



GASTROPOD DIVERSITY PATTERNS AND EVOLUTIONARY TEMPO DURING THE EARLY RIFTING PHASE (JURASSIC) OF THE KUTCH BASIN

SHILADRI S. DAS

GEOLOGICAL STUDIES UNIT, INDIAN STATISTICAL INSTITUTE,
203 B. T. ROAD, KOLKATA – 700 108.
E-mail: shiladri@isical.ac.in

ABSTRACT

The Kutch sea formed as a result of Gondwana fragmentation about 170 million years ago. This newly opened up sea-way between Africa and India provided new habitats for the immigrant faunas which invaded the Kutch Basin. They underwent rapid speciation events as clearly evident from diversity patterns of different taxa of Kutch. The present paper deals with the diversity patterns and evolutionary tempo shown by the gastropods during the Late Bathonian to the Oxfordian. Archacogastropod community is the most diverse group in Kutch (Das *et al.*, 1999, 2005; Jaitly *et al.*, 2000; Das, 2004), showing strong Tethyan affinity, especially with Europe at genus level, but display stunning endemism at species level. The great diversity and abundance of the Kutch species can be explained by the range of expansion of the genera from their ancestral area. Mass migration or colonization of the European forms into Kutch also coincided with a global marine transgression. The extensive shallow epicontinental sea with a large habitable area and subtropical palaeolatitudinal position of Kutch are two other extrinsic factors for the great diversity.

Keywords: Gastropod diversity patterns, evolutionary tempo, Jurassic, Kutch Basin

INTRODUCTION

The Kutch Basin was developed at the northwestern margin of the Indian plate during the Middle Jurassic (Bajocian–Bathonian) and as a result of fragmentation of the Gondwana (Biswas, 1991). This newly opened-up sea way between Africa and India, covered vast continental area as providing new habitats for the immigrant fauna which quickly and opportunistically invaded the newly emerged water body and underwent a kind of adaptive radiation explained by Simpson (1944, 1953) as a consequence of mainly three factors which are:

- 1) Origination of major evolutionary novelties.
- 2) Opening up of new ecospace left by extinct predators.
- 3) Combination of the above two.

Stanley (1978) attributed another factor, that is, opening up of a new habitat is also causally related with the adaptive radiation. There are many examples where adaptive radiation was triggered by the formation of new ecospace. Valentine and Moores (1970) showed a correlation between the diversity of marine invertebrates and continental fragmentation during the Phanerozoic. Davis (1978) explained the hydrobioid gastropod adaptive radiation along the Mekong River delta of Vietnam in terms of plate movement. This river system was formed after collision between Indian and Asian plates during the Miocene. The ancestral gastropods which were carried by the Indian plate evolved rapidly in the new habitat.

Because of the continental separation, a wide area of epicontinental shelf was developed on either side of the newly emerged Kutch embayment. These areas are marked by stunning faunal homogeneity among diverse taxa including ammonites (Spath, 1927-33; Jana, 2002; Jana *et al.*, 2005), which attract attention of the palaeontologists worldwide. Among the ammonites, many are time-diagnostic taxa that provide finer time resolution and help in establishing regional standard chronostratigraphy and intercontinental correlation with Europe and other areas. Gastropod assemblages co-occur with

many time-diagnostic ammonite species.

A large number of gastropod specimens (about 1350) have been systematically collected with a precise stratigraphic background. The present gastropod assemblage has a stratigraphic range from the Upper Bathonian to Lower Berriasian. But fossil abundance is mainly restricted to the time interval between the Late Bathonian to Oxfordian and Middle