadhada Sandstone Member.

Association : Keckia, Gyrolithes, Susterigichnus

ICHNOGENUS

Isopodichnus BORNEMANN 1889, P.25

ICHNOSPECIES

Isopodichnus problematicus BCHINPEWOLF 1828

Plate 33

Diagnosis : Dimorphous trace fossils consisting of small, straight or curved double-ribbon trails upto about 6 mm wide transversely striated by fine furrows, both "ribbons" separated by median ridge, trail may be inter mittent, associated with "Coffee-bean" shaped impressions of corresponding size.

Description : The Kutch form is straight to gently curved, parallel to bedding plane and consisting of series of small coffee-bean shaped [double-ribbon] like bilobed trails separated by median furrow [0.1 to 0.15 cm]. Small band-like structure also consists commonly with unevenly spaced transverse ridges on the lobes. The maximum observed length is about 37.0 cm, width 2.0 cm, with coffee-bean shaped having dimension of 0.7 to 0.8 cm. It is interpreted as locomotions trails of small arthropods [Seilacher 1963, Bromley and Asgaard 1972].

Preservation : Preserved in convex relief on soles of beds.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Didymaulichnus, Gyrochorte, Crossopodia, Scolicia, Palaeophycus, Planolites, Helminthopsis

Isopodichnus problematicus Location : Gadhada

ICHNOGENUS

Keckia GLOCKER 1841, P.319

Diagnosis : Fillings of cylindrical tunnels with transverse annulation, single 'segments' bent, burrows straight or slightly curved, branched, 1 to 2 cm wide of varing length, lying on bedding plane, similar to Taenidium but much larger, filling probably fecal material passed through gut of animal.

ICHNOSPECIES

Keckia annulate GLOCKER 1841

Plate 30 [ii]

Diagnosis : Cylindrical, gently curved with equidistant transverse annulations. Burrow diameter constant throughout.

Description : K. annulata is sediment filled straight to gently curved, unbranched, thinly lined horizontal burrows. Length of the burrow is 8.0 cm and diameter of 0.7 cm, transverse laminae more or less equidistant [0.2 cm]. Burrow lying on bedding plane and fill identical to host rocks.

Discussion and Interpretation : Keckia [Glocker 1841] is similar to Taenidium [Heer 1877] but much larger from it.

Preservation : Concave and covex hyporelief, endichnial burrows, active fill, identical to matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Phycodes, Muensteria, Planolites, Palaeophycus, Megagrapton, Thalassinoides, Spongeliomorpha

ICHNOGENUS

Kouphichnium NOPCSA 1923, P.146

Diagnosis : Heteropodous tracks of great variability, complete track consisting of 2 kinds of imprints : [1] Two chevron-like series each of 4 oval or rounded holes of bifid V-shaped impressions of scratches, forwardly directed [made by anterior 4 pairs of feet]; and [2] One pair of digitate or flabellar, tow-shaped or otherwise variable imprints, track with or without median drag mark.

ICHNOSPECIES

Kouphichnium Sp. NOPCSA 1923

Plate 34

Description : The trace consists of straight symmetrical two parallel rows of marking impression, which is separated by median furrow [central telson groove]. The biserial row of transverse grooves are similar to made by modern limulid trackways. The trackways width about 4.0 cm and 30.0 cm long.

Preservation : Hypichnia [trackways] concave hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Gyrochorte, Scolicia, Volkichnium

Plate : 34

Kouphichnium Sp.

Location : Gadhada

ICHNOGENUS _

Lanicoidichna CHAMBERLAIN 1971, P.223

Type Species : Lanicoidichna metulata CHAMBERLAIN 1971.

ICHNOSPECIES

Lanicoidichnus metulata CHAMBERLAIN 1971

Plate 35

Diagnosis : U-shaped burrows, vertical to bedding, 1 to 3 secondary gallaries branching at base of 'U' from main burrow and running parallel with it, yielding W-shaped structures, occasionally linked at base by horizontal or oblique burrows, most additional burrows are smaller than primary gallery, individual burrows 2 to 7 mm wide, interval of limbs of 'U' or W-shaped structure 2 to 3 cm or more.

Description : Slender vertical galleries that are 2.5 to 3.0 cm wide and over 50.0 cm high that make perfect 'U' turns at the bottom. One or more additional vertical gallaries merge with the main gallery. Oblique and horizontal galleries are found linking adjacent gallaries at the base. One to three vertical gallaries branch from the primary gallary and many are smaller than the primary gallery.

Remarks : Chamberlain [1971], derived the ichnogeneric name from the similarity of the burrows to dwelling tubes of the polychaete Lanice. The specific name refers to the behaviour of the animal in its apparent preference for sand sized sediment, thus metu-fear, anxiety, Luta-mud.

Lanicoidichnus metulata

Location : Gadhada

This form is known at present from the Wapanucka Limestones near Hartshorne, Oklahoma [Chamberlain 1971]. The Kutch form is comparable to the Hartshorne form but has larger dimensions.

Preservation : Full relief, endichinal burrow belong to domichinal groups.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Ganeshpur Calcareous Sandstone Member.

Association : Monocraterion, Bergaueria, Cylindrichnus, Cylindrium

ICHNOGENUS

Lockeia JAMES 1879, P.17

Diagnosis : Small almond-shaped oblong bodies preserved in convex hyporelief, tapering to sharp and obtuse points at both ends, surface commonly smooth, mostly symmetrical, length varing from 2 to 12 mm.

ICHNOSPECIES

Lockeia Sp. JAMES 1879

Plate 36

Description : The Kutch specimen of Lockeia is almond-shaped elongate structure occuring on bedding plane. Surface of the trace is commonly smooth. In vertical section the true appears U-shaped. The length of traces vary from 0.5 to 1.8 cm, width 0.4 to 0.7 cm, height upto 0.8 cm and may be developed as clustered forms.

Preservation : Convex hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Pelecypodichnus, Planolites, Phycodes, Fustiglyphus

[i] Lockeia Sp.
[ii] Planolites annularis

Location : Ratanpur

ICHNOGENUS

Mammillichnis CHAMBERLAIN 1971, P.238

Type Species : Mammillichnis aggeris Chamberlain 1971.

ICHNOSPECIES

Mammillichnis aggeris CHAMBERLAIN 1971

Plate 37

Diagnosis : Sub-hemispherical teat-like protuberances 9 to 12 mm wide, 7 mm high, preserved in convex hyporelief, each mound consists of 3 to 5 mm hemicircular apex and wide flange.

Description : A positive hyporelief consisting of smooth, sub-hemispherical protuberances with circular or elliptical terminal projections. Structures are scattered on bedding plane, with diameter of 2.0 to 4.0 cm and relief is upto 0.8 cm. The top most part of the burrows are eroded and form circular ring.

Discussion and Interpretation : The structure compare closely with Mammillichnus aggeris Chamberlain [1971]. Chamberlain acknowledges that the exact nature of form is difficult to establish but suggest that it was produced by an organism resting or hiding in the sediment. Crimes et al [1981, P.976] suggest that specimens of this form from the polish carpathion and Swiss flysch deposits may be resting traces of an anthozoan. Mammillichnus and Bergaueria are probably related and may represent preservational end members of continum of forms.

Mammillichnus aggeris

Location : Gadhada

Preservation : Positive hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Bergaueria, Calycraterion, Cylindricum

ICHNOGENUS

Megagrapton KSIAZWIEWICZ 1968, P.5, 14

Diagnosis : Networks consisting of irregular polygons and rectangles which are never closed, formed by slightly curved or straight cylindrical strings, 1 to 5 mm wide, rather regular intervals of branching at nearly right angles.

ICHNOSPECIES

Megagrapton irregulare KSIAZWIEWCZ 1968

Plate 38

Diagnosis : Many second order undulations with few anastomoses, which result in large meshes of unequal size, resembling a political map [Seilacher 1977, P.321].

Description : The Kutch forms are large with relatively few and wide meshes of irregular shape. The burrows are, circular in cross-section, form cylindrical stringe with diameter of 1.5 cm and found to associate on the same bedding plane.

Preservation : Positive hyporelief, endichnial burrow.

Stratigraphic Distribution : Found in the Gadhada Sandstone Member.

Association : Helminthopsis, Gyrochorte, Didymaulichnus, Planolites, Rhizocorallium

Megagrapton irregularie Location : Vavdi

ICHNOGENUS

<u>Merostomichnites</u> PACKARD 1900, P.67

ICHNOSPECIES

<u>Merostomichnites strandi</u> STORMER 1934

Plate 39

Diagnosis : Two parallel rows of circular bow or spindle-shaped feet impressions, transversely or slightly obliquely arranged, opposite to each other.

Description : The Kutch forms, simple, unbranched and characterized by two parallel rows of ribbon-like raking trail with narrow poorly preserved median furrow, rows transversely arranged and opposite to each other. The trail is straight to gently curved, 13.0 cm long and 1.7 cm wide, occurs on the top of the bedding plane.

Preservation : Preserved is hypichnial trackways concave and convex hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Hadibhadang Pir Member.

Association : <u>Gyrolithes</u>, <u>Cochlichnus</u>, <u>Curvolithus</u>, <u>Chondrites</u>, <u>Protopaleodictyon</u>

[i] Merostomichnites strandi Location : West of Umrapur
[ii] Planolites Sp.

ICHNOGENUS

Mesichnium GILMORE 1926, P.34

Type Series : *Mesichnium benjamini* GILMORE 1926.

ICHNOSPECIES

Mesichnium benjamini GILMORE 1926

Plate 40

Diagnosis : Two parallel lines of footpoints with median row of suboval regularly spaced depressions, trackway about 20 mm wide, stride about 15 mm long.

Description : Hypichnial trails consisting of two parallel lines of oval footpoints with faint medial depressions. Ovals are usually bilaterally symmetrically distributed on either side of the furrows and arranged on one straight line and forms trackways, 1.2 cm wide and 15.0 cm long. Ovals are upto 0.2 cm in diameter with relief of 0.1 cm.

Preservation : Preserved as hypichnia.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Hadibhadang Dungar Member.

Association : *Pelecypodichnus* and bivalve boring.

Plate : 40

Mesichnium benjamini

Location : East of Umrapur

ICHNOGENUS

Monocraterion TORELL 1870, P.13

Diagnosis : "Trumpet Pipes", funnel structure penetrated by central straight or slightly curved plugged tube, perpendicular to bedding plane, never branched, diameter commonly 5 mm; upto 8 cm long, funnel simple or multiple, diameter of funnels usually 1 to 4 cms; greatest depth about 2 cm; tubes commonly abundant but never crowded like Skolithos. Funnel obviously constructed by upward migration of animal inhabiting tube is reflected by downward warping of surrounding bedding planes toward central tube.

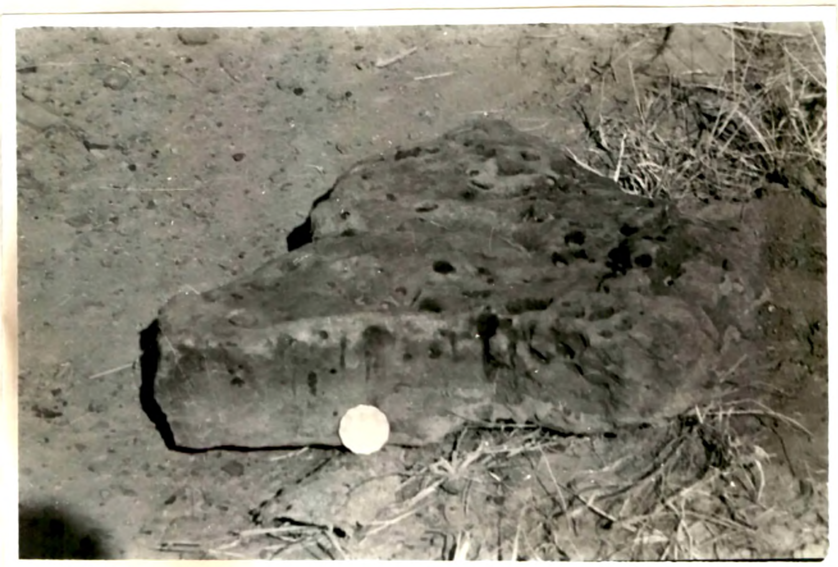
ICHNOSPECIES

Monocraterion tentaculatum TORÉLL 1870

Plate 41

Diagnosis : Vertical, more or less cylindrical shafts having a broad, funnel like opening at the upper end.

Description : The trace consists of straight, cylindrical burrows which are unbranched and filled with surrounding substrate. They occur either as closely spaced or isolated on bedding plane, mostly seen as circular to sub-circular outline on the top surface. Burrows oriented normal to bedding plane, which very often pass upward into ovate funnel. Several specimens show funnels with raised rims, which may reflect linings to the funnels. Funnel diameter is variable, the maximum observed being 4.1 cm at the upper most widest part, shafts diameter varies from 1.7



Monocraterion tentaculatum

Location : Bambanka

to 2.3 cm with maximum observed length of 27.0 cm. Funnels vary in height in different burrows population.

Discussion and Interpretation : The author found frequently Monocraterion in associations with Skolithos burrows. This confirms the view of Hallam and Swett [1966] that the difference between the burrows of these two ichnogenera is not due to different tracemaker organisms but to different rate of sedimentation. Skolithos is formed under conditions of slow sedimentation and Monocraterion occurs with conditions of relatively rapid sedimentation. Monocraterion is considered to be the dwelling structures of a worm-like organism, possibly a polychaete, for which the tube of Diapatra caprea may be a modern analog [Mayers 1970, Barwis 1985]. Monocraterion also occur in high densities.

Preservation : Positive hypichnial mold, circular scour with resistant burrow.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Ratnasar Calcareous Sandstone Member and Bambanka Member.

Association : Skolithos, Arenicolites, Ophiomorpha, Cylindrichnus

ICHNOGENUS

Muensteria VON STERNBERG 1833, P.31

Diagnosis : Long, horizontal to subhorizontal, straight to slightly curved, unbranched, unlined cylindrical burrow. Arcuate maniscate structure indicate backfilling traces.

Remarks : Trace fossils with back-fill structures are either called Planolites montanus [Richter 1937], Taenidium [Heer 1877], Keckeia [Glocker 1842] or Muensteria [Sternberg 1833]. According to Fursich [1974] there is no basic difference between these ichnogenera and the former are, therefore, regarded as synonyms to Muensteria which has priority. According to Frey and Howard [1985] Muensteria includes distinctly maniscate, cylindrical to subcylindrical burrows having discerniable but lined walls. The taxon as suggested by these authors need systematic revision. The Kutch forms appear to be correlative to the coralline [upper Jurassic] specimens described by Fursich [1974] and are, therefore, generalised as Muensteria Sp.

ICHNOSPECIES

Muensteria Sp. STERNBERG 1833

Plate 51.b[ii]

Description : The trace consists of long, straight or moderately sinuous, cylindrical, unbranched unlined burrow, having a transverse meniscate packing pattern. The transverse section also reveals an internal structure in the form of concave-convex segments. The surface of the burrows clearly indicate the nature of segmentation either by its concentric rings or by its annular constrictions. The rings have arcuate ridge-like structure, width of which 0.6 to 9.0 cm and 0.2 to 0.4 cm apart. Maximum observed length is about 29.0 cm and diameter of 1.3 cm. Burrows are circular to subcircular in cross-section and filled identical to the host racks.

Discussion and Interpretation : In a detailed analysis of Planolites montanus and Taenidum, Richter [in Fursich 1974, P.14] interpreted cup-shaped segments as back fill structures made by deposit feeders. Probably, the worm-like animal was eating its way through the sediment and filled the thus created tunnel immediately in a backward direction by the periodic release of waste. These segments of waste were then pressed into each other by animal, resulting in their cup-shaped arrangement. Richter's interpretation is well in agreement with the observations made on the Kutch specimen by the author who therefore regards Muensteria as the fodinichnia of a deposit-feeder [probably a worm].

Preservation : Convex hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Planolites, Palaeophycus, Phycodes, Keckeia, Rhizocorallium

ICHNOGENUS

Neonereites SEILACHER 1960, P.48

Type Species : Neonereites biserialis Seilacher 1960, P.48.

ICHNOSPECIES

Neonereites biserialis SEILACHER 1960

Plate 51.a[iii]

Diagnosis : Bimorphous, shape depending on its hypichnial or exichnial preservation, as negative epireliefs consisting of irregularly curved chains of deep, smooth walled dimples, chain restricted in length, some bordered laterally by flabby structures caused by burrowing, corresponding hypichnia form a median string, irregularly curving or straight or rarely meandering consisting of single or double-lined clay [fecal] pellets or small plates.

Description : The Kutch specimen of Neonereites biserialis is straight horizontal and consists irregular pods or pellet of sediment arranged in double row. The pods are arranged in one line and form chain on top of the bedding plane. Pods are either isolate or adjacent but never overlapping. It is roughly elliptical in cross-section, 1 mm high and 1.5 mm wide. Chains 7.0 to 10.0 cm in length.

Discussion and Interpretation : Neonereites biserialis is characterised by double row of pods without an axial groove, and commonly found in deep-water deposits exposed on land [Seilacher 1962, 1964].

Neonereites is a facies-crossing ichnospecies and has been reported in strata of late Precambrian [Fedonkin 1977] to Tertiary [Hantzschel 1975] age.

Preservation : Preserved in convex hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Rhabdoglyphus, Scolicia

ICHNOGENUS

Nereites MACLEAY 1839, P.700

Type Species : Myrianites macleaii Macleay 1839.

Diagnosis : Meandering trails, consisting of narrow median furrow, flanked on both sides by regularly spaced leaf-shaped, ovate or pinnate lobes, closely spaced, commonly finely striated, meanders may be densely spaced, width of trail 1 to 2 cm, meanders variable in form in width, shape and size of the lateral lobe-like projections.

ICHNOSPECIES

Nereites MACLEAY 1839

Plate 32.a[ii]

Description : Straight to gently curved epichnial horizontal trail with median furrow flanked on both sides by smooth rounded lobes. Length of the trails upto 13 cm and width of about 1 cm. The trails are commonly preserved on top of the bedding plane and infilled by darker material.

Discussion and Interpretation : Nereites is considered by Seilacher [1964] to be typical of deep sea water but examples have been described from undoubted shallow-water sediments, in the Carboniferous of Kansas [Hakes 1976], Devonian of north Spain [Garcia Ramos, 1976] and the Precambrian-Cambrian Nama Group of Namibiba [Crimes and Grams, 1982] in Crimes and Anderson 1965 [P.327]. According to Hantzschel [1962] the trails are made by annelids or gastropods.

Preservation : Preserved on convex and concave hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Neonereites, Scolicia

ICHNOGENUS

Ophiomorpha LUNDGREN 1891

Diagnosis : Three-dimensional burrows systems, vertical and horizontal, cylindrical tunnels dichotomously branching, generally at acute angles, with local swelling close to or at points of branching, tunnels internally burrow lining characteristically mammillate due to presence of discoidal or ovoid pellets, which are several mm, rarely more, in diameter, tunnels may also be only partly lined by small pellets, longitudinal ridges occur on outer surface of some burrow fillings. Burrows occasionally penetrating sediment for more than 1 m in depth.

ICHNOSPECIES

Ophiomorpha nodosa LUNDGREN 1891

Plate 42.a

Diagnosis : Burrow walls consisting predominently of dense, regularly distributed discoid, ovoid and irregularly polygonal pellets.

Description : The Kutch specimens of Ophiomorpha nodosa are usually in the large-scale branched or unbranched burrow systems of shafts and horizontal to gently inclined tunnels. Almond-shaped structures, are very common on bedding plane view. The walls of the burrow are usually smooth on their interior and typically mammilated exterior surface. The exterior burrow wall consists predominently of dense regularly distributed single pellets. Length and diameter of burrows are variable in different burrows population. Somewhat enlarged chambers occurs at point of bifurcation.

Diameter of the burrow is upto 4.0 cm and length is upto 70 cm; no apertural necks observed. Burrows are filled with sediment like that of the surrounding substrate, but unfilled tube segments are also very common.

Discussion and Interpretation : The ichnogenera Ophiomorpha Lundgren 1891 and Thalassinoids Ehrenberg 1944 were treated as Junior subjective synonyms of Spongiliomorpha saporta 1887 by Fursich [1973], who recognized S. nodosa as valid ichnospecies. This assessment subsequently was challanged on a number of points by Bromley and Frey [1974 P.312-313] and later Frey et al [1978] not only in recognizing the ichnogenus Ophiomorpha but also in their redefinition of its species.

Jurassic burrow forms in Kutch clearly can be referable to O. nodosa, the type species, characterized by dense, regularly distributed predominently single pellet mode of wall formation [Frey et al 1978]. Pellet form somewhat ranging from discoid to oval are also found sometimes in Kutch. According to Frey et al [1978] O. nodosa, burrows are formed by macroinvertebrate Callianassa major say and other callianassid species, which live in near shore and lower foreshore of barrier island beaches in normal marine salinity.

Preservation : Full relief, burrow filled identical to matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member,

[a] <u>Ophiomorpha nodosa</u> Location : West of Umrapur

[b] <u>Ophiomorpha borneensis</u> Location : Vavdi

Hadibhadang Pir Member and Ganeshpur Calcareous Sandstone Member.

Association : Skolithos, Arenicolites, Lanicoidichnus, Monocraterion

ICHNOSPECIES

Ophiomorpha borneensis KEIJ 1965, P.224-226

BROMELY AND FREY 1974

Plate 42.b

Diagnosis : Burrow walls consisting predominently of dense regularly distributed bilobate pellets.

Description : Branched burrow systems of shaft and horizontal to gently inclined tunnels, having thick clayey walls with smooth interiors and distinctly mamillated to irregular regose surface packed with the bilobated pellets. Length of the burrow is about 20 cm and diameter of 2.5 cm. Burrow enlarged at point of bifurcation. Unfilled tubes are very common, but author also observed burrows normally filled with like that of surrounding matrix.

