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Environmental Distribution of Scleractinian Corals in the Jurassic of Kachchh, Western India

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Abstract : Scleractinian corals commonly occur at specific horizons and localities, in carbonate and in siliciclastic sediments, throughout the Jurassic (Bajocian to Oxfordian) of Kachchh as meadows, biostromes, boulder beds and as scattered specimens. In many cases they are part of the autochthonous benthic fauna and in others they suffered short intra-basinal transport. Cerioid forms of low diversity (*Amphiastraea*, *Isastraea*, etc.) abound in high-energy siliciclastic sediments. High diversity coral faunas, which include thamnasterioid (*Microsolena*, *Dimorpharaea* and *Kobya*) and solitary (*Trocharaea* and *Trochoplegma*) taxa with fenestrate septa and plocoid forms (*Stylina*), dominate in carbonate sediments deposited in low energy, deeper-water environments. The solitary *Montlivaltia* exhibits a great physiological tolerance of environmental stress. In all, eight coral assemblages have been recognized within the ?Early Bajocian to Late Callovian sediments of the Kachchh basin.

The distribution of scleractinian coral assemblages has been governed mainly by the rate of sedimentation and particularly by the influx of coarse siliciclastic material. As a consequence the distribution pattern reflects onshore-offshore gradients and the general deepening of the Kachchh basin towards the Oxfordian.

Keywords: Scleractinian corals, Environment, Jurassic, Kachchh, Gujarat.

INTRODUCTION

The pericratonic Kachchh basin, situated at the western part of India, is famous for its Jurassic invertebrate fauna. Scleractinian corals in Kachchh were first classified into 71 species, 65 of them new, by Gregory (1900). In recent years, Beauvais (1978), Pandey and Fürsich (1993), Fürsich et al. (1994a), Pandey and Lathuilière (1997) and Pandey et al. (1999) studied the taxonomy and ecology of corals from Kachchh.

Shape, attachment area and growth bands of Recent scleractinian corals reflect water energy, substrate, light intensity, temperature, sediment input and indirectly also depth, turbidity, nutrient supply, salinity, etc. (e.g. Wells, 1967; Chappell, 1980; Hubbard and Pocock, 1972; Glynn and Wellington, 1983; Veron, 1995; Hüssner, 1994; Barnes and Lough 1999). The present paper records the distribution of scleractinian corals in the Jurassic sediments of Kachchh and relates differences in species composition and variability of morphological features to changes in the palaeo-environment.

Jurassic rocks of Kachchh are exposed in three parallel-faulted WNW-ESE trending anticlinal ranges, besides some isolated outcrops such as Kunwar Bet, Kakindia Bet, Gangta Bet and Wagad (Fig.1). The Kachchh basin is a rift basin originating in the Late Triassic (Biswas, 1991). Earliest sediments are non-marine, while marine sediments range in age from Bajocian (Middle Jurassic) to Albian (Middle Cretaceous). They comprise nearshore coarse-grained siliciclastics to offshore argillaceous silt and carbonates of a storm-dominated ramp to carbonates deposited well below storm wave base. Lithostratigraphically, the sediments have been grouped into Khavda, Patcham, Chari, Katrol and Umia Formations (Waagen, 1873; Pandey et al. 1984; Fürsich et al. 1994b). A more refined lithostratigraphic scheme has been provided by Biswas (1980). In the present paper, the two lithostratigraphic schemes have been combined (Fig.2).

CORAL ASSEMBLAGES

Corals have been collected from 60 horizons. Except for a few examples of coral meadows and small coral patch reefs (Fürsich et al. 1994a), all occurrences consist of scattered colonial and solitary corals. Although a precise

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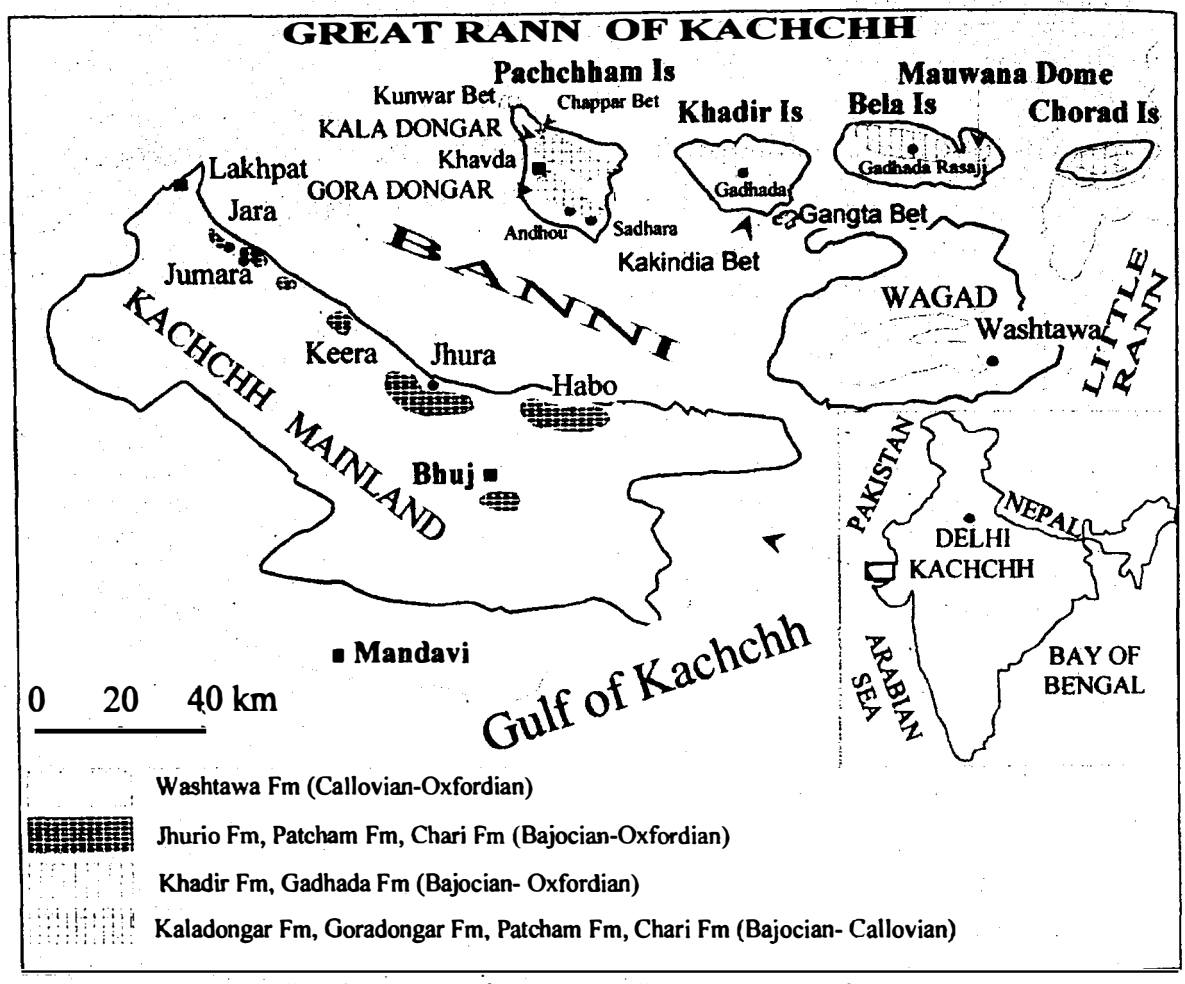


Fig.1. Locality map of Jurassic corals in Kachchh basin, western India.

correlation of the coral horizons has not been possible due to the scarcity of index fossils (ammonites), eight intervals with coral populations can be distinguished in the Kachchh basin during Bajocian to Oxfordian time (Fig.3). They are termed assemblages, because in most cases they do not correspond to relicts of fossil communities, but define biofacies belts. These are, in some cases, preserved *in situ* such as in the case of the *Amphiastraea piriformis* patch reef of Mauwana Dome. More often, they represent transported relicts of coral meadows or rare individuals that were minor constituents of bivalve/brachiopod–dominated communities. These assemblages do not seem to correspond to discrete chronostratigraphic units but, especially in the lower part of the sequence, are diachronous, following onshore-offshore facies patterns.

In the following discussion, (r) stands for rare, (o) for occurring, (c) for common and (a) for abundant.

