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PALAEOECOLOGY OF MIDDLE TO LOWER UPPER JURASSIC MACROFAUNAS OF THE KACHCHH BASIN, WESTERN INDIA : AN OVERVIEW

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ABSTRACT

Jurassic sediments of the Kachchh Basin contain a rich fauna of marine macroinvertebrates dominated by bivalves and brachiopods. They show distinct distribution patterns in environments that range, with increasing depth, from brackish lagoons to nearshore high energy ramp, storm-wave influenced ramp, storm-flow influenced ramp to quiet episodically dysoxic, basinal settings beyond storm influence. Bed-by-bed bulk sampling of several sections produced a data base of more than 27,000 specimens in 370 samples. More than 40 benthic associations and several assemblages were defined statistically by means of a cluster analysis. These associations are considered to be relicts of former communities, the distribution of which was largely controlled by the environmental parameters, namely substrate, energy level, salinity, temperature, nutrient supply, and oxygen availability. These parameters changed along onshore-offshore gradients and so did the faunal composition. Changes in faunal composition through time were partly in response to large-scale regional changes in climate and partly controlled by fluctuations in relative sea level documented by parasequences and 3rd order cycles.

Key words: Kachchh Basin, India, Jurassic, benthic macrofauna, palaeoecology.

INTRODUCTION

It has been repeatedly demonstrated that benthic macrofaunas are valuable tools for palaeoenvironmental reconstructions (e.g. Fürsich and Werner, 1986; Oschmann, 1994a) Moreover, in relatively monotonous deposits organisms may record faint changes in environmental conditions that cannot be deduced solely from the sediments (e.g. Fürsich, Oschmann, Jaitly and Singh, 1991). However, the potential of benthic macrofaunas in basin analysis has not yet been fully exploited and, due to the high number of variables involved, we are still far from developing widely applicable models. In order to achieve this goal, we need additional case studies. This was the rationale behind more than a decade of studies in the Middle to lower Upper Jurassic of the Kachchh Basin of western India by an international (German-British-Indian) group of palaeontologists and stratigraphers. The Kachchh Basin was chosen because it is a rift basin of moderate size, reasonable exposures, with a great diversity of facies, and a rich and diverse fauna of macroinvertebrates. In the Jurassic, the basin was situated at the western margin of the Indian plate, opening into the so-called Malagassy Gulf, a southern extension of the Tethyan Ocean (fig. 1).

Middle Jurassic sediments reach a thickness of up to 750 m. The best exposures of early Middle Jurassic sediments are found in the Islands bordering the southern margin of the Great Rann of Kachchh (fig. 1). Sedimentation started with predominantly terrigenous siliciclastics of Bajocian and possibly Aalenian age, indicative of alluvial fans (e.g. on Cheryar Bet) and flood plain deposits (soil horizons, fluvial channels, lakes). Going up-section, however, soon marine influence becomes noticeable in form of trace fossils such as *Diplocraterion* and shell concentrations of brackish water bivalves (e.g. *Tancredia, Pronoella, Indocorbula lyrata*). Repeated changes between marine and terrestrial facies characterise much of the Bajocian and Early

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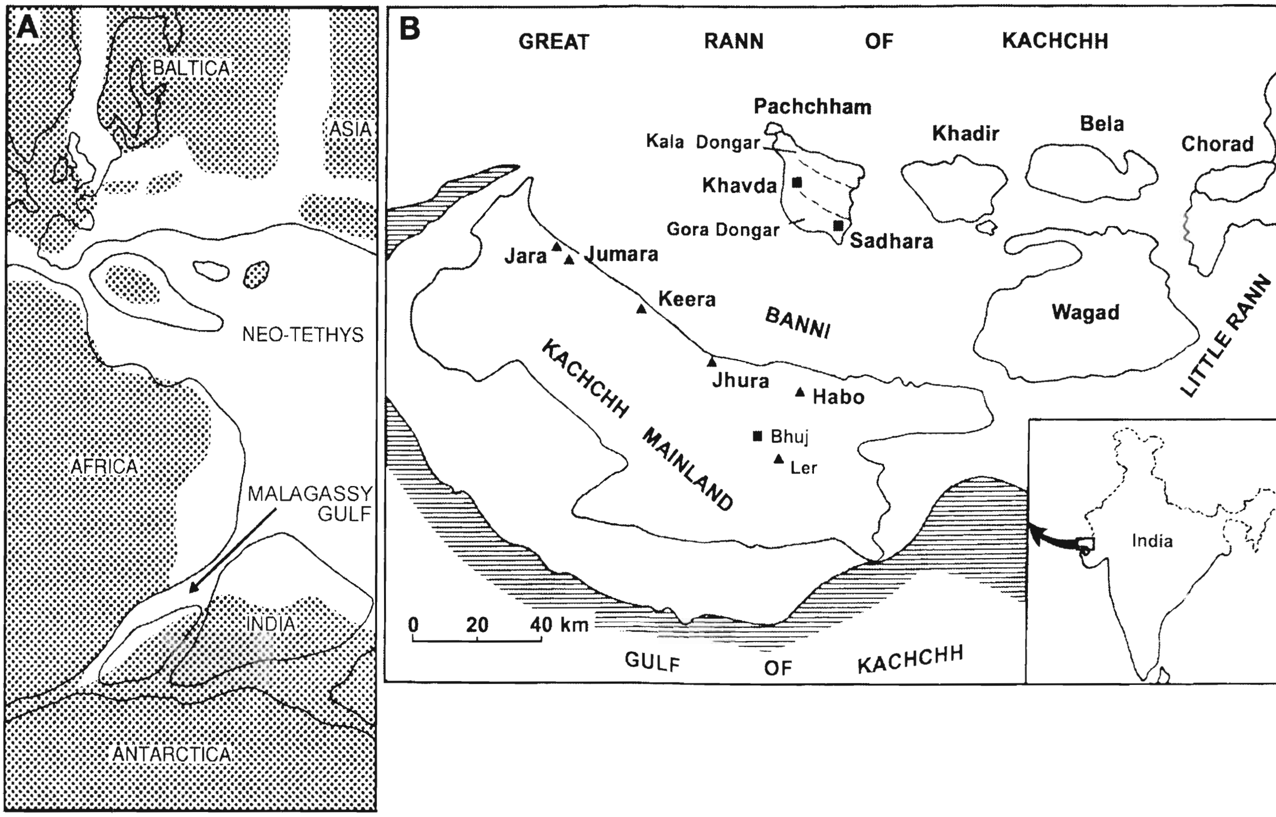


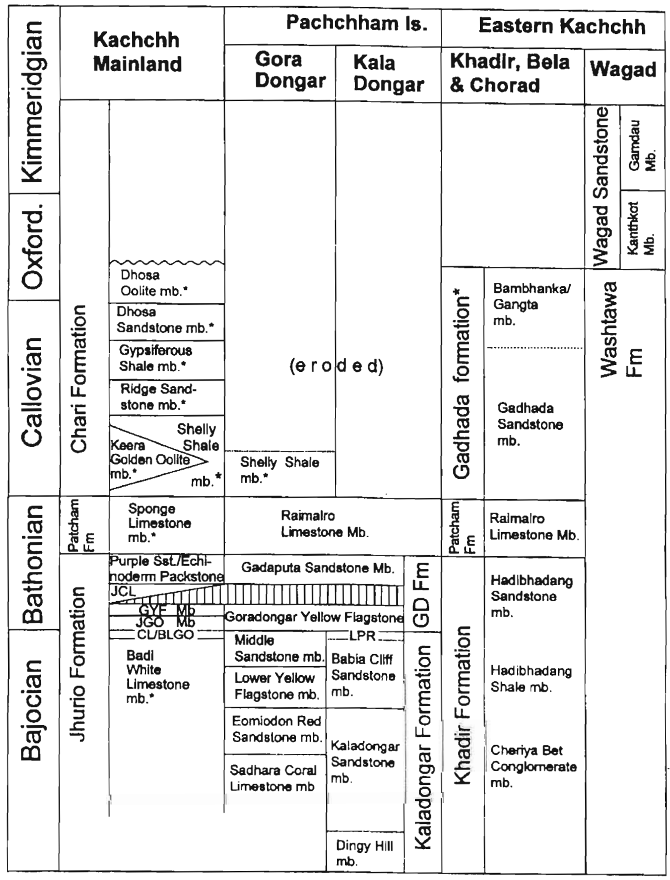
Fig. 1. Generalised palaeogeography of part of the Neo-Tethys during the Middle Jurassic (A) and locality map (B). Palaeogeography modified after Riccardi (1991) and Enay and Cariou (1997).

Bathonian, but towards the Middle Bathonian the marine influence increased distinctly. With respect to lithostratigraphy, the scheme of Biswas (1980) was followed with some modifications (fig. 2; Fürsich, Pandey, Callomon, Jaitly and Singh, 2001).

On Kachchh Mainland, only early Late Bathonian to Oxfordian sediments are exposed, except in the Jhura Dome, where the oldest rocks are at least as old as Bajocian. On the Mainland, sediments are exclusively marine in nature whereby a general deepening trend towards the Oxfordian can be noticed (e.g. Fürsich and Oschmann, 1993; Fürsich, *et al.*, 2001). Greatest depths within the outcrop belt may have reached mid shelf values and certainly were far below storm wave base. Sedimention followed a cyclic pattern, whereby cycles of different orders of magnitude can be recognised (Fürsich *et al.*, 2001). Likewise, the benthic macrofauna exhibits distinct distribution patterns that can be related to differences in palaeoenvironmental settings. It is the purpose of this paper to give, for the Kachchh Basin, (a) an overview of the various faunal assemblages that can be recognised in the Middle Jurassic by statistical means, (b) briefly discuss the main environmental parameters that governed the faunal distribution, and (c) illustrate the distribution pattern by placing the various faunal associations in four idealised onshore-offshore transects that represent the time slices Bajocian, Middle Bathonian, Late Bathonian, and Callovian, respectively. A more comprehensive description of the palaeoecology of the area including the data set is in preparation.

MATERIALS AND METHODS

In the course of 11 field trips to the area, all major Middle Jurassic outcrops have been visited with the exception of Kunwar Bet. Detailed sections were measured and the macrofauna was bulk-sampled wherever possible yielding around 370 statistical samples with approximately 27,000 individuals. This information was supplemented with sedimentological, ichnological and taphonomic observations.



JCL: Jumara Coral Limestone mb.*; GYF: Goradongar Yellow Flagstone Mb.; JGO: Jhura Golden Oolite mb.*; CL/BLGO: Canyon Limestone/Badi Lower Golden Oolite; LPR: Leptosphinctes Pebbly Rudstone; GD Fm: Goradongar Formation.

Fig. 2. Stratigraphic framework of Bajocian-Oxfordian rocks of the Kachchh Basin. Based partly on Biswas (1980). Informal units are marked with an asterisk. See also Fürsich *et al.* (2001). Several new correlations are given.

Because a sound taxonomic basis is the prerequisite for any palaeoecological analysis, much of the benthic macrofauna of the Kachchh Basin has been monographed and earlier accounts have been thoroughly revised (Fürsich and Heinze, 1998; Fürsich, Heinze and Jaitly, 2000; Jaitly, Fürsich and Heinze, 1995; Jaitly, Szabo and Fürsich, 2000; Mehl and Fürsich, 1997; Pandey and Fürsich 1993; Pandey, Fürsich and Heinze, 1996). After preparation and identification of the fauna, faunal lists for each sample, giving relative abundances of the taxa, were constructed and subjected to a cluster analysis. Beforehand, however, 102 samples had to be excluded from the analysis because of their small size (less than 30 specimens). Another 40 samples were excluded because they exhibit signs of transport and faunal mixing. In the end, 220 samples representing 23,500 individuals were used for the cluster analysis.