Discussion and Interpretation : This form of Ophiomorpha was located only in Gadhada Calcareous Sandstone unit. According to Frey et al [1978] the morphology of this forms like O. nodosa and O. irregularise could be genetically related. Fursich [1973] considered O. borneensis synonym as to Spongiliomorpha satonica but failed to consider the bilobate pellets.

Preservation : Full relief, burrow wall constructed by bilobate pellets and filled with surrounding matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member and Ganeshpur Calcareous Sandstone Member.

Association : Skolithos, Arenicolites, Planoites, Palaeophycus

ICHNOSPECIES

Ophiomorpha irregularie

Plate 43.a

Diagnosis : Burrow walls consisting predominantly of dense, varying shape and size irregularly distributed nodosa structures.

Description : These include large straight vertical unbranched cylindrical burrows. Usually occurs in groups. The walls of these burrow forms are usually thick and made up of clayey material [sediments], interiorly smooth and exteriorly lined with irregularly distributed discoid and ovoid pelletoidal structures. Pellets are upto 0.45 cm in diameter. The maximum observed length of the burrows is 50.0 cm and diameter of upto 4 cm. Burrow collapse and unfilled structure are very common in Ganeshpur section. Some burrows are eroded on the top of the bedding plane and form as funnel shape to misguiding with Monocraterion Torell 1870, but immediately after the concealed nodos structures are very well preserved. In few tubes, burrow line is distinct and commonly filled with surrounding material.

Discussion and Interpretation : This form of Ophiomorpha exhibits pelleted to rugose exterior wall surface where the patterns of Pellet arrangement is not nearly as regular and distinct as that is found in species of Ophiomorpha nodosa Lundgren 1871 [single pelleted wall] or Ophiomorpha borneensis Keij 1965 [double pelleted wall].

Preservation : Full relief. Burrow collapse structure may indicate unfilled segments.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Ganeshpur Calcareous Sandstone Member.

Association : Skolithos, Bergaueria, Cylindrichnus, Arenicolites, Cylindricum

ICHNOSPECIES

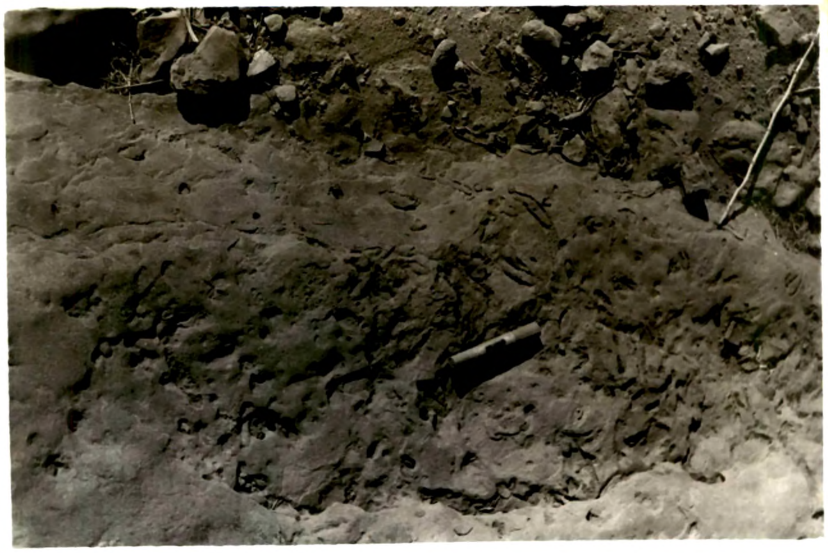
Ophiomorpha Sp. LUNDGREN 1871

[Boxwork Burrows]

Plate 43.b

Description : These include the large, pelletoidal [single or double] horizontal network burrow systems that branch in an orderly manner to form polygonal patterns in the horizontal plane and is confined to single

Plate : 43



[a] Ophiomorpha irregularie Location : West of Umrapur

[b] Ophiomorpha Sp. [Box-work burrows Location : Gadhada

level in the individual facies. Branches in such burrows are seen typically enlarged [6 cm] at the point of their bifurcation. Individual burrow tubes are 3.5 to 4.0 cm in diameter. The burrow network is spread and covering an area of about 50 x 30 cm. Most of the burrows in the network are circular in cross-section and have fills identical to their matrix.

Discussion and Interpretation : The burrow morphology are identical with single pelletoidal forms of Ophiomorpha Lundgren 1870 [Ophiomorpha nodosa] and network burrow systems probably were constructed to form support of combined dwelling/feeding activities. According to Curren and Frey [1977] and Frey et al [1978], ghost shrimp Callianassa biformis formed [or constructed] the boxwork burrow system where as C. major is characterized by shafts and tunnels.

Preservation : Full relief, preserved as epichnia, hypichnia and endichnia.

Facies : Micritic Sandstone.

Stratigraphic Distribution : The species is common in the Hadibhadang Pir Member.

Association : Skolithos, Gyrolithes

ICHNOGENUS

Palaeophycus HALL 1847

Type Species : Palaeophycus tubularis HALL 1847. Hantzschel 1975, Pemberton and Frey 1982, Howard and Frey 1984.

Diagnosis : Cylindrical or subcylindrical burrows, usually sinuous, oriented more or less obliquely to bedding. Commonly unbranched, though may be branched occasionally. Surface of walls smooth or rarely with faint longitudinal striae. Palaeophycus is distinguished from Planolites by having a distinct wall lining and sediment fill typically different from the lithology of the host sediments.

Remarks : Palaeophycus originally defined by Hall [1847] has confusing taxonomic nomenclatural history. There are 54 ichnospecies assigned to Palaeophycus. Pemberton and Frey [1982] grouped these into five main species of Palaeophycus. These are recognized on the basis of wall linings and burrow sculpting as :

[1] Distinctly lined, smooth walled, unornamented burrows.

- [a] Thick walled burrows - P. heberti
- [b] Thin walled burrows - P. tubularis

[2] Very thinly lined logitudinal striated burrows.

- [a] Continuous parallel striae - P. striatus
- [b] Irregularly anastomosing striae - P. sulcatus
- [c] Alternatively striae and annulate - P. alternatus

ICHNOSPECIES

Palaeophycus tubularis HALL 1847

PEMBERTON AND FREY 1982

Plate 44.a

Description : Cylindrical to slightly flattened, straight to slightly curved more or less smooth walled burrow, parallel to a slightly oblique to the stratifications. Branching is rare. Burrow walls are irregular and the burrow fill is structureless and identical to host rock. Width and length of the burrow tubes are variable in different burrows population. Maximum observed length is 27 cm with diameter of 3.2 cm Burrow collapse structures are very common, representing incomplete filling by sediments.

Discussion and Interpretation : P. tubularis, the species of Palaeophycus is distinguished from P. heberti by the consistently thicker wall lining of the later and from other species by the absence of persistent, well-developed striae [Pemberton and Frey 1982].

Preservation : Preserved as endichnia, hypichnia or epichnia.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member and Hadibhadang Pir Member.

Association : Planolites, Phycodes, Muensteria, Rhizocorallium.

[a] [i] Palaeophycus tubularis Location : ENE of Vavdi
[ii] Muensteria

[b] Palaeophycus striatus Location : Ratanpur

ICHNOSPECIES

Palaeophycus striatus HALL 1852

PEMBERTON AND FREY 1982

McCANN AND PICKERILL 1988

Plate 44.b

Description : Cylindrical, branched, straight to undulose of flexuous burrows bearing numerous fine, continuous essentially parallel longitudinal striations. Burrows tends to exhibit less collapse compare to other species. Length of the burrow is 14 cm and diameter varies from 1.8 to 2.7 cm. Burrow fill structureless and identical to enclosing sediments.

Discussion and Interpretation : P. striatus is distinguished from P. alternatus by consisting longitudinal striatious rather than alternating striations in the later.

Preservation : Preserved as epichnia near lithologic interfacies or more commonly as hypichnial ridges.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Planolites, Thalassinoides, Spongeliomorpha, Phycodes, Rhizocorallium

ICHNOSPECIES

Palaeophycus heberti SAPORTA 1872

PEMBERTON AND FREY 1982

Plate 45.a

Diagnosis : Smooth, unornamented, thickly lined cylindrical burrows.

Description : Straight to slightly curved, branched or unbranched, smooth-walled cylindrical burrows. Diameter more or less remain constant, collapsed burrows are common. Burrow wall linings typically consist of agglutinated sediment, coarser and better seated than that of adjacent host rock. Burrow length of 27 cm and diameter of 3.2 cm, burrow fill structureless and identical to enclosing sediments.

Discussion and Interpretation : Original specimens of Palaeophycus heberti were assigned initially to the ichnogenus Siphonites [Saporta 1872] although their affinity with Palaeophycus was noted subsequently [Saporta and Marion, 1883]. Pemberton and Frey [1982] confirm Siphonites as a junior synonym of Palaeophycus.

The thick wall lining distinguishes P. heberti from P. tubularis. Interpenetrations and branchings are somewhat less common than to P. tubularis.

Preservation : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Rhizocorallium, Thalassinoides, Skolithos, Planolites, Phycodes

ICHNOSPECIES

Palaeophycus sulcatus MILLER AND DYER 1878

PEMBERTON AND FREY 1982

McCANN AND PICKERILL 1988

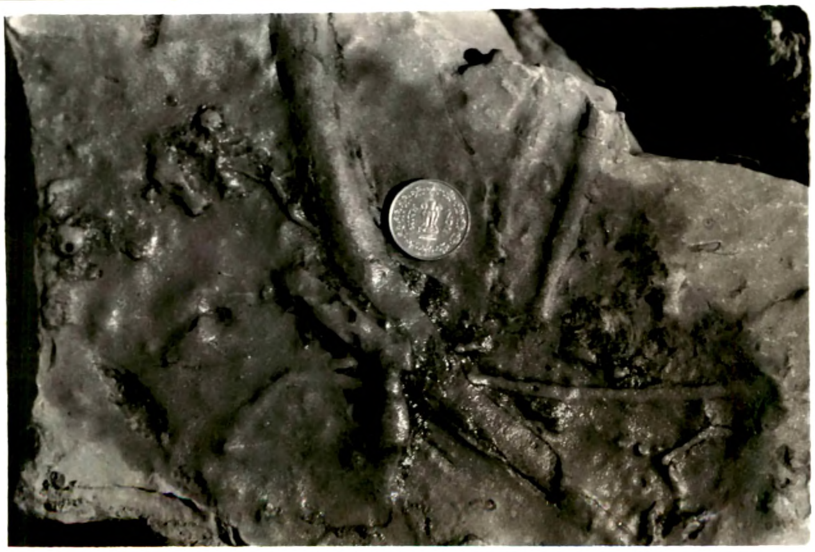
Plate 45.b

Diagnosis : Irregularly subcylindrical thinly lined burrows ornamented with sharp, anastomosing, thread-like striations.

Description : Burrows infrequently branched, curved thinly lined, slightly oblique to horizontal burrows, distinctly sculpted with interwoven small ridges and grooves. Length of burrow 21 cm and diameter of 2.7 cm. Burrow diameter is somewhat changed from one side to another. Burrow fill structureless and identical to enclosing sediment.

Discussion and Interpretation : The close affinity between Fucusopsis and Palaeophycus or Planolites was recognized by Osgood [1970], but he suggested that synonym await reassessment of Palaeophycus. Pemberton and Frey [1982] confirms that Fucusopsis is junior synonym of Palaeophycus although original concept of Fucusopsis remains valid at the species level. The material of Miller and Dyer [1878] thus become type specimens and name-bearers for this ichnospecies. Burrow collapse features are some what less common in P. sulcatus than in P. tubularis and P. heberti. P. heberti is distinguished from P. striatus by

[a] [i] Palaeophycus heberti Location : East of Umrapur
[ii] Rhizocorallium jenense



[b] Palaeophycus sulcatus Location : East of Umrapur

anastomosing rather longitudinal striations and from P. alternatus by consistant, rather than alternating striations.

Preservation : Semi relief, endichnial burrows.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Hadibhadang Pir Member.

Association : Planolites, Ophiomorpha, Rhizocorallium, Phycodes

ICHNOGENUS

Paleodictyon MENECHINI in MURCHISON 1850, P.484

Diagnosis : Honeycomb-like network of ridges in hyporelief, consisting of remarkably regular hexagonal polygons, may be also 4 to 8 sided, reticulate pattern of considerably varying size but diameter of meshes constant within individual net, walls of meshes 0.5 to 2 mm wide and occasionally consisting of small circular or oval "pimples" closely arranged in rows which may cross one another regularly, network may cover large areas upto about 1 sq.m; polygons sometimes elongated due to current action.

Remarks : Paleodictyon is distinctive trace fossil consisting of a regular or irregular net. According to Chamberlain [1971] more than 10 generic and more than 20 species names have been proposed for these trace. Seilacher [1977] grouped into three sub ichnogenus and seven ichnospecies based on mesh shape and outlet arrangement.

ICHNOSPECIES

Paleodictyon imperfectum SEILACHER 1977, P.325

Plate 46

Diagnosis : Large form with fairly wide meshes of unequal size and shape, outline of the system angular, probably, hexagonal.

Description : Burrow represents development of network of ridges to form meshes of unequal size and shape. The meshes are four to six sided,

Paleodictyon imperfectum Location : East of Umrapur diameter of meshes also variable, wall of meshes 0.2 cm to 0.3 cm wide. Burrows preserved as hyporelief in fine to medium grained calcareous sandstone. Mesh of the burrow of moderate size 1.5 cm to 3.0 cm.

Preservation : Preserved in convex hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Hadibhadang Pir Member.

Association : Chondrites, Cochlichnus, Beaconichnus

ICHNOGENUS

Palmichnium RICHTER 1954, P.267

Type Species : Palmichnium palmatum Richter 1954.

ICHNOSPECIES

Palmichnium Sp. RICHTER 1954

Plate 47

Diagnosis : Large, Plant-like track about 11 cm wide opposed symmetrical rows of [leg] impressions, median keel, divided at regular intervals, bordered by longitudinally directed club-shaped impressions distinctly set off toward interior, but distinctly toward exterior.

Description : Large, irregular, horizontal, plank-like track, consisting of spreiten structures built of curved ridges. These ridges are preserved on either side of the median furrow. It has no well defined boundary and are formed by an overlapping series of small cheveron like marks. Furrow has maximum length about 17 cm and is 5 to 7 cm wide. Richter [1954] interpreted such burrows as crawling tracks made by arthropod, probably eurypterid.

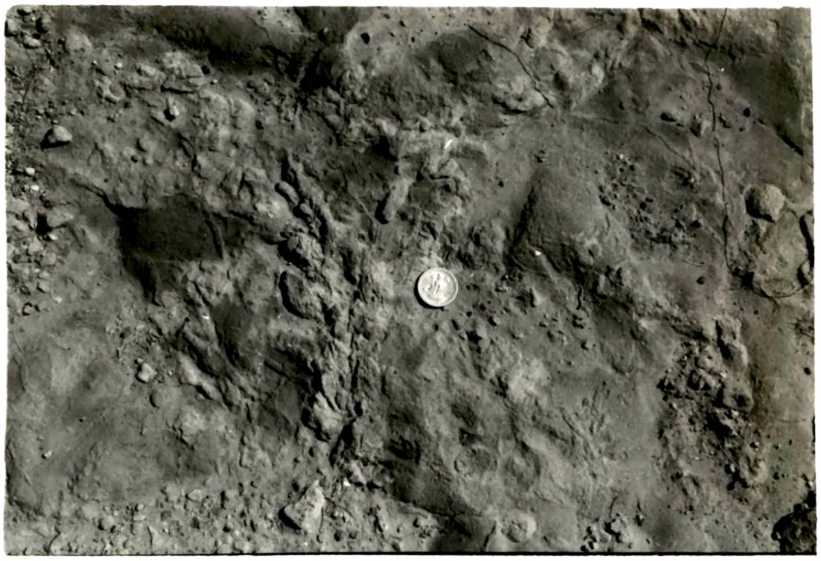
Preservation : Preserved in convex hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Gyrolithes, Muensteria, Planolites

Plate : 47



Palmichnium Sp. Location : Ratanpur

ICHNOGENUS

Pelecypodichnus SEILACHER 1953, P.105

Type Species : *Pelecypodichnus amygdaloides* Seilacher 1953.

ICHNOSPECIES

Pelecypodichnus amygdaloides SEILACHER 1953

Plate 48.a

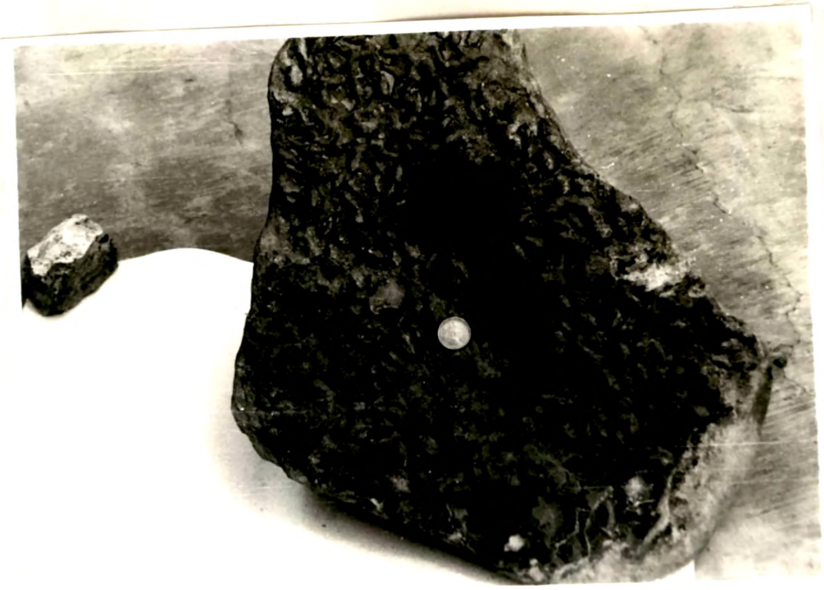
Diagnosis : Almond-shaped structure preserved in either convex relief on the soles of beds or concave relief on the tops.

Description : Small almond-shaped proturberances on bedding planes which frequently occur in great abundance and may show parallel to subparallel alignment. Surface usually smooth and both ends may be pointed. In vertical section, they are usually U-shaped. The length varies from 2.0 to 4.0 cm, width ranges from 1.0 to 1.8 cm and height varies from 0.8 to 5 cm.

Discussion and Interpretation : Eager, 1974 [in Hakes 1970] demonstrated that the non-marine bivalve *carbonicola* was the likely producer of some forms of *Pelecypodichnus.* Such forms are also reported from fully marine environment by Seilacher [1953]. It is therefore, not possible to indicate a definite producer or a salinity range on these basis. The Kutch form by its association appears to have marine influence.

Preservation : Preserved as full relief, convex hyporelief.

Plate : 48



[a] <u>Pelecypodichnus amygdaloides</u> Location : Gadhada

[b] <u>Pelecypodichnus czaranockii</u> Location : Vavdi

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Lockeia, Planolites, Palaeophycus, Rhizocorallium, Muensteria

ICHNOSPECIES

Palecypodichnus czaranockii KARASZEWSKI 1974

Plate 48.b

Description : Hypichnical, small asymmetric, strongly concave, drop-shaped trace fossils. One end is sharp and opposite end broad. This form is larger than P.amygdaloides. The maximum observed length is about 4.5 cm and 2.5 cm broad. Note the trace make being preserved.

Preservation : Concave hypichinial traces.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member and Hadibhadang Pir Member.

Association : Mesichnium and bivalve boring.

ICHNOGENUS

Phoebichnus BROMBLEY AND ASGAARD 1972, P.29

Type Species : *Phoebichnus trochoides* Bromley and Asgaard 1972.

Diagnosis : Central shaft 6 to 8 cm; in diameter nearly vertical to bedding with numerous, long, straight radial burrows oriented more or less parallel to bedding, radial burrows about 1.5 cm in diameter including distinct, annulated wall lining about 5 mm thick, mica flakes infilling of radial burrows oriented in descrete concave-convex planes, concave towards the central shaft, total length of shaft and tunnels unknown.

ICHNOSPECIES

Phoebichnus Sp. BROMLEY AND ASGAARD 1972, P.29

Plate 49

Description : The Kutch specimen *Phoebichnus Sp.* is large and characterized by central shaft [covered by the sediments] about 4 to 6 cm in diameter and perpendicular to bedding plane with six, long, straight cylindrical radial burrows, oriented parallel to the bedding plane. Length of the radial burrows varies from 9 to 17 cm and diameter of 2.0 to 3.2 cm. Burrow preserved on convex hyporelief.

Bromley and Asgaard [1972] interpreted that central shaft of burrow as dominichnia and radial burrows as fodinichnia of some unknown animal.

Preservation : Full relief, preserved as epichnia, hypichnia and

Plate : 49

Phoebichnus Sp. Location : East of Umrapur endichnia.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Hadibhadang Pir Member.

Association : Phycodes, Planolites, Palaeophycus, Muensteria, Spongeliomorpha, Thalassinoides

ICHNOGENUS

Phycodes RICHTER 1850, P.205

Diagnosis : Bundled structures of flabellate or broom-like pattern consisting of horizontal tunnels, proximal part of main tunnels unbranched, distal tunnels divide at acute angles into several free cylindrical tunnels showing delicate annulation beneath thin smooth "bark", main branches may show structure similar to retrusive spreiten vary considerably in morphology from type species which is also variable, about 15 cm, long in entirely generally preserved as convex hyporelief in quartzites.

ICHNOSPECIES

Phycodes palmatum HALL 1852

Plate 50.a

Diagnosis : Fan or radial system of horizontal branching burrows. Burrow essentially uniform with througout, long linear or slightly curving, branching close together.

Description : The Kutch specimens are characterized by long, thick horizontal arm like burrows with palmately branching burrows [finger like] system which are more or less parallel to each other and terminates in rounded end. The branching burrows are unilobed, the individual burrows being about 6.0 cm to 7.0 cm long, 1.3 cm in diameter, the palm dimension is 4 x 3 cm and main tubes 7.0 cm long and 3.8 cm diameter.