(1) *Amphiastraea - Isastraea* Assemblage (?Early - Middle Bajocian)

Composition and ecological features: The assemblage is characterized by massive cerioid coralla, dominated by *Amphiastraea piriformis* (a) and *Isastraea* (*I. limitata, I. hemispherica, I. propinqua*) (o). Other taxa found rarely in this assemblage are *Cyathophora bourgueti, Lochmaeosmilia trapeziformis, Collignonastraea* sp., *Stylina dubia, Melikerona parva,* and thamnasterioids. In *Isastraea* and *Cyathophora* the calices are deep. In the Kachchh basin *Amphiastraea* exhibits a range of morphological characters: corallite diameter and size variation, crowding of septa, development of an endothecal ring and eccentricity of the columnar axis. In this assemblage corallites are large (> 3.0 mm), of variable diameter (from 3.0 mm to 8.0 mm), endothecal ring is well developed, septa are unevenly distributed and axis is eccentric.

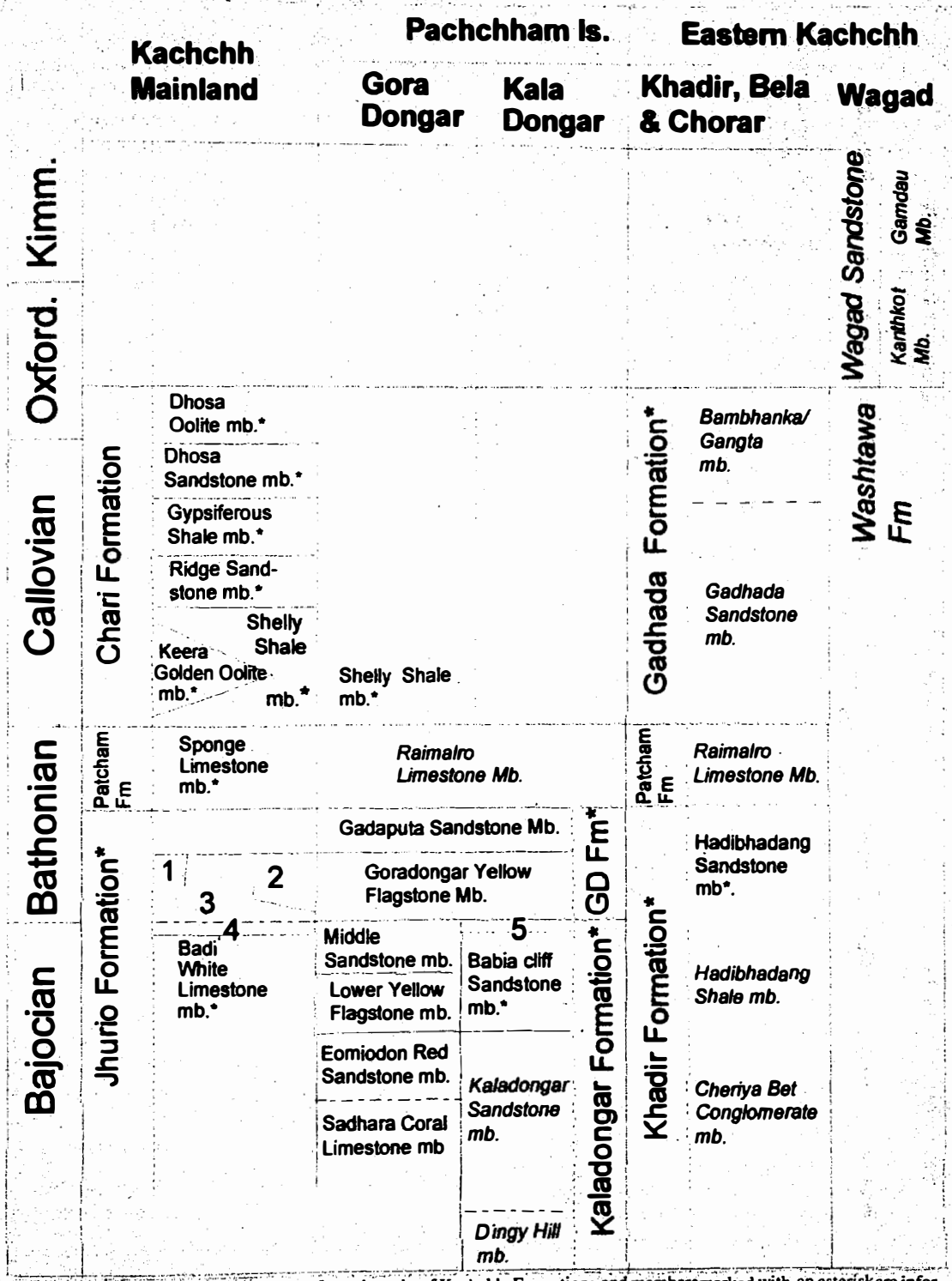


Fig.2. Lithostratigraphic framework of Middle Jurassic rocks of Kachchh. Formations and members marked with an asterisk are infor al and await formal description (Fürsich et al. *in prep.*). Lithostratigraphic units of Gora Dongar after Fürsich et al. (1994b). Units in italics are those of Biswas (1980). 1 - Jumara Coral Limestone mb.*, 2 - Goradongar Yellow Flagstone Mb., 3 - Jhura Golden Oolite mb.*, 4 - Canyon Limestone/Badi Lower Golden Oolite*, 5 - *Leptosphinctes* Pebbly Rudstone*. G.D. - Gora Dongar

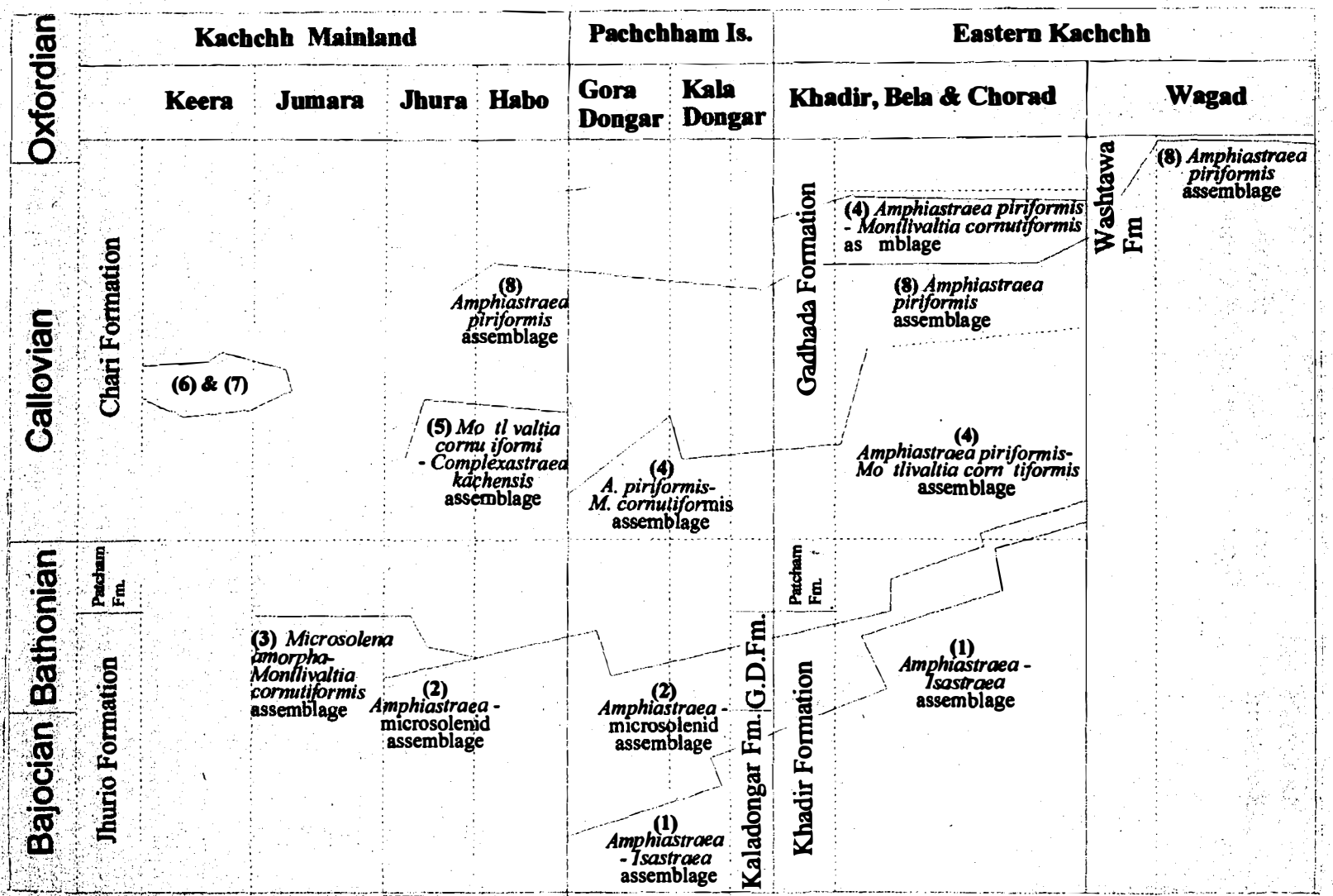


Fig.3. Spatial and temporal distribution of coral assemblages in the Middle Jurassic sediments of the Kachchh basin. (6) *Ampakabastraea exserta* - *Isastrea propinqua* assemblage, (7) *Goniocora turbinata* assemblage.