For the cluster analysis several methods (Single Linkage method, Ward method with the Squared Euclidian Distance and Ward method with the Single Euclidian Distance) were tried. The three methods yielded similar results whereby the third method, namely the Ward method with the Single Euclidian Distance, was preferred as it produced the highest resolution (fig. 3). With this method, the data matrix was clustered twice: the samples combined in the most distinct cluster (the Bositra buchi association; 1) during the first run were removed during second run in order to obtain a greater resolution of the remaining data matrix. Thus, the dendrogram in fig. 3 is a combination of the cluster 1 obtained from the first run and the remaining clusters obtained during

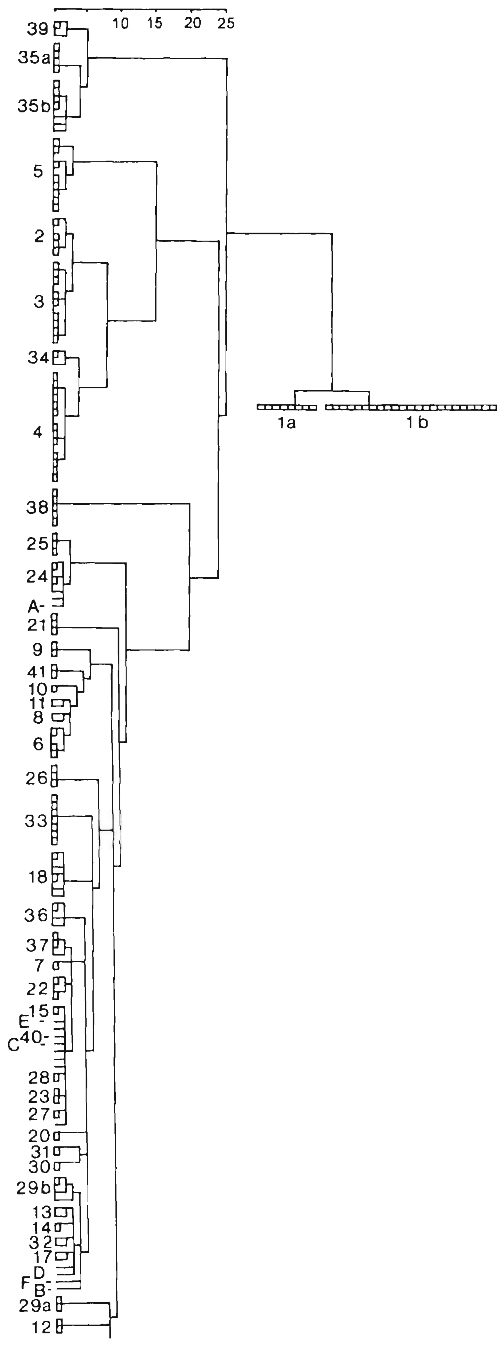


Fig. 3. Dendrogram of samples analysed with the WARD method (Single Euclidian Distance). Numbers refer to associations listed in the text. Capital letters refer to assemblages. Some associations listed in the text are not included in the dendrogram. Horizontal scale: Rescaled Distance Cluster Combine. Note that the dendrogram is the result of a twofold analysis of the data matrix: After analysis of the total matrix, the cluster 1 (Bositra buchi association) was removed from the matrix which was then analysed again to achieve a greater resolution. The cut-off level varies slightly between clusters, because the biological significance of the clusters was taken into account for defining associations.

the second run. The cut-off level used to define associations varies to some extent (fig. 3), because the clusters derived by using a certain cut-off level at the distance of similarity were subsequently screened for their biological meaning. If the samples grouped in a cluster did not produce a biologically meaningful entity, the cut-off level was changed and accordingly the cluster size.

FACIES AND DEPOSITIONAL ENVIRONMENTS

A detailed facies analysis was necessary in order to put the benthic faunas in their environmental framework. Here, only a very brief review of the major facies associations that correspond to different environments is given.

The geomorphologic setting of the Kachchh Basin was not that of an open passive margin, but a shallow embayment. Within this embayment various shallow marine depositional environments from coastal plain to the middle shelf were developed. However, the extent of individual environmental domains was narrow and changed rapidly in space and time. Instead of using the terminology of an open shelf - continental margin coastline, the depositional system has been designated as a ramp. Different parts of the ramp represent different depositional environments, physical processes, and macrobenthic community relicts. Two basic settings of the ramp are identified i.e., the siliciclastic ramp and the carbonate ramp.

Coastal plains consist essentially of deposits of non-marine coastal areas, while siliciclastic and carbonate ramp deposits consist of different environments of the shelf-coastal zone in siliciclastic and carbonate depositional systems, respectively. The mixed carbonate-siliciclastic deposits are primarily deposits of transgressive systems tracts on the shallow shelf.

Coastal Plains

Coastal plain deposits are restricted to the island belt and generally belong to the oldest part of the succession. The following environments could be distinguished:

Floodplains: Floodplain deposits consist mainly of dark-red to variegated, poorly sorted argillaceous to sandy silts, occasionally with thin intercalation of laminated to small ripple-bedded fine-grained sandstones. The latter are interpreted as crevasse splays or the distal ends of sheet floods. At certain horizons caliche nodules are abundant. They indicate, together with the red colour of the sediments, a semiarid climate.

Fluvial channels: Fluvial channels, characterised by fining upwards, fine- to coarse-grained trough cross-bedded arkosic sandstones with erosional base, occur only in the older (Bajocian) part of the sedimentary sequence on the islands. Rip-up mud clasts near the base and rootlet beds at the top are common. In some cases large tree trunks are found at the base.

Lakes: A several metres thick package of uniform, dark-grey, unfossiliferous silty marl rich in plant debris occurs in the middle of the steep northern slopes of the Mouwana Dome. The sediments are best interpreted as low energy deposits of a lake.

Siliciclastic ramp

Siliciclastic ramp deposits are very widespread and characterise parts of the Bajocian-Bathonian and all of the Callovian basin fill. The following depositional environments were identified with their characteristic deposits.

Brackish water embayments and lagoons: The deposits are strongly bioturbated sandy to silty sediments with a variable content of carbonate, and occasionally rich in plant debris. The lowered salinity could be reconstructed only on the basis of the abundant but very low diverse molluscan fauna (see below). This facies association occurs only in the Bajocian sediments of the islands.

Deltas: Delta sequences as such are not widespread in the Jurassic rocks of Kachchh, though coastline deposits are widespread. Only at a few localities delta sequences have been identified. The thick sandstones occurring in the Callovian of the western islands (Mouwana, Bela, Khadir) may be deltaic sand bodies. Westwards in the Habo Dome thick lensoid sand bodies with intervening shales are developed in the Middle Chari Formation. They are interpreted as prodelta to delta front deposits. Shells are rare in these sandstones and nearly invariably allochthonous. Thick, cross-bedded, coarsening-upward sandstone bodies of Oxfordian age, often with plant remains, overlie bioturbated silts at Kanthkot Hill (Wagad Dome). They represent a well developed progradational prodelta-delta front succession.

Sheet sands: Few metres thick but widespread blanket sands are common, extending over tens of kilometres in the inner ramp setting. They are well sorted, fine- to coarse-grained sandstones with dune field development. Of deltaic origin, they have been spread over large areas by waves and currents during destructive delta phases or transgressive events. In shallower areas, the sandstones are cross-bedded and contain trace fossils such as *Ophiomorpha*. Further offshore, they are generally fine-grained to silty, thoroughly bioturbated by *Zoophycus* and *Chondrites*, and commonly contain an autochthonous benthic macrofauna. They are widespread in the Middle Callovian of the Kachchh Mainland.

Storm-wave influenced ramp: The deposits form alternations of silt or argillaceous silt and thin intercalations of sandstone beds with sharp erosional base and hummocky cross-bedding. This zone was located between the fair-weather wave-base and the storm wave-base and represents deposition in a water depth of only a few metres, where sediments intermittently were affected by storm waves. This area corresponds to the transition zone of the shelf (Reineck and Singh, 1980), often referred to as lower shoreface.

Storm-flow-influenced ramp: Centimetre-thick, fine-grained sandstone beds with sharp base, often exhibiting tool marks and flute casts occur intercalated inbetween a background sedimentation of bioturbated argillaceous silt. Grading, small ripple bedding and/or parallel lamination are characteristic features of the sandstones. This zone was located below storm wave-base where storm-generated currents carrying suspended sand caused the deposition of sand layers. It corresponds to the inner shelf zone of the continental margin.

Outer ramp: The sediments are argillaceous silt to silty clay, in places marly, indistinctly laminated to strongly bioturbated (*Chondrites*). A low to moderately diverse softground fauna dominated by nuculids, *Cingentolium* and *Bositra* is widespread. The sediments were deposited below storm wave base in low energy environments. The outer ramp corresponds to the middle shelf zone of the continental margins. Oxygen levels may, for short periods of time, have been low (laminated horizons). Ferruginous concretions, at some levels also calcareous concretions, or concretions originally rich in pyrite, are a characteristic feature. Repeatedly, such early diagenetic concretions became exhumed, reworked, bored and encrusted (Fürsich, Oschmann, Singh and Jaitly, 1992). Together with molluscan shells they form thin lag deposits that are evidence of transgressive pulses. Thin shell beds that occur at some levels are the product of winnowing by gentle currents during times of low sediment supply (Fürsich and Oschmann, 1993). This facies type is characteristic of the Lower and Upper Callovian of the Kachchh Mainland.

Protected bays with iron-oolitic silts: The sediments are primarily iron-ooid bearing silts, marls, and wackestones formed in low energy protected bays. This facies was produced essentially during sea-level lowstand. The oolites are invariably matrix-supported; bioturbated by *Chondrites* and other trace fossils indicative of low energy conditions. The facies is widespread near the top of the Callovian on Kachchh Mainland.

Iron-oolitic shoals and channels: Iron ooids and ferruginized bioclasts, formed during sea level lowstand, were commonly reworked during transgression to produce shoals far away from the coastline. At the Keera Dome they formed several metre thick, grain-supported, large-scale cross-bedded shoals. These shoals were actively worked upon by waves and currents and occupied positions above the fair-weather wave-base. Similar but thinner bodies occur in the Middle Bathonian Goradongar Yellow Flagstone Member of the Jhura Dome and Pachchham Island and in the Jhurio Formation of the Jhura Dome. Thin lenticular bodies in the Middle Callovian of the Keera Dome and in the Middle Bathonian of the Jhura Dome, consisting of iron ooids and ferruginized bioclasts, are interpreted as channels, in which sediment was transported from the ooid shoals into deeper parts of the ramp.

Starved shelf : Due to very rapid rise in sea level, supply of sediment on the shelf may be almost completely cut-off, and a starved shelf is developed. Typical features are ferruginous crusts, ferruginous oncoids, hardgrounds, erosion surfaces, multiple-reworked pebbles and concentrations of shells (Singh, 1989; Fürsich *et al.*, 1992). They indicate maximum flooding of the basin resulting in sediment starvation. Oxfordian sediments of the Kachchh Mainland are only 20-40 cm thick and are highly condensed. The complex history of the sediments and presence of major gaps (e.g. lack of Upper Oxfordian ammonites) show, however, that several deepening-shallowing phases are superimposed; apparently, there was very little net deposition of new sediment.

Carbonate Ramp

In the Jurassic of the Kachchh Basin, a carbonate depositional system developed only for a limited period of time. Sediments of a carbonate ramp are represented by Middle to Upper Bathonian rocks of the Mainland and Islands and represent the following specific environments.

Fair-weather wave-influenced ramp: The sediments are thickly bedded pack- to grainstones with scour and fill structures, shell pockets and shell lenticles, generally large-scale trough cross-bedded, and with a certain amount of quartz sand. The characteristic development is exhibited by the Raimalro Limestone Member of western Gora Dongar and Kala Dongar. The sediments belong strictly speaking to the mixed carbonate-siliciclastic environments (see below) and are the shallowest preserved part of the carbonate ramp, located in the high energy coastal zone exposed to wave action and also current action. This area essentially corresponds to the coastal sand zone, which includes foreshore, shoreface, sand bars and shoals of the coastline.

Storm-wave-influenced ramp: The sediments are essentially grainstones with hummocky cross-bedding, and sharp erosional base. Successive beds are commonly amalgamated. The background sediment consists of bioclastic marl. Fossils (scattered bivalves) are very rare. These deposits are found in the Raimalro Limestone Member of the Habo Dome. A somewhat more distal development occurs in the Goradongar Yellow Flagstone Member of the Jhura Dome. The outer ramp corresponds to the transition zone of the open continental shelf, with prominent storm activity and their deposits.

Ramp influenced by storm-induced currents: The sediments are bioturbated bioclast-rich marl and wackestone with thin (5-10 cm) intercalations of pack- to grainstones. The latter are graded, horizontally laminated, and exhibit a sharp erosional base. Towards the centre of the basin, at the Jumara Dome, thin graded rudstones consisting of shells of the bivalves *Bositra* or *Eligmus* are common. The facies is most characteristically developed in the Sponge Limestone member of the Jhura Dome and the Jumara Coral Limestone member of the Jumara Dome. It corresponds to the inner shelf where storm sand beds are commonly deposited.

Outer ramp: The deposits are marl and well bedded mud- and wackestones with marly interstices characterising the deepest carbonate environments of the exposed basin fill. Autochthonous relicts of benthic communities and parautochthonous coral meadows occur. The outer ramp corresponds to the middle shelf out of reach of storm-induced sedimentation.

Carbonate sand blankets: Up to several metres of thickly bedded, bioturbated ferruginous echinoderm packstones with scattered quartz grains, some reworked shells, and remains of cross-bedding are present in the inner to middle ramp. They are interpreted as transgressively reworked lowstand carbonate sediments with little or no supply of new sediments during early transgression. A characteristic example occurs at the base of the Sponge Limestone member of the Jumara Dome.