Discussion and Interpretation : The tunnels of Phycodes palmatum are more slender and finger-like than the club-shaped tunnels of Asterosoma radiciforme. In addition, they branch from a common burrow of nearly horizontal orientation where as Asterosoma radiciforme a central, shaft-like burrow enters the radiating patterns at a hing Phycodes curvipalmatum by its larger size, straight burrows and lack of recurvature. Phycodes commonly occurs in the off-shore portion of the littoral zone where sufficient organic material can accumulate and support deposit feeding endobenthos [Martino 1989].

Preservation : Full relief, convex hyporelief, fill identical to substrate.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Planolites, Palaeophycus, Muensteria, Keckeia, Magagrapton

ICHNOSPECIES

Phycodes Sp. RICHTER 1850

Plate 50.b

Description : Horizontal, ramifying and branching burrow systems. Individual burrows possess a tube-like form [common burrow] proximally but distally split into finger like straight to gently curved branches. Common burrows may be unilobed, bilobed or rarely trilobed, 0.5 to 0.9 cm in diameter and 7.0 to 11.0 cm in length. Cross-cutting of the

[a] [i] <u>Phycodes palmatum</u> Location : Vavdi
[ii] <u>Planolites Sp.</u>

[b] <u>Phycodes Sp.</u> Location : Vavdi

burrows may form a wide net-like pattern. The branched terminations may occur in isolation or may overlie one another, Phycodes represent the systematic mining by a worm having a fixed base moving downward and outward through the sediments. Externally the burrows are smooth and they sometimes have a bioturbàted filling.

Preservation : Full relief convex hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Rhizocorallium, Muensteria, Planolites, Siphonites, Spongiliomorpha

ICHNOGENUS

Planolites NICHOLSON 1873, P.289

Type Species : Planoites vulgaries Nicholson and Hinde 1875, P.139.

Diagnosis : Unlined, rarely branched, straight to tortuous, smooth to irregular walled or annulated burrows, circular to elliptical in cross-section of variable dimensions and configuration infillings essentially structureless, differing in lithology from host rock.

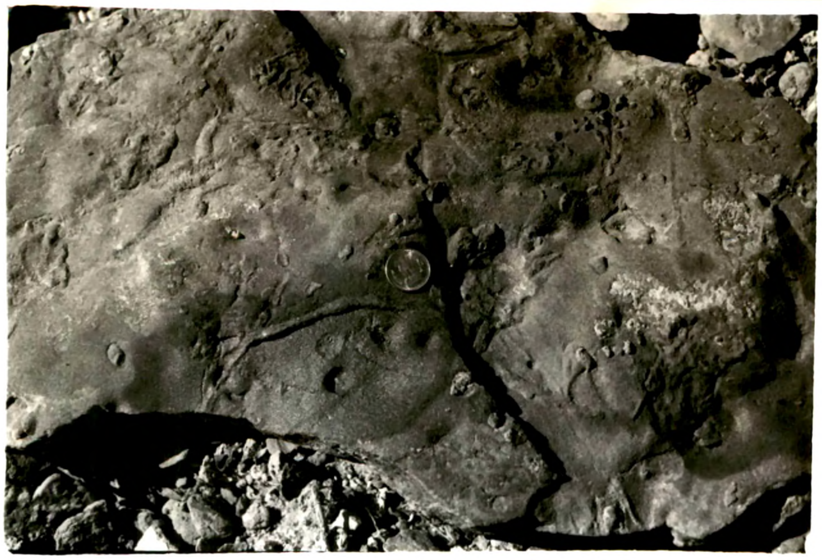
Remarks : The definition of Planolites is given by Hantzschel [1962] and Crimes and Anderson [1985]. According to these authors Planolites is a broad ichnogenus ranging from Precambrian to Recent and is simple in form that many different animal species were probably responsible for it. This definition is so simple that many irregular burrows can meet the specifications. In the years following Nicholson [1875] work at least 30 additional ichnospecies of Planolites have in same way or another been named and described. Recently Pemberton and Frey [1982] have grouped these species into three distinct forms. Planolites beverlyensis, P. annualaris, and P. montanus primarily upon size and curvature and wall characteristics :

[1] Small, curved to tortuous burrows - P. montanus,

[2] **Large**, straight to gently curved burrows - P. beverlyensis,

[3] Transversely annulated burrows - P. annularis.

Planolites is distinguished from Palaeophycus primarily by having unlined



[a] [i] Planolites beverlyensis
[ii] Scolicia Type B
[iii] Neonereites Sp.

Location : Ratanpur

[b] [i] Planolites montanus
[ii] Muensteria Sp.

Location : Ratanpur

walls and burrows fills differing in texture from that of the adjacent rocks. Fill also differ in fabric, composition and colour as well. Infills of Planolites represent sediments processed by the trace maker, especially through deposit feeding activities of mobile endobionts.

Careful petrographic study of the specimens and their field relationship with physical stratification has often helped the author for their identification.

ICHNOSPECIES

Planolites beverlyensis BILLING 1862

PEMBERTON AND FREY 1982

McCANN AND PICKERILL 1988

Plate 51.a

Diagnosis : Relatively large, smooth to somewhat irregularly walled, essentially cylindrical burrows, straight to gently curved or undulant.

Description : Predominently cylindrical, smooth-walled rarely to irregularly branched or unbranched burrows, typically oriented more or less parallel with bedding. Rare specimens display discontinuous, poorly developed annulations. Burrows occurs single isolated specimens to crowded masses in which, crossovers, interpenetrations and reburrowed segments are common. Dimension varies from different burrows population. Length of burrow is varied from 18 to 23 cm and diameter of 0.8 to 1.3 cm.

Discussion and Interpretation : Planolites Nicholson, 1873 and its ichnospecies have been reviewed by Pemberton and Frey [1982] and as previously noted, apart from minor emendation at the ichnogeneric level by Fillon and Pickerill [1984], is considered the most workable nomenclatural system. Pemberton and Frey [1982] used size, curvature and wall characteristics to differentiate between the three ichnospecies they regarded recognizable, namely P. beverlyensis [Billing 1882], P. annularis Walcott [1890], and P. montanus Richter [1937].

Planolites annularis is distinctly annulated and is the most easily recognizable of the three ichnospecies. Unfortunately, the Kutch specimens overlap in size between P. beverlyensis and P. montanus as indicated by Pemberton and Frey [1982] [P. beverlyensis, average 10 mm, rarely less than 8 mm, P. montanus, average 3 mm, rarely greater than 5 mm]. However, P. montanus tends to be more contorted and therefore, the specimens are considered to be more akin to P. beverlyensis. Planolites represents on endichnial burrow produced and actively filled by diposit-feeding endobenthos [Pemberton and Frey 1982] of worm-like animals [Hantzschel 1975].

Preservation : Preserved is hypichnial and endichnial ridges.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member, Ganeshpur Calcareous Sandstone Member and Hadibhadang Pir Member.

Association : Muensteria, Palaeophycus, Keckeia, Phycodes

Planolites annularis Locality : Vavdi

ICHNOSPECIES

Planolites montanus WALCOTT 1890

Plate 51.b

Diagnosis : Relatively small, curved to contorted burrows.

Description : Irregularly cylindrical, sinuous, undulose and meanders small horizontal burrows. Burrows length and diameter more or less constant but in some case it slightly show small scale variation. True branching is relatively rare, horizontal erosional trunction of vertically or obliquely oriented segments gives appearance of knobby bedding surface. Burrow fills tend to consist of cleaner, better sorted sediments than the host matrix. The Kutch specimens have length 3.0 cm to 11.0 cm and diameter range of 0.5 cm to 0.8 cm.

Discussion and Interpretation : P. beverlyensis and P. montanus are more abundant in Kutch. The specimen has consistently smaller size and more tortuous appearance which distinguish P. montanus from P. beverlyensis [Pemberton and Frey 1982].

Preservation : Preserved or endictivion, hypichnial ridges and epichnial grooves.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Phycodes, Muensteria, Rhizocorallium, Thalassinoides

ICHNOSPECIES

Planolites annularis RICHTER 1937

Plate 52

Diagnosis : Distinctly annulated, subcylindrical burrows.

Description : Predominantly horizontal, straight to sinuous or undulose burrows exhibiting prominent annulations. Annuli may be regular size and spacing, burrow tends to be more or less constant diameter. Most of the burrows are straight to slightly curved and are oriented parallel or sub-parallel to bedding. True branching has not been observed. Length of the burrows varies from 6.0 cm to 10.0 cm with diameter range 1.2 cm to 1.4 cm.

Discussion and Interpretation : P. annulasis is distinguished from other two species of Planolites by its distinct annulations [Pemberton and Frey 1982]. Annulations presumably reflect peristialtic movements by the trace maker.

Preservation : Preserved as hypichnial ridges and shallow endichnia, undolose specimens exhibit both preservations.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Ganeshpur Calcareous Sandstone Member and Hadibhadang Pir Member.

Association : Ophiomorpha, Rhizocorallium, Paleodictyon

ICHNOGENUS

Psammichnites TORELL 1870, P.9

Diagnosis : Large ribbon-like trails with narrow longitudinal median ridge, convex upper surface, mostly very flexuous, about 2 to 5 cm; wide with very fine transverse ridges closely spaced.

ICHNOSPECIES

Psammichnites Sp. TORELL 1870

Plate 53

Description : Horizontal, straight, ribbon-like trails with narrow median groove. The trails is 11.0 cm long, 2.1 cm wide, with very fine transverse ridges closely spaced. The transverse ridges 0.6 to 0.8 cm long, 0.2 cm wide and 0.1 cm high and at right angles to medium groove, each transverse ridges separated by corresponding 0.1 to 0.15 cm furrows.

Preservation : Preserved concave epirelief and convex hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member and Hadibhadang Pir Member.

Association : Scolicia, Gyrochorte, Didymaulichnus, Curvolithus, Crossopodia

Psammichnites Sp. Location : East of Umrapur

ICHNOGENUS

Rhabdyoglyphus VASSOEVICH 1951, P.61

Type Species : Rhabdyoglyphus grossheimi Vassoevich 1951.

Diagnosis : Cylindrical tubes consisting of short, closely space, invaginated "calyces", some with short branches, preserved in convex hyporelief.

ICHNOSPECIES

Rhabdyoglyphus Sp. VASSOEVICH 1951

Plate 54

Description : Straight cylindrical axial burrow, consisting heart-shaped expansion at regular intervals. Some specimen consist closely spaced short branches, bifurcate on either side of the burrow at same point. Length of the burrow is about 14.0 cm with heart shaped expansion, 3.0 to 4.0 cm apart. Preserved in convex and concave hyporelief, filled identical to matrix.

Preservation : Convex and concave hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Gyrolithes, Muensteria, Planolites.

Plate : 54

Rhabdoglyphus Sp. Location : Vavdi

ICHNOGENUS

Rhizocorallium ZENKER 1836

Diagnosis : U-shaped spreiten-burrows, parallel or oblique to bedding plane, limbs more or less parallel and distinct.

ICHNOSPECIES

Rhizocorallium jenense ZENKER 1836

Plate 55.a

Diagnosis : Simple U-tube with spreite, generally protrusive or somewhat oblique to bedding, "arms" more or less parallel several cm apart, very rarely branched, occasionally with lateral flaps, tube relatively thick, commonly initially vertical for several cm downward, than sharply bending at right angle, outer side of many tubes often marked by numerous striae interpreted as scratch marking indicative of crustanceans, *pills* of ellipsoidal excrements may be incorporated in walls or within tube, median line of "U" often curved, horizontal forms on bedding planes characteristically winding.

Description : R. jenense is long sinuous, horizontal to subhorizontal, unbranched U-shaped tube, containing spreiten. It is easily recognized because of its U-tubes lying on bedding plane [PL-55.a]. The tubes are filled with fine to medium grained sediments, usually each arm of the tubes, is 6.5 cm long and 1.2 cm wide [PL-55.a]. The distance between the "arms" is about 3.0 cm, spreiten commonly are 0.25 cm thick.

Very often R. jenense tubes in Kutch extended subhorizontally and follow the ripple crest onto the top of the sediments until the lower end of the tube become horizontal, parallel to bedding plane. After the compaction only the lower part of the burrow appears to have been preserved.

Preservation : Full relief, fill identical with the matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member and Hadibhadang Pir Member.

Association : Palaeophycus, Planolites, Phycodes, Ophiomorpha, Arenicolites, Skolithos, Pelecypodichnus.

Discussion and Interpretation : The Kutch R. jenense has a long and somewhat sinuous form exclusively protrusive spreiten that almost follow the ripple surface. Similar forms were interpreted by Fursich [1974b] as the burrow of deposit-feeding animals mining nutrient-rich sediment on the rippled top. Faint scratch marks on the tube walls of Kutch specimen suggest that the animal may have been a deposit-feeding crustacean. Such an observation is also made by Seilacher [1967] and Crimes [1975].

ICHNOSPECIES

Rhizocorallium irregularie MAYER 1954

Plate 55.b

Diagnosis : Long, straight or slightly sinuous planispiral U-shaped spreiten burrows, mostly horizontal.

[a] Rhizocorallium jenense Location : Gadhada

[b] [i] Rhizocorallium irregularie Location : Vavdi
[ii] Palaeophycus heberti
[iii] Planolites Sp.

Description : Long, straight to sinuous, horizontal to unbranched U-shaped spreiten burrow. The structure consists of partial preservation of two parallel marginal tubes of lateral burrows separated by a furrow curving numerous, closely spaced irregular protrusive asymmetrical spreiten. The burrow outline, straight to sinuous and curved. The limbs are closely parallel, except where the burrows bend sharply. Some very faint scratch marks are found on to the burrow tubes. Tubes are circular to oval in cross section with maximum diameter of 1.0 cm. The distance between the two arms varies from 4.5 to 6.0 cm maximum observed length is 30.0 cm.

Preservation : Positive epirelief sediment fill identical to matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Ophiomorpha, Skolithos, Monocraterion, Isopodichnus.

Discussion and Interpretation : R. irregularie differs from R. jenense having very long sinuous parallel burrow systems with intervening asymmetrical protrusive spreiten. The traces crossing several asymmetrical current ripples and mining nutrient rich sediments on the top of the ripples indicate burrow of deposit feeding crustacean animals [Fursich 1974b, Eagar et al 1985]. As suggested by Seilacher [1967] the animal used the spreiten technique for efficient exploration of the sediment in search for food.

ICHNOGENUS

Rosselia DAHMER 1937, P.532

Type Species : Rosselia socialis Dahmer 1937.

Diagnosis : Cylindrical pencil-thick burrows, commonly oblique to bedding, lower end not observed, opening expanded and filled with concentric layers of matrix which as a rule are strongly weathered.

ICHNOSPECIES

Rosselia Sp. DAHMER 1937, P.532

Plate 56

Description : The Kutch specimen Rosselia Sp. is funnel-shaped vertical or oblique burrow preserved in full relief. Upper flared portion upto 4.0 cm in diameter and characterized by concentrically laminated fill. Unfilled burrow structures are very common and represented by the tube. Depth of the burrow is upto 13.0 cm. Most of the specimens are circular in cross-section, although a few are elliptical.

Discussion and Interpretation : Funnel-shaped morphology in the Kutch specimens is variable. Many specimens have steep-sided funnel which are identical to Monocraterion. Few specimens are exposed on bedding plane. Flared portions at these burrows are characterized by concentric laminae tapering downward into a concentric walled stem.

Chamberlain [1971] interpreted Rosselia as a feeding burrow made by

Plate : 56

Rosselia Sp. Location : West of Ganeshpur worm-like animal but some specimens of Rosselia may be dwelling burrows as argued by Chamberlain and Clark [1973].

Preservation : Full relief, unfilled structures are very common.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Ganeshpur Calcareous Sandstone Member.

Association : Bergaueria, Conostichus, Ophiomorpha, Spirophyton.

ICHNOGENUS

Saportia SQUINABAL 1891

Type Species : Zonarides striatus Squinabal 1888.

Diagnosis : Long large cylindrical burrows, 1 to 2 cm in diameter, commonly in dendriform arrangement, branching dichotomously surface with rhombic pattern produced by delicate arched parallel striations in 2 systems.

Remarks : Borrello [1966, P.20] observed that there are only small differences in shape between his Palaeosaportia from Ordovician of South America [Argetina] and Saportia from the Tertiony of Italy. According to Hantzschel [1975], a new generic name is not required for such burrow which vary considerably in shape.

ICHNOSPECIES

Saportia Sp. SQUINABAL 1891

Plate 57

Description : Long, cylindrical burrows which branch dichotonomously. Branching in a twig shaped fushion. Diameter of the individual branch is 1.5 to 2.3 cm. Surfce is slightly annulated and consists of, longitudinal striations. Length of the burrow is 28.0 cm and branching interval is 4.5 cm.

Discussion and Interpretation : Presence of striations on burrow surface

Saportia Sp.

Location : Vavdi

can be interpreted as feeding structure of crustacean.

Preservation : Preserved as endichnia, or more commonly hypichnial ridges.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Palaeophycus, Rhizocorallium, Phycodes, Planolites, Thalassinoides

ICHNOGENUS

<u>Scalarituba</u> WELLER 1899, P.12

Type Species : <u>Scalarituba missouriensis</u> Weller 1899.

Diagnosis : Subcylindrical burrows, 2 to 10 mm in diameter, sinuous, parallel, oblique or nearly vertical to bedding; marked by transverse "scalariform" ridges situated at average distances of 2 to 3 mm, which may be only poorly preserved or lacking in argillaceous rocks.

ICHNOSPECIES

<u>Scalarituba missouriensis</u> WELLER 1899

Plate 58

Diagnosis : Straight or sinous burrows upto 1 cm wide and characterized by closely spaced [2-3 mm] transverse scalariform ridges. Burrow are parallel to stratification.

Description : Straight to sinuous, subcylindrical back-filled burrows, oriented parallel to bedding plane. Burrow 8.0 to 10.0 cm long, 2.1 cm in diameter, marked by curved transverse ridges [indistinct], 2 to 3 mm apart.

Preservation : Hypichinial burrows, filled with darker material.

Facies : Shelly Siliciclastic Limestone.

Stratigraphic Distribution : It occurs in Hadibhadang Pir Member.

Association : <u>Cylindricum</u>, <u>Thalassinoides</u>

Scalarituba missouriensis Location : West of Umrapur

ICHNOGENUS

Scolicia DE QUATREFAGES, P.49

Diagnosis : Horizontal bilaterally symmetrical gastropod trails of great variability long band-like morphology depending on their origin as surface trails a internal trails; varied sculpture caused by different methods of burrowing, creeeping and removing sediment, upto about 4 cm wide.

Remarks : Classification of Scolicia and the "Scolicia Group: is in confusion and clearly warrants a thorough taxonomic revision [Hantzschel 1975, Smith and Crimes 1983]. This group is represented by highly variable endogenic trails, usually of a highly flattened ribbon-like shape often with transverse pads of sediments. Longitudinal burrows in various arrangements are observed in these species. Recognition of similar situation led Seilacher [1955] and Hantzschel [1962, 1975] to suggest several probable generic synonyms for scolicia e.g. Bolonia, Psammichnites, Curvolithus, Olivellites etc. Some of these forms located in the Khadir Island are described in under their original generic names.

Scolicia has been attributed to the creeping or feeding activities of gastropods [Hantzchel 1975, Ksiazkiewicz 1977] or furrowing echinoids [Smith and Crimes 1983]. Scolicia is a eurybathic trace fossil and has been reported in strata of early Cambrian [Crimes and Anderson 1985] to Holocene [Kitchell and Clark 1979] age.

Based on surface sculpture two different species of Scolicia has been described herein.

ICHNOSPECIES

Scolicia Species A

Plate 59

Description : This form is large, straight, horizontal, bilaterally symmetrical, flat-ribbon like shaped with V-shaped median burrow. Lobes are distinct and comprised of evenly spaced series of obliquely transverse pods of sediments preserved in convex hyporelief. The trail is typically 3.5 cm wide; 34.0 cm in length, pod dimension 1.2 x 0.8 cm; and median furrow is 0.5 cm in width and 0.15 cm in depth. Along lateral peripheries of trace, annulation [transverse pods] tend to be deflected slightly, evidently representing sediment somewhat during the forward progress of the animal.

Preservation : Epigenic of endogenic, full relief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

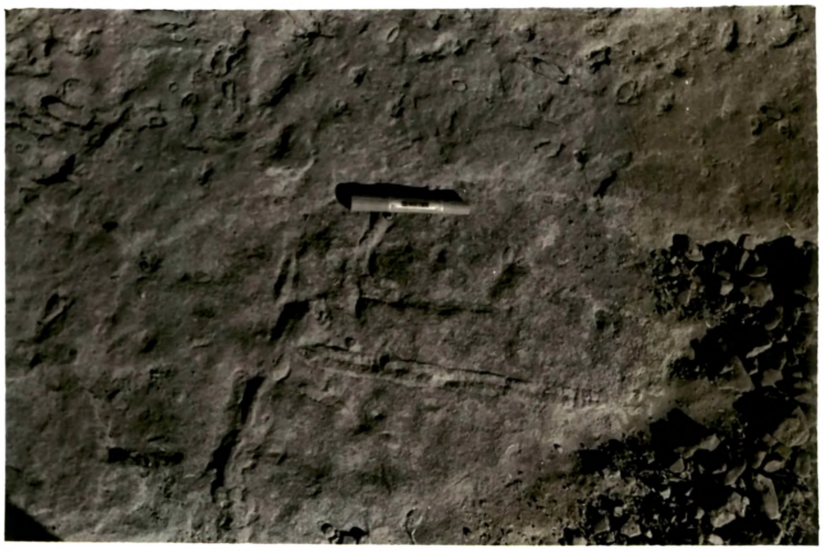
Association : Curvolithus, Didymaulichnus, Crossopodia.

ICHNOSPECIES

Scolicia Type B

Plate 51[ii]

Description : Straight to gently curved, bilaterally symmetrical trails,



[i] Scolicia Sp. A
[ii] Steigerwaldichnium Sp.

Location : Gadhada

with fine transverse ridges preserved in convex hyporelief. Trail consists of two parallel lobes separated by median furrow. Trails are V-shaped in cross-section. The maximum observed length is about 16.0 cm, width is 3.0 cm, median furrow is 1.8 cm in width and 0.4 cm in depth; lobes height is 0.2 cm.