The deep calices in *Isastraea* and *Cyathophora* colonies suggest that the polyps were firmly anchored in the skeleton (Hubbard, 1973).

Lithostratigraphic and environmental distribution: This is the oldest coral assemblage established during the early phase of marine transgression of the basin during the Bajocian or even earlier and ranging up to the Middle Bajocian. Lithostratigraphically, it occurs from the Dingy Hill Member of Kunwar Bet and Chappar Bet (Figs.1-3), through the Kaladongar Sandstone Member up to part of the Babia Cliff Sandstone Member which crops out along the northern scarp of Kala Dongar, north of Pachchhmaipir, Babia Cliff and south of Narveri Wandh. The assemblage extends eastward along Khadir Cliff and along the northern slope of Mouwana Dome in the lower sandy part of the Hadibhadang Sandstone Member of the Khadir Formation.

In the Dingy Hill Member, the corals occur in coarse-grained, gravelly to pebbly (with granitic pebbles), trough crossbedded sandstones with shell fragments of brackish water bivalves such as *Indocorbula*, *Modiolus* or *Protocardia*. At some levels, tree trunks, oysters, gastropods or rhynchonellid brachiopods are associated with the corals. Preservation of the corals is poor, most specimens being abraded and profusely bored and clearly reworked. The sediments, which replace the underlying non-marine red beds and fluvial sandstones, reflect nearshore high-energy conditions. The Kaladongar Sandstone Member of the northern slopes of Kaladongar consists predominantly of well sorted, occasionally crossbedded sandstones with intercalated thin shell beds and silty marl units. Corals could be recovered only from the scree. From the lower part of the Babia Cliff Sandstone Member rare specimens of *Cyathophora bourgueti* have been recovered.

In the Hadibhadang Sandstone Member along Khadir Cliff, Bela, and Mouwana Dome, the corals occur in close stratigraphic vicinity of marginally marine sediments of the Hadibhadang Shale Member, characterised by brackish water bivalves such as *Indocorbula lyrata*, *Eomiodon*, and *Tancredia*. In the lower part of the Hadibhadang Sandstone Member of Mouwana Dome, reworked colonies of *Amphiastraea piriformis* occur in a massive sandstone with granitic pebbles.

(2) *Amphiastraea* - Microsolenid Assemblage (Late Bajocian - Middle Bathonian)

Composition and ecological features: The *Amphiastraea* – microsolenid assemblage marks the first appearance of microsolenids (*Microsolena amorpha*) (o), *Montlivaltia* (o), *Actinastraea* (r), *Trocharaea patelliformis* (r), *Collignonastraea* (r), *Axosmimilia* aff. *sessilis* (r), *Microphyllia* sp. (r) and *Actinastrea pentagonalis* (r). *Amphiastraea piriformis* (c) *Isastraea* (r) and *Lochmaeosmilia trapeziformis* (r) continue from the assemblage below, but *Amphiastraea* shows a remarkable change in morphology: the corallites are small (diameter < 3.0 mm), almost uniform in diameter (2.0-3.0 mm), possess a poorly developed endothecal ring, evenly distributed septa and a less eccentric axis compared to its occurrence further down in the stratigraphic column. *Isastraea* (maximum diameter 2.5 mm as opposed to more than 5.0 mm at lower levels) and *Lochmaeosmilia* (maximum diameter 1.1mm as opposed to more than 2.0 mm) have also small corallites. *Amphiastraea, Isastraea* and *Actinastraea* exhibit a very similar morphotype. All three taxa are cerioid, have a uniform corallite diameter (1.0 - 2.5 mm), similar number of septa (12 -17) and a similar theca (septo-paratheca). In *Amphiastraea*, the septa are thick and either occasionally one of the septa reaches the central axis or else the corallites show a rudimentary endothecal ring. In *Isastraea*, in contrast, only in one specimen there is a corallite, in which one of the septa extends up to the center with no sign of an endothecal ring and columella. In *Actinastraea* the septa are thin and a pseudocolumella exists.

The small size of the corallites, their uniform diameter, and the evenly and symmetrically distributed septa are interpreted here as recording favourable water energy for coral growth. Generally, massive growth forms and a dominance of flat shapes indicate high energy conditions. However, low influx of siliciclastic sediments, highly bioturbated sediments and dominance of traces of deposit-feeders suggest low energy conditions below the fair-weather wave-base in the case of the Goradongar Yellow Flagstone Member (Fürsich et al. 1994b). The flat shapes of the corals are here interpreted to indicate a soft substrate or low intensity of light rather than high energy conditions as the main factors controlling coral growth.

Lithostratigraphic and environmental distribution: The earliest occurrence of the assemblage is in the 5-7 m thick so-called *Leptosphincetes* Pebbly Rudstone of Kala Dongar, a prominent ledge situated approximately 40 m below the top of the Babia Cliff Sandstone Member and containing the earliest ammonite found in the Kachchh basin so far (Singh et al. 1982). The large-scale trough cross-bedding, the pebbly nature of the sediment (intraformational, granitic and quartz pebbles), presence of wood fragments and abraded shell material and reworked coral fauna indicate high-energy, nearshore conditions. The assemblage also occurs in its lateral equivalent, the so-called Canyon Limestone of the Jhurio Formation. The thick, hard, massive, bioclastic rudstone with coarse bioclastic debris, limestone

pebbles and common reworked coral heads belonging to the family Microsolenidae, forms vertical cliffs and gorges near the centre of Jhura Dome (about 2-2.5 km SW of Jhura village). Towards the northwest, in Badi Nala, the unit becomes a Fe-oolitic grain- to rudstone with several layers of reworked and bored pebbles, shells beds and scattered coral heads. Corals at this locality are *Amphiastraea* sp., *Isastraea* sp., and *Microphyllia* sp. The unit corresponds to member C of the Jhurio Formation of Biswas (1980, p. 41). The assemblage continues into the Goradongar Yellow Flagstone Member of Kaladongar, Goradongar and Jhura Dome, a mixed siliciclastic/carbonate unit consisting of alternations of fine sandy silty marl and thin laminated and ripple-bedded sandstones deposited by storm flows. The moderate coral diversity along with ammonites and a rich bivalve fauna (Fürsich et al. 1994b) indicates fully marine conditions.

(3) *Microsolena amorpha - Montlivaltia cornutiformis* Assemblage (late Middle Bathonian to Late Bathonian)

Composition and ecological features: This is the most diverse coral assemblage in the Kachchh basin, occurring as coral meadows (Jumara Coral Beds) (Fig.5c). The assemblage comprises the *Microsolena amorpha - Montlivaltia frustriformis* association of Fürsich et al. (1994a), which can be regarded as the relict of a former coral-dominated community. The thamnasterioid *Microsolena amorpha* dominates the association followed by *Montlivaltia cornutiformis*. Microsolenids, represented only by two species in the *Amphiastraea* - microsolenid assemblage, are very diverse being represented by *Trochoplegma tenuilamellosa* (a), *Microsolena amorpha* (c), *Dimorpharaea stellans* (c), *Kobya crassolamellosa* (o), *Tricycloseris triangularis* (o), *Trocharea patelliformis* (o), and *Microsolena subturbinata* (r). The corals exhibit a wide range of specialization as demonstrated by their range of skeletal structures. Corals such as *Microsolena amorpha* and *Lochmaeosmilia trapeziformis* have comparatively large colonies (10 cm and 15 to 20 cm respectively) suggesting more rapid growth and a higher reproductive potential than most of the other taxa, a sign of optimum conditions for these corals. When all microsolenids are considered, those with pennular trabeculae dominate. About two-thirds of the taxa in the assemblage made here their first appearance in the Kachchh basin. Characteristic forms include *Trochoplegma tenuilamellosa* (c), *Dimorpharaea stellans* (c), *Stylina kachensis* (c), *Epistreptophyllum cornutiformis* (c), *Gregorycoenia magna* (o), *Kobya crassolamellosa* (o), *Tricycloseris triangularis* (r), *Microsolena subturbinata* (r), *Complexastrea kachensis* (r), *Goniocora socialis* (r), *Lophosmilia tenuicaulata* (r), *Comophyllia thamnasterioides* (r), and *Craterastraea crateriformis* (r).