Mixed carbonate-siliciclastic environments

In the Jurassic succession of the Kachchh Basin, a significant thickness of sediments is represented by mixed carbonate-siliciclastic deposits. They are found where sediments of a carbonate ramp received siliciclastics from a nearshore source (e.g. coastal sands, deltas) to produce a succession of mixed lithologies. Such deposits can be classified either with siliciclastic or carbonate ramps depending on the relative importance of the two components. Under the present heading we are including the deposits on the ramp, where lowstand sediments of one type (usually siliciclastic) were reworked during transgression and became incorporated in the second type (usually carbonate). They are basically transgressive systems tract deposits. A large part of the marine Middle Jurassic sediments of the basin contains prominent horizons of such deposits. Most of them can be grouped with one of the following two types:

Low to medium energy sediments of transgressive systems tracts: Silty to fine sandy micrite and marl with thin intercalations of storm beds and a rich fauna often represent sediments of early transgression developed on the inner shelf. Thin pebble lags, shell beds, but also beds with an autochthonous fauna are commonly associated. A characteristic element of the trace fossil fauna is *Rhizocorallium irregulare*.

High energy sediments of transgressive systems tracts: Large-scale cross-bedded sandy rudstones, grainstones or calcareous sandstones with scattered quartz granules, granitic-gneissic pebbles, quartz pebbles, or intraformational pebbles, shells, and wood fragments are interpreted as deposits of early transgression formed essentially on inner to middle ramp areas. Characteristic examples are the so-called Leptosphinctes Pebbly Rudstone and the Raimalro Limestone Member of the Islands (Fürsich *et al.*, 2001). The major part of the coarse clastic material associated with these deposits represents LST deposits, which have been totally reworked and redeposited during early transgression, with negligible supply of new sediment.

EXPLANATION OF PLATE I

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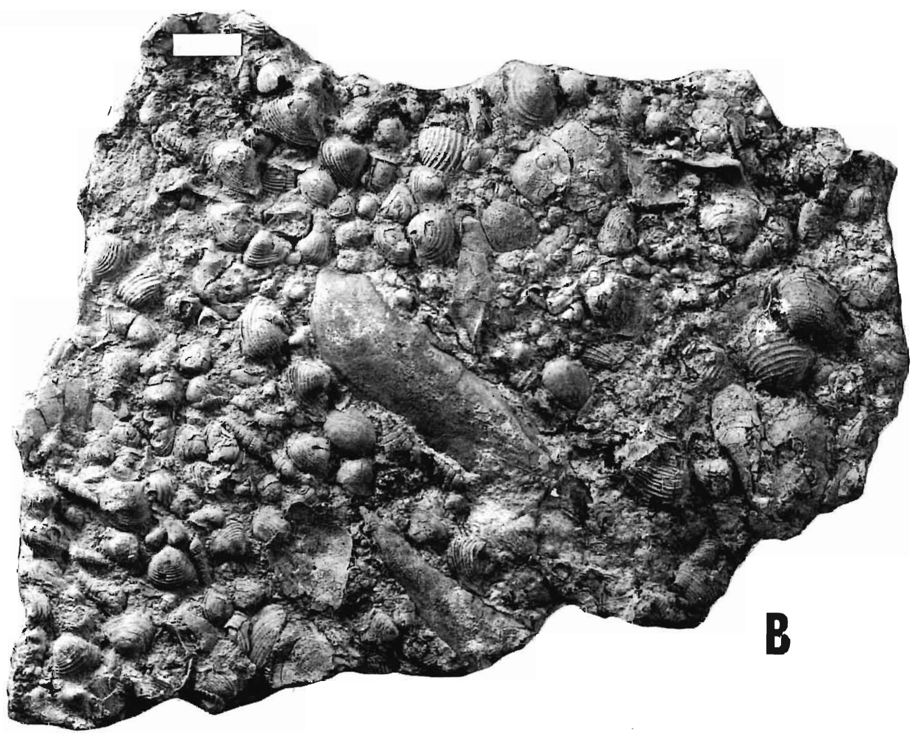
A. *In situ* concentration of articulated members of the low diversity Indocorbula lyrata – Protocardia grandidieri association, indicative of brackish water conditions. Khadir Formation, Mouwana Dome. I: *Indocorbula lyrata,* P: *Protocardia grandidieri.* Scale bar: 1 cm.

B. Upper surface view of winnowed concentration of the Indocorbula basseae association. Gadhada Formation, Mouwana Dome. Scale bar: 1 cm.

Plate I

A



B

MACROBENTHIC ASSOCIATIONS

Associations are defined here as re-occurring autochthonous to parautochtonous relicts of former communities (e.g. Fürsich, 1984). Most of the associations described below exhibit minor time-averaging. Single occurrences of characteristic faunal groupings are termed assemblages. In several cases, these are probably also relicts of former communities that could not be defined statistically. In other cases they represent transported and reworked faunas in which mixing from different stratigraphic levels or neighbouring environments is evident.

Most of the associations, which have been defined by means of a cluster analysis (fig. 3), are dominated by bivalves. The second-most important group are brachiopods, gastropods, serpulids, and bryozoans are generally only minor elements. As a rule, sponges, scaphopods, and corals are rare, but dominate an association each. The validity of the associations is corroborated by additional observations in the field and by additional quantitative samples too small to be used for cluster analysis.

In the following, the macrobenthic associations of the Kachchh Basin are briefly described with information on their stratigraphic and geographic occurrence in the basin.

(1) *Bositra buchi association (33 samples)*: The bivalve *Bositra buchi* is the dominant taxon. Depending on the degree of dominance of *Bositra* and the species diversity, two sub-associations can be distinguished, one characterised by a moderate diversity and dominance of *Bositra* (1a), the other one by a very low species diversity and a strong dominance of *Bositra* (often 80-90% in terms of relative abundance (Pl. I, fig. b).

Distribution: In mudstones and wackestones of the Jumara Coral Limestone member at the Jumara Dome and in silty clay and argillaceous silt of the Callovian Chari Formation of the Kachchh Mainland.

(2) *Bositra buchi – Praesaccella juriana association (7 samples)*: In this association *Bositra* occurs together with several species that characterized soft substrate conditions, the commonest of which is the nuculid *Praesaccella juriana*. Species diversity is medium, the substrate ranges from argillaceous to sandy silt.

Distribution: Chari Formation of the Kachchh Mainland.

(3) *Praesaccella juriana – Nicaniella pisiformis association (12 samples)*: This characteristic softground association consists predominantly of small-sized infaunal bivalves along with many deposit-feeding nuculids. The species diversity is high, the substrate is silt.

Distribution: Chari Formation.

(4) *Cingentolium partitum – Corbulomima macneilli association (16 samples)*: Softground association, in which the opportunistic bivalve *Cingentolium* is the characteristic element. Epifauna and infauna are of equal abundance. The species diversity is medium to high. Typical substrates are silt and fine sand.

Distribution: Gypsiferous Shales member (Chari Formation) of the Kachchh Mainland.

(5) *Cingentolium partitum association (11 samples)*: In this association, the free-living epifaunal suspension-feeder *Cingentolium* accounts usually for 80 to 95% of the individuals. As a result, the species diversity is very low. Preferred substrates are silt and fine sand.

Distribution: Middle and Upper Chari Formation of the Kachchh Mainland.

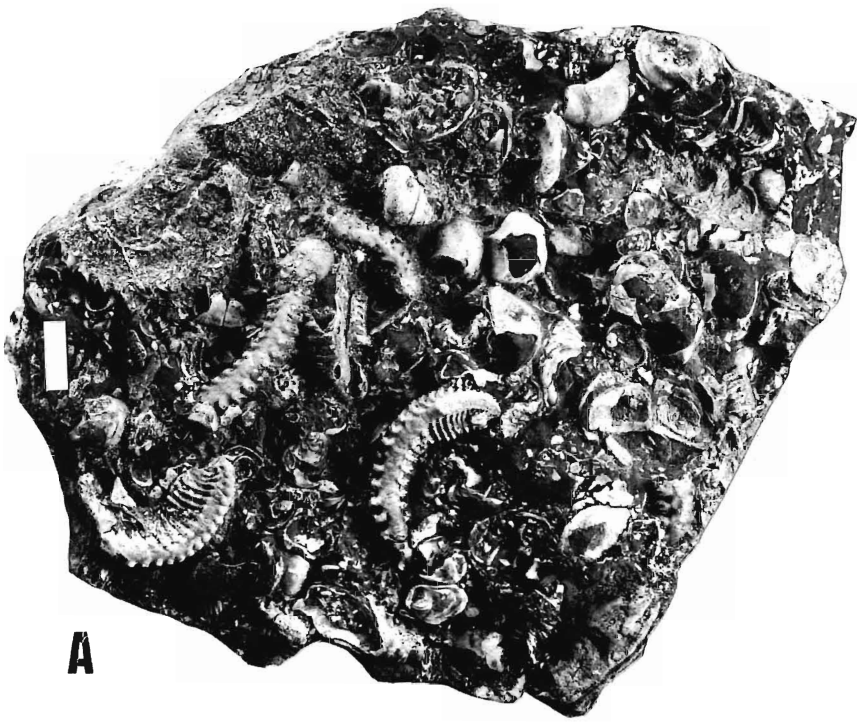
(6) *Nuculoma wynnei – Palaeonucula cuneiformis association (5 samples)*: The

EXPLANATION OF PLATE II →

A. Upper surface view of shell bed composed of mainly articulated *Eligmus rollandi*. This shell bed is a slightly winnowed concentration of elements of the Eligmus rollandi association. Jumara Coral Limestone member, Jhurio Formation of the central Jumara Dome. Scale bar: 1 cm.

B. Upper surface view of loosely packed shell bed containing the Actinostreon erucum – Nanogyra nana association. Gypsiferous Shales member, Chari Formation of the eastern Habo Dome. Scale bar: 1 cm.

Plate II



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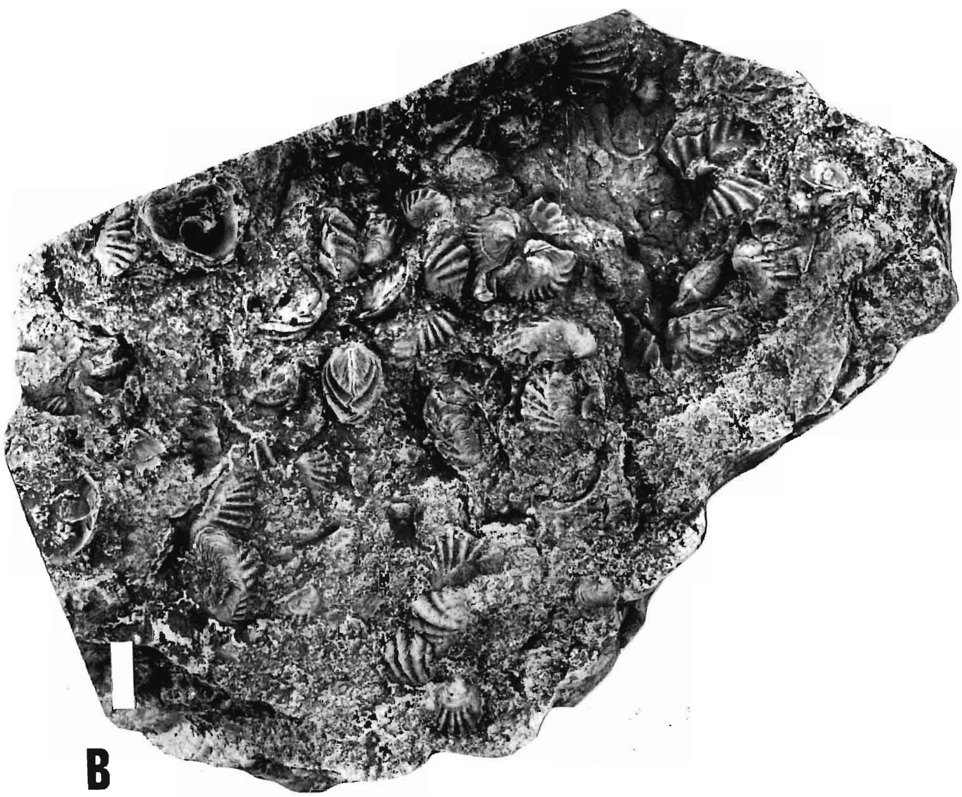

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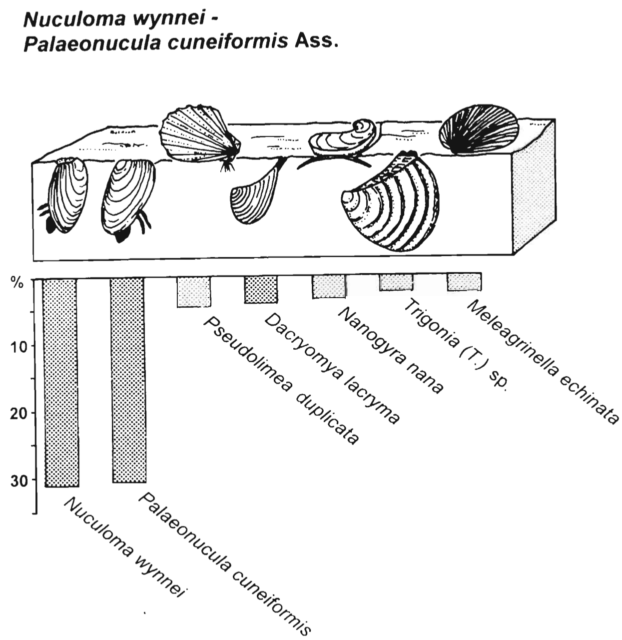

Fig. 4. Trophic nucleus of the Nuculoma wynnei – Palaeonucula cuneiformis association. Dark stippled bars denote deposit-feeders, light stippled bars suspension-feeders.

association is characterised by three to five species of deposit-feeding nuculids (fig. 4). The species diversity is low to medium, the preferred substrate is silt.