Preservation : Concave epirelief and convex hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Gyrochorte, Psammichnites, Curvolithus, Crossopodia

ICHNOGENUS

Siphonites DE SAPORTA 1872, P.110

Diagnosis : Tubes several cm long and about 1 cm in diameter, with sandy lining, mostly washed out and collapsed on bedding plane.

ICHNOSPECIES

Siphonites Sp. DE SAPORTA 1872

Plate 60

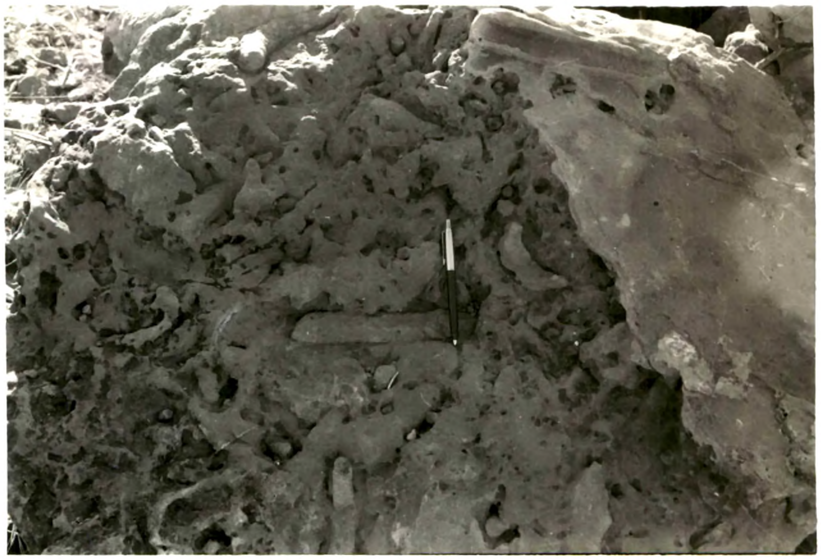
Description : Long, horizontal, straight to slightly curved, unbranched smooth-walled cylindrical burrow. Except in collapsed specimens, the diameter of the burrows more or less constant, burrow collapsed features are very common. The maximum observed length is about 23.0 cm with width of about 5.5 cm. Wall lining typically consists of agglutinated sediment, coarser and better sorted than of adjacent rocks.

Preservation : Preserved is hypichnial ridges, less commonly as endichnial or epichnial groove.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Phycodes, Thalassinoides, Planolites, Palaeophycus



[i] Siphonites Sp.
[ii] Palaeophycus heberti

Location : Palanpur [West of Gadhada]

ICHNOGENUS

Skolithos HALDEMAN 1840, P.3

Diagnosis : "Ordinary Pipes" straight tubes or pipes perpendicular to bedding and parallel to each other, subcylindrical, unbranched 1 to 15 mm in diameter, constant for each tube, few cm upto 30 cm [maximum 100] long, inner walls may be finely annulated, tubes commonly closely crowded, but also may show widely spaced gradations, frequent in arenaceous sediments.

Remarks : According to Fursich [1974] the taxonomy of these simple vertical burrows is in urgent need of revision. Morphological features such as funnel shaped apertures in Monocraterion Torell [1870] or less crowding tubes as in Tigillites Ronalt [1850] according to him do not justify separation at the ichnospecific or ichnogeneric level. All straight and unbranching vertical burrows are, therefore, regarded by him as synonyms of Skolithos Haldeman [1840] which he claims to have priority.

ICHNOSPECIES

Skolithos linearis HALDEMAN 1840

Plate 61.a

Diagnosis : Cylindrical burrows, straight to slightly curved and vertical to inclined, wall smooth or rarely corrugated.

Remarks : Skolithos linearis is only the ichnospecies of Skolithos described by Alpert [1974], that can accomodate the lengths attained by the vertical burrow in Kutch specimens.

Description : Straight, vertical and steeply inclined, unbranched, cylindrical or sub-cylindrical, lined or unlined burrow, perpendicular to bedding plane with a structureless fill. No funnel-shaped apertures have been found in most of the burrow tubes. It occurs crowded or isolated on bedding plane. Burrow wall distinct and lined with a thin film of dark homogenous material and agglutinated sand grains. Transverse annulations not observed. The maximum observed length of the burrows is about 30.0 cm with diameter range from 0.5 to 1.3 cm. Burrow filled identical to matrix.

Discussion and Interpretation : According to Chamberlain [1977] Skolithos is widely recognized in shallow-water, intertidial deposits, and in flood-plain facies. Skolithos is interpreted as the dwelling burrow of a suspension feeding animal by Alpert [1974]. According to Seilacher [1967] and Crimes [1975] it is common in sandstone deposited under high energy tidal and near shore conditions. The Kutch form is envisaged to represent similar environmental aspects.

Preservation : Full relief, fill identical with matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member, Hadibhadang Pir Member and Ganeshpur Calcareous Sandstone Member.

[a] Skolithos linearis Location : Gadhada

[b] Skolithos verticalis Location : WSW of Gadhada

Association : Ophiomorpha, Aenicolites, Monocraterion, Rhizocorallium, Lanicoidichnus

ICHNOSPECIES

Skolithos verticalis HALL 1843

Plate 61.b

Description : Simple, straight, vertical to steeply inclined, unbranched, cylindrical to subcylindrical J-shaped unlined burrow perpendicular to bedding plane. Burrow wall distinct and made up of ferrugineous material while infill material is identical to matrix. Some tubes show thin dark lining on the bedding plane to mark contrast to the host sediment and others are eroded and form as tunnel-shaped to misguiding with Monocraterion. Dimension varies in different burrow population. Length of the burrows varies from 9.0 to 17.0 cm and diameter also varies from 0.9 to 1.3 cm. The burrows probably were the dwelling tubes of suspension feeding animal such as polychaete worm in accordance with the interpretation of Curren [1985].

Preservation : Vertical to oblique burrow preserved as endichnia.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Arenicolites, Ophiomorpha, Monocraterion

ICHNOGENUS

Spirophycus HANTZSCHEL 1962, P.215

Type Species : Muensteria bicomis Heer 1877.

ICHNOSPECIES

Spirophycus Sp. HEER 1877

Plate 62

Diagnosis : Cylindrical bulges, about 5 to 20 mm thick, transversely folded or rugose, curved like horns or bent spirally at ends.

Description : Smooth, unbranched, essentially horizontal thick cylindrical burrows with diameter from 2.8 to 3.2 cm. Burrow tends to bent and forms nearly rectangular shape and opens at one corner and forms irregular meanders. Burrow preserved in convex hyporelief and fill identical to host sediments.

Remarks : The ichnogenus has been reported in strata of Mississippian to Tertiary age [Hantzschel 1975, McCann and Pickerill 1988] and in deep water flysch trace [Kern 1978].

Preservation : Preserved as convex and concave relief. Fill identical to the matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Phycodes, Phoebichnus, Saportia.

Spirophycus Sp. Location : Charan ki Wandh

ICHNOGENUS

Spirophyton HALL 1863

Diagnosis : Similar to spirally coiled forms of Zoophycos but differing by smaller size and by circular outline of laminae which are also compared to lamillae, laminae not tending to lobute forms, 1 to 4 mm thick, sloping outward from aixs, then flatting and bent upward to margin in dextrogyrate or sinistral spirals, curving ridges on laminae convex in the sense of the rotation, diameter of last whorl up to about 10 cm; central axis J-shaped.

Remarks : Simpson [1970] defined Spirophyton as a three dimensional feeding burrow consisting of a central vertical tube around which as spreite is spirally wound and differs from Zoophycos in its smaller size. In the Kutch equivalents, Spirophyton occurs as circular areas [horizontal layers of the spreite] on bedding planes surrounding a central tube. In the Tally areas described by Miller and Johnson [1981] similar structures like Kutch are found except the top of the specimens are not eroded and spiral lamellae are well preserved.

ICHNOSPECIES

Spirophyton Sp. HALL 1863

Plate 63

Description : Spirally coiled burrows oriented more or less vertically and composed of thin laminae around the central axis. Dimensions of burrows varies in different burrow population. The maximum observed

Spirophyton Sp. Location : West of Ganeshpur outer diameter is being 4.0 cm; with central axis J-shaped with diameter 1.0 cm; length is varies from 7.0 to 9.0 cm.

Discussion and Interpretation : Simpson [1970] interpreted Spirophyton and Zoophycos as resulting from the feeding activities of a bilaterally symmetrical animal.

Preservation : Full relief, fill identical with matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Skolithos, Arenicolites.

ICHNOGENUS

Spongeliomorpha SAPORTA 1887

Type Species : Spongeliomorpha iberica Saporta 1887.

ICHNOSPECIES

Spongeliomorpha iberica SAPORTA 1887

Plate 64

Diagnosis : Cylindrical branching burrow systems with both vertical and horizontal elements, branching Y or T-shaped, burrow walls unlined, with pelletal or smooth lining, or covered with longitudinal ridges [scratch marks] dwelling burrow of crustacean.

Remarks : Similar burrows were originally regarded as fossil algae by Goeppart [1942], sponges by De Laubenfels [1955], according to Reis [1922] burrows similar to Rhizocorallium, "a rather unsatisfactory ichnospecies". According to Kennedy [1967] and Fursich [1973], there most probably are arthropod dwelling burrows. Fursich et al [1981] suggested there as predominently suspension feeding arthropods and possibly polychaete burrows.

Description : The Kutch specimens include cylindrical Y-shaped branched burrow system with mostly horizontal elements. Burrows, usually circular a oval in cross-section. Dimension vary from different burrows populations. Maximum observed length 32.0 cm with diameter range from 2.5 to 3.8 cm, side branches have usually a smaller diameter than the main trunk

[i] Spongeliomorpha iberica
[ii] Ophiomorpha nodosa

Location : Gadhada

and often terminate after as short distance. Burrow collapse structure are very common may indicate unfilled segments. The burrows wall are smooth.

Preservation : Full relief, the burrow fill identical with the matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : The burrows occur in the Gadhada Sandstone Member.

Association : Thalassinoides, Rhizocoallium, Saportia, Megagrapton.

ICHNOGENUS

Steigerwaldichnium KUHN 1937, P.366

Diagnosis : Straight, rarely curved, tunnel traces parallel to bedding with distinct longitudinal rows of tiny projections and impressions from doubtful Parapodia.

ICHNOSPECIES

Steigerwaldichnium Sp. KUHN 1937

Plate 59[ii]

Description : These are long cylindrical curved burrows, tunnels traces more or less parallel to bedding plane. Burrow consists very poorly preserved transverse ridges. The Kutch specimen of Steigerwaldichnium turns nearly 90 and at the end project slightly vertically to the bedding plane. The total maximum observed length is about 19.0 cm; with constant diameter [3.0 cm].

Preservation : Convex hyporelief, fill identical to surrounding substrate.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Scolicia, Planolites, Palaeophycus.

ICHNOGENUS

Sustergichnus CHAMBERLAIN 1971, P.231

Diagnosis : Carinate burrows, irregularly sinuous, 1 to 10 mm wide, 1 to 7 mm high, numerous fine striae crossing exterior surface obliquely and converging near lower apex, this outer structure not always present, inner structure consisting of sand rod with smooth internal surface, almond-shaped in cross-section, preserved as hyporelief and full relief.

ICHNOSPECIES

Sustergichnus Sp. CHAMBERLAIN 1971

Plate 65

Description : Horizontal, straight to gently curved, lined cylindrical [cross-section] burrows. The trace consists of very fine poorly developed fine numerous striae which are crossing each other and covers the exterior surface. The burrow thick and terminate in bulge at the end. The maximum observed length is about 14.0 cm with diameter varies from 1.2 cm [one end] to 0.5 cm [at the other end]. Burrow is identical to surrounding substrate.

Preservation : Preserved in concave and convex hyporelief. Sediment filled surrounding the matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Halopoa, Steigerwaldichnium.

Susterigichnus Sp. Location : Ratanpur

ICHNOGENUS

Taenidium HEER 1877, P.117

Type Species : Taenidium serpentinum Heer 1877.

ICHNOSPECIES

Taenidium Sp. HEER 1877

Plate 66

Diagnosis : Cylindrical burrows with distinct stuffed structure, mostly branched, umbellated, root-like system of burrows radiating downward, burrows with transverse segmentation reminiscent of "Orthoceras", segmentation may also be observed on outside as annular constrictions.

Description : Horizontal, straight, cylindrical tubes, upto 11.0 cm long, 1.3 to 2.3 cm wide, possessing symmetrically arranged and distinct transverse annulation, 0.5 cm wide. Burrow preserved hypichnial ridges and fill identical to host sediment, typically unbranched, segmentation also indicate on outside by annular constrictions.

Discussion and Interpretation : Taenidium has been reported from the Mesozoic and Cenozoic flysch of Europe by Heer 1877 and from the Ouachita mountains [Ordovician] by Chamberlain [1971]. The cylindrical burrow exhibits typical periodic filling of tunnel in backward direction.

Preservation : Concave and convex hyporelief, endichnial burrows, active filled, identical to matrix.

Plate : 66

Taenidium Sp. Location : Ratanpur

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Keckia, Muensteria, Planolites.

ICHNOGENUS

Taphrhelminthopsis SACCO 1888, P.170

Type Species : Taphrhelminthopsis auricularis Sacco 1888.

ICHNOSPECIES

Taphrhelminthopsis auricularis Sacco 1888

Plate 67

Diagnosis : Bilobate trails, 1 to 3 cm; wide mostly very long, morphology varying, more or less straight, freely winding or even meandering with distinct rather larger median furrow 3 to 10 mm wide flat, lateral ridges may be transversely striated, trails varying in size and relief.

Description : The trace consists of smooth, bilaterally symmetrical, gently winding bilobate structures with well developed median furrows, each lobe possesses a well developed ridge, 0.2 to 0.4 cm high, which slope gently toward median furrow, total width 1.8 cm. Length of the trails vary in different burrow population, maximum being about 30.0 cm.

Remarks : In Sacco's original description of Taphrhelminthopsis none of the specimens exhibited a guided type of meandering [Ksiazkiewicz 1977]. The designation of Tahrhelminthopsis auricularis as the type ichnospecies by Andrews [1955] and subsequently followed by Hantzschel [1964, 1975], however, included meandering forms within Taphrhelminthopsis, Ksiazkiewicz [1977] which consists morphologically similar bilobate systematically meandering traces with tendency to coil. The Kutch

Taphrhelminthopsis auricularis

Location : Palanpur
[West of Gadhada]

specimens are regarded as conopecific with Taphrhelminthopsis auricularis. Bilobate traces of these types are normally inferred to have been produced by gastropods [Hantzschel 1975, P.113].

Preservation : Preserved in convex and concave hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Helminthopsis, Planolites.

ICHNOGENUS

Thalassinoides EHRENBERG 1944, P.350

Diagnosis : Cylindrical burrows forming 3 dimensional branching system consisting of horizontal network connected to surface by more or less vertical shafts, 1 to about 20 mm; in diameter, regularly branching, Y-shaped bifurcations, in horizontal systems forming polygons, typical swelling at points of branching or elsewhere.

ICHNOSPECIES

Thalassinoides suevicus KENNEDY 1967

Plate 68.a & b

Diagnosis : Large and idiomorphic, predominently horizontal more or less regularly branched essentially cylindrical components forming large burrow system. Diachotonous bifurcation more common than T-shaped branching and typically enlarge at points of bifurcation. Burrow dimensions variable within a given system.

Description : Large, smooth, cylindrical horizontal T-shaped branching burrow system. The burrows are circular in cross-section and enlarging at point of bifurcation. Burrow dimensions variable within a given system. The maximum observed length is about 45.0 cm with diameter 4.0 cm. The burrow fill commonly has the same colour and texture as the surrounding sediments.

Discussion and Interpretation : Thalassinoides is a common and widespread

[a] Thalassinoides suevicus Location : West of Umrapur

[b] Thalassinoides suevicus Location : West of Umrapur

ichnogenus in Mesozoic and Tertiary rocks [Frey 1975]. Typically, the regular branching network or polygons with swelling common at points of bifurcation [Hantzschel 1975]. Because of these features is shown by specimens from the Kutch and they are included in the ichnospecies of Thalassinoides suevicus. Thalassinoides is interpreted as a dwelling/feeding burrow of a one or more crustaceans, an interpretation corroborated by occurrence of thalassid shrimps within burrows [Hantzschel 1975].

Preservation : Preserved as endichnia, epichnia and hypichnia.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Rhizocorallium, Planolites, Spongeliomorpha, Skolithos, Palaeophycus, Phycodes.

ICHNOGENUS

Treptichnus MILLER 1889

Type Species : Treptichnus bifurcus Miller 1889.

Diagnosis : Straight or curved row of short individual burrows of equal length, arranged alternating to right and left, tending upward, resulting in a zigzag feather stitch pattern, comparable to symboidal ramification of plants.

ICHNOSPECIES

Treptichnus Sp. MILLER 1889

Plate 69

Description : The Kutch specimens as Treptichnus Sp. is relatively flat horizontal burrow system with short and indistinct branches. Burrow system with regular short branched, tending curved upwards, resulting in zigzag feathers stitch pattern. Burrow usually are thin, parallel to bedding plane, some times merge into the host sediments. Total length of the burrow is about 30.0 cm.

Preservation : Positive hyporelief, collapse structures are very common.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Planolites, Phycodes Taenidium.

[i] Treptichnus Sp.
[ii] Planolites annularis

Location : ENE of Vavdi

ICHNOGENUS

<u>Tylichnus</u> OSGOOD 1970, P.371

Type Species : Rusophycus as per Miller and Dyer 1878.

Diagnosis : Weakly bilobate burrow, preserved in convex hyporelief subquadrate in cross section, showing an unusual pustulose ornamentation consisting of 3 to 9 parallel rows of transversely elongated nodes in form of zipper like pattern, node may in addition be distributed randomly over surface.

ICHNOSPECIES

Tylichnus Sp. OSGOOD 1970, P.371

Plate 70

Description : The Kutch specimen Tylichnus Sp. is essentially straight, horizontal, cylindrical burrows consists of pustulose ornamentation of 3 to 5 rows of transversely elongated nodes. Burrow preserved in convex hyporelief fill identical to surrounding matrix. Burrow length varies from 5.0 to 13.0 cm with diameter of 3.2 cm.

Preservation : Preserved in convex hyporelief.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in Gadhada Sandstone Member.

Association : Gyrochorte, Planolites, Muensteria.

[i] Tylichnus Sp.
[ii] Palaeophycus heberti

Location : ENE of Vavdi

ICHNOGENUS

Volkichnium PFEIFFER 1965, P.1266

Diagnosis : Starlike trace fossil, about 5 cm in diameter consisting of 6 to 8 tunnel shaped "rays", vertical shaft not observed.

ICHNOSPECIES

Volkichnium Sp. PFEIFFER 1965

Plate 71

Description : The Kutch specimens of Volkichnium Sp. consisting of straight, horizontal tunnels which radiating outward from a central burrow [Knobby structure] 1.5 cm in diameter. The radiating structures externally smooth and consists of five arms, which tapering towards the rounded terminations. Individual tunnels vary in length [5 to 8 cm] and wide [0.8 to 8.1 cm] in radiating clusters. The total diameter is 15.0 cm. The burrow tubes are fill identical to host substrate.

Discussion and Interpretation : Volkichnium volki contrasts with Teichichnus stellatus in respect of the cross-sectional form of the rays. V. volki has little or no vertical thickness [Pfeiffer 1965] where as rays of T. stellatus are wall like. Similarly the curvature of the rays in the vertical plane is concave up in V. volki but concave-down in T. stellatus. The irregular pattern of arms on observed specimens of V. volki appears to be the product of variation in position of insertion of each arm into the presumed central master shaft.

Volkichnium Sp.

Location : ENE of Vavdi

Preservation : Preserved as convex hyporelief sediment fill identical to matrix.

Facies : Micritic Sandstone.

Stratigraphic Distribution : It occurs in the Gadhada Sandstone Member.

Association : Phycodes, Phoebichnus, Spongeliomorpha, Thalassinoides.

ICHNOGENUS

Zoophycos MASSALONGO 1855

Diagnosis : Shallowly conical, spiral form, consisting of 3 main parts; spirally coiled spreite, major and minor lamellae contained within the lamina, and a cylindrical tunnel, axis of spiral vertical to bedding, height small, single volutions conelike, sloping outward, diameter of successive whorls generally increasing downward, occasional inverse direction of coiling, based diameter of structure upto 60 cm or more, whorls comprising lamina variable in outline; circular, arcuate or lobate, occasionally first volutions, lobate and larger and deeper ones nearly circular in outline, laminae exhibit major and minor lamellae, appear lunate in cross section, and curve radially from axis of spiral, major lamellae branch at acute angle toward axis forming minor lamellae, cylindrical tunnels with axial and marginal part forms the axis of spreite, has same thickness as spreite, may continue for a part or for whole length of lamina and then may be open to sediment at both ends planer forms of Zoophycos similar to closed spiral spreits may also be antler-like, thickness 1 to 7 mm.