Most of the parautochthonous, scattered coralla are hemispherical to discoidal in shape; branched growth forms are rare. The pennular and perforated septa of many of these corals are characteristic of a comparatively deep environment (Lathuilière and Gill, 1995). This bathymetric interpretation is supported by the dominance of microsolenids. Fürsich et al. (1994a) had interpreted the *Microsolena amorpha - Montlivaltia cornutiformis* association to have lived in warm, fully marine and well aerated waters on a muddy bioclastic sea floor, close to the lower boundary of the photic zone and well below fair weather wave base, only occasionally disturbed by the fringes of storms. The corals served as substrate for a boring (bivalves, sponges, acrothoracicans) and encrusting biota (serpulids, oysters, sclerosponges). Associated faunal elements include abundant brachiopods, bivalves and gastropods.

Lithostratigraphic and environmental distribution: The Jumara Coral Beds refer to three closely adjacent horizons occurring near the base of the Jumara Coral Limestone Member (Jhurio Formation) of Jumara Dome. Based on own sedimentological observations, the member corresponds to the lowest part of Middle to Late Bathonian carbonate ramp.

(4) *Amphiastraea piriformis - Montlivaltia cornutiformis* Assemblage (Callovian)

Composition and ecological features: This assemblage occurs in the basal part of the Shelly Shale Member of the Lower Chari Formation of Gora Dongar and the basal part of the Gadhada Sandstone Member on the southern slopes of Bela Anticline and Mouwana Dome (Early Callovian). On Khadir Island, it occurs at several levels of the Gadhada Sandstone Member north and south of Gadhada village, ranging in age from early to late Callovian.

(a) In the Lower Callovian, the corals usually occur as scattered specimens and are associated with bivalves and ammonites. Corals consist both of colonial and solitary taxa. *Amphiastraea piriformis* (80%) reappears as the dominant taxon with the onset of siliciclastic sedimentation (silty clay to fine-grained sandstones) at the base of the Callovian. *Montlivaltia cornutiformis* (c), a eurytopic coral, continued from the underlying calcareous into the argillaceous facies. Another cerioid form is *Isastraea hemispherica* (r). The cerioid colonies from Gora Dongar (basal Chari Formation, east of Khavda) have smaller corallites than those from Mouwa a Dome (basal Gadhada Sandstone Member north of Mouwana village). The good preservation and lack of

abraded edges suggest no or very little transport. The large, flat colonies of *Amphiastraea piriformis* had very tiny attachment areas and large resting areas and were bored from both upper and lower surfaces. This suggests a relatively soft substrate and sporadic high energy conditions during which the corals were overturned. On the basis of lateral facies variations it is evident that the coral colonies of Mouwana Dome lived closer to the shoreline than those of Gora Dongar.

(b) In the Middle Callovian Gadhada Sandstone Member, north of Gadhada village, *Amphiastraea piriformis*, associated with *Montlivaltia cornutiformis*, *Gregoricoenia magna* and *Lochmaeosmilia trapeziformis*, occurs at two levels in fine- to medium-grained sandstone. The predominating *Ampiastraea* exhibits massive, flat colonies with a maximum diameter of about 15 cm, a tiny attachment area and a large resting area, the latter providing a stable position on the sea floor. The corallites are small (<4mm). They are heavily bored but rarely encrusted.

(c) In the Upper Callovian, *Amphiastraea piriformis* (58.5%) only little dominates over *Montlivaltia cornutiformis* (41.5%) in a matrix of ferruginous argillaceous fine-sandy silt. Apart from a few large specimens of *Amphiastraea piriformis*, the majority of coralla, whether of the colonial *Amphiastraea piriformis* or the solitary *Montlivaltia cornutiformis*, are small, nodular and of more or less similar size (<6 cm). Both taxa are commonly bored, worn, and fragmented, indicative of transport for some distance. *Montlivaltia cornutiformis* occasionally exhibit sharp edges, most likely due to fish predation. The fauna immediately below the coral level consists of suspension-feeders such as the epibyssate *Indogrammatodon*, cemented *Nanogyra* and pedunculate rhynchonellid brachiopods in addition to deposit-feeding infaunal nuculids. The matrix and the associated benthic fauna indicates a low-energy environment. Small attachment areas and the small size of corallites of *Amphiastraea piriformis* suggests that the corals originally lived on soft substrate, subject to only minor influx of siliciclastic material. Hence transport, possibly in connection with major storms, appears to have been restricted to within habitat.

Lithostratigraphic and environmental distribution: The lower part of the Shelly Shale Member, having argillaceous silt with occasional intercalations of thin sandstones, calcarenites and shell beds, is widely exposed on Kachchh Mainland and represents generally offshore, low energy conditions far below fair weather wave base. The muddy sea floor did not encourage coral growth. Consequently, corals occur only at few localities.

Gadhada Sandstone Member, exposed on the lower southern slopes of Khadir Island, Bela Dome, and Mouwana Dome, consists mainly of sandstone with occasional argillaceous silt intercalations. The crossbedded sandstone is interpreted here as delta front sands. The basal part of the member, which corresponds to the basal Chari Formation, has yielded, in addition to scattered, exclusively cerioid corals, some bivalves and very few ammonites. In the upper part of the member, well exposed south of Gadhada village on Khadir Island, corals occur in a ferruginous fine-grained sandstone. The associated fauna consists of astartids, *Indogrammatodon*, rhynchonellids and the ammonites *Obtusicostites*, *Kinkeliniceras*, etc.

(5) *Montlivaltia cornutiformis* - *Complexastraea kachensis* Assemblage (Early Callovian)

Composition and ecological features: This assemblage is contemporary with assemblage (4). *Montlivaltia cornutiformis* (c) strongly dominates and *Complexastraea kachensis* (r) accounts for the rest. The specimens of *Montlivaltia* are larger in size than at any other locality of this stratigraphic level within the basin. They are mostly well preserved except for the epitheca, which is found only in traces. In both the genera the calicular surface is very shallow. *Montlivaltia* shows deposition of laminar layers on the septal surfaces (Pandey and Fürsich, 1993), with consequent increase in thickness of septa and decrease of the interseptal area.

Low coral diversity points to adverse conditions for growth due to a muddy sea floor and turbid water conditions. The increase in thickness of septa due to deposition of laminar layers of aragonite on the septal surfaces and consequently decrease of interseptal area are interpreted here as reflecting maturity. Thickness and complexity of septa has been correlated with length of tentacles (Hubbard and Pocock, 1984), which are mostly used for catching prey and sediment shedding. Narrow interseptal space may be related to thinning of polyp tissue, which in turn defines the capacity of the organism to survive adverse periods (Barnes and Lough, 1999). The shallow, more or less flat-floored calice of *Montlivaltia* suggests poor structural strength of the polyp and an altogether less efficient polyp (Hubbard, 1973).

Lithostratigraphic and environmental distribution: The assemblage occurs in the Shelly Shale Member of Habo Dome, a muddy lower ramp subject to occasional storm influence.

(6) *Ampakabastraea exserta* - *Isastraea propinqua* Assemblage (late Early Callovian)

Five closely associated ferruginous shell beds in the

upper part of the Lower Chari Formation of Keera Dome contain two coral assemblages, viz. the *Ampakabastraea exserta - Isastraea propinqua* assemblage (6) and the *Goniocora turbinata* assemblage (7).

Composition and ecological features: Assemblage (6) is dominated by sub-thamnasterioid corals. *Ampakabastraea exserta* (52%) is the most abundant taxon. The other corals are *Isastraea propinqua* (o), *Actinastrea pentagonalis* (o). *Epistreptophyllum cornutiformis* (o), microsolenids (r), *Dimorpharaea stellans* (r), *Thamnasteria* sp. (r), *Goniocora turbinata* (r), *Stylina dubia* (r), *Craterastraea crateriformis* (r), *Trocharea patelliformis* (r), *Dimorphastrea* ? (r), *Kobya* aff. *crassolamellosa* (r), *Periseris* cf. *elegantula* (r), and *Stibastraea* sp. (r). The very poor state of preservation (many specimens are bored, abraded and fragmented) suggest that they were transported for a considerable distance. The flat, massive sub-thamnasterioid to cerioid shapes of the colonies hint at an original environment of the corals in which sediment influx was negligible, illumination was plentiful (this is suggested by the high integration of the corallites and hence most likely photosymbiotic nature of the taxa), and water energy conditions were at least episodically high.

Lithostratigraphic and environmental distribution: The coral-bearing skeletal concentrations in the upper part of the Shelly Shale Member are transported and mixed assemblages derived from shallower areas probably by storm processes. Associated faunal elements are oysters, *Ctenostreon*, *Trigonia*, *Palaeonucula*, rhynchonellid brachiopods, ammonites, and fragments of crinoids and echinoids.