Distribution: Chari Formation.

(7) *Grammatodon jurianus – Corbulomima macneilli association (2 samples)*: This is a typical softground association in which, apart from the two index species, *Indogrammatodon virgatus, Praesaccella juriana,* and *Protocarda striatula* are common. Diversity values are medium to high, the substrate is silt.

Distribution: Upper Chari Formation.

(8) *Trigonia distincta association (2 samples)*: The low diversity softground association occurs in fine-grained sandstone.

Distribution: Chari Formation of the Kachchh Mainland.

(9) *Nicaniella extensa association (3 samples)*: Softground association of medium diversity. Shallow infaunal deposit-feeding nuculids and small, suspension-feeding bivalves account for most of the individuals. The association occurs as parautochthonous winnowed lags within silt. The samples of the association may have undergone some degree of sorting.

Distribution: Chari Formation of the Kachchh Mainland.

(10) *Dacryomya lacryma association (2 samples)*: A low diversity softground association in which nuculids dominate. Occurs in silt and marly silt.

Distribution: Chari Formation of the Kachchh Mainland.

(11) *Dentalium sp. – Palaeonunula cuneiformis association (2 samples)*: Softground association in which shallow infaunal taxa dominate. The species diversity is low, the substrate is silt. Occurs in prodelta settings.

Distribution: Washtawa Formation of the Wagad Dome.

(12) *Nicaniella khadirensis association (3 samples)*: Softground association, in which the index taxon *Ninaciella* strongly dominates. Confined to silt. Occurs as reworked but parautochthonous shell concentrations, in relatively nearshore areas.

Distribution: Upper Callovian part of the Gadhada formation, Khadir Island.

(13) *Indocorbula basseae association (2 samples)*: Apart from the corbulid *Indocorbula*, two species of the shallow infaunal suspension-feeding bivalve *Protocardia* and the mobile epifaunal gastropod *Procerithium (Cosmocerithium) nysti* dominate (Pl. I, fig. B). Suspension-feeders prevail. The association occurs in silt.

Distribution: Gadhada formation of the Mouwana Dome.

(14) *Neocrassina subdepressa association (2 samples)*: Consisting nearly exclusively of suspension-feeders. Apart from the shallow burrowing *Neocrassina* nearly all other faunal elements lived on the sediment surface. The substrate was an iron-oolitic marly wackestone.

Distribution: Upper Chari Formation of the Kachchh Mainland.

(15) *Highly diverse softground association (2 samples)*: The main characteristic feature is the extremely high diversity, possibly a result of time-averaging, and the occurrence of several rare taxa which are confined to this level. The most abundant taxa are, however, also dominant elements in some other associations. The association characterises the maximum flooding zone of a depositional cycle. Occurs in silty micrite.

Distribution: Dhosa Sandstone member of eastern Kachchh Mainland ("Pachyceras Bed").

(16) *Eomiodon baroni – Protocardia lycetti association (3 samples)*: The association consists nearly exclusively of shallow burrowing suspension-feeding bivalves (fig. 5). The dominance of *Eomiodon*, a typical Jurassic brackish water taxon (e.g. Fürsich, 1994), the very low diversity, and the close association with terrestrial sediments (e.g. red silt and fine-grained sandstone with caliche nodules) indicate that the association lived in oligohaline to mesohaline waters. The substrate is fine- to medium-grained sandstone.

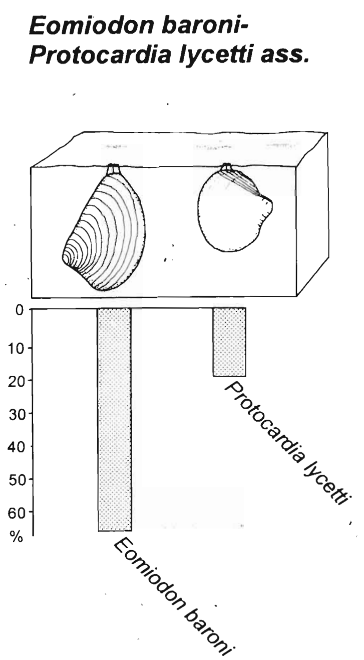

Fig. 5. Trophic nucleus of the low diversity Eomiodon baroni – Protocardia lycetti association indicative of brackish water conditions. Both taxa are shallow infaunal suspension-feeders.

Distribution: Kaladongar Formation of Pachchham Island.

(17) *Eomiodon baroni – Placunopsis socialis association (2 samples)*: Dominated by infauna of low diversity, the association is found in low energy, mixed carbonate-siliciclastic environments characterised by salinity values deviating slightly from those of the open sea.

Distribution: Kaladongar Formation of Pachchham Island.

(18) *Indocorbula lyrata association (7 samples)*: Characterised by low to medium species diversity and consisting largely of infaunal and epibyssate suspension-feeders, the association lived in relatively quiet environments on mixed carbonate-siliciclastic substrates. The bivalve *Indocorbula lyrata* apparently was very euryhaline, occurring in waters of strongly reduced salinity (see below) but also in fully marine environments as is the case with the present association.

Distribution: Goradongar Formation of the Islands.

(19) *Indocorbula lyrata – Protocardia grandidieri association (2 samples)*: The two shallow infaunal index species account for more than 90% in terms of relative abundance (Pl. I, fig. A). As a result the species diversity is very low. Both species managed to live in waters of reduced salinity. Typical substrate is silty marl. The association lived in low salinity (oligohaline to mesohaline), protected bays. This interpretation is supported by the close association with rootlet horizons.

Distribution: Khadir Formation of the eastern Islands.

(20) *Thracia viceliacensis association (2 samples)*: A very characteristic association which is restricted to very few and thin horizons. Apart from the index species the large, deep burrowing bivalves *Pholadomya (Bucardiomya) lirata* and *Osteomya dilata* as well as members of softground associations occur. Species diversity is medium, the substrate is silt.

Distribution: Chari Formation of the Kachchh Mainland.

(21) *Low diversity Pseudolimea duplicata association (4 samples)*: The association consists of only very few species and is restricted to iron-oolitic cross-bedded grainstones (high energy shoals) and to thin shell beds which represent the reworked, transported and slightly sorted concentrations of association (22). Epibyssate taxa prevail.

Distribution: Lower Chari Formation of the Kachchh Mainland.

(22) *Medium to high diversity Pseudolimea duplicata association (4 samples)*: Similar in composition to the preceding association buit with a lower dominance of *Pseudolimea*. Epifaunal and infaunal elements are of equal abundance, suspension-feeders dominate. The association occurs in silt and echinoderm packstones.

Distribution: Lower Chari Formation of the Kachchh Mainland.

(23) *Nanogyra nana – Palaeonucula cuneiformis association (3 samples)*: Poorly defined association with the small oyster *Nanogyra* as the characteristic element. *Nanogyra* occurs together with predominantly infaunal bivalves and is a eurytopic form found in several associations. The diversity varies from low to high. The substrate is silt to micritic siltstone.

Distribution: Chari Formation of the Kachchh Mainland.

(24) *Nanogyra nana association (5 samples)*: The main difference to the preceding association is the strong dominance of *Nanogyra*. As a result, the species diversity is generally low. Occurs in silt, sandstone and bioclastic grainstones.

Distribution: Chari Formation of the Kachchh Mainland.

(25) *Actinostreon erucum – Nanogyra nana association (5 samples)*: This epifaunal suspension-feeding association is dominated by cementing oysters (Pl. II, fig. A) and occurs in thin horizons intercalated between softground associations. Species diversity is medium, substrate is silt.

Distribution: Chari Formation of the Habo Dome and at Ler.

(26) *Gryphaea alimena association (5 samples)*: In this association the faunal density is often very high, probably due to winnowing of finer sediment particles. Apart from cementing bivalves (*Gryphaea alimena* in the juvenile stage, *Plicatula peregrina)* also some typical softground taxa occur. Diversity is low to medium, the substrate is silt.

Distribution: Very common in the Shelly Shale member (Chari Formation) of the western part of the Kachchh Mainland (Jumara Dome, Jara Dome).

(27) *Nanogyra nana – Gryphaea alimena – Plicatula peregrina association (2 samples)*: This association, characterised by cementing taxa, is clearly related to the previous association and the Nanogyra nana association. The diversity varies considerably. Some of the samples possibly have been affected by time-averaging. The sediments are siltstone and sandy grainstone.

Distribution: Shelly Shale member of the Kachchh Mainland.

(28) *Nanogyra nana – Ataphrus belus – Ceratomyopsis striata association (2 samples)*: In this highly diverse association a large number of guilds is represented ranging from deposit-feeding mobile infauna (e.g. nuculids) to cemented suspension-feeding epifauna (oysters), mobile grazing gastropods (e.g. *Ataphrus)* and echinoids *(Pseudodiadema cutchensis)*, and free-living microcarnivores *(Amphiastraea piriformis)*. The sediment is ferruginous sandy siltstone.

Distribution: Restricted to a thin horizon in the Washtawa Formation (Callovian) of the Wagad Dome.

(29) *Eligmus rollandi association (7 samples)*: This association is represented by a low diversity (29a) and a high diversity (29b) variant. An additional characteristic faunal element is the rhynchonellid brachiopod *Cryptorhynchia pulcherrima*. Byssate suspension-feeding epifauna dominates (Pl. II, fig. B); the substrate is marl, wackestone and packstone.

Distribution: Jumara Coral Limestone member (Jhurio Formation) of the Jumara Dome.

(30) *Bakevellia waltoni association (2*

samples): Dominated by epi- and endobyssate bivalves (fig. 6), the low diversity association occurs in fine-grained sandstone of nearshore origin.

Distribution: Gadhada formation of the Island.

(31) *Modiolus imbricatus association (2 samples)*: Many elements are similar to those of the Bakevellia waltoni association, but their relative abundances differ. Diversity is low, the substrate is fine-grained sandstone and sandy packstone.

Distribution: Khadir and Gadhada formations of the eastern Islands, Chari Formation of the Habo Dome.

(32) *Amphiastraea piriformis association (2 samples)*: This association forms a marker bed in the Ridge Sandstone member of the Habo Dome. Associated with the coral *Amphiastraea* are a number of byssate (*Modiolus, Plagiostoma, Trichites, Isognomon*) and cementing bivalves (*Plicatula, Liostrea*) and several gastropods (*Pseudomelania (Oonia), Globularia*).The coral heads, some of them more than an metre in diameter, are reworked and form a boulder bed. The eurytopic *Amphiastraea piriformis* was adapted to turbid waters and shifting sandy substrates (Fürsich, Pandey, Oschmann, Jaitly and Singh, 1994b). The species diversity is low.

Distribution: Apart from the Ridge Sandstone member (Chari Formation) of the Habo Dome the association occurs at time-equivalent levels in the Gadhada Sandstone member of the Bela Anticline and the Mouwana Dome. At the latter two localities the corals form small patch reefs (Pandey and Fürsich, 2001).

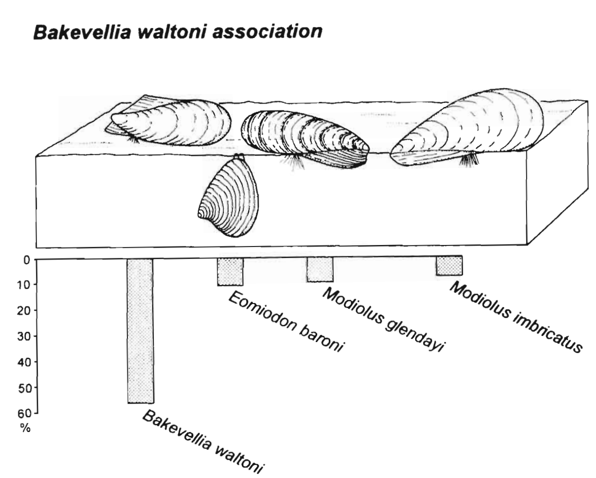

Fig. 6. Trophic nucleus of the Bakevellia waltoni association. All taxa are epibyssate suspension-feeders except for the shallow infaunal *Eomiodon baroni.*

(33) *Microsolena amorpha – Montlivaltia frustriformis association (8 samples)*: The association is dominated by a highly diverse fauna of solitary and colonial corals that were adapted to live in a bioclastic carbonate mud (Fürsich *et al.*, 1994b). Associated with the corals occurs an equally diverse fauna of gastropods, bivalves, and brachiopods with infaunal, cementing, byssate, pedicle-attached, reclining, or mobile life habits.