ICHNOSPECIES

Zoophycos Sp. MASSALONGO 1855

Plate 72

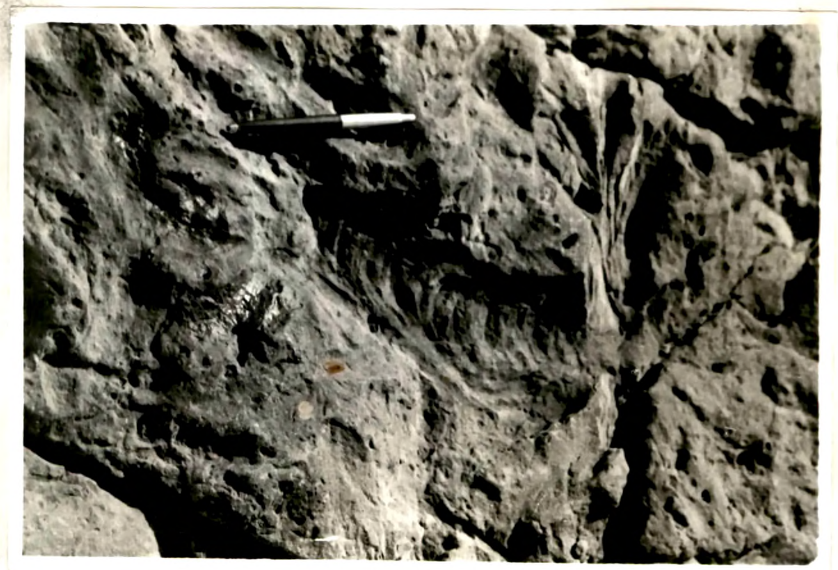
Description : The Kutch specimens are flat, curved, subhorizontal with a planer imprint of an uncoiled spiral arrangement. The spreite appears in cross-section as a series of thick irregularly lunate or crescents packed tightly to gather form in a curved concave-up single line with variable length. The maximum observed length is about 22.5 cm with diameter varies from 4.0 to 7.0 cm.

Discussion and Interpretation : The successive addition of lunate or crescent-shaped laminae in Zoophycos Sp. are displayed by the addition of new segment constructed alongside the previous one as the animal retracted and proceeded on its new course. This type burrow indicate efficient mining of a nutrient rich substrate. Each course of the burrow represents the action of a vermiform organism as it moves in the substrate and ingested sediment. The outer edge of the spreite consists of marginal tunnel. This is possibly an open tube maintained by the organism as it probed in the sediment in closely spaced lamellae which branch off the marginal tube [Ekdale 1977].

Zoophyos is regarded as an intrastratal trace made by soft-bodied, worm-like animals engaged in a systematic pattern of grazing [Hantzschel 1975]. Although originally interpreted as traces which were characteristic of outer sublittoral to bathyl marine environments. Recent workers have reported occurrences in shallow sublittoral [Simpson 1970, Martino and Curren 1982] interdistributary bay [Tonkard and Barwis 1982] back-barrier lagoonal [Miller and Knox 1985], intertidal [Miller and Johnson 1981] and Marginal Marine [Martino 1989] environments.

Preservation : Endogenic, full relief, fill identical to matrix.

Facies : Micritic Sandstone.



Zoophycos Sp. Location : West of Umrapur

Stratigraphic Distribution : It occurs in the Hadibhadang Pir Member.

Association : Skolithos, Paleodictyon, Chondrites.

TABLE : 6

ETHOLOGICAL STRATONOMIC AND PHYLOGENETIC CLASSIFICATION OF THE KHADIR FORMATION

ETHOLOGIC	ICHNOGENERA	STRATONOMIC	PHYOGENETIC
[I] DOMICHNIA	Arenicolites	Endogenic, Full relief	Polychaete
[DWELLING STRUCTURES]	Cylindrichnus	Endogenic, Full relief	Annelids/Polychaete
Permanent shelters	Cylindricum	Endogenic, Full relief	Annelids/Polychaete
of vagile or hemi-	Diplocraterion	Endogenic, Full relief	Crustacean/Polychaete
sessile animals	Lanicoidichna	Endogenic, Hyporelief	Polychaete
procurring food	Monocraterion	Endogenic, Full relief	Worm
outside sediment	Ophiomorpha	Endogenic, Full relief	Callianassid major
	Palaeophycus	Intergenic, Hyporelief	Worms/Crustacean
	Skolithos	Endogenic, Hyporelief	Worm
	Siphonites	Intergenic, Hyporelief	Worms/Crustacean
	Spongeliomorpha	Endogenic, Full relief	Custacean
	Scalarituba	Intergenic, Full relief	Worm
[II] FODICHNIA	Chondrites	Endogenic, Full relief	Worm
[FEEDING TRACE]	Ctenopholeus	Inter-endogenic, Hyporelief	Worm
Deposit feeding burrows which also	Dactylophycus	Endogenic, Hyporelief	Worm
served as shelter.	Gyroliths	Endogenic, Full relief	Decapod crustacean
	Keckia	Inter-endogenic, Hyporelief	Worm
	Muensteria	Inter-endogenic, Hyporelief	Worm
	Phycodes	Intergenic, Hyporelief	Polychaete
	Phoebichnus	Endogenic, Full relief	?
	Rhizocorallium	Endogenic, Full relief	Crustacean/Annelid
	Rosselia	Endogenic, Hyporelief	Annelid/Crustacean
	Spirophycus	Intergenic, Hyporelief	?
	Spirophyton	Endogenic, Full relief	Polychaete
	Steigerwaldichum	Endogenic, Hyporelief	Polychaete
	Susterigichnus	Endogenic, Hyporelief	?
	Saportia	Endogenic, Hyporelief	Polychaete
	Thalassinoides	Endogenic, Full relief	Crustacean
	Taenidium	Endogenic, Hyporelief	Worm
	Treptychnus	Endogenic, Hyporelief	?
	Volkichnium	Endogenic, Hyporelief	Worm
	Zoophycos	Endogenic, Full relief	Polychaete

[CONTD]

TABLE : 6 [CONTD]

ETHOLOGIC	ICHNOGENERA	STRATONOMIC	PHYOGENETIC
[III] PASCICHNIA [FEEDING TRAILS] Deposit feeding vagile mud ingesters with simple back filling	Compaginatichnus	Epigenic, Semi-relief	Annelid
	Cochlichnus	Epi-endogenic, Hyporelief	Annelid
	Fustiglyphus	Positive Hyporelief	Annelid
	Helminthopsis	Intergenic, Hyporelief	Annelid
	Halopoa	Intergenic, Hyporelief	Episammonts
	Megagrapton	Findichnia Positive Hyporelief	?
	Planolites	Intergenic, Hyporelief	Annelid
	Paleodictyon	Endogenic, Hyporelief	Annelid/Polychaete
	Circulichnus	Intergenic, Hyporelief	Worm
	Dendrotichnium	Endogenic, Hyporelief	?
	Rhabdoglyphus	Epigenic, Hyporelief	Annelid
	Taphrhelminthopsis	Epigenic, Epirelief	Gastropod
[IV] REPICHNIA [CRAWLING TRAILS] Trail left during direction of locomotion	Beaconichnus	Intergenic, Hyporelief	Arthropod
	Bolonia	Epi-Endo-Intergenic Epi-Hypo-relief	Gastropod
	Curvolithus	Epichnial, Semi-relief	Gastropod
	Crossopodia	Endogenic, Negative Epirelief	Arthropod
	Didymaulichnus	Intergenic, Hyporelief	Gastropod
	Gyrochorte	Negative Epirelief	Apalcophore
	Isopodichnus	Intergenic, Hyporelief	Arthropod
	Kouphichnium	Hypichnia, Concave	Limulis Crustacean
	Merostomichnites	Hypichnia, Hyporelief	Phyllopods
	Neonereites	Convex, Hyporelief	Gastropod/Annelid
	Nereites	Convex and Concave Hyporelief	Gastropod/Worm
	Psammichnites	Epigenic, Hyporelief	Gastropod
	Scolicia	Epigenic, Epirelief	Holothurian/Gastropod
	Mesichnium	Concave, Hyporelief	?
	Palmichnium	Epigenic, Epirelief	Arthropod
	Tylichnus	Endogenic, Hyporelief	?
[V] CUBICHNIA [RESTING TRACE] Structure made by vagile benthos digging down for temporary rest	Bergaueria	Intergenic, Hyporelief	Actinarian sea anemone
	Conostichnus	Epichnial, Hyporelief	Worm
	Calycraterion	Epichnial, Full relief	?
	Mammillichnus	Epichnial, Full relief	?
	Lockiea	Convex, Hyporelief	Bivalves
	Pelecypodichnus	Epichnial, Full relief	Bivalves

CHAPTER : IX

ICHNOFACIES

"Ichnofacies" is a sedimentological term meaning a certain appearance [face = facies] imparted to sediment by lebensspuren [trace]. As suggested by Hertweck [1975, P.469], the term "ichnofacies" has to be used in harmony with the term "biocoenose" [community of organisms]. Recognition of biofacies ultimately leads to the reconstruction of an ichnocoenose [trace fossil association] and ichnofacies stand today as one of the more elegant concepts in ichnology.

In ichnological investigation 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 the ichnocoenoses related to different substrate one can evaluate bioturbation features that are common to several or to a single environment along the profile. The individual lebensspuren of an ichnocoenoses thus then reflect ethological and ecological response of the trace-making organism in a specific environmental condition.

The ichnofacies can further be defined and evolved from careful examination of the distribution and association of numerous trace fossils from units of varying age and environmental implications. Seilacher [1967] noted, that in marine environments many parameters that govern the abundance and distribution of trace-makers [such as temperature, food, supply and intensity of wave or current agitation] tend to change progressively with water depth. As further postulated by him, it is important to define the physical environment of an ichnocoenose [i.e. characteristic trace must be defined by its particular sedimentological characters such as composition and grain size, content of organic matter, aeration] and depositional sedimentary structures including indicators of current and wave action and rate of sedimentation, reworking or erosion and oceanographic factors such as water depth, salinity, water circulation and many others.

Originally Seilacher [1964, 1967] named six ichnofacies on the basis of worldwide observation of trace fossil associations [or assemblages] in rocks of all ages. These basis form relative scale of bathymetry and include **Scoyenia**, **Glossifungites**, **Skolithos**, **Cruziana**, **Zoophycos** and **Nereites** ichnofacies. Frey and Seilacher [1980] redefined the **Glossifungites** ichnofacies concept restricting it to firm but unlithified marine substrate and introduced, the new **Trypanites** ichnofacies for fully lithified marine substrate or organic substrate such as bones, sells and wood. These trace fossil biofacies for a long time have served as models in determining Paleo-environments. Lately, Frey and Pemberton [1984], argued seven recurrent ichnofacies of which only one is nonmarine viz. **"Scoyenia"**.

Based on the above criteria, the author was able to confirm the existance of five ichnofacies in the Khadir Formation of Kutch. His ichnofacies include **Glossifungites**, **Skolithos**, **Cruziana**, **Zoophycos** and **Nereites** ichnofacies. Detailed description and interpretation of these ichnofacies is attempted after brief review of Seilacher [1967] universal ichnofacies concept.

BRIEF REVIEW OF UNIVERSAL ICHNOFACIES CONCEPT [After Seilacher 1964, 1967, Frey and Seilacher 1980, Frey et al 1984, Pemberton and Frey 1984, Frey and Pemberton 1984].

Glossifungites Ichnofacies [Firm Substrates] :

The **Glossifungites** ichnofacies is an intermidiary between unconsolidated deposits of the **Skolithos** and **Cruziana** ichnofacies and consolidated ones of **Trypanites** ichnofacies [Frey and Seilacher 1980]. This ichnofacies is thus somewhat intergradational with **Trypanites** and consists of ethologic mixtures of traces, mostly burrows and borings that are attributable mainly to bivalves.

The **Glossifungites** ichnofacies tends to have areal extent relative to most other ichnofacies.

CHARACTERISTIC TRACE FOSSILS :

These include vertical, cylindrical, 'U' or tear-shaped borings or boring like structures, sparsely or densely remified dwelling burrows, fan-shaped **Rhizocorallium** and **Diplocraterion** burrows. Such structures are located in tidal and intertidal zones where the diversity of individual species is usually low, but the given kind of structures are many times far abundant.

BENTHIC ENVIRONMENT AND BATHYMETRY :

Biogenic structures which can be assigned to the **Glossifungites** ichnofacies occur on firm but unlithified marine littoral and sublittoral omission surfaces, especially on semiconsolidated carbonate firm-grounds, or stable, coherent, partially dewatered muddy substrates either in protected, moderate energy settings, in areas of somewhat higher energy conditions where clastic, semiconsolidated substrates offer resistance to erosion.

Skolithos Ichnofacies [Shifting Substrate] :

The **Skolithos** ichnofacies ordinarily grade landward into supratidal or intertidal zones and seaward into the **Cruziana** ichnofacies [subtidal zone]. The landward boundary tends to be more abrupt than the later, where substrate are suitable, the **Skolithos** ichnofacies also adjoin or intertonge laterally with the **Glossifungites** or **Trypanites** ichnofacies [Radwanski 1970, Pemberton and Frey 1984b]. With the reduced energy, it also grades into intertidal or shallow subtidal extensions of the **Cruziana** ichnofacies [Radwanski et al, 1975]. Mixed **Skolithos** - **Cruziana** ichnofacies [associations] are common in both recent and ancient settings [Howard and Frey 1975]. Episodic erosion and deposition may result in alternatel y protusive and retrusive spreiten structures.

CHARACTERISTIC TRACE FOSSILS :

Characteristic trace fossils in **Skolithos** ichnofacies include vertical, cylindrical or U-shaped dwelling burrows, protrusive and retrusive spreiten, mainly in response to substrate aggradation or degradation [escape or equilibrium structures] and **Ophiomorpha** consisting predominently of vertical or steeply inclined shafts. Trace making animals chiefly are suspension feeders. Diversity of trace markers is low, yet given kinds of burrows may be abundant.

BENTHIC ENVIRONMENT AND BATHYMETRY

Lower littoral to infralittoral, moderate to relatively high energy conditions. Slightly muddy to clean, well sorted, shifting sediments subjected to abrupt erosion or deposition [higher energy increases physical reworking and obliterates biogenic sedimentary structures, leaving a preserved record of physical stratification].

Cruziana Ichnofacies :

The **Cruziana** ichnofacies is characterized by subtidal, poorly sorted, unconsolidated substrates where the energy levels are reduced. Food supply consists of both suspension and deposited components that are locally predominent. Characteristic animals include, both suspension and deposit feeders as well as mobile carnivores and scavangers. Because of lower energy level, less abrupt shifting of sedients and also less abrupt change in temperature and salinity the bioturbation structures are mainly characterized by feeding and grazing traces. Increased energy and allied parameters thus represent a temporary excursion of **Skolithos** type conditions into a **Cruziana** type setting. With an abundance of potentially cohesive mud, this varient of the **Cruziana** ichnofacies might integrade locally with the **Glossifungites** ichnofacies.

CHARACTERISTIC TRACE FOSSILS :

Abundant crawling traces, both epi-and intrastratal, are present and include U-shaped burrows with protrusive spreiten [feeding swaths], forms like **Rhizocorallium**, **Ophiomorpha** and **Thalassinoides** consisting of regular and inclined horizontal components and scattered vertical cylindrica burrows. Trace making animals are mobile curnivores and both suspension and deposit feeders. Diversity and abundance are generally high.

BENTHIC ENVIRONMENT AND BATHYMETRY :

Intralittoral to shallow circalittoral substrates, below wave base but not storm base to somewhat quiter offshore type conditions. Moderate to relatively low energy conditions result into well sorted silts and sands, to be interbedded with muddy and clean sands. The common type of depositional environments include esturies, bays, lagoons, tidal flats, as well as continental shelves or eperic slopes.

Zoophycos Ichnofacies :

Zoophycos ichnofacies is typically considered as an intermidiary between the **Cruziana** and **Nereites** ichnofacies. It has an extremely broad batheymatric range and depositional gradients and characterized by flysch-molasse area below wave base and free from tubidity currents. **Zoophycos** mainly consists of U- and J-shaped nets, formerly related to oxygen-deficiencies and later may indicates a respiratory connection with oxygenated bottom waters.

CHARACTERISTIC TRACE FOSSILS :

Relatively simple to moderately complex, efficiently executed grazing traces and shallow feeding structures, spreiten typically planar to gently inclined, distributed in delicate sheets, ribbons or spirals. Animals virtually all deposit feeders. Low diversity, given structures may be abundant.

BENTHIC ENVIRONMENT AND BATHYMETRY :

Circalittoral to bathyal, quiet-water conditions, nearly thixotropic muds or muddy sands rich in organic matter but somewhat deficient in oxygen-below storm wave base to fairly deep water, in areas free of turbidity flows or significant bottom currents. Watery surficial sediments are difficult to exploit by epibenthos, resulting in both low diversity and abundance and poor preservation of epistratal traces. Whether relict or palimpsets substrates are present, espicially if swept by shelf-edge or deeper water contour currents, this ichnofacies may be omitted in the transition from infralittoral to abyssal environments.

Nereites Ichnofacies :

Nereites ichnofacies is characterized by bathyl and abyssal zone, where quiet water conditions and oxygenated substrates usually persists. Because of this reason, grazing traces and feeding structures are, here predominent.

CHARACTERISTIC TRACE FOSSILS :

The characteristic forms comprise complex grazing traces and feeding-dwelling structures, reflecting highly organized, efficient behaviour, spreiten structures, typically nearly planar and multilobed or otherwise very complex biogenic structures. Numberous crawling, grazing traces and sinuous fecal castings [**Neonereites**, **Helminthodia**, **Cosmorhaphe**], mostly intrastral also can be located. Animal originators chiefly are deposit feeders or scavangers, although many others may have 'farmed' microbe cultures within their more or less permanent, open domicile structures [**Paleodictyon**]. Diversity and abundance are significant in flysch deposits and in more distal regions of basinal slopes.

BENTHIC ENVIRONMENT AND BATHYMETRY :

Bethyl to abyssal, mostly quiet but oxygenated waters, in place inturrupted by down carry on bottom currents or turbidity currents [flysch deposits], stable and slowly accreting substrates. In more distal regions, the record is mainly one of continuous deposition and bioturbation. The stable deep-sea flore is not universally bioturbated, however, at least not usully intensively at every site.

DISTRIBUTION OF ICHNOFACIES IN VARIOUS STRATIGRAPHIC UNITS IN KHADIR :

The author has described in the earlier Chapter [IV], the Khadir Formation [Jurrasic age] and its eight members. These members are mainly characterized by mixed siliciclastic-carbonate sediments that have yielded an extremely diverse and abundent trace fossils forms. These trace fossils are distributed variously in the sediments through the entire stratigraphic column, viz. Hadibhadang Dungar Member, Hadibhadang Pir Member, Ratnasar

Plate : 73

Rivularites - Pseudo trace fossil Location : Chamwa Wandh

TABLE : 7

DISTRIBUTION OF ICHNOFACIES AND THEIR ASSOCIATED TRACE FOSSILS IN DIFFERENT MEMBERS OF KHADIR FORMATION

MEMBERS	ICHNOFACIES				
	GLOSSI-FUNGITES	SKOLITHOS	CRUZIANA	ZOOPHYCOS	NEREITES
HDM	Bivalve Boring	-	-	-	33
HPM	Bivalve Boring	15, 51	2, 13, 16, 32, 41, 43, 45, 48, 62	66	6, 8, 9, 17, 37, 40, 45 46
RCSM	-	14, 34, 54	-	-	-
GSM	-	1, 3, 5, 12, 14 15, 19, 27, 29, 38, 39, 54	4, 11, 13, 20, 21, 23, 25, 26, 30, 41, 43, 44, 45, 46, 48, 50, 53, 55, 57, 59, 60, 62, 63, 64, 65,	-	7, 18, 22, 24, 35, 36, 42, 45, 47, 52, 61
GSCM	-	3, 10, 28, 38, 49, 56,	-	-	-
BM	-	34	45	-	-

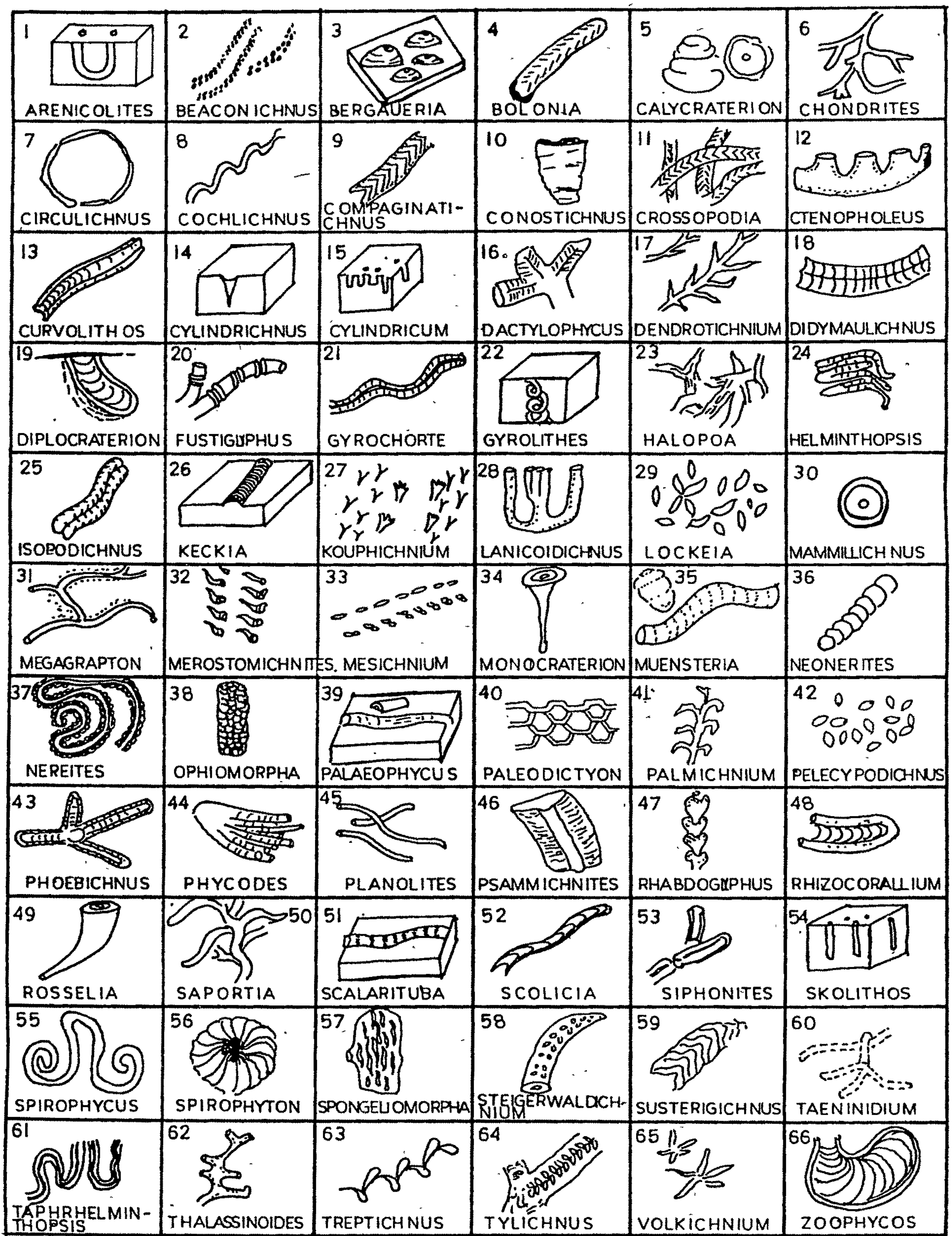


FIG.34 ILLUSTRATION OF VARIOUS ICHNOGENERA OF KHADIR FORMATION

Calcareous Sandstone Member, Gadhada Sandstone Member, Ganeshpur Calcareous Sandstone Member and Bambanka Member. The oldest Chhariya Bet conglomerate member however, is devoid of any trace fossil remains, while the Chamwa Wandh Fossilliferous Limestone Member includes pseudo trace fossils such as Rivularites [Plate : 73] and hence do not supply any information based on ichnofacies concepts.