(7) *Goniocora turbinata* Assemblage (late Early Callovian)

This is assemblage is characterised by the branching, dendroid coral *Goniocora turbinata* which has suffered comperatively little breakage (Fig. 4A). The delicate dendroid form suggests reduced water energy. The abundance of corals and their reasonable preservation suggests only limited transport. The associated molluscan debris and presence of small reworked and bored concretions point to the influence of short-lived high energy events that caused mixing of faunal elements from various habitats.

(8) *Amphiastraea piriformis* Assemblage (Middle and Late Callovian)

The assemblage is well developed at four localities (Habo and Mouwana Domes, Bela Anticline and north of Washtawa, Wagad Dome) and characterized by mono-specific concentrations of *Amphiastraea piriformis*. The form and shape of the colonies vary in these localities from cerioid platy or globular to cerioid ramose.

(a) *Habo Dome:* The coral bed can be followed laterally for much of the crest of central Habo Dome. It also occurs on the northern flank of the dome, south of Dhrang village. At the latter locality, coral heads are usually clean, rarely bored and encrusted, closely packed, and oriented in all directions whereby regenerated growth at an angle to the previous one is commonly observed. The *A. piriformis* colonies vary in shape from platy to asymmetrically globular, and in diameter from 2 to 160 cm. The attachment area is either small or tiny. Larger colonies exhibit prominent 2.5-4.5 cm thick growth bands seen on the weathered surface (Fig.6B). Associated fauna includes bivalves such as *Plagiostoma*, *Falcymytilus*, several species of gastropods, and echinoid spines. At the crest of Habo Dome, the coral layer locally reaches up to 85 cm in thickness. Again all coral heads appear to have been turned around and do not form a cemented framework. Rather than a biostrome, the coral layer represents a boulder bed, the corals having been reworked by one or several major events such as storms.

On the crest of Habo Dome sediments just below the coral layer consist of 1.5 m thick, bioturbated, mostly unfossiliferous fine-grained sandstone, locally with small heads of *Amphiastraea piriformis* in growth position and with a sharp upper surface. The matrix of the coral layer is a heavily bioturbated, fine- to medium-grained sandstone with scattered echinoid spines. The coral layer is overlain by a calcareous, poorly sorted sandstone (10 - 40 cm thick) with *Astarte*-like shells, gastropods, small, reworked colonies of *Amphiastraea piriformis* and reworked ferruginous concretions, topped by a megaripple surface.

Fürsich et al. (1994a) discussed in detail the depositional environment of the Coral Boulder Bed at Habo Dome. The bed occurs within a transgressive phase, as is indicated by the high density of shells and coral heads. The corals apparently lived on a firm but occasionally shifting substrate, in a moderate to high energy environment with low rate of sedimentation. Hubbard (1973) suggested that cerioid colonies were not very efficient when removing sediment particles with the help of tentacles and hence one would not expect *Amphiastrea* in nearshore sandy environments. Thus, the distinct preference of *Amphiastrea* for sand-sized siliciclastic sediments in the Kachchh basin indicates that the corals were either opportunists, being able to invade sandy environments during phases of reduced sediment input, or else specialists with some - yet unknown - adaptations to cope with coarse siliciclastic sediment. The large size of some of the colonies (maximum diameter 160 cm) shows that reasonable living conditions prevailed

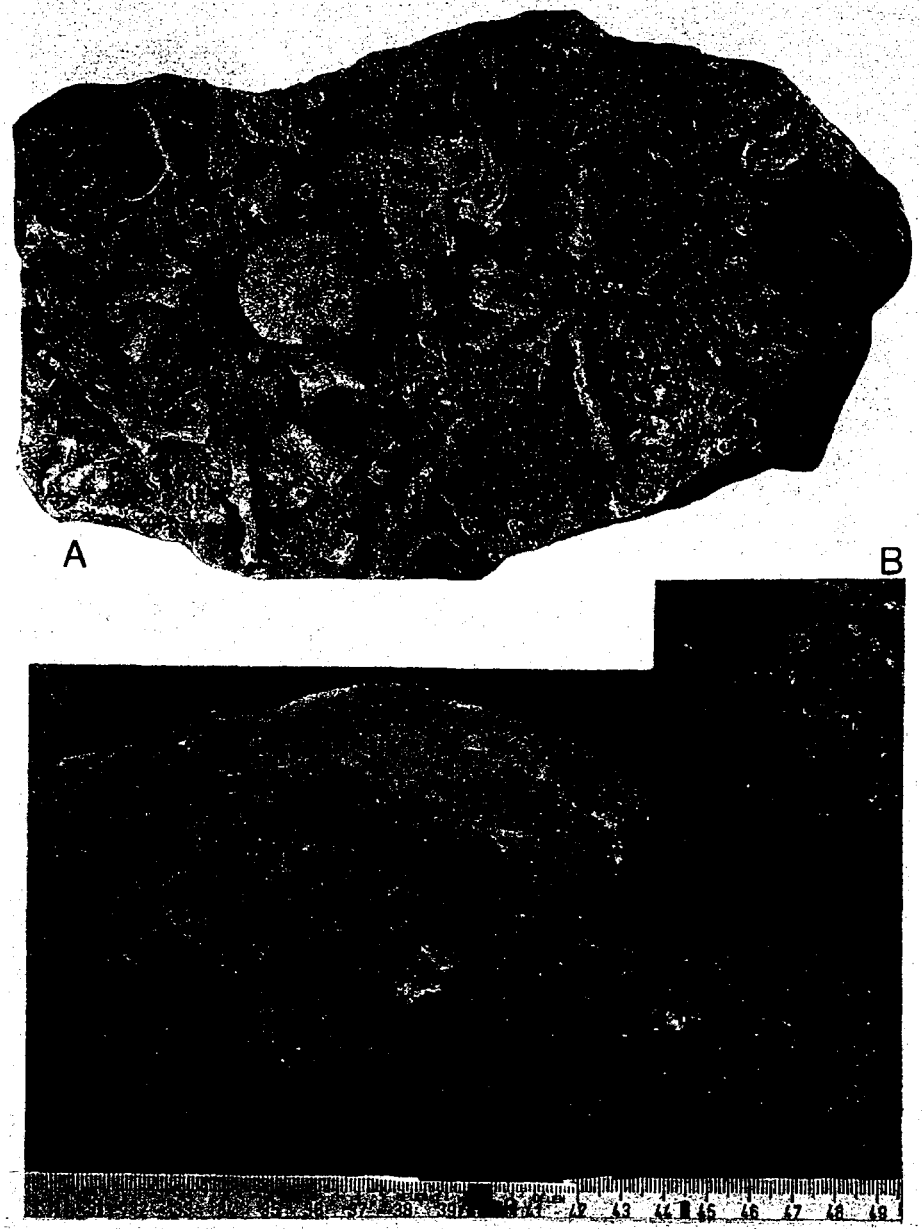


Fig.4. **A.** *Goniocora turbinata*, a branching, dendroid coral in the upper part of the lower Chari Formation (late Early Callovian) exposed at the northern slope of Keera Dome. **B.** Heads of *Melikerona parva* in growth position from the Sadhara Limestone Member of central Sadhara Dome, Gora Dongar, Pachchhham Island.

for an extended period of time. Numerous cases of regeneration of toppled corals indicate at least intermittent high energy events. That the environment did not reflect optimal living conditions for the corals can also be seen from the asymmetrical shape of the colonies, which is most likely related to an increased turbulence level.