Distribution: Jumara Coral Limestone member (Jhurio Formation) of the Jumara Dome.

(34) *Camptonextes auritus association (3 samples)*: The epibyssate bivalve *Camptonectes auritus* is the diagnostic species of the association. The species diversity is medium. Numerous life habit groups (shallow infaunal, byssate, cementing, suspension-feeding, deposit-feeding) are present. The substrate is fine sand.

Distribution: Chari Formation of the Kachchh Mainland.

(35) *Lophrothyris euryptycha association (13 samples)*: The association occurs in a low (35a) and a high species diversity (35b) variant. In the latter, numerous, partly epifaunal, partly infaunal taxa (bivalves, some gastropods, the irregular echinoid *Collyrites,* and other brachiopods) are associated with the brachiopod *Lophrothyris*. The low species diversity may reflect chemical sorting, i.e. selective dissolution of aragonitic shells.

Distribution: Dhosa Sandstone member (high diversity variant) and Dhosa Oolite member (low diversity variant) of the Kachchh Mainland.

(36) *Kutchithyris hypsogonia association (4 samples)*: The association is highly diverse. Apart from *K. hypsogonia* additional brachiopods (e.g. *Kallirhynchia versabilis, Kutchithyris ingluviosa, Torquirhynchia inconstans, Rhynchonelloidella brevicostata)* are components of the association.

Among bivalves, byssate and cementing taxa prevail. The substrate is fine-grained sandstone.

Distribution: Chari formation of Kachchh Mainland.

(37) *Rhynchonelloidella brevicostata association (4 samples)*: The association consists, apart from *Rhynchonelloidella,* of several other brachiopod taxa. Among the bivalves, epibyssate and vementing forms dominate, deposit-feeders are absent. Species diversity is medium to high. The association occurs in siltstone and packstone.

Distribution: Gypsiferous Shales member (Chari Formation) of Kachchh Mainland.

(38) *Kutchithyris breviplicata association (6 samples)*: The index species occurs in small nests in silty micrite concretions and is associated with only few other taxa. The species diversity is low. Many individuals are preserved in growth position.

Distribution: Gypsiferous Shales member (Chari Formation) of Jumara and Jara domes.

(39) *Cycloserpula association (3 samples):* This association is characterised by abundant free living serpulids associated with *Lophrothyris euryptycha* association and may represent a successional stage (sere) of the Lophothyris euryptycha association, in the close vicinity of which it occurs. In an additional sample *Cycloserpula* has been replaced by *Tetraserpula.* Apart from that the composition and ecological structure is unchanged. This sample has been classified as *Tetraserpula* assemblage. The substrate is fine sand.

Distribution: Shelly Shale member (Chari Formation) of the Habo Dome.

(40) *Platychonia schlotheimi association (1 statistical sample, numerous additional field observations)*: The diverse epifauna consists predominantly of 13 species of sponges, especially demosponges, and several taxa of brachiopods (e.g. *Torquirhynchia inconstans, Cryptorhynchia pulcherrima*) (Mehl and Fürsich, 1997). Infauna is extremely rare. The association occurs in marl and wackstone and formed meadows on the sea floor.

Distribution: Sponge Limestone member (Patcham Formation) of the Jumara Dome and Jhura Dome.

(41) *Palaeonucula cuneiformis – Palaeonucula stoliczkai association (3 samples)*: The association is dominated by nuculid bivalves and characterised by a very low species richness. The bivalves form loosely packed shell beds in silt and fine-grained sandstone, apparently suffered short-time reworking, and probably underwent some degree of sorting.

Distribution: Restricted to the Katrol Formation.

Macrobenthic assemblages

Apart from the macrobenthic associations described above, several assemblages can be recognised in the Middle Jurassic of the Kachchh Basin. The assemblages differ from the associations described above in that they are encountered only once. They are either dominated by brachiopods (*Somalirhynchia africana* assemblage (A), *Kallirhynchia versabilis* assemblage (B)), by crinoids (crinoid assemblage (C)), serpulids (*Tetraserpula* assemblage (D)), or by bivalves (*Bucardiomya lirata* assemblage (E), *Sphaera rogeri* assemblage (F)). Some of them probably are the result of strong time-averaging, others are probably autochthonous community relicts that could not be documented sufficiently. Yet some others may be allochthonous concentrations in response to storms.

Several samples of macrobenthic fossils could not be assigned to any association nor are they characteristic enough to be recognised as assemblages. They are therefore not discussed further.

ENVIRONMENTAL PARAMETERS CONTROLLING FAUNAL DISTRIBUTION

The distribution of the benthic fauna is primarily controlled by the depositional environment. To understand the spatial and temporal changes in the fauna, it is imperative to have a proper understanding of the various environmental factors controlling the fauna. In the following, the major environmental parameters that governed the distribution of individual taxa and finally also of associations of the macrobenthos in the Kachchh Basin are briefly discussed. They are substrate, energy level, light, salinity, oxygen availability, temperature, and nutrient supply.

Substrate

Substrate, i.e. grain size, composition, sorting, and consistency, exerts a major control on the distribution of benthic organisms. In the Jurassic of the Kachchh Basin this is clearly seen, for example, in the distribution of deposit-feeding nuculid bivalves such as *Nuculoma, Palaeonucula, Mesosaccella, Praesaccella,* and *Dacryomya.* These taxa exclusively occur in argillaceous silt, silt and silty fine sand except when reworked. This distribution pattern is identical to that of present-day members of the group (e.g. Sanders, 1958; Parker, 1975) as well as of other Jurassic occurrences (e.g. Duff, 1975; Fürsich, 1976). Similarly, the small astartids *Nicaniella extensa* and *N. pisiformis* and the corbulid *Corbulomima macneilli* occurred preferentially in argillaceous silty substrates. The free living epifaunal pectinid *Cingentolium partitum,* in turn, has the peak of its distribution in silty fine sand and fine sand. Consequently, associations dominated by these bivalves exhibit signs of a corresponding substrate control.

Substrate consistency (soft, firm, or hard) influences in particular the distribution of epifaunal and infaunal guilds. Soft substrates were populated mainly by nuculid bivalves and a range of small infaunal suspension-feeding bivalves such as *Nicaniella* and *Corbulomima.* Epifaunal elements were usually rare and restricted to small forms that were able to colonise small benthic islands (e.g. dead shells lying on the sea floor). Soft substrate conditions appear to have been very widespread in the Shelly Shale and Gypsiferous Shale members of the Chari Formation and are represented by a range of associations (see above). In firmer substrates, deep burrowing suspension-feeding bivalves (e.g. *Pleuromya, Pholadomya)* commonly occurred. In addition, such substrates were colonised by epifaunal groups such as terebratulids and byssate bivalves. Typical examples of firm substrate associations are the Rhynchonelloidella brevicostata association that occurs in siltstone of the Dhosa Sandstone member at the Habo Dome and the Kutchithyris breviplicata association of the lower Gypsiferous Shales member of the Jara Dome. Hard substrates are dominated by cemented and byssate taxa, less abundant are endolithic bryozoans, bivalves, and acrothoracican barnacles. They occur either where low rates of sedimentation produced shell pavements that served as secondary hard substrates (e.g. in the case of the Gryphaea alimena association) or where, due to omission and erosion, synsedimentarily formed concretions became exhumed and formed a cobble substrate colonised by brachiopods, serpulids, and byssate, boring and encrusting bivalves (e.g. the Actinostreon erucum –Nanogyra nana association).

Energy level

Under the energy level of an area we understand the extent of wave and current activities, which are controlled by water depth and basin morphology. In general, three energy levels are identified. Low-energy conditions usually go hand in hand with soft, fine-grained substrates, without regular sediment reworking events. Intermediate energy levels produce silty to fine sandy sediments where occasional reworking of the sediment surface by 1-2 cm takes place. High energy levels are characterised by continuous reworking and movement of sand-sized sediment particles by migration of larger bedforms. Several centimetres of sediment are constantly reworked.

The energy level strongly influences substrate properties and distribution of particulate organic matter. Low energy conditions therefore are characterised by faunas that are dominated by small, shallow infaunal taxa such as corbulids, astartids, and Protocardia. As particulate organic matter accumulates in the sediment, deposit-feeding nuculids are common. Such conditions prevailed for much of the Lower and Upper Chari Formation. Characteristic are the Praesaccella juriana – Nicaniella pisiformis, the Dacryomya lacryma, and the Palaeonucula cuneiformis-Nuculoma wynnei associations.

Intermediate energy levels often exhibit signs of winnowing, but large-scale transport of fauna is not the rule. The benthic associations are dominated by suspension-feeders whereby, depending on the availability of secondary hard substrates, epifaunal (e.g. Cingentolium partitum association) or infaunal taxa (e.g. Neocrassina subdepressa association) prevail. Associations in which deep burrowing bivalves dominate (e.g. Thracia viceliacensis association of the lower Chari Formation) most likely also record somewhat elevated energy levels.

Communities living in high energy environments usually are not preserved in situ except when having suffered catastrophic burial. Thus, the nests of articulated *Neocrassina* occurring in cross-bedded pack- to grainstone at the top of the Raimalro Limestone member at Khavda indicate that the bivalves apparently colonised a shifting high energy substrate. Members of the low diversity Pseudolimea duplicata association occurring in cross-bedded ferruginous oolites of the Keera Dome probably were able to cope with the effects of high energy conditions. In most cases, however, organisms living in such substrates are not preserved *in situ* but occur as reworked shell beds, scour fills, and as shell pavements on the foresets of large-scale cross-beds.

Light

Although most of the Middle Jurassic environments of the Kachchh Basin appear to have been shallow and well within the photic zone, corresponding organisms such as calcareous and boring algae are hardly present. Their lack in the diverse coral meadows of the Microsolena amorpha – Montlivaltia frustriformis association prompted Fürsich *et al.* (1994b) to assume that the corals grew near the lower end of the photic zone which, due to turbid conditions, did not extend to particular great depth.

Salinity

Sedimentological (e.g. rootlet horizons, close association with terrestrial facies) and palaeoecological evidence (e.g. low species diversity, dominance of typical euryhaline taxa) suggests that salinity commonly deviated from fully marine conditions in marginally marine environments of the Kachchh Basin. This situation is particularly common in the Island belt (from Pachchham in the west to Chorad in the east). During the early Middle Jurassic, this area was situated close to the palaeoshoreline so that non-marine and marine environments intertongued. Fürsich *et al.* (1994a) described the Eomiodon indicus – Protocardia sp. A association (= E. baroni – P. lycetti association; 16) from reddish, poorly sorted fine sand of the *Eomiodon* Red Sandstone member of the Sadhara Dome. Judging from the low species diversity, close association with coastal plain environments with caliche, and the fact that *Eomiodon* is a typical brackish water taxon elsewhere in the Jurassic (e.g., Fürsich, 1994), mesohaline conditions are inferred. *Eomiodon* is a common element in nearshore to lagoonal environments in the Bajocian and lower Bathonian rocks of the Islands, but by no means the only taxon indicative of lowered salinity conditions. Silty marl full of articulated specimens of *Indocorbula lyrata* and *Protocardia grandidieri* occur next to rootlet beds in the Khadir Formation of the Mouwana Dome. This low diversity association is also interpreted to reflect strongly reduced salinity in the mesohaline range. The bivalves *Tancredia* and *Pronoella,* common elements of Bajocian marginal marine environments of the island belt, often co-occur with *Eomiodon* and most likely were also able to tolerate strongly reduced salinities.

There are many examples of reduced salinity at several stratigraphic levels of the Island belt. We would like to argue that this region was characterised by numerous small coastal drainage systems, which seasonally contributed large amounts of freshwater to the basin. Thus, in areas close to the point source of freshwater (river mouth) salinity fluctuated strongly and generally low salinity values prevailed. In adjacent areas, away from river mouths, normal salinity values persisted.

Considering the regional climatic situation, with the large land mass of Gondwanaland producing a trade wind/monsoonal climatic regime in which wet and dry seasons alternated, it is feasible that salinity fluctuated in both directions, i.e. from brackish to hypersaline. However, no direct evidence is available so far to support the existence of hypersaline conditions.