Details of ichnofacies and their associated trace fossils are represented in different members of Khadir Formation [Table : 7].

Hadibhadang Dungar Member [HDM] :

In contrast to the lower member of Khadir Formation [Chhariya Bet conglomerate], the Hadibhadang Dungar Member is characterized by occurrence of vertical cylindrical burrows and borings, which mark the evidence of typical marine influence in high energy conditions. This member is represented by whitish to pinkish and buff yellow mixed siliciclastic-carbonate sediments and greyish shale. Here the **Glossifungites-Skolithos** ichnofacies appears to be intimately associated with the lithological unit. Calcarenite sediments and greyish shale chiefly exhibit vertical burrows with high density and low diversity. The mixed calcareous sediments on the other hand represent vertical burrows with resting traces of bivalves [**Pelecypodichnus**] and their boring. The biogenic sedimentary structures of the Hadibhadang Dungar Member show narrow range of behavioural habits and mainly include dwelling structures of suspension feeding animals such as worm and resting traces and boring of bivalves.

On the whole, the **Glossifungites-Skolithos** ichnofacies dominate and represents a zone of densely populated by the suspension feeding dwelling animals. The associated sediments very often indicate development of trough cross stratification, ripple marks and distinctly occuring slump structures. Coarse clastic sediments and angular bioclastic fragments 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 may be concluded that the high energy environments in the basin favoured deep burrowing and suspension feeding organisms to prevail.

Hadibhadang Pir Member [HPM] :

The ichnofacies of the Hadibhadang Pir Member display maximum diversity in trace fossil distribution when compared to any other stratigraphic unit of the Khadir Formation. It represents a classical gradation from **Glossifungites, Skolithos, Cruziana, Zoophycos** and **Nereites** type ichnofacies and indicate possible bathymetric changes in the basin. This unit is further characterized by broad range of forms and several behavioural activities including dwelling, feeding, grazing, crawling and resting traces of worms, crustacean, bivalves and gastropods. Each of the ichnofacies observed in the HPM can now be described separately.

GLOSSIFUNGITES ICHNOFACIES :

This ichnofacies is found with **Skolithos-Cruziana** ichnofacies in siliciclastic limestone lithofacies. The characteristic trace fossils mainly include flasked shaped bivalve boring. The development of such ichnofacies indicate low to moderately high energy conditions while at omission surfaces semi-consolidated sediments seems to have offered resistance to erosion by wave or currents.

SKOLITHOS ICHNOFACIES :

Skolithos ichnofacies of HPM is represented by less number of traces with moderate frequency. The presence of **Cylindrium**, **Cylindrichus** and **Skolithos** indicate moderate to high energy condition with slow sedimentation and an unconsolidated shifting substrate located in intertidal zone.

CRUZIANA ICHNOFACIES :

The **Cruziana** ichnofacies is represented by large number of traces with high frequency and diversity and greater dimensions. This ichnofacies developed in fine-grained siliciclastic limestone indicate offshore type conditions with relatively low energy and slow rate of sedimentation. Occurrence of **Dactylophycus**, **Rhizocorallium**, **Phoebichnus**, **Thalassinoides**, **Planolites**, **Curvolithus**, **Beaconichnus** etc. indicate dwelling, feeding, grazing and crawling activities of worms, crustaceans and gastropods.

ZOOPHYCOS ICHNOFACIES :

Zoophycos ichnofacies of HPM characterized by planispiral spreiten structures, indicate deposit feeding activity of worm like organisms in fine grained siliciclastic limestone lithofacies, displaying low density.

Such forms are considered to represent quite and probably deeper water conditions or basinal slope where rate of sedimentation is rather slow [Chamberlain 1978].

NEREITES ICHNOFACIES :

Nereites ichnofacies is dominated by chiefly grazing and crawling traces. Density and diversity of the traces are much higher as compared to any other ichnofacies in HPM. The traces are typically complex horizontal deposit feeding patterns, preserved mainly as convex hyporelief. The high density and low abundance of specialized form in this member is typical of a stable but low resource environments. The apparent high number of trace fossils, however, may be because of the long time which few individuals successfully were able to reworked the slowly depositing sediments.

Ratnasar Calcareous Sandstone Member [RCSM] :

In contrast to HPM, the RCSM is characterized by very low diversity of traces by very few suspension feeding and dwelling organisms. It mostly consists of vertical cylindrical burrows such as **Cylindrichus**, **Monocraterion** and **Skolithos**, which typically display the presence of **Skolithos** ichnofacies.

The depositional conditions of the RCSM thus appear to have changed with the advent of the HPM deposition. These changes are well documented by lithology, which is characterized by alternation of siliciclastic limestone and shale. It further displays concentration of **Cylindrichus**, **Monocraterion**, **Skolithos**, burrowss, which are intimately related to this lithofacies. **Skolithos** ichnofacies of the RCSM indicate moderate to high energy conditions with high rate of sedimentation, shifting sediments. High energy environments offered vertical burrows to prevail to unconsolidated sediments. The dense population of **Skolithos** traces in this unit is thus very significant.

Gadhada Sandstone Member [GSM] :

Gadhada Sandstone Member consists of highest frequency of traces as compared to any other members and needs some critical comments on its ichnofacies distribution. The member as a whole passes through the **Skolithos - Cruziana - Nereites** ichnofacies; **Skolithos - Cruziana** ichnofacies at its base, followed by **Skolithos - Cruziana - Nereites** ichnofacies and then once again by **Skolithos - Cruziana** ichnofacies at the top of the sequence, and finally with the **Skolithos** ichnofacies at the topmost part of the entire lithofacies unit in the stratigraphic sequence. All these changes appear to be very significant. The broad swings are marked by dwelling, feeding, grazing, crawling and resting structures made by polychaete, crustacean and molluscan [Pelecypod, Gastropod] animals during their life activity. Density and diversity are usually very high.

NEREITES ICHNOFACIES :

This ichnofacies is observed in sandy-micritic lithofacies of Gadhada Sandstone Member and contain large number of crawling and feeding, horizontal to inclined structures along the bedding planes [Plate:26,32]. The feeding methods employed by these various organism are generally designed for maximum efficiency, not only with respect to resource utilization, or thorough coverage of space during deposit feeding activity, but possibly also in response to competition or other biologic pressures. The higher density and the apparent large number of traces could be due to stable conditions and reduced effect of erosional forces in the depositional basin. Most common traces include **Circulichnus**, **Gyrolithus**, **Didymaulichnus**, **Helminthoposis**, **Neonerites**, **Planolites**, **Scolicia** etc.

CRUZIANA ICHNOFACIES :

Cruziana ichnofacies of GSM consist abudunt trace fossils with high diversity. This ichnofacies appears three times in stratigraphic column with **Skolithos** and **Nereites** ichnofacies. Its presentation is always marked by a thickly populated zone of trace fossils. The trace fossils of GSM as a whole show a broad range of form and behavioral activity, including dwelling, feeding, grazing and crawling traces of worms and crustacean.

Higher frequency and greater dimension of traces indicates unconsolidated substrate, low to moderate energy levels in shallow marine environments with less erosion. Large horizontal structure further indicate well oxygenated substrates, less abrupt shifts in temperature and salinity.

SKOLITHOS ICHNOFACIES :

Skolithos ichnofacies is found to occur with **Cruziana** ichnofacies and also independently in the whole stratigraphic column of the Gadhada Sandstone Member. Independent occurrence of this ichnofacies indicate supratidal zones of landward side and with **Cruziana** ichnofacies indicate deposition of the sediments towards seaward side. Density of the individual burrows [or given kinds of burrows] are very high but diversity is very low. On the whole the Gadhada Member is characterized by vertical cylindrical and 'U' shaped [with or without spreiten] burrows, concentrations of **Arenicolites, Bergaueria, Calycraterion, Cylindrichus, Diplocraterion, Ophiomorpha, Pelecypodichnus, Kouphichnium** and **Skolithos.** These forms indicate behavioral activity of suspension feeding, dwelling and resting organisms such as polychaetes, crustaceans and bivalves. The dense population of **Ophiomorpha** burrows in this unit is rather significant. The **Ophiomorpha** burrows with vertical and horizontal branches form network that terminate progressively higher up in younger bedding planes indicate deposition on erosional bedding plane. The high frequency of **Skolithos** species also represent zone of suspension feeding polychaetes.

In conclusion deep burrowing, high frequency and greater dimension of the traces in Gadhada Sandstone Member suggests deposition in moderate to high energy conditions in subtidal, intertidal and supratidal sediments with thickly populated zone of suspension feeding animals.

Ganeshpur Calcareous Sandstone Member [GCSM] :

This member shows significant change in trace fossil occurrence when compared to Gadhada Sandstone Member. Top most bed of the Gadhada Sandstone Member which includes **Skolithos** ichnofacies, is found to occur as the bottom bed below the Ganeshpur Calcareous Sandstone Member. The GCSM is further represented by only **Skolithos** ichnofacies throughout to entire sequence. It contains concentration of **Skolithos**, **Ophiomorpha**, **Rosselia**, **Spirophyton**, **Bergaueria** and **Conostichus** traces. These traces are mostly represented by behavioral activity of dwelling suspension feeding invertebrate organisms such as annelids and crustacean. Diversity of individual trace fossil genera is rather low but the density is very high.

The overall sequence thus is characterized by varing lithologies, micritic sandstone and siliciclastic limestone and display considerable occurrence of trace fossils alongwith physical sedimentary structures such as planer and cross beddings and wave ripples. Cross-beddings are dominent through the whole sequence, but at the middle of the sequence, wave ripples are found in siliciclastic limestone [Plate : 8], which are devoid of any sort of traces and other biogenic structures. On the basis of both the physical and biogenic sedimentary structures, the stratigraphic sequence of Ganeshpur Calcareous Sandstone Member can be interpreted as a tidal bar deposit in high to very high energy conditions with low rate of sedimentation.

Bambanka Member [BM] :

This is the youngest member of Khadir Formation and comprises fossiliferous siliciclastic limestone [with ammonites and oysters], ferruginous sandstone, khakhi grey shales and sandy micrites. Trace fossils are intemately related to this lithofacies and characterized by mix **Cruziana Skolithos** ichnofacies at the base ultimately leading to the **Skolithos** ichnofacies at the top of the sequence. Density and diversity of trace fossils in both these

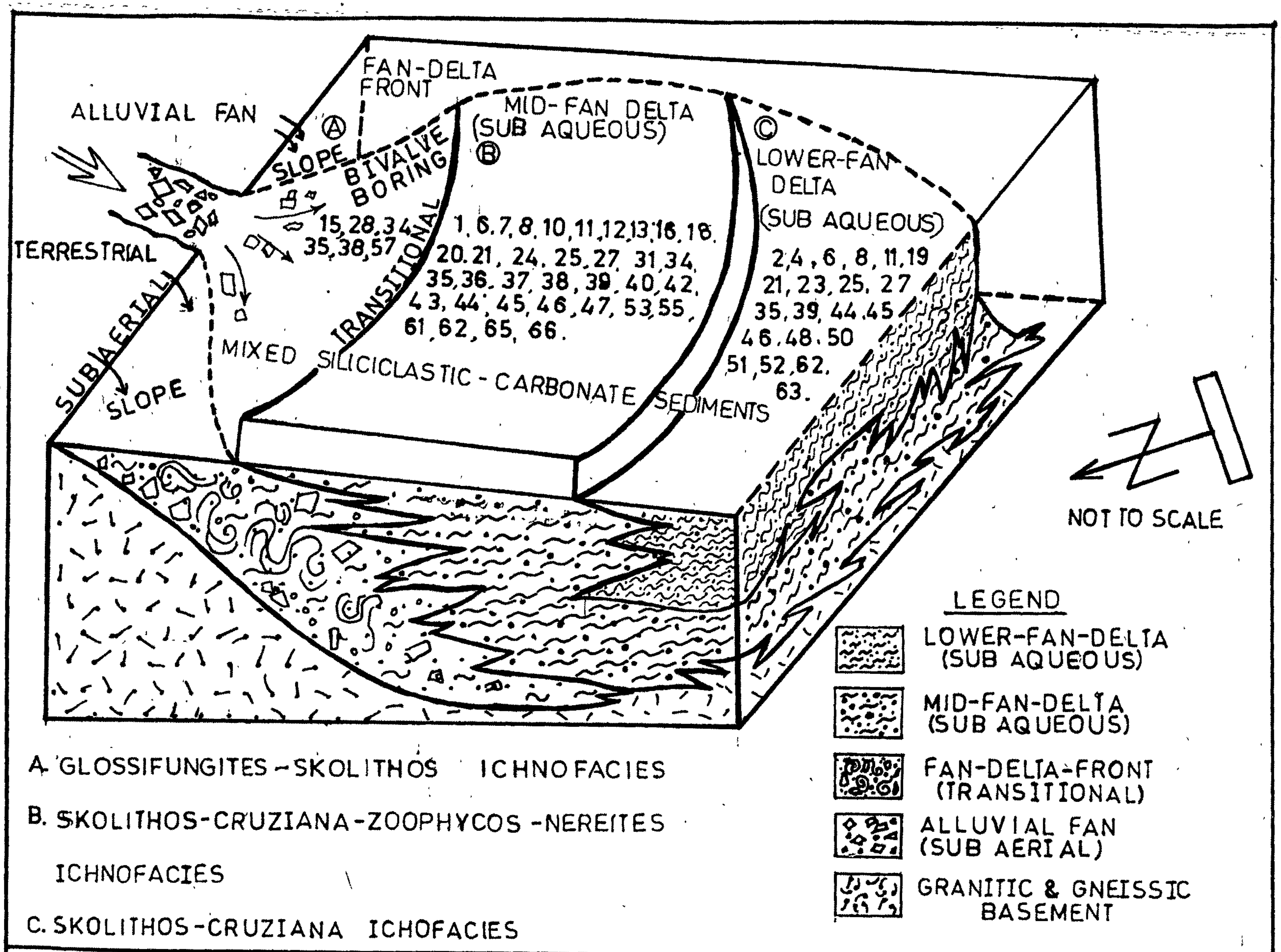


FIG. 35 SCHEMATIC REPRESENTATION OF ICHNOFACIES & THEIR ASSOCIATED TRACE FOSSILS IN FAN DELTAIC ENVIRONMENT OF KHADIR FORMATION (SEE FIG 34 FOR ICHNOGENERA)

ichnofacies are comparatively very low.

The lower part of the Bambanka Member consists of mainly horizontal traces [mainly planolites] in an initial stage of deposition in low to moderate energy conditions and on an unconsolidated soft sediments substrate. Progressively, in upward direction population of vertical burrows increases, indicates shallowing upward of the basin and changes to moderate to high energy conditions in intertidal to supratidal zone. The trace fossils of Bambanka Member as a whole thus show chiefly dwelling and feeding activity of worms and crustacean. **Monocraterion** with **Planolites, Microspherichnites,** and large Megafossils [oyster and ammonites] indicate shallow marine depositional environments in intertidal zone. Fine to medium grained nature of the sediments with physical sedimentary structures such as small scale cross-beeding and ripple marks, also support such view.

ICHNOFACIES AND THEIR INTERPRETATION :

Figure : 35 illustrates and summarises the ichnofacies, environmental zones and common trace fossil occurrence in the Khadir Formation of Western Kutch. The existance of **Glossifungites, Skolithos, Cruziana, Zoophycos** and **Nereites** ichnofacies in the sediments provide excellent guides to the bathymetric conditions of the basin.

Glossifungites Ichnofacies :

Glossifungites ichnofacies occurs with **Skolithos** ichnofacies in Hadibhadang Dungar Member and with **Cruziana** ichnofacies in Hadibhadang Pir Member and are represented by flask shaped bivalve boring. The ichnofacies has limited areal extent. It's occurrence with **Skolithos** and **Cruziana** ichnofacies suggest intertidal to subtidal depositional environments. According to Frey and Pemberton [1984], such ichnofacies often represent firm but unlithified substrate, with stable, cohesive deposits in somewhat protected, moderately low energy setting, or omission surface in high energy setting, where unconsolidated substrates offer resistance to erosion by wave or currents.

Skolithos Ichnofacies :

Skolithos ichnofacies occurs at several horizons throughout the Khadir Formation. Population of trace fossil genera varies in different member but maximum development is found in Gadhada Sandstone Member. The main characteristic of GSM is that the **Skolithos** ichnofacies is always dominated by the presence of vertical cylindrical tube or U-shaped [with or without spreiten] burrows of crustacean and worms. The other members mainly include vertical cylindrical or funnel shaped burrows. As established by Seilacher [1964] the **Skolithos** ichnofacies always represent littoral and very shallow littoral zone inhabited mainly by suspension feeding organisms. According to Frey and Pemberton [1984], the **Skolithos** ichnofacies is indicative of relatively high levels of wave or current energy, and is typically developed in clean, well sorted, loose or shifting particulate substrates. Abrupt change in rates of deposition, erosion and physical reworking of sediments are frequent in these environments. Such high energy environmental conditions commonly occur on the foreshore and shoreface of beaches, bars and spits. Because of constant reworking of sediments the trace fossils are generally more sparce is further reflected in the low diversity and higher density of individual trace fossil genera. The coarsening upward sequence of the GSM very well documents all these features repeatedly because of their prograding nature.

Cruziana Ichnofacies :

Ecologic and sedimentologic conditions make the trace fossil associations in the **Cruziana** ichnofacies the most diverse of all the ichnofacies in behavioral and preservational types. With reduced energy levels and well distributed food at both suspended [in overlying water column] and deposited component in substrate [Purdy 1964], the characteristic organisms include suspension and deposit feeders, as well as mobile carnivores and scavangers. Because of lowered energy and less abrupt shifts in temperature and salinity levels, burrows tend to be constructed horizontally rather than vertically, although scattered vertical or steeply inclined burrows occur. Trails of epibenthonic and endobenthonic animal also may be common and reflect, the abundance, diversity, and accessibility of food. Thus, the **Cruziana** ichnofacies is dominated by dwelling and feeding structures as well as by the crawling and resting traces.

In the Khadir Formation, the **Cruziana** ichnofacies has been well documented in Hadibhadang Pir Member and Gadhada Sandstone Member.

It may however to be noted as postulated by Frey and Pemberton [1984] that the **Cruziana** ichnofacies exhibit considerable diversity and occurs in low to moderate energy levels in shallow water, where characteristic sediments, are poorly sorted and are in unconsolidated substrates.

Zoophycos Ichnofacies :

The **Zoophycos** ichnofacies is placed in flysch-molasse area below wave base and free of turbidite currents, within a broad depositional gradient by Seilacher [1963, 1964]. **Zoophycos** as postulated by Osgood [1972] has an extremely broad paleobathymetric range, hence, its designation as name bearer for supposely depth-related ichnofacies has been long contraversial. Again the genus **Zoophycos** is found to be in shallow water epiric deposits [Seilacher 1978, Marintsch and Finks 1982], shallow and deep water deposits [Chamberlain 1971, 1975, Osgood and Szmuc 1972, and Ekdale 1978] and deep water flysch of Europe [Seilacher 1964, 1967].

Zoopycos animals have thus adopted broad ecologic aspects and tolerated numerous substrate type, variable food resources and different energy and oxygen levels. Therefore, its traces appear in the **Cruziana** through **Nereites** ichnofacies [Frey 1970, Crimes 1973, Miller and Johnson 1981, Crimes et al 1981]. According to Frey and Pemberton [1984], in numerous places the ichnofacies is hardly descrenible in the broad transition from **Skolithos** or **Cruziana** to the **Nereites** ichnofacies, especially, on unstable ancient slopes originally subject to turbidity flows or swept by shelf-edge or contour currents. **Zoophycos** and **Zoophycos** ichnofacies in particular are, therefore, different from place to place and the bathymetric adoptation seems to range from near shore to [abyssal conditions] intracontinental slope.

The **Zoophycos** genera located in the Hadibhadang Pir Member include other eurybenthic and cosmopolitan forms such as **Chondrites**, **Thalassinoides**,

Rhizocorallium, **Palaeophycus**, **Planolites** etc. represent shallow-water environments within restricted circulation or epiric environments or self edged settings.

Nereites Ichnofacies :

Bathymetric implication of the **Nereites** ichnofacies in bathyl to abyssal quiet water oxygenated surface consists traces of deepest and most distal marine environments. Although numerous trace fossils of typical shallow-marine deposits occasionally range into deep sea deposits [Kern and Warme 1974, Crimes 1977], the reverse is not ordinarily true because some meshwork burrow system [**Paleodictyon**] is virtually unknown outside the **Nereites** ichnofacies.

The main characteristic of the **Nereites** ichnofacies is the predominance of feeding traces represented by numerous crawling-grazing traces that represent a highly organized and efficient processing of resource utilization from the sediments [Seilacher 1964, 1967].