(b) *Mouwana Dome:* Of the two monospecific *Amphiastraea piriformis* horizons in the middle part of the Gadhada Member north of Mouwana village, the older coral horizon, about 51 m above the base of the Gadhada Sandstone Member and intercalated between two sandstone units, is referred to as a coral biostrome. Massive

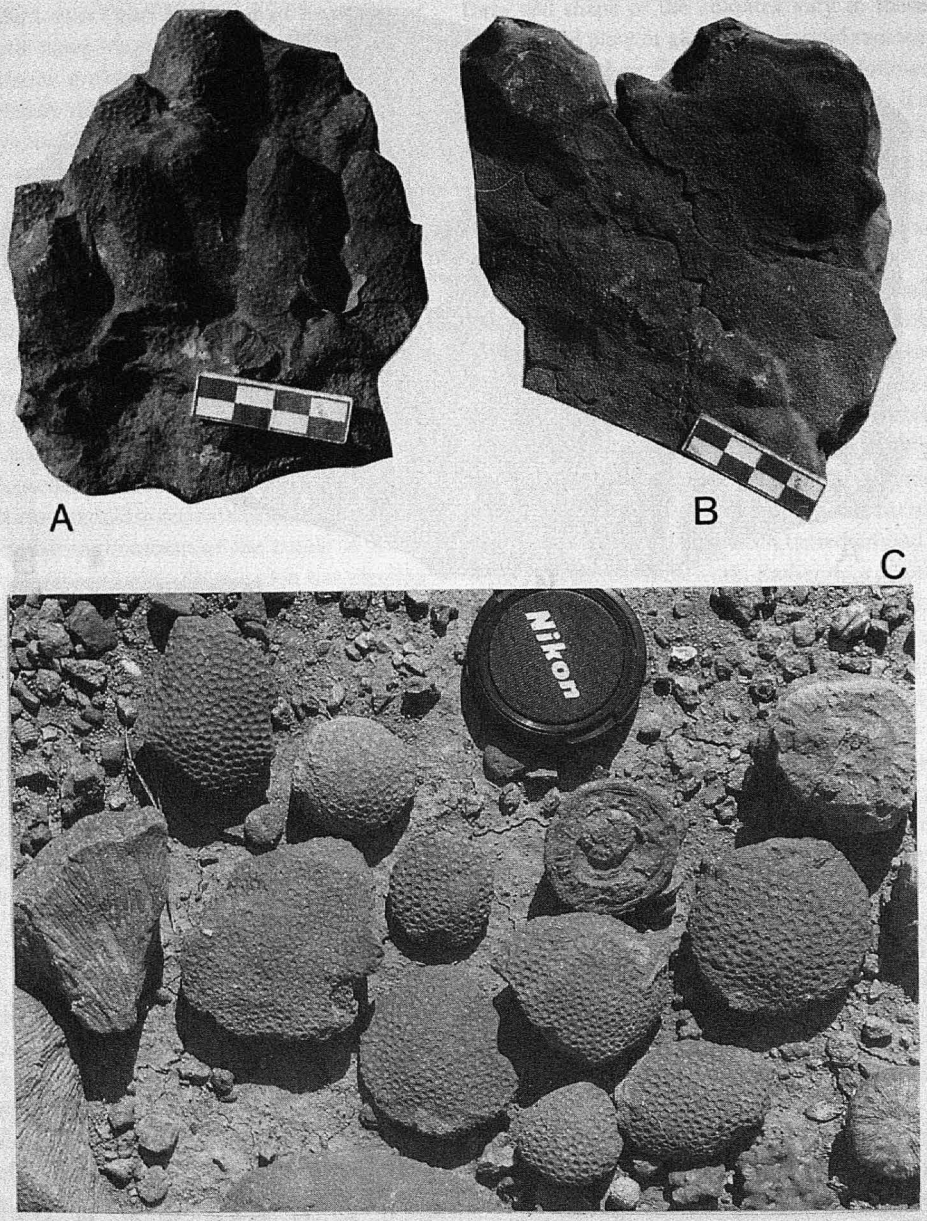


Fig.5. A. *Amphiastraea piriformis* from the Middle Callovian of Mouwana Dome, exhibiting digital growth. **B.** *Amphiastraea piriformis* from the same horizon and locality. The coral heads form a cemented framework with neighbouring colonies commonly joined leaving almost no space between them. **C.** Coral meadow representing the *Microsolena amorpha - Montlivaltia cornutiformis* assemblage from the Jumara Coral Limestone member (late Middle to Late Bathonian) at the core of Jumara Dome. Most figured specimens belong to *Stylina kachensis*.

coral heads encrust each other and form a rigid framework, on average 1 m in thickness. *Amphiastraea piriformis* started growth as massive, platy colonies, whereby neighbouring colonies commonly joined leaving almost no space between them (Fig. 5B). This growth pattern was succeeded either by columnar and near the top somewhat conical growth of the colonies, separated from each other by thin sheets of sediment or by digital growth (Fig. 5A). In some cases, sediments and coral skeletons are so strongly recrystallized that it is very difficult to differentiate between them. A single

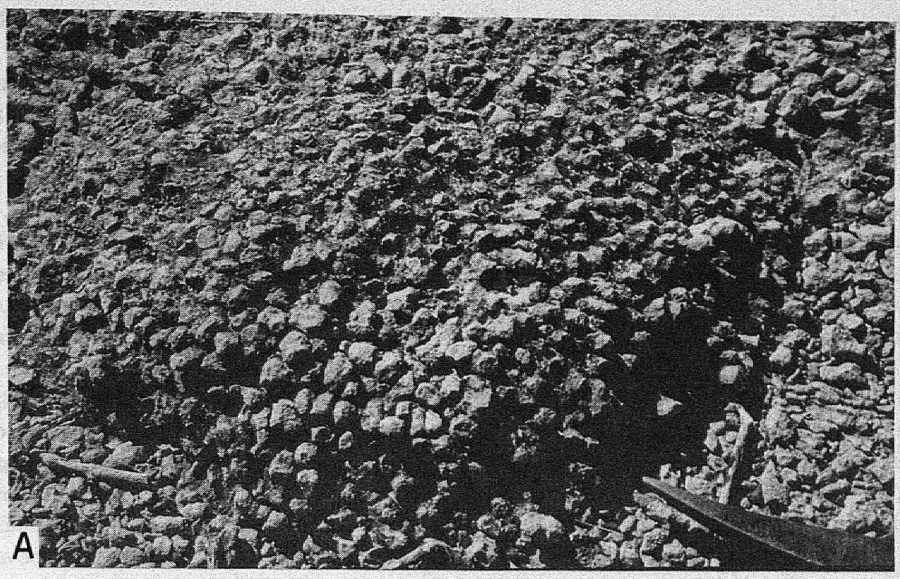


Fig.6. A. *Amphiastraea piriformis* colony in growth position in the middle part of the Gadhada Sandstone Member (Middle Callovian), north of Gadhda Rasaji, Bela Island. **B.** Large colony of *Amphiastraea piriformis* with prominent, 2.5 - 4.5 cm thick growth bands on the weathered surface. Coral Boulder Bed of the Middle Chari Formation (Middle Callovian), south of Dhrang, Habo Dome.

poorly preserved *Lochmaeosmilia trapeziformis* colony has also been collected from this horizon. The biostrome suggests a break in sedimentation. The change in growth pattern towards the top of the biostrome indicates that the rate of sedimentation gradually increased and that death of the biostrome was caused by renewed sedimentation, possibly in connection with a relative fall in sea level.

The younger *Amphiastraea piriformis* horizon is about 120 m above the base of the Gadhada Sandstone member. The coral colonies are either platy or globular with small attachment area and large resting area. The platy colonies

are up to 30 cm in diameter and exhibit 1.0 - 2.5 cm thick growth bands similar to the specimens from Habo Dome described above. They are much more symmetrical in shape than in the small globular colonies. The corals are tilted and apparently regenerated from all directions. Regeneration is more common in the lower part. This suggests repeated phases of reworking in connection with fluctuating energy conditions. Whether the growth bands reflect seasonal cycles or small-scale perturbations has still to be judged. The poorly sorted, bioclastic, fine to coarse sandy matrix also suggests fluctuating energy conditions.

(c) *Bela Dome:* The sediments underlying and overlying the *Amphiastraea piriformis* horizon north of Gadhada Rasaji are fine-grained sandstones. The massive, platy, cerioid heads occur *in situ* and apparently grew in patches on a firm, shelly, sandy substrate forming a layer 20-30 cm in thickness. During later growth stages, coral form changed into ramose or columnar (Fig.6A). The matrix is a silty bioclastic wackestone. The initial massive coral growth, with small attachment areas and large resting areas of the coralla and the associated fauna (*Modiolus, Plagiostoma, Chlamys,* gastropods and echinoid spines) suggest normal marine, moderately agitated water conditions and a low rate of sedimentation. Most likely, the growth of corals relates to a short-lived transgressive event. The ramose to columnar forms of the later stage represent an adaptation to higher rates of sedimentation, either due to an increase in the energy level or more influx of sand into the basin. The coral bed probably is the lateral equivalent of the Mouwana Coral Biostrome.

(d) *Wagad Dome:* In the Washtawa Formation north of Washtawa, *Amphiastraea* occurs in ferruginous sandy siltstone containing a rich autochthonous fauna of gastropods and burrowing and byssate bivalves suggestive of a low rate of sedimentation. The corals are small, colonial, massive, globose to flat, moderately well preserved cerioid heads with large resting areas. The corals, which constitute between 5-10% of the benthic macrofauna are very similar with respect to growth form, to those of the *Amphiastraea piriformis* - *Montlivaltia cornutiformis* assemblage (4).