Oxygen availability

There are no black shales indicative of anoxic conditions in the Jurassic of Kachchh and the basin appears to have been generally well aerated. However, in the Upper Callovian Gypsiferous Shale member of the Chari Formation cm-thick horizons of shaley silty clay full with fragments or complete specimens of the bivalve *Bositra buchi* (e.g. at Ler) possibly indicate intervals of dysoxic conditions. The shaley nature of the sediment points to lack of bioturbation, in contrast to the rest of the sediment, which has been thoroughly bioturbated. The strong dominance of *Bositra*, usually accounting for 80% to 90% of the macrofauna, and the resulting low species richness and evenness, indicate stress conditions. *Bositra* is a common element of oxygen-poor environments elsewhere in the Jurassic (e.g. the Toarcian Posidonia Shales of southwestern Germany) but by no means restricted to such environments. It clearly is a eurytopic, opportunistic species adapted to cope with lowered oxygen conditions (e.g., by possessing a relatively large mantle surface which might have served for additional uptake of oxygen). The softground associations, dominated by infaunal bivalves (nuculids, *Protocardia, Corbulomima,* and *Nicaniella*), which characteristically occur in the bioturbated parts of the Gypsiferous Shale member, are represented only by few species. This points to lowered oxygen values at least in the uppermost layers of the sediment. Recently, Oschmann (1994b) had proposed a planktic mode of life for *Bositra*, this way explaining its occurrence in oxygen-poor environments such as the Toarcian black shales of Europe. However, its distribution pattern in the Kachchh Basin and its concentration at certain levels point to a benthic mode of life (see also Etter, 1996; Röhl *et al.*, 2001) and to the ability of the bivalve to cope with lowered oxygen conditions.

Temperature

There is no straightforward way of reconstructing palaeotemperatures from fossils. Using ^{18}O values of skeletal material requires diagenetically unaltered shells which are only rarely available in the Jurassic rocks of Kachchh. Nevertheless, both stable isotope data of belemnites and brachiopods and clay-mineralogical analyses enabled the reconstruction of large-scale trends in palaeotemperature of the basin (Fürsich, Singh, Joachimski, Krumm, Schlirf and Schlirf, submitted). Additional evidence, although only qualitative in nature, can be obtained from fossils and facies. Thus, the wide distribution of carbonates in the Middle and Late Bathonian points to a relatively warm and arid to semi-arid climate. This is corroborated by the high diversity coral meadows occurring in the upper Middle Bathonian of the Jumara Dome, which indicate tropical water temperatures. At the same locality and stratigraphic level, several bivalve taxa abound, which exclusively occur at these levels in the basin. They are *Eligmus rollandi,* an epibyssate oyster-like member of the family Malleidae, and several species of the subfamily Opinae (*Coelopis pulchella, C. ceratoides, C. deshayesi, Pachyopis ganeshi* and *Opis (Trigonopis) acuta*). These taxa have the peak of their distribution in tropical seas of the Jurassic. Their short-lived occurrence in the Kachchh Basin during the Middle Bathonian suggests that, at that time, sea water temperature reached tropical levels and provided suitable living conditions for these faunal elements.

The general change from carbonates to siliciclastics around the Bathonian-Callovian boundary probably reflects a drop in temperature in combination with a higher humidity which resulted in increased run-off and sediment input into the basin. Thus, sediment pattern and faunal distribution point to a change in climate from predominantly semi-arid in the Middle and Late Bathonian to humid and possibly only warm-temperate in the Callovian and Oxfordian.

Nutrient supply

Information about the nutrient supply can be gained, apart from geochemical analyses of the sediment, by analysing the feeding modes of the benthic fauna. A striking feature of the benthic associations of the Callovian part of the basin fill is the abundance of nuculid bivalves, especially in the more offshore parts of the basin. Nuculids are deposit-feeders that collect organic particles from the sediment with the help of labial palps. Their great abundance indicates that there was plenty of detrital organic matter supplied to the basin, which goes hand in hand with a greater humidity as suggested above.

Conversely, high diversity coral assemblages like those from the upper Middle Bathonian of the Jumara Dome not only require suitable temperatures, but also nutrient-poor waters.

Thus, it appears that with a change from semi-arid to humid conditions at the Bathonian-Callovian boundary there was also a concomitant oceanographic change from oligotrophic to eutrophic conditions that can be deduced from the lower diversity of benthic associations and the bloom of deposit-feeding nuculids.

ONSHORE-OFFSHORE TRENDS IN FACIES AND FAUNAL DISTRIBUTION

Combining palaeoecological data with sedimentological data enables us to reconstruct onshore-offshore trends in facies and faunal distribution. Figs. 7-10 diagrammatically depict the distribution of the main facies and characteristic macrobenthic associations for the following time slices: (a) Bajocian, (B) Middle Bathonian, (C) Late Bathonian, and (D) Callovian. Not all these transects span the whole environmental range from shoreline to basin centre, because of limited outcrops and the fact that the basin changed in extension and depth with time.

During the Bajocian (fig. 7), the basin was relatively shallow and shallow-water nearshore depositional areas were widespread. Rocks of this time interval can be studied in the centre of the Jhura Dome and in the island belt. Due the common interfingering of marine and non-marine environments, brackish biota are common. They are represented by marl and sandstone of coastal lagoons and bays containing, for example, the Indocorbula lyrata – Protocardia grandidieri and the Eomiodon baroni – Protocardia lycetti associations. Other brackish water associations appear to have lived under estuarine conditions occurring in silt and sandstone. Usually reworked and concentrated in shell beds, they are occasionally preserved as autochthonous relicts (e.g., the Indocorbula lyrata association, the Eomiodon baroni – Tancredia gibbosa and the nerineid assemblages). Open shelf conditions well above storm wave base, are represented by low diversity assemblages of rhynchonellid brachiopods, scattered coral heads, or the bivalves *Nanogyra* and *Bakevellia.* These areas are designated as open ramp and represent essentially deposits of the transition zone. In the northern part of the Jhura Dome (Badi Nala) Bajocian strata are represented by sheets of ferruginous ooids (shoals) that intertongue with a generally calcareous facies (marl, calcareous mudstone, and wackestone) that only contains a sparse fauna of brachiopods (e.g. *Cryptorhynchia, Kutchirhynchia).* These calcareous facies represent deposition below storm wave base in offshore shelf regions, where supply of terrigenous clastics was low.

Lower Bathonian rocks, so far not documented by ammonites and therefore difficult to correlate, probably show similar trends as the following Middle Bathonian succession.

By the Middle Bathonian (fig. 8), the shoreline had receded and there was reduced supply of terrigenous clastics from land. Environments ranged from mixed carbonate-siliciclastic sediments deposited below fair-weather wave-base (Gorandongar Yellow Flagstone Member of the Pachchham Island) to outer ramp calcareous mudstone, wackestone and marl with thin distal tempestite intercalations (Jumara Coral Limestone member) of the Jumara Dome. The former contains a moderately rich fauna dominated by bivalves (Indocorbula lyrata association), the latter is characterised by highly diverse coral meadows (Microsolena amorpha – Montlivaltia frustiformis association), the Eligmus rollandi and the Bositra buchi association. The Goradongar Yellow Flagstone Member of the Jhura Dome occupies an intermediate position having been deposited around storm wave base and containing only a sparse fauna of brachiopods (in particular *Kutchirhynchia kutchensis)* and some bivalves.

In the Late Bathonian (fig. 9), the northern part of the basin was characterised by a carbonate ramp. Carbonate sands with variable admixture of quartz grains (the Raimalro Limestone Member of the Pachchham Island) were deposited nearshore under the influence of fair-weather waves. Most shells are allochthonous and have been concentrated in lenticles and on foresets of cross-beds. Occasionally, however, rapid burial caused the preservation of the benthic fauna *in situ*. For example, clusters of the bivalves

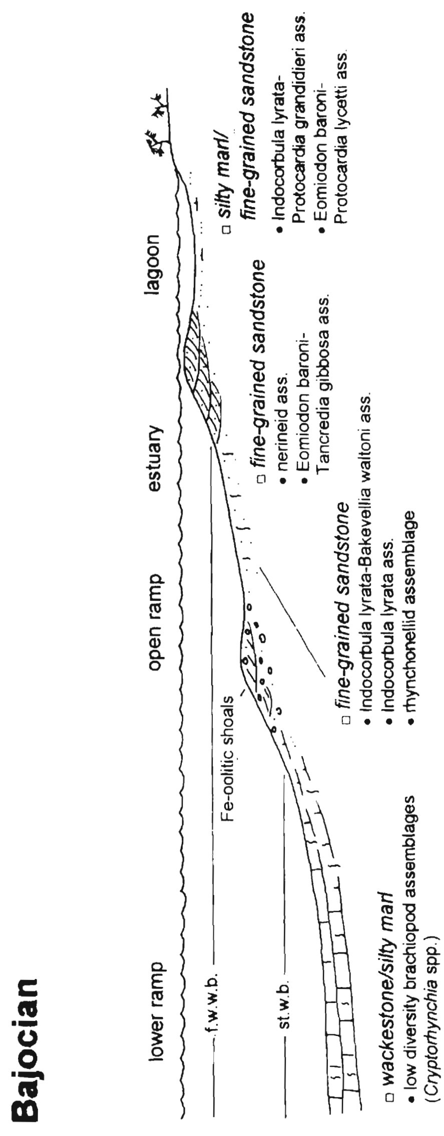

Fig. 7. Idealised onshore-offshore transect showing nature of sediments and distribution of macrobenthos associations in the Kachchh Basin during the Bajocian. Note that only some associations are given as examples. The open ramp corresponds to the transition zone and shows terrigenous clastic influx. A few iron oolite shoals may be present. The lower (outer) ramp corresponds essentially to the inner to mid shelf with little clastic influx. Estuarine deposits are shown as sand bars developed as estuarine mouth bars. f.w.w.b.: fair-weather wave-base, st.w.b.: storm wave-base.

Neocrassina in growth position, some gastropods, and scattered coral heads indicate that these faunal elements are the relict of a former community dominated by the shallow burrowing bivalve. Further offshore, on the storm-wave influenced ramp (e.g. in the Habo Dome), skeletal sands with hummocky cross-bedding and scours are nearly unfossiliferous except for occasional disarticulated shells of *Modiolus glendayi.* Towards the basin centre (Jhura Dome, Jumara Dome) bioclastic marl and wackestone are interbedded with graded grain- to packstones of storm flow origin. The tempestites contain only shell fragments, but in the fine-grained background sediment a rich fauna of sponges belonging to the

Lithistida, Hexatinellida and Calcarea (Mehl and Fürsich, 1997) thrived. This Platychonia association formed meadows on the sea floor and consists, apart from sponges, of a diverse fauna of bivalves and brachiopods.

In the Callovian (fig. 10), the different climatic setting and corresponding oceanographic changes led to a drastically different facies and faunal pattern. The carbonate ramp was replaced by a siliciclastic ramp and deposit-feeders played a far more important role than during the Bathonian. Marginally marine settings are not preserved and sediments deposited under the influence of fair-weather waves (e.g. the Ridge Sandstone member of the Habo Dome) generally contain only reworked faunal elements. Shallow ramp environments with sandy, occasionally bioclastic substrates under the influence of frequent storms are characterised by the Bakevellia waltoni, Cingentolium partitum, Actinostreon erucum – Nanogyra nana, Gryphaea alimena, Indocorbula basseae, and Amphiastraea piriformis associations. The ferruginous oolite shoals of the Keera Golden Oolite member, Keera Dome, contain the Pseudolimea duplicata association. Nutrient-rich prodelta sandy silts are characterised by the Dentalium sp. – Palaeonucula cuneiformis association. In more offshore, slightly deeper environments below storm wave base the Thracia viceliacensis association and the Bucardiomya lirata assemblage thrived on argillaceous silty to sandy silty substrates, in which deep burrowers such as *Osteomya, Pleuromya, Pholadomya,* and *Thracia* were common elements. Firm substrates of the same bathymetric range were inhabited by members of the Kutchithyris breviplicata association. The outer ramp (middle shelf) environments with argillaceous to marly silt were colonised by a range of softground associations such as the Palaeonucula cuneiformis – Nicaniella pisiformis association (subjected only to gentle winnowing). Parts of the basin in the outer ramp region experienced seasonal or episodic fluctuations in the