The **Nereites** ichnofacies are well developed in Hadibhadang Pir Member and Gadhada Sandstone Member. The ichnofacies display high diversity but low abundance of specialized forms. This, therefore, is thought to be typical of a stable but low-resource environments [after Valentine 1971]. The high frequency and relatively greater dimensions of **Chondrites**, **Paleodictyon** and **Planolites** from HPM and **Didymaulichnus** from GSM, thought to be persistent with quiet water oxygenated substrate where few organisms successfully were able to rework the sediments.

In conclusion the sediments of Khadir Formation in eastern Kutch in most of the stratigraphic units show marked fluctuations of depth from shallow to deep marine water with corresponding change in their trace fossil assemblages. The bathymetric interpretation of the **Zoophycos** and **Nereites** ichnofacies in the HPM and GSM, however, remains as elusive as elsewhere.

On the whole the presence of the particular ichnofacies seems to fit the general and classification model for each ichnofacies, but not without engendering some questions.

CHAPTER : X

ICHNOCOENOSES

An "Ichnocoenoses" as defined by Dorjes and Hertweck [1975] is an association of lebbensspuren reflecting life activities of individuals of a biocoenose i.e. a community of organisms on or in the substratum. This association of lebbensspuren can be related to one definite biocoenose. Such a community of traces can then be recognized and described as an individual. The lebbensspuren to be incorporated may be surface traces, dwelling structures, or other internal traces of a contemporary animal community, as well as preserved lebbensspuren originating from a previous or emigrated community. The individual lebbensspuren of an ichnocoenose further reflect ethological and ecological responses of the trace-making organisms of a paleo-biocoenose to the substratum. Additionaly, in case of uncertain systematic and taxonomic position of the organisms, the functional morphology of trace-making organisms may be advantageously reconstructed.

The physical environment of an ichnocoenose or a characteristic lebbensspuren is defined by its particular sedimentological characters, such as grain size, content of organic matter, depositional sedimentary structures including indicators of currents, wave action, rates of deposition, and reworking or erosion. Moreover, characteristic lebbensspuren are usually not the only bioturbation structures in an ichnocoenose. Associated lebbensspuren also provide representative frequencies and abundances of trace making organisms.

It is rather significant to ascertain in the above context that the distribution of trace fossils in different stratigraphic sections of Khadir exhibit a distinct non-random pattern of this distribution. Out of eight members of Khadir Formation two are without any trace fossil content. The concentration of trace fossil on the other hand is observed in eastern part of the Island. The Gadhada Sandstone Member of the Khadir Formation having several meter thickness of sediments comprises predominence of a variety of trace fossils while Hadibhadang Pir Member occupies second position in exhibiting several other trace fossil varieties. Some trace fossils are seen occurring together recurrently, whereas the others are never found in the same piece of rock. These relationships are easily recognizable in the field. 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 sediment.

The group of trace fossils occurring together as recognized by the author constitute eight ichnocoenoses [Fig.37-38] in Khadir. Each ichnocoenoses thus recognized is named after its mort important trace fossil member. Detail description and significance of each of these ichnocoenose is dealt with the following paragraphs.

OPHIOMORPHA ICHNOCOENOSE :

This ichnocoenose consists exclusively of **Ophiomorpha** and can be observed in Gadhada Sandstone Member and Hadibhadang Pir Member exposed in the eastern part of Khadir Island. In Gadhada, the density is heigh and may indicate high sediment influx. A low rate of reworking seems to

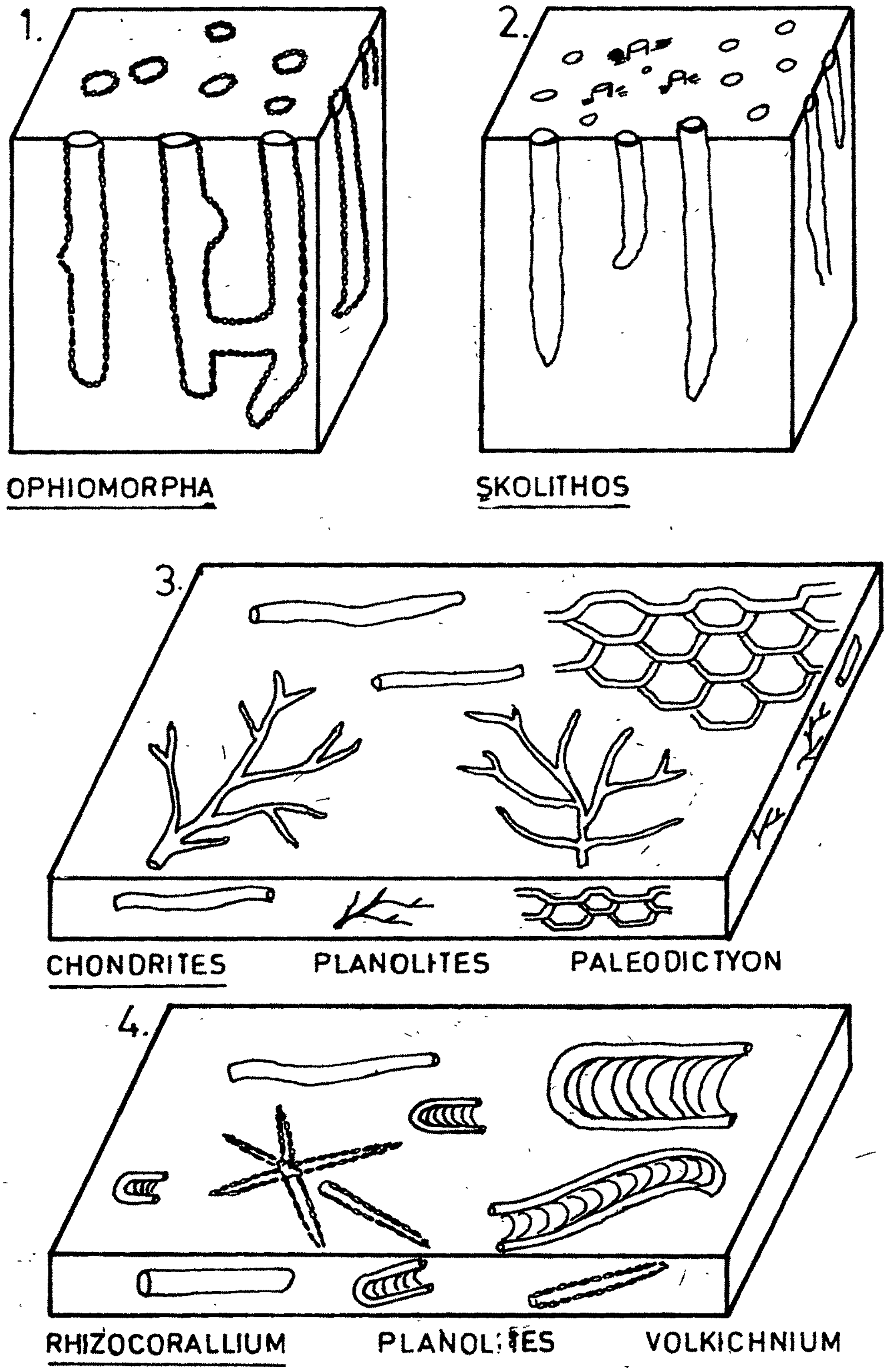


FIG.36 DISTRIBUTION OF ICHNOCOENOSES IN KHADIR ISLAND.

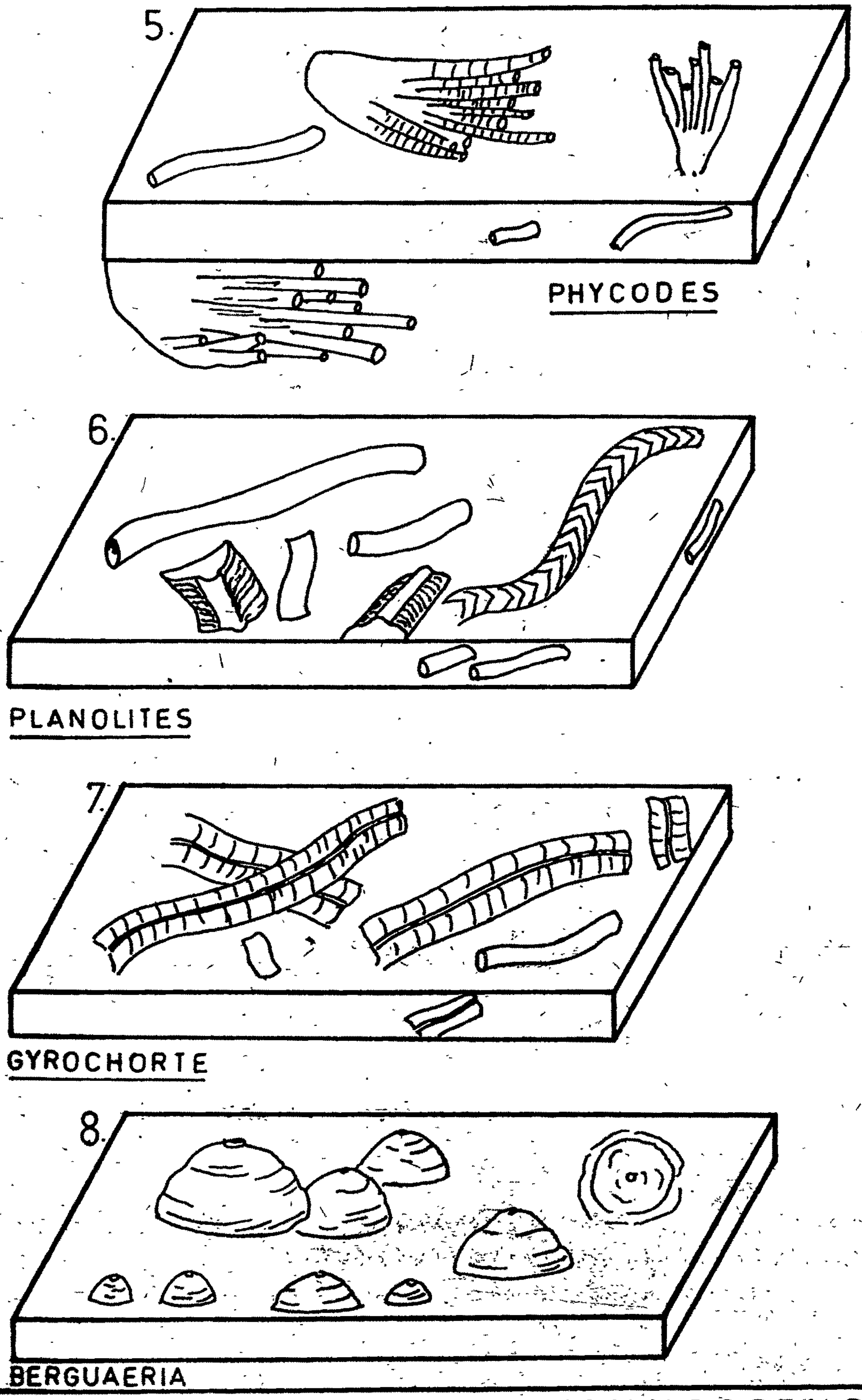


FIG.37 DISTRIBUTION OF ICHNOCOENOSES IN KHADIR ISLAND.

be a precondition for the construction of these structures in Hadibhadang Pir Member as indicated by the clay-ball lined walls in **Ophiomorpha** are concerned, while near Gadhada, it shows considerably high rate of reworking where the structures remain absent. 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 et al [1971] seems to be a resemble explanation.

It is well known that **Ophiomorpha** as trace fossil has been produced by many different organisms [Frey et al 1978] among which are **Callianassa**, **Upogebia**, **Axius** and **Thalassina.**

GYROCHORTE ICHNOCOENOSE :

This ichnocoenose is dominated by the ichnospecies of **Gyrochorte comosa**, **Dendritichnium**, **Curvolithus** and **Planolites.** The ichnocoenose generally shows a high degree of bioturbation indicating relatively slow sedimentation and little physical reworking. The small scale, ripple laminated sandstone with **Gyrochorte** very often found in the Gadhada Sandstone Member indicate increase water agitation with concomitent increase in sediment transport, but not necessarily increase of sediment influx.

The **Gyrochorte** ichnocoenose represent the activity of crawling which is similar to amphipod trails.

CHONDRITES ICHNOCOENOSE :

This association is characterized by **Chondrites, Paleodictyon** occasional **Planolites** and is found in the micritic sandstone of Hadibhadang Pir Member and Gadhada Sandstone Member. The association appears to be related to sediments formed in mid-fan delta environment and represents a low energy regime. **Chondrites** and **Paleodictyon** further represent regularly branched burrow system constructed by endobenthic deposit-feeding organisms of unknown taxonomic affinity, where the burrows are emphaced well below the water sediment interface. The nature of such burrow occurrence in the field indicate that the burrow was kept open by its inhabitant and has later filled passively with sediment from above. The occurrence of **Chondrites** in a deposit according to Bromley and Ekdale [1984] indicate very low oxygen levels in the interstitial waters within the sediment at the site of burrow emplacement. Thus oxygen-poor conditions influence the distribution of **Chondrites** making organisms to a much more significant degree. In short **Chondrites** reflect an environmental tolerence of oxygen levels 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.

RHIZOCORALLIUM ICHNOCOENOSE :

The ichnocoenose cosists primarily of **Rhizocorallium jenses & R. irregularei** with other characteristic elements including **Palaeophycus, Phoebichnus, Dactylophycus, Compaginatichnus** and **Planolites.** Most elements of this association are shallow, burrowing deposit feeders found in fine to medium grained mixed siliciclastic carbonate sediments of shelly sandy limestone subfacies of Hadibhadang Pir Member which similar to the sandy micrites in the Gadhada Sandstone Member. Development of **Rhizocorallium** ichno-coenose is thought to be low energy in mid-fan deltic areas as suggested by Eagar et al 1985.

The other two species namely **R. jenese** and **R. irregularae** indicate high energy and low energy marine conditions respectively. It has been recently shown by Buckman J.L. [1990] that in some cases **R. jenese** may indicate non-marine or marginal marine conditions and also possibly a sediment feeding mode of life. The **Rhizocorallium** assemblage in Gadhada Sandstone Member may therefore reveal prevalance of marginal marine conditions.

PLANOLITES ICHNOCOENOSE :

This ichnocoenose is mainly dominated by sediment feeding traces [Planolites] with occassional occurrence of crawling traces [**Psammichnites, Merostomichnites** and **Compaginatichnus**]. Dimensions [length 3 to 23 and Diameter 0.8 to 1.3 cm.] of the planolites traces varies from place to place and are found to occurs in the shelly sandy limestone subfacies of Hadibhadang Pir Member, Gadhada Sandstone Member and Ratnasar Calcareous Sandstone Member.

As postulated by Frey and Pemberton [1985] the **Planolites** ichnocoenose appears to have been produced by the burrowing activities of large and small organisms over a broader range of depth in the substrates.

According to Nicholson and Hinde [1875, P.139], **Planolites** are cast of burrows of marine worms formed by the ejecta of the animal and the infill of **Planolites** represent sediment processed by the tracemaker, especially through deposit feeding activities of mobile endobiants.

SKOLITHOS ICHNOCOENOSE :

The **Skolithos** ichnocoenose consist of monodominent **Skolithos** burrows and are very well observed in Gadhada Sandstone Member and Hadibhadang Dungar Member. In Gadhada Sandstone Member, **Skolithos** are thickly populated and generally show high degree of bioturbation to indicate 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.

According to Vosslar and Pemberton [in Press] Oppurtunistic ichnocoenoses are commonly heavily dominated by **Skolithos linearis.**

Following the above discussion, it could be concluded that the monospecific **Skolithos** ichnocoenoses in Khadir had their development in high energy mid-fan deltic environments.

PHYCODES ICHNOCOENOSE :

The **Phycodes** ichnocoenose in Khadir is characterized by varieties of **Phycodes** species with minor **Planolites.** These are located in fine-grained thinly bedded calcareous sandstone shale sequence of Gadhada Sandstone Member. The ichnocoenose represents systematic mining of sediments by sessile organisms, that constructed horizontal structures or traces in the basin/sediments. Here the **Phycodes** ichnocoenose generally show a high degree of bioturbation [upto 100%], and the fine-grained nature of enclosing sediments in traces, indicate low energy environment and slow rate of sedimentation.

BERGAUERIA ICHNOCOENOSE :

This ichnocoenose is dominated by various resting traces [**Bergaueria, Calycraterion, Pelecypodichnus**] with few dwelling traces [Arenicolites]. It is observed in Gadhada Sandstone Member and Ganeshpur Calcareous Sandstone Member. The possible interpretation of Paleoenvironment for the **Bergaueria** following Pemberton et al [1988] is that, this ichnocoenose represent its development in the muddy thixotropic substrate in nature, in subtidal conditions where fluctuations in water level caused the animals to be stranded on the existed mud flats.

In general, the trophic and behavioral characteristics of the ichnocoenoses [Fig.38] indicate a gradient in bottom water agitation. The suspension feeding **Ophiomorpha** and **Skolithos** ichnocoenose represent the highest energy levels followed by trophically diverse **Bergaueria** ichnocoenose. The deposit feeding **Phycodes** and **Rhizocorallium** ichnocoenoses reflect progressively lower energy conditions. On the other hand **Chondrites. Planolites** and **Gyrochorte** ichnocoenoses are characterized by extremely low energy conditions where slow deposition and less erosion prevailed.

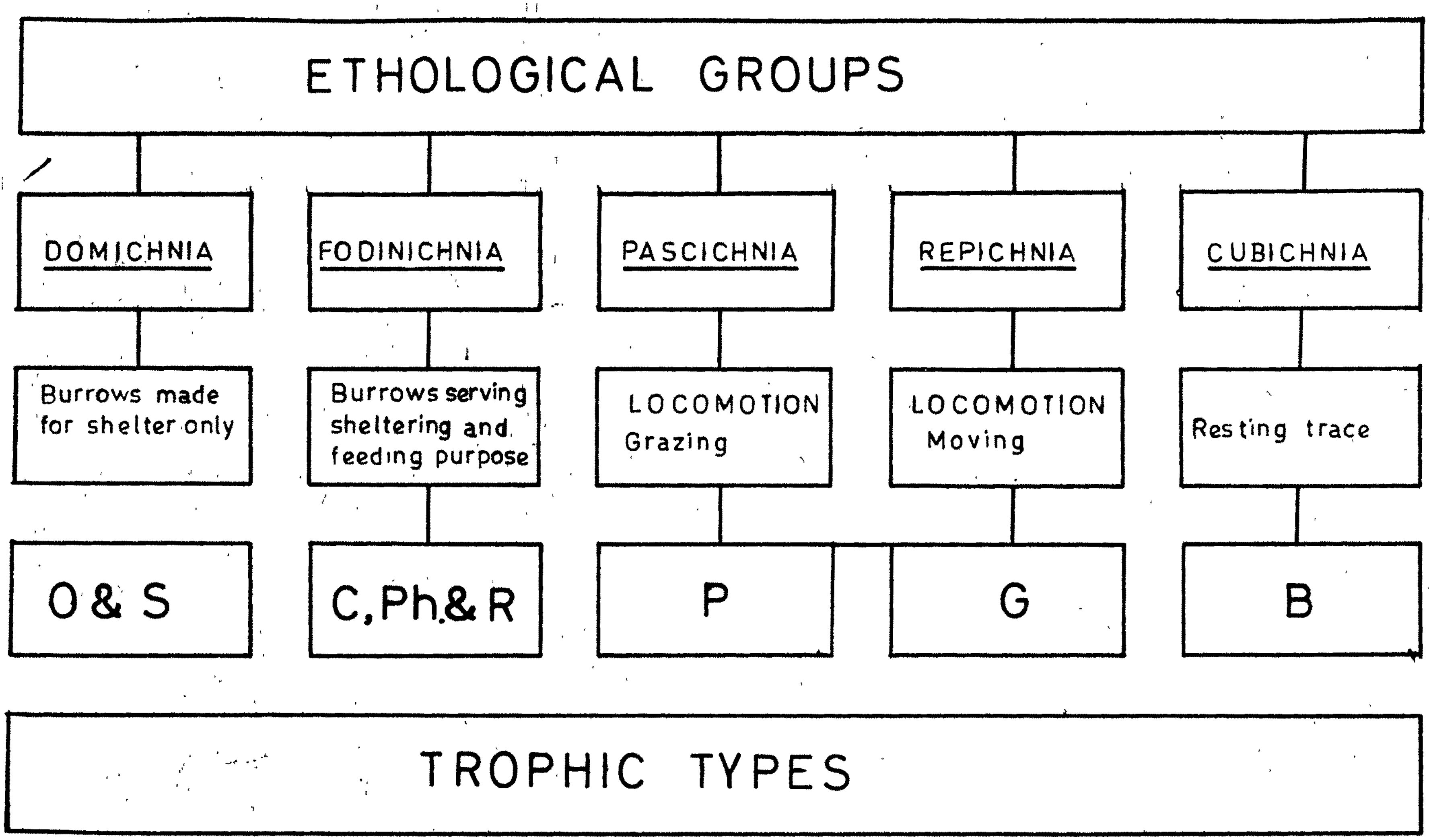


FIG 38 CHART SHOWING RELATION BETWEEN THE ETHOLOGICAL GROUPS TRACE FOSSILS ASSEMBLAGE (ICHNOCOENOSES) AND TROPHIC STRUCTURES

Finally, the trophic diversity of trace fossil data reflect different types of substrate conditions, varing rate of sedimentations, 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 the sedimentary units of Khadir.

ETHOLOGICAL GROUPING OF THE TRACE FOSSILS :

The trace fossils of Khadir Formation comprises a number of well defined ichnogenera and ichnospecies as well as some less distinct forms. These have been interpreted in terms of origin and behaviour of their producers in Chapter : VIII. Their resulting ethological groups are summarized in Table : 6.

All the trace fossils reveal tangible evidence of the behaviour of animals, and the most natural way to classify them is according to their behavioral patterns. The ethological classification devised by Seilacher [1953a, 1964] serves this purpose and is in general use in trace fossils description and interpretation. Based on the trace fossil morphology alone, it is divided in five ethological groups. This has been represented in Table : 5. Brief description of the ethological groups is given below.