Other Coral Occurrences

Several coral occurrences in the Jurassic of Kachchh are too poorly represented to be placed in one of the assemblages described above.

(a) *Reworked heads* of *Lochmaeosmilia trapeziformis*? are common in a 120 cm thick conglomeratic Fe-oolitic grainstone topped by a megaripple surface. The bed, informally designated here as the Badi Coral Bed, overlies nodular silty micrites and crossbedded Fe-oolitic grainstones which are the oldest unit exposed in Badi Nala of Jhura Dome.

(b) *A few scattered compound corals*, generally poorly preserved, reworked, bored and recrystallized, occur in Raimalro Limestone Member in the islands and equivalent beds on Kachchh Mainland, are *Stylosmilia* cf. *michelini*, *Stylina dubia*, *Lochmaeosmilia trapeziformis*, *Cryptocoenia* sp. (east of Khavda, Gora Dongar), *Lochmaeosmilia trapeziformis* (north of Umrapur, Khadir Island), *Collignonastraea* sp. (Bela Island; Rann) and *Amphiastraea piriformis*, *Collignonastraea* sp. and a massive cerioid coral (north of Mouwana village, Mouwana Dome). Their growth form is predominantly phaceloid or plocoid. The diversity is rather high considering the low number of specimens. The Raimalro Limestone Member of the islands, a massive to the well bedded, crossbedded limestone with shell pockets, chert nodules and a variable admixture of sand grains and pebbles, has been deposited above fair weather wave base. The unit becomes sandy in an easterly and northerly direction.

(c) *Coral heads* of *Melikerona parva* in growth position (Fig.4B) occur in fine sandy micrite and fine sandy, bioclastic grainstone associated with oscillation ripples in the Sadhara Coral Limestone Member exposed on the eastern part of Gora Dongar.

(d) *Montlivaltia chariensis*, *M. cornutiformis*, *Amphiastraea piriformis*, *Cryptocoenia* sp., *Melikerona parva*, *Microsolena amorpha* and *Brachyseris* ? cf. *discontinua* occur in a well sorted, fine-grained sandstone, 30 metres below the top of the Dhosa Oolite in Jhura Dome, southwest of Jhura and Jhura Camp villages and north of Kamaguna village. The corals are generally well preserved, commonly occur in growth position and form part of an autochthonous benthic community. *Montlivaltia chariensis*, the dominant taxon, exhibits minor and major growth lines or bands on the epitheca. Associated faunal elements are bivalves, rhynchonellid brachiopods, and ammonites.

(e) *A well preserved Montlivaltia cornutiformis* was found as stray sample in the Gypsiferous Shale Member, south of Dhrang village, Habo Dome.

(f) *Montlivaltia* aff. *patela* occurs scattered and oriented in different directions in a red, fossiliferous flaggy sandstone, intercalated in an argillaceous silt facies, above the Ridge Sandstone Member of Jara Dome. Unlike in Jhura Dome, the specimens of *Montlivaltia* are very small, button-like (maximum diameter about 11 mm) and appear to be juveniles. Associated faunal elements are ammonites and bivalves.

(g) *Moderately large*, massive-cerioid heads of *Isastraea* sp. occur in the Bambhanka Member (Upper Callovian-

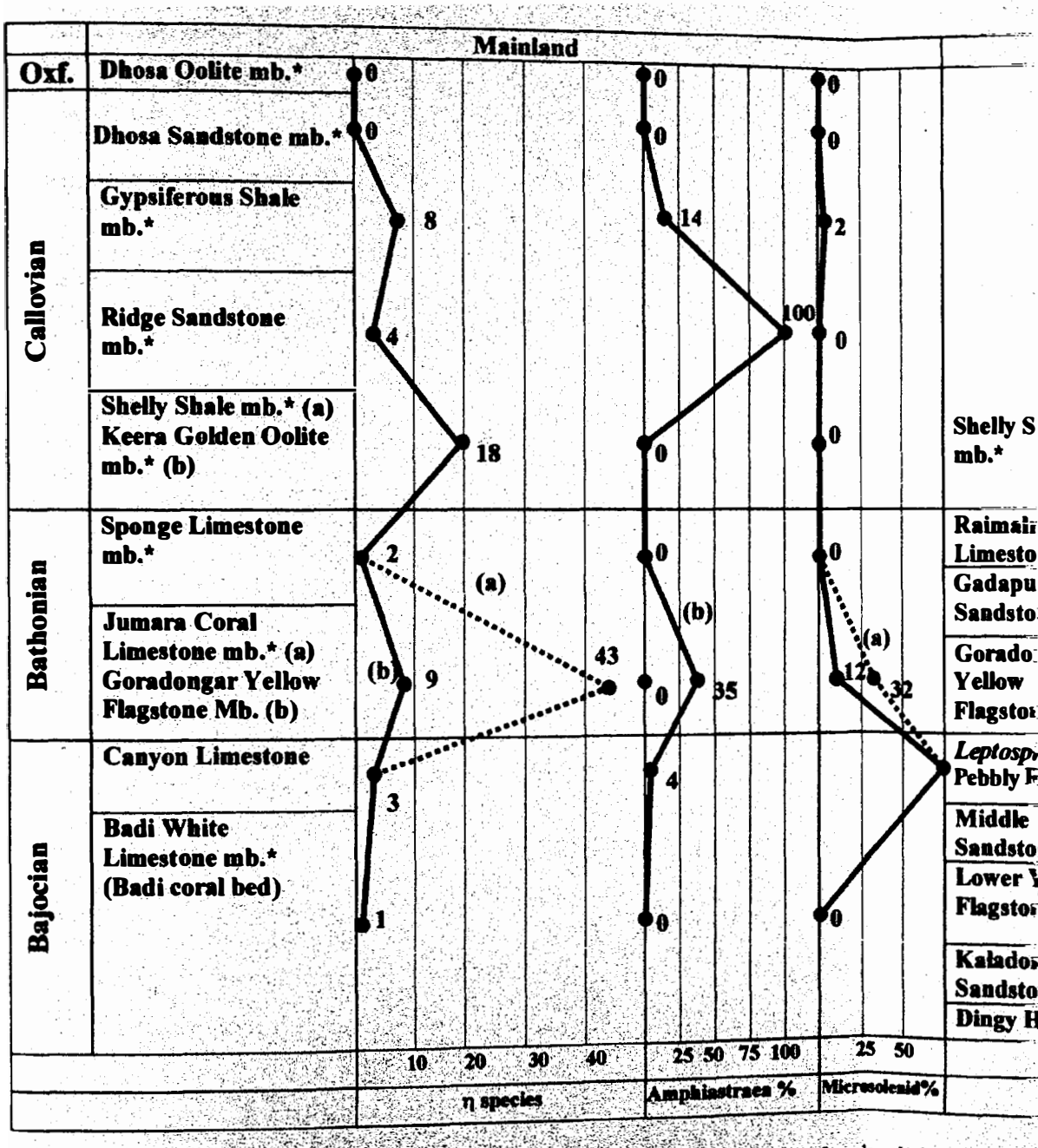
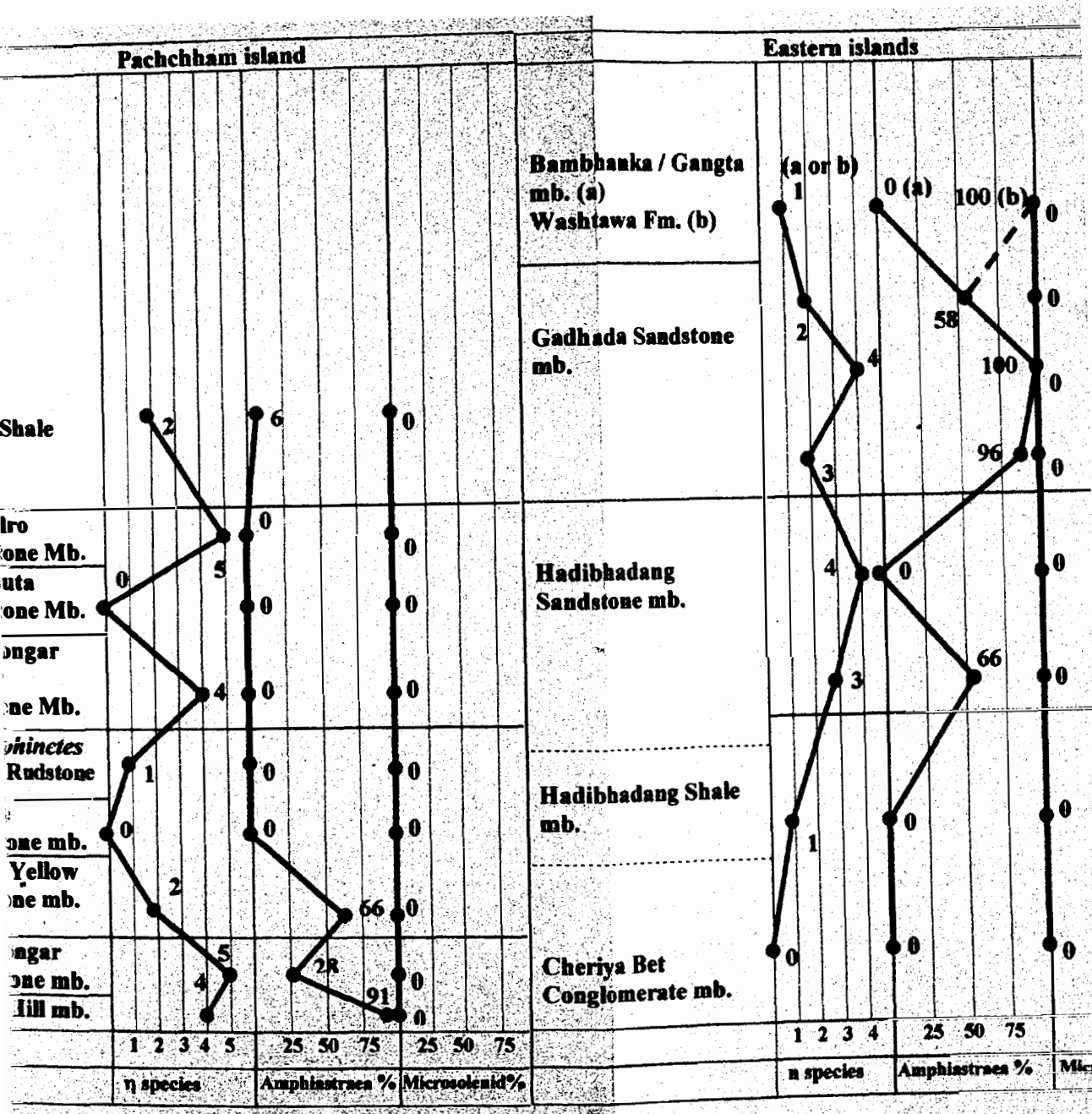