Middle Bathonian

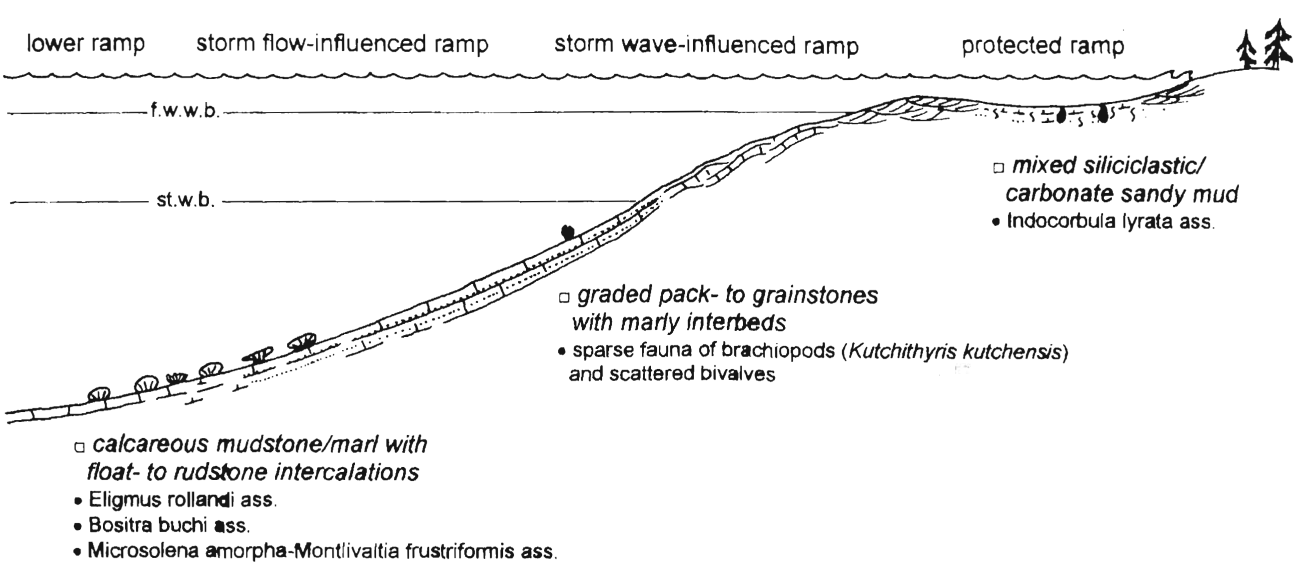

Fig. 8. Idealised onshore-offshore transect and distribution of facies and macrobenthos associations in the Kachchh Basin during the Middle Bathonian. Note that only some associations are given as examples. The protected ramp corresponds to protected bays or open lagoons. The storm wave-influenced ramp is the transition zone with strong storm influence. The storm flow-influenced ramp corresponds to the inner shelf with many storm beds. The lower (outer) ramp is the middle shelf with little influence of physical processes (waves and currents). During this time slice supply of terrigenous clastics was strongly reduced and deposition of mainly carbonates took place. f.w.w.b.: fair-weather wave-base, st.w.b.: storm wave-base.

oxygen content. It is in these parts that the Bositra buchi association is widespread. Investigations of cores drilled in areas west of the present outcrop belt (Suthri-1, Sanadara wells), i.e. closer to the Malagassy Gulf, showed that there the Callovian macrobenthos was nearly exclusively represented by *Bositra buchi.*

Thus, the Callovian onshore-offshore transect documents a change of the macrobenthos from epifaunal associations dominated by suspension-feeding bivalves in nearshore shallow areas subject to fair-weather wave processes or frequent storms to associations characterised by deep infaunal bivalves or terebratulid brachiopods in more offshore areas below storm wave base. In still deeper water, offshore environments, deposit-feeding nuculids became increasingly important until oxygen stress led to the establishment of very simple-structured communities dominated by the opportunist *Bositra.*

FAUNAL RESPONSE TO RELATIVE CHANGES IN SEA LEVEL

The presence of sedimentary cycles in the Kachchh Basin reflects changes in relative sea level of several orders of magnitude (e.g., Fürsich and Oschmann, 1993; Fürsich *et al.,* 2001). Most prominent are 3rd order cycles and parasequences. The latter are highly asymmetric deepening-shallowing cycles, in which the transgressive part is usually represented only by a thin lag often rich in shells, shell debris, and occasionally associated with pebbles that represent reworked synsedimentarily formed concretions (Fürsich, Oschmann, Jaitly and Singh, 1991). These authors demonstrated that these shell lags are characterised by a benthic macrofauna that differs distinctly from that of the regressive parts of the parasequences. In the Gypsiferous Shale member (Chari Formation) at Ler the latter are characterised by infaunal softground associations with a noticeable percentage of deposit-feeding nuculids alternating with the low diversity Bositra buchi and Bositra buchi – Praesaccella juriana associations indicative of dysaerobic conditions. In contrast, the lags contain a benthic macrofauna dominated by suspension-feeding epifaunal taxa, either brachiopods, oysters, or byssate bivalves (Fürsich *et al.*, 1991, Pl. I). This drastic change in guild structure of the former

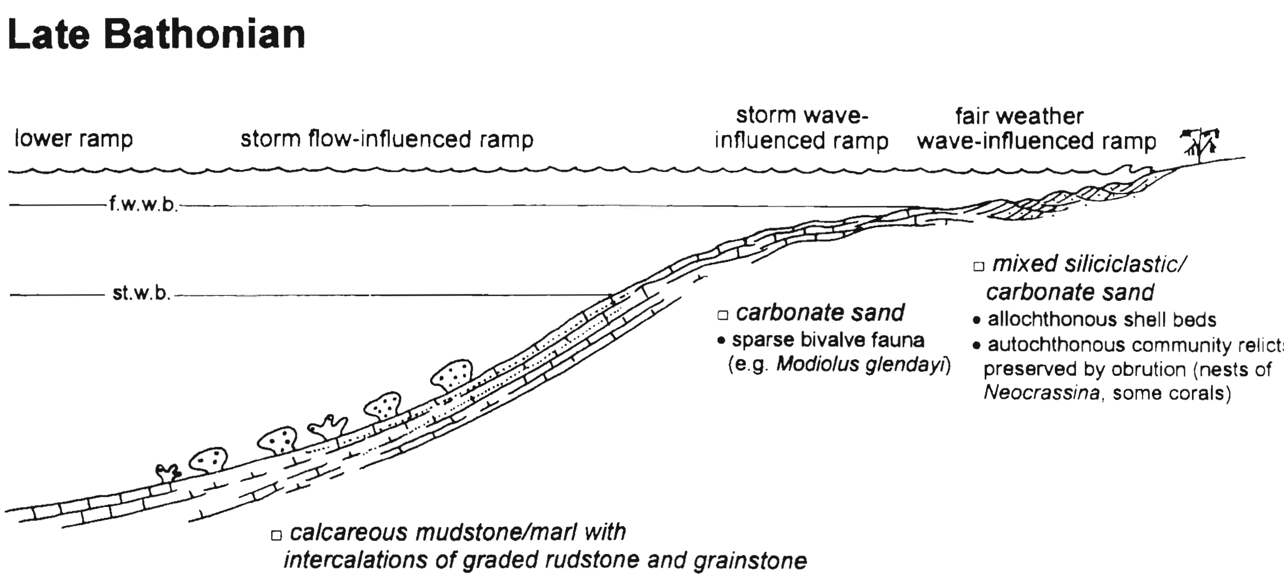

Fig. 9. Idealised onshore-offshore transect and distribution of facies and macrobenthos associations in the Kachchh Basin during the Late Bathonian. Note that only some associations are given as examples. In nearshore areas no low-energy protected environments such as bays and lagoons existed. The nearshore deposits are characterised by high-energy shoreline deposits in shoreface areas (fair-weather wave-influenced ramp). The storm wave-influenced ramp represents the transition zone with strong storm effects. The storm flow-influenced ramp corresponds to the inner shelf with abundant thin, distal storm beds. The lower (outer) ramp corresponds to the middle shelf with rare intercalations of storm beds. During the Late Bathonian, supply of terrigenous clastics was low, and a carbonate-dominated depositional system became established. f.w.w.b.: fair-weather wave-base, st.w.b.: storm wave-base.

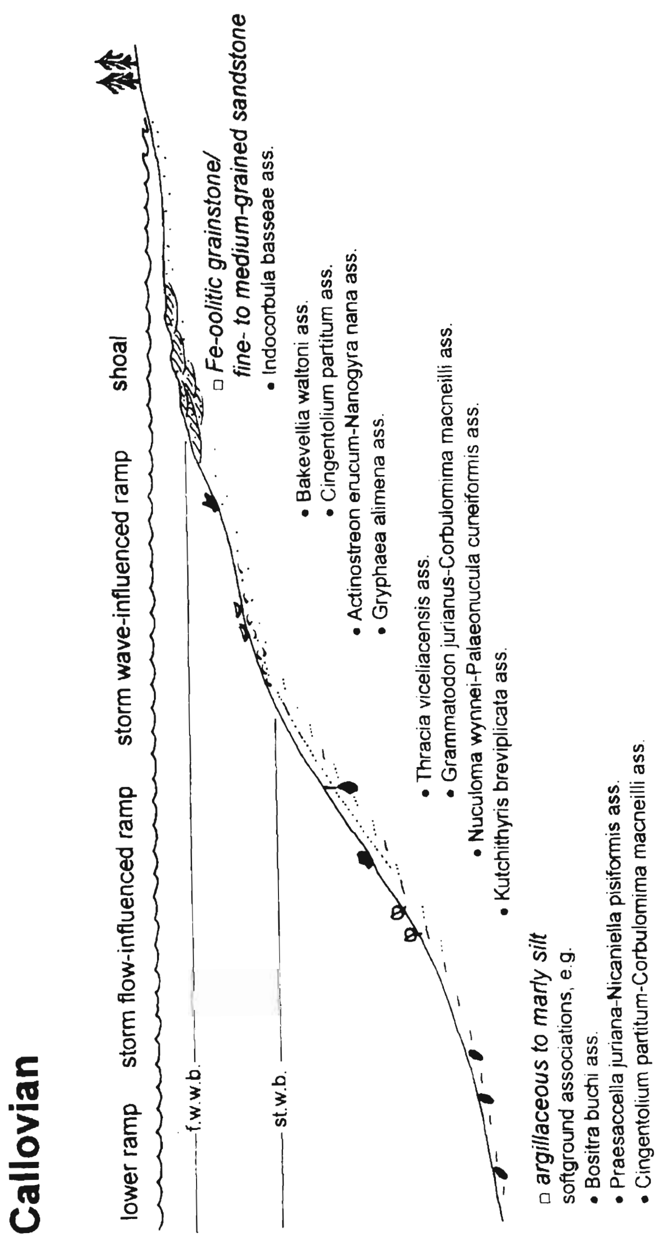

Fig. 10. Idealised onshore-offshore transect and distribution of facies and macrobenthos associations in the Kachchh Basin during the Callovian. Note that only some associations are given as examples. Nearshore iron-oolitic shoals were prominent in the high-energy coastal zone. Similarly, the storm wave-influenced ramp (transition zone) and the storm flow-influenced ramp (inner shelf) were prominent features. Lower (outer) ramp deposits corresponding to the middle shelf generally lack signs of wave and current activity. Due to the poor water circulation, occasionally oxygen-poor conditions became established in these areas. f.w.w.b.: fair-weather wave-base, st.w.v.: storm wave-base.

communities apparently reflects the increased input of organic matter into the basin during regression and suggests that the parasequences are, at least partly, climate-controlled, a wetter climate leading not only to increased sediment input into the basin, but also to an increased input of nutrients which enhanced primary production.

The base of transgressive systems tracts of third order cycles in the Kachchh Basin is often characterised by high densities of skeletal elements. In most cases, however, these shell concentrations are the result of reworking, mixing, and transport and are therefore heavily distorted community relicts not suitable for palaeoecological analysis. The situation is different at the maximum flooding zone. There, too, shell densities are often high due to reduced sediment input and corresponding faunal condensation. The fauna is, however, in general autochthonous (see also Abbott, 1997; Fürsich and Pandey, 2003). A characteristic example is the so-called *Pachyceras* Bed assemblage that can be traced from the Habo Dome to Ler. It occurs in a 5-10 cm thick, somewhat nodular layer of silty micrite situated about 8 m below the top of the Chari Formation. The fauna consists of numerous bivalves, rare scaphopods, brachiopods, gastropods, bryozoans, crinoids, and serpulids, in addition to belemnites, nautiloids, and ammonites. Typical faunal elements are those of the Grammatodon jurianus – Corbulomima macneilli association augmented by deep burrowing bivalves such as *Pholadomya inornata* and *Pholadomya (Bucardiomya) lyrata,* a number of shallow burrowing taxa (e.g., *Isocyprina, Anisocardia, Unicardium*), endobyssate species (*Inoperna, Gervillella)* and epibyssate ones (e.g., *Eonavicula, Pteria, Bakevellia, Limatula, Pseudolimea, Meleagrinella).* Most epifaunal and shallow infaunal taxa are disarticulated, but nearly all deep burrowers are articulated and some of them occur in growth position. Lack of sorting and random orientation of shells point to *in situ* accumulation of the fauna during times of sediment starvation. The assemblage is thus time-averaged whereby, due to the long time involved, also rare taxa had the chance to become preserved, pushing the species richness of the assemblage (close to 40 taxa) far above that of stratigraphically adjacent associations (5 to 17 taxa). This is what one would expect in a so-called mid-cycle condensed shell bed (Abbott, 1997) corresponding to peak treansgression (see also Fürsich and Pandey, 2003).

A more detailed account of the relationship between sedimentary cycles and benthic macrofauna will be published elsewhere.

CONCLUSIONS

(1) The Bajocian to Oxfordian strata of the Kachchh Basin contain the remains of more than 40 macrobenthic communities, most of them dominated by bivalves, some by brachiopods, corals, gastropods, sponges, or serpulids. They inhabited a basin that deepened gradually with time towards the Oxfordian and possessed a ramp morphology.

(2) The main environmental parameters governing the distribution of these associations are substrate, energy level, and salinity, in the deeper parts of the basin also oxygen.