Cubichnia [Resting Traces] :

These are shallow depressions made by animals that temporarily settle onto, or dig into substrate. Emphasis is upon reclussion.

These structures are found isolated, but sometimes intergrade with crawling traces or escape structures. The resting traces investigated by the author in Khadir Formation are mostly represented by conical sheets as well as almond shaped individuals and include **Bergaueria**, **Conostichus**, **Calycraterion**, **Pelecypodichnus**, **Lockeia** etc.

Repichnia [Crawing Traces] :

Repichnia are trackways and epistratal or intrastratal trails made by organisms travelling from one place to another and reflect directed locomotion rather than any other activity. Most typically these traces follow bedding planes. Certainly the animals may have been feeding as it progressed, but this activity is not directly registered in the morphology of the trace fossil. Repichnial traces are found in sediments of Gadhada Sandstone Member and Hadibhadang Pir Member of Khadir Formation and represented by linear or sinuous of various types include **Beaconichnus**, **Didymaulichnus**, **Gyrochorte**, **Isopodichnus**, **Kouphichnium**, **Merostomichnites**, **Mescichnium**, **Psammichnites**, **Scolicia** etc.

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 trackway or locomotion trace follows a meandering or spiral coarse, 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 derive from similar behaviour at a level beneath the seafloor.

The grazing traces in Khadir are mostly unbranching, non-overlapping. Curved to slightly coiled patterns, reflecting maximum utilization of surficial food available to the animals. Many complete forms are well preserved include **Compaginatichnus**, **Cochlichnus**, **Fustiglyphus**, **Helminthopsis**, **Megagrapton**, **Planolites**, **Rhabdoglyphus**, **Taphrhelminthopsis** etc.

Fodinichnia [Feeding Structures] :

This category is characterized by the combined function of deposit feeding and dwelling. Thus, the structure has some degree of permanence, and yet its morphology reflects exploitation of the substrate for food. The Khadir Formation representatives include single branched or unbranched, cylindrical to sinuous shafts or U-shaped burrows, a complex parallel to concentric burrow repititions [Spreiten Structures]. Burrows are found oriented at various angles with respect to bedding plane. Many complete forms are found preserved and include **Chondrites**, **Gyrolithes**, **Keckia**, **Muensteria**, **Phycodes**, **Rhizocorallium**, **Rosselia**, **Spirophycus**, **Spirophyton**, **Saportia**, **Thalassinoides**, **Volkichnium**, **Zoophycus** etc.

Domichnia [Dwelling Structure] :

These are burrows, borings or dwelling tubes providing more or less permanent domiciles. The trace-maker may be a sessile suspension feeder, on 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. The dwelling structures investigated by the author in Khadir are mostly represented by simple, kind, bifurcated or U-shaped structures perpendicular or inclined at various angles to bedding or branched burrows having vertical or horizontal components in different sedimentation level. Dwelling traces are found in sediments of Gadhada Sandstone Member, Hadibhadang Pir Member, Hadibhadang Dungar Member, Ganeshpur Calcareous Sandstone Member and Bambanka Member of Khadir Formation and include **Arenicolites, Cylindrichus, Diplocraterion, Monocraterion, Ophiomorpha, Palaeophycus, Skolithos, Spongilimorpha** etc.

PALEOECOLOGICAL CONSIDERATION AND TRACE FOSSIL DISTRIBUTION :

Trace fossils have great paleoecological utility because they are [i] widespread in space and time, [ii] found in place and [iii] largely the record of animal behaviour and response, making them ideal indicators of environmental conditions.

In the recent ecological research it is a general practice 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 is the number of individuals per taxon per unit sample of sea floor. This parameter is usually expressed as a diversity index and is used to characterized the taxonomic structure and temporal stability of a benthic community [Rhoads 1975].

"Faunal Diversity" means absolute abundance of trace of body fossils, in the terms of abundance of living organisms at any particular time. This is, however, elusive so far trace fossils are considered. For this reason, measure of biotic density - numbers of individual per taxon are usually not calculated for fossil assemblages. However relative abundances can be used to estimate common are rare species during life of the assemblage [Rhoads 1975]. According to Levinton and Bambach [1970], 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. 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.

"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 herbivours, carnivorous or scanvengers, 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].

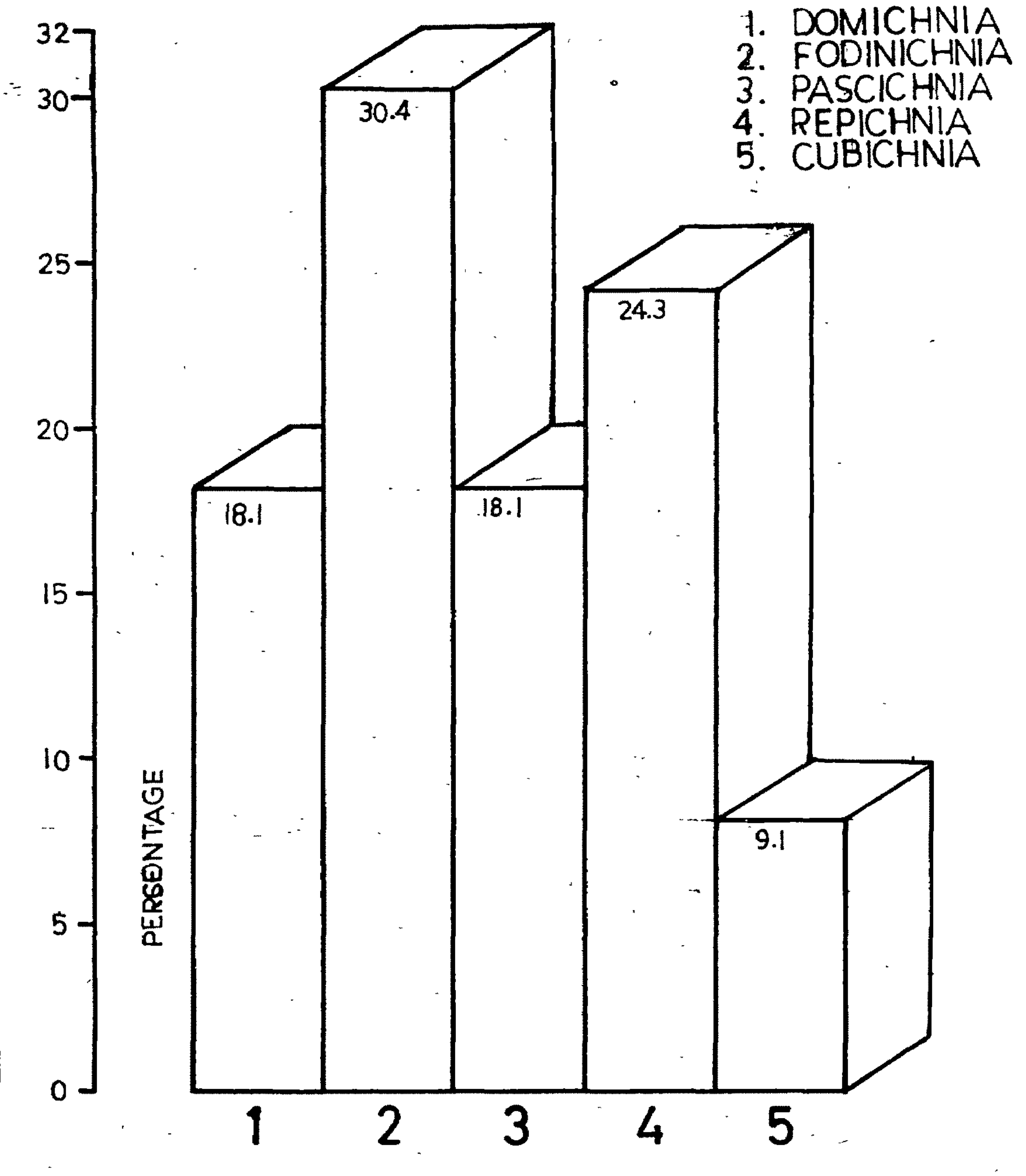
As regards the rocks of the Khadir Island of Kutch are concerned, they contain a variety of lithofacies and as such several factors which operated differentally in each subenvironment appear to have controlled the preservation of the biogenic structures in the siliciclastic carbonate sediments. Although, preservation biases do effect 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 are lotted in the histograms [Fig.39].

The average percentage of each ethological group were calculated for the whole Khadir Formation. To obtain percentage of ethological groups in Khadir Formation, number of ichnogenera present in each group were multiplied by hundred and divided by the total number of ichnogenera present in the entire formation. The histogram show that the feeding structures are predominent, followed by crawling, dwelling, grazing and resting traces. In turn, this also indicate that the Khadir Formation was chiefly populated by deposit feeders and with less abundance of suspension feeders and carnivores.

To obtain more information about substrates preference by the trace makers, the abundance of their traces were observed by recording in each unit presence or absence of the bio-sedimentary structures and classifying them according to their occurrences into four groups as [1] abundant, [2] Common, [3] Spurse, and [4] Rare [Table : 8].

The abundance of individual trace fossils in various substrate type also not give a clear picture. Many forms including **Arenicolites, Planolites, Phycodes, Ophiomorpha, Rhizocorallium, Palaeohycus, Gyrochorte, Muensteria** and **Scolicia** are found in a variety of sediments. Abundance

Figure 39 -Frequency diagram showing average relative abundance of the ethological groups in Khadir Formation.



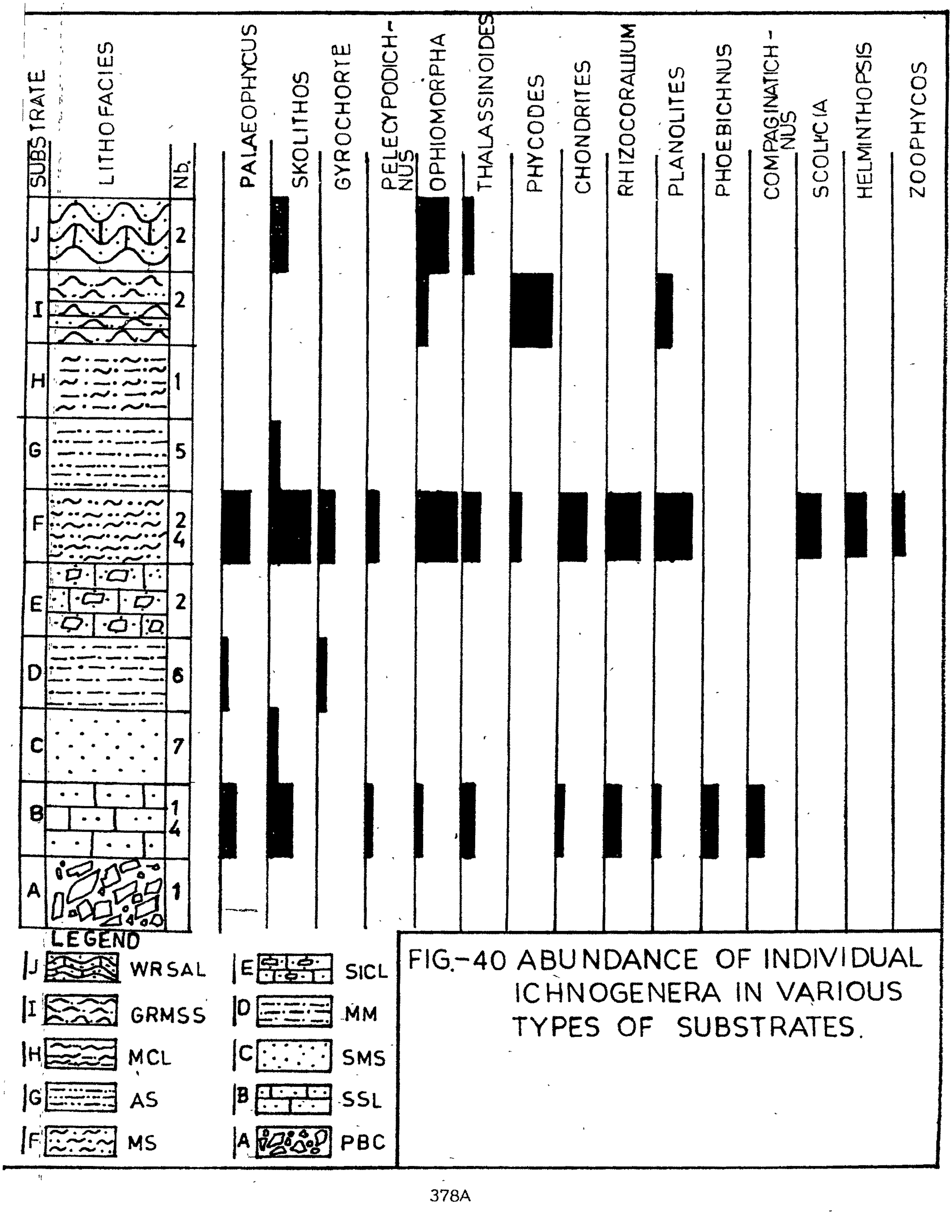


FIG.-40 ABUNDANCE OF INDIVIDUAL ICHNOGENERA IN VARIOUS TYPES OF SUBSTRATES.

TABLE : 8

ETHOLOGICAL DISTRIBUTION OF TRACE FOSSILS IN DIFFERENT MEMBERS AND THEIR RELATIVE ABUNDANCE

ICHNOGENERA	1	2	3	4	5	6	7	8	9	10	11	12
Arenicolites				+			S	+				
Beaconichnus		+					R				+	
Bergaueria				+	+		C-S					+
Bolonia				+			R				+	
Calycraterion				+			S					+
Chondrites		+		+			A		+			
Circulichnus				+			R			+		
Cochlichnus		+					S-R			+		
Compaginatichnus		+					S			+		
Conostichus					+		S					+
Crossopodia				+			S				+	
Ctenopholeus				+			S-R		+			
Curvolithus		+		+			S-R				+	
Cylindrichnus			+	+			C-R	+				
Cylindricum		+		+			S-R	+				
Dactylophycus		+					R		+			
Dendrotichnium		+					R			+		
Didymaulichnus				+			C				+	
Diplocraterion			+	+			C-R	+				
Fustiglyphus				+			R			+		
Gyrochorte				+			A-C				+	
Gyrolithes				+			C		+			
Halopoa				+			S			+		
Helminthopsis				+			R			+		
Isopodichnus				+			S				+	
Keckia				+			R		+			
Kouphichnium				+			R				+	

[CONTD]

TABLE : 8 [CONTD]

ICHNOGENERA	1	2	3	4	5	6	7	8	9	10	11	12
Lanicoidichna				+			R	+				
Lockiea			+	+			R					+
Mammillichnus				+			R					+
Megagrapton				+			C			+		
Merostomichnites		+					S				+	
Mesichnium	+						S				+	
Monocraterion			+			+	S	+				
Muensteria				+			C		+			
Neonereites				+			R				+	
Nereites				+			R				+	
Ophiomorpha				+	+		A	+				
Palaeophycus		+		+			S	+				
Paleodictyon		+					C-R			+		
Palmichnium				+			S				+	
Pelecypodichnus	+			+			A					+
Phoebichnus		+		+			S		+			
Phycodes				+			A		+			
Psammichnites		+		+			C				+	
Rhabdoglyphus				+			R			+		
Rhizocorallium		+		+			C-S		+			
Rosselia					+		R		+			
Saportia			+	+			C			+		
Scalarituba		+					R	+				
Scolicia		+		+			C-R				+	
Siphonites				+			R	+				
Skolithos	+		+	+	+		A	+				
Spirophycus				+			C-R		+			
Spirophyton					+		A		+			

[CONTD]

TABLE : 8 [CONTD]

ICHNOGENERA	1	2	3	4	5	6	7	8	9	10	11	12
Spongeliomorpha				+			R	+				
Steigerwaldichnium				+			R		+			
Susterigichnus				+			R		+			
Taenidium				+			R		+			
Taphrhelminthopsis				+			R			+		
Thalassinoides		+		+			C-R		+			
Treptichnus				+			R		+			
Tylichnus				+			R				+	
Volkichnium				+			R		+			
Zoophycos		+					R		+			

1 = HDM
2 = HPM
3 = RCSM
4 = GSM
5 = GCSM
6 = BM

7 = A = Abundant
C = Common
S = Sparse
R = Rare
8 = Domichnia
9 = Fodinichnia
10 = Pascichnia
11 = Repichnia
12 = Cubichnia

of **Ophiormorpha** and **Skolithos** are especially found in sandy micrite of Ganeshpur Sandstone Member, but in this same facies horizontal traces occur such as **Planolites, Palaeophycus, Phycodes, Rhizocorallium, Compaginatichnus** etc. on the other hand **Gyrochorte, Halminthopsis** and **Muensteria** are preserved in the ferruginous sandy micrites.

In general the results obtained from Fig. 40 suggest that most of the Khadir trace fossils 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 Khadir Sediments and no clear picture can be obtained when only one of such factor [substrates] was considered by the author in the above studies.

Fig. 41 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 paleogeographic setting.

Interpretation of sediments in terms of lithofacies sometimes indicate relationships between the trace fossils and the environments intense **Ophiormorpha** and **Skolithos** burrows are found associated with trough cross-bedded sandy micritic sediments of Gadhada Sandstone Member and indicate a moderate to high energy environment. **Planolites, Paleophycus, Phycodes, Rhizocorallium, Thalassinoides, Scolicia** etc. in Hadibhadang

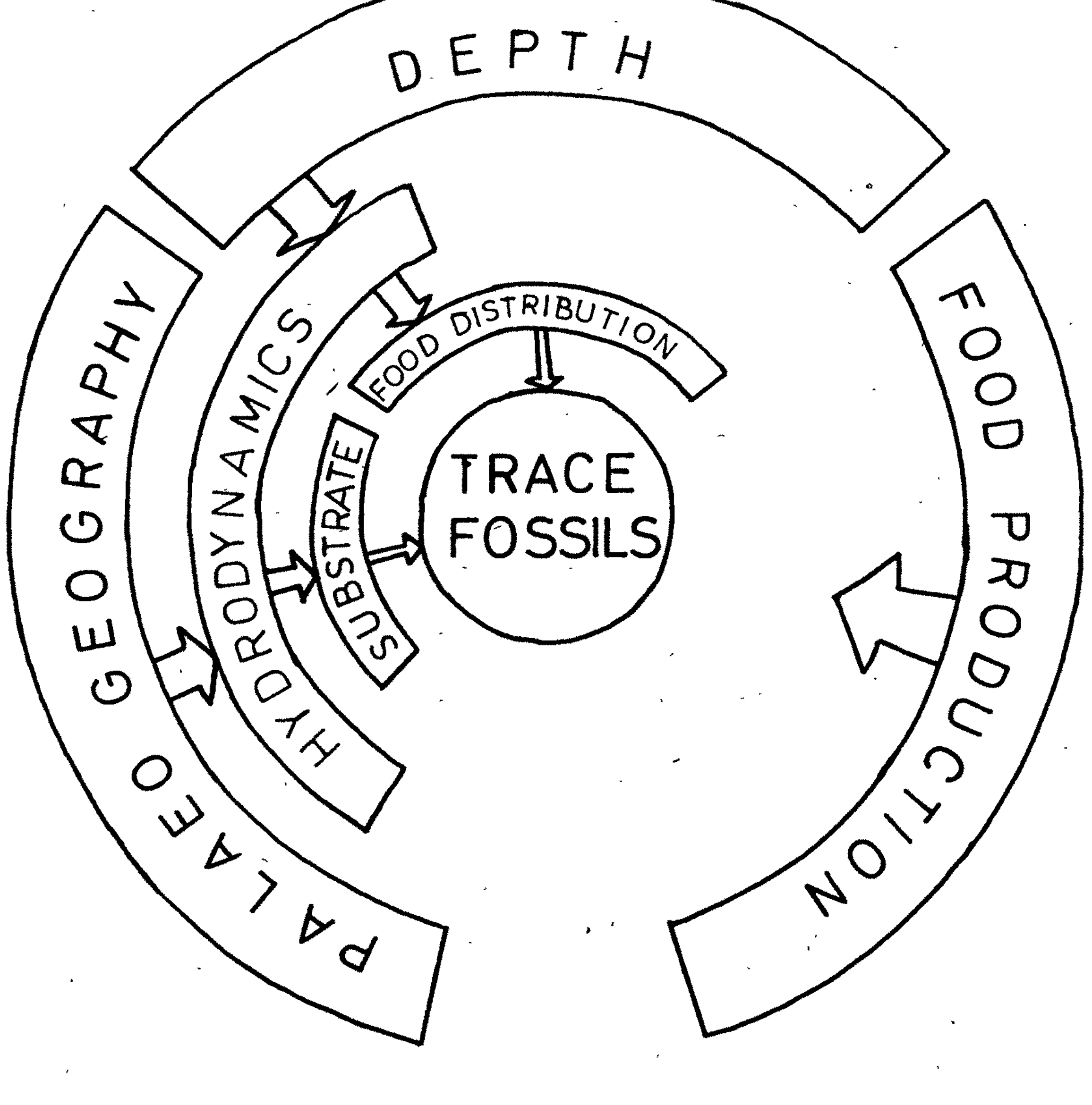


FIG.41 SIMPLIFIED MODEL OF THE RELATIONSHIP BETWEEN TRACE FOSSILS AND THEIR ENVIRONMENTS MORE IMPORTANT RELATIONS ARE INDICATED BY ARROWS (AFTER FURSICH 1974)

Pir Member and Gadhada Sandstone Member in shaly sandstone facies in low energy environments. As confirmed earlier the suspension-feeders as expected show higher diversity in the finner sediments also reflect the energy conditions. In 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 deposit feeders. Some deposit feeders present in all sediments and environments seems to have found equally suitable conditions everywhere while suspension-feeders are found strongly dependent on turbulence or current for their food intake.

It is, therefore concluded that the hydrodynamic conditions together governed by depth and paleogeography played the most important role in the distribution of the trace fossils in Khadir Island. High energy environments favoured deep burrowing suspension feeding and low energy environments shallow burrowing and deposit feeding organisms.