Fig.7. Spatial and temporal diversity pattern of corals and relative abundance
whereas the former species dominates in nearshore sandy areas. The



ce of *Amphiastraea piriformis* and microsolenids. Note that the latter are restricted to Kachchh Mainland, e deepest parts of the basin, represented by the Dhosa Oolite member, are devoid of corals.

Oxfordian) at the southernmost margin of Khadir Island, south of Jawarn (south of Gadhada). The corals are reworked and almost completely recrystallized. The associated sediments are intraformational conglomerates with belemnites, wood fragments, ammonites and a number of bivalves (e.g. *Neocrassina*, *Trigonia*, *Actinostreon marshi*, and *Meleagrinella*). Several levels of erosion and pockets of relict sediments indicate that this unit is highly condensed. The ammonites *Aspidoceras*, *Perisphinctes*, etc. are comparable with those from the Dhosa Sandstone Member of Kachchh Mainland.

CORAL DISTRIBUTION IN KACHCHH BASIN DURING THE MIDDLE JURASSIC

According to palaeogeographic reconstructions (e.g. Smith and Briden, 1977; Barron et al. 1981), the Kachchh basin was situated in the southern hemisphere, just south of the Tropic of Cancer during the Jurassic. Assuming a warm-temperate to subtropical climate, the water temperatures of the southern extension of the Tethys ("Malgassy Gulf") with which the Kachchh basin was connected, should have been high enough, even though not optimal, for coral growth.

Contrary to their scarce documentation in the literature, scleractinian corals are surprisingly common in Jurassic sediments of Kachchh occurring in carbonate and in siliciclastic sediments. They either formed meadows of scattered heads, thin biostromes, boulder beds or were scattered. The corals are either autochthonous and constitute part of the benthic fauna or exhibit signs of intra-basinal transport for variable distances.

The eight coral assemblages that have been recognized above represent the following broad time intervals:

?Early - Middle Bajocian:	*Amphiastraea* - *Isastraea* ass.
Late Bajocian - Middle Bathonian:	*Amphiastraea* - microsolenid ass.
Late Middle Bathonian - Late Bathonian:	*Microsolena amorpha* - *Montlivaltia cornutiformis* ass.
Early Callovian:	*Amphiastraea piriformis* - *Montlivaltia cornutiformis* ass. *Montlivaltia cornutiformis* - *Complexastraea kachensis* ass.
Late Early Callovian:	*Ampakabastraea exserta* - *Isastraea propinqua* ass. *Goniocora turbinata* ass.
Middle Callovian:	*Amphiastraea piriformis*
	Amphiastraea piriformis - *Montlivaltia cornutiformis* ass.
Late Callovian:	*Amphiastraea piriformis* - *Montlivaltia cornutiformis* ass. *Amphiastraea piriformis*

As can be seen from the list, several of the assemblages have overlapping ranges. In order to elucidate the reason for the temporal distribution pattern, the spatial distribution of the corals, particularly with respect to onshore-offshore gradients, needs to be studied. Fig. 7 schematically depicts the distribution in terms of relative abundance of two of the most important coral taxa in the Kachchh basin, i.e. *Amphiastraea piriformis* and microsolenids. *A. piriformis* occurs more abundantly in the older parts of the depositional sequence and more abundantly in the eastern and northern parts of the outcrop belt, close to the palaeoshoreline than in younger, deeper offshore areas of the southern outcrop belt. It clearly is a eurytopic species that managed, in contrast to most other corals, to thrive in areas with relatively high input of terrigenous sediment. It is interesting to note that the apparent exception to this is its high abundance in the Middle Callovian Ridge Sandstone Member of Habo Dome: Characteristically, it occurs there in a sandy facies that records very shallow, nearshore, high energy conditions within the otherwise quieter and deeper parts of the Chari Formation. Microsolenids, in contrast, largely occur in carbonate environments. In the Middle Bathonian this is the Goradongar Yellow Flagstone Member of Pachchham Island and the coral meadows within the Jhurio Formation of Jumara Dome.

The diversity trend exhibits a similar pattern (Fig. 7). In the Bajocian-Bathonian, the number of taxa is low, ranging from 1-5 in the various lithostratigraphic units, if present at all. The same is true of the Callovian of the island belt. The highest species diversity is reached in the Jumara Coral Limestone member of Jumara Dome (43), followed by the Shelly Shale member of the Lower Chari Formation (18) and the Goradongar Yellow Flagstone Member of Jhura Dome (9). Thus species diversity is highest in offshore carbonate environments and decreases towards the palaeoshoreline, i.e. towards the east and the north where the increasing siliciclastic input impeded coral growth. Likewise, corals are rare to absent in argillaceous silt of the Chari Formation representing soft substrates and water depths unsuitable for colonisation by most corals.

CONCLUSIONS

On the basis of the stratigraphic and spacial distribution

of corals and their diversity pattern, the following conclusions can be drawn regarding their occurrence in the Kachchh basin during the Middle Jurassic:

1. Cerioid corals, *Amphiastraea piriformis* and *Isastraea limitata* preferentially occur in siliciclastic sediments and were among the first to invade the basin colonising shallow water, high energy environments. The eurytopic *Amphiastraea piriformis* ranges from the Early Bajocian to Callovian.
2. The reduction in size of corallites of *Amphiastraea piriformis* from the *Amphiastraea - Isastraea* assemblage (?Early Bajocian to Middle Bajocian) to the *Amphiastraea* - microsolenid assemblage (Late Bajocian to Middle Bathonian) and in still younger occurrences (Middle to Late Callovian) probably reflects the change from nearshore, high energy environments with a high influx of coarse sediments to more offshore environments with a reduced sediment supply.
3. The solitary *Montlivaltia cornutiformis* was eurytopic, occurring both in siliciclastic and calcareous sediments and had a high physiological tolerance of environmental stress. In Kachchh it occurred from the Middle Bathonian to the Late Callovian.
4. Corals with fenestrate and pennular septa (thamnasterioids, e.g. *Microsolena, Dimorpharaea, Kobya* and solitary taxa, e.g. *Trocharaea* and *Trochoplegma*) and plocoid forms (*Stylina*) occur exclusively in calcareous sediments. They dominantly flourished in low energy environments below fair weather wave base.
5. Diversity and specialization of corals was controlled mostly by the rate of influx of siliciclastic sediments and increased towards offshore carbonate environments.
6. In nearshore areas, corals are often tied to transgressive events.

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