(3) The interlinked factors climate and nutrient supply are responsible for large-scale changes in facies and faunas around the Bathonian-Callovian boundary: Carbonates are replaced by siliciclastics and high diversity faunas indicative of tropical affinities and oligotrophic conditions by lower diversity faunas indicative of warm-temperate, eutrophic conditions.

(4) Onshore-offshore trends in faunal composition during four time slices (Bajocian, Middle Bathonian, Late Bathonian, and Callovian) reflect directed changes, from coastal to basinal areas, in facies (in particular grain size), salinity, energy level, and oxygen availability.

(5) Superimposed on any large-scale trends in faunal distribution are smaller-scale changes of several orders of magnitude resulting from changes in relative sea level. The benthic macrofauna is an additional tool to recognise cyclic changes in the sedimentary sequences of the basin.

In summary, the main factors that controlled the Jurassic marine ecosystem of the Kachchh Basin were climate, synsedimentary tectonics, eustatic sea level changes, and subsidence (fig. 11). During the Jurassic, the degree of humidity and consequently rainfall in the area varied considerably as can be shown by the analysis of clay minerals (Fürsich *et al.*, submitted). As a result, either arid/semi-arid or humid conditions prevailed, which greatly influenced the sedimentation pattern (carbonate-dominated versus siliciclastic-dominated) within the basin. The degree of synsedimentary tectonic activity both within the basin and the hinterland also influenced the sedimentation pattern, favouring carbonate deposition during phases of tectonic quiescence and resulting low rates of sedimentation. In contrast, during phases

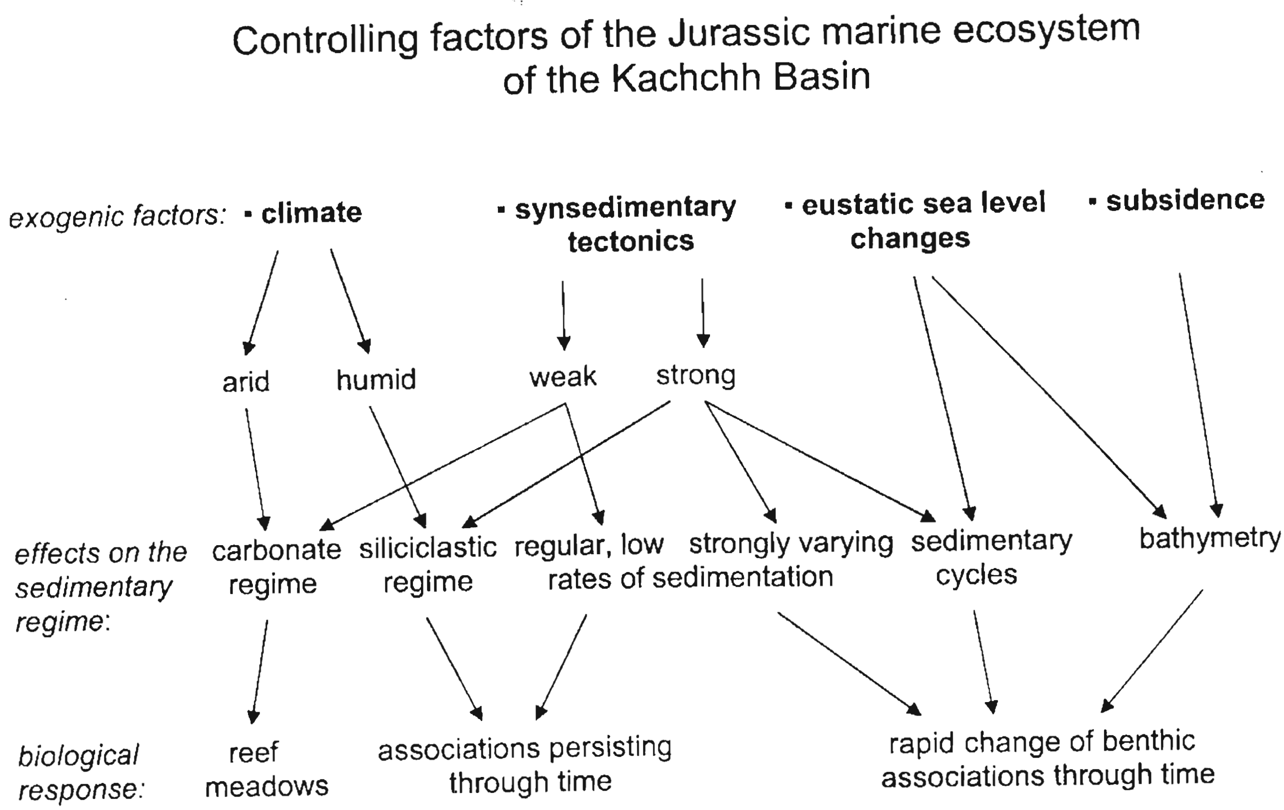

Fig. 11. Controlling factors of the Jurassic marine ecosystem of the Kachchh Basin. Only major relationships are shown in the flow chart. For explanation see text.

of increased block faulting, uplift in the hinterland and increased subsidence in the basin led to an increase in sediment supply and a greater accommodation space in the basin. This resulted in deposition of siliciclastics in most parts of the basin and a deepening in offshore areas. Eustatic sea-level fluctuations also changed the water depth within the basin and produced sedimentary cycles. The benthic fauna reacted to these changes in the sedimentary regime and bathymetry. For example, tropical sea water temperatures in connection with low rates of sedimentation favoured the establishment of reef meadows on carbonate substrates. Within the siliciclastic regime, stable conditions led to establishment of benthic associations that persisted for long periods of time. In contrast, during times characterised by strongly varying rates of sedimentation, caused either by tectonic activity, climatic changes, eustatic sea-level changes or a combination of these factors, the composition of benthic associations fluctuated rapidly.

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REFERENCES

Abbott, S.T. 1997. Mid-cycle condensed shellbeds from mid-Pleistocene cyclothems, New Zealand: implications for sequence architecture. *Sedimentology*, **44**: 805-824.

Barron, E.J., Harrison, C.G.A., Sloan, J.L., II and Hay, W.W. 1981. Paleogeography, 180 million years ago to the present. *Eclogae geol. Helv.* **74**: 443-470.

Biswas, S.K. 1980. Mesozoic rock-stratigraphy of Kutch, Gujarat. *Quart. Jour. Geol. Min. Metallurg. Soc. India*, **49**:1-52.

Duff, K.L. 1975. Palaeoecology of bituminous shale – the Lower Oxford Clay of central England. *Palaeontol.* **18**: 443-482.

Enay, R. and Cariou, E. 1997. Ammonite faunas and palaeobiogeography of the Himalayan belt during the Jurassic: Initiation of a Late Jurassic austral ammonite fauna. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* **134**: 1-38.

Etter, W. 1996. Pseudoplanktonic and benthic invertebrates in the Middle Jurassic Opalinum Clay, northern Switzerland. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* **126**: 325-341.

Fürsich, F.T. 1976. Fauna-substrate relationships in the Corallian of England and Normandy. *Lethaia,* **9**: 343-356.

Fürsich, F.T. 1984. Palaeoecology of Boreal invertebrate faunas from the Upper Jurassic of central East Greenland. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **48**: 309-364.

Fürsich, F.T. 1994. Palaeoecology and evolution of Mesozoic salinity-controlled benthic macroinvertebrate associations. *Lethaia*, **26**: 327-346.

Fürsich, F.T. and Heinze, M. 1998. Contributions to the Jurassic of Kachchh, Western India. VI. The bivalve fauna. Part III. Subclass Palaeoheterodonta (Order Trigonioida). *Beringeria,* **21**: 151-168.

Fürsich, F.T. and Oschmann, W. 1993. Shell beds as tools in basin analysis: the Jurassic of Kachchh, western India. *Jour. Geol. Soc. London*, **150**: 169-185.

Fürsich, F.T. and Pandey, D.K. 2003. Sequence stratigraphic significance of sedimentary cycles and shell concentrations in the Upper Jurassic-Lower Cretaceous of Kachchh, western India. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* **193**: 285-309.

Fürsich, F.T. and Werner, W. 1986. Benthic associations and their environmental significance in the Lusitanian Basin (Upper Jurassic, Portugal). *N. Jb. Geol. Paläont. Abh.*, **172**: 271-329.

Fürsich, F.T., Heinze, M. and Jaitly, A.K. 2000. Contributions to the Jurassic of Kachchh, Western India. VIII. The bivalve fauna. Part IV. Subclass Heterodonta. *Beringeria*, **27**: 63-146.

Fürsich, F.T., Oschmann, W., Jaitly, A.K. and Singh, I.B. 1991. Faunal response to transgressive-regressive cycles: example from the Jurassic of western India. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **85**: 149-159.

Fürsich, F.T., Oschmann, W., Singh, I.B. and Jaitly A.K. 1992. Hardgrounds, reworked concretion levels, and condensed horizons in the Jurassic on Western India and their significance for basin analysis. *Jour. Geol. Soc. London*, 149: 313-331.

Fürsich, F.T., Pandey, D.K., Callomon, J.H., Jaitly, A.K. and Singh I.B. 2001. Marker beds in the Jurassic of the Kachchh Basin, western India: their depositional environment and sequence-stratigraphic significance. *Jour. Pal. Soc. India*, **46**: 173-198.

Fürsich, F.T., Pandey, D.K., Callomon, J.H., Oschmann, W. and Jaitly, A.K. 1994a. Contributions to the Jurassic of Kachchh, western India. II. Bathonian stratigraphy and depositional environment of the Sadhara Dome, Pachchham Island. *Beringeria*, **12**: 95-125.

Fürsich, F.T., Pandey, D.K., Oschmann, W., Jaitly, A.K. and Singh, I.B. 1994b. Ecology and adaptive strategies of corals in unfavourable environments: Examples from the Middle Jurassic of the Kachchh Basin, Western India. *N. Jb. Geol. Paläont. Abh.* **194**: 269-303.

Fürsich, F.T., Singh, I.B., Joachimski, M., Krumm, S., Schlirf, M. and Schlirf, S. 2004. Palaeoclimate of the Jurassic of Kachchh (Western India) based on palaeoecological, oxygen isotope, and clay mineralogical data. *Palaeogeogr., Palaeoclimatol., Palaeoecol. (submitted)*.

Jaitly, A.K., Szabo, J. and Fürsich, F.T. 2000. Contributions to the Jurassic of Kachchh, Western India. VII. The gastropod fauna. Part I. Pleurotomarioidea, Fissurelloidea, Trochoidea and Eucycloidea. *Beringeria*, **27**: 31-61.

Jaitly, A.K., Fürsich, F.T. and Heinze, M. 1995. Contributions to the Jurassic of Kachchh, Western India. IV. The bivalve fauna. Part I. Subclasses Palaeotaxodonta, Pteriomorphia, and Isofilibranchia. *Beringeria*, **16**: 147-257.

Mehl, D. and Fürsich, F.T. 1997. Middle Jurassic Porifera from Kachchh, western India. *Paläont. Z.*, **71**: 19-33.

Oschmann, W. 1994a. Der Kimmeridge Clay von Yorkshire als ein Beispiel eines fossilen Sauerstoff-kontrollierten Milieus. *Beringeria*, **9**: 3-153.

Oschmann, W. 1994b. Adaptive pathways of benthic organisms in marine oxygen-controlled environments. *N. Jb. Geol. Paläont. Abh.*, **191**: 393-444.

Pandey, D.K. and Fürsich, F.T. 1993. Contributions to the Jurassic of Kachchh, Western India. I. The coral fauna. *Beringeria*, **8**: 3-69.

Pandey, D.K. and Fürsich, F.T. 2001. Environmental distribution of scleractinian corals in the Jurassic of Kachchh, western India. *Jour. Geol. Soc. India*, **57**: 479-495.

Pandey, D.K., Fürsich, F.T. and Heinze, M. 1996. Contributions to the Jurassic of Kachchh, Western India. V. The bivalve fauna. Part II. Subclass Anomalodesmata. *Beringeria*, **18**: 51-87.

Parker, R.H. 1975. *The study of benthic communities*, Elsevier, Amsterdam.

Riccardi, A.C. 1991. Jurassic and Cretaceous marine connections between the southeast Pacific and Tethys. *Palaeogeogr. Palaeoclimatol., Palaeoecol.* **87**: 155-189.

Röhl, H.J., Schmid-Röhl, A., Oschmann, W., Frimmel A. and Schwark, L. 2001. The Posidonia Shale (Lower Toarcian) of SW Germany: an oxygen-depleted ecosystem controlled by sea level and palaeoclimate. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* **165**: 27-52.

Sanders, H.L. 1958. Benthic studies in Buzzards Bay. I. Animal-sediment relationships. *Limnol. Oceanogr.* **3**: 245-258.

Singh, I.B. 1989. Dhosa Oolite – A transgressive condensation horizon of Oxfordian age in Kachchh, Western India. *Jour. Geol. Soc. India*, 34: 152-160.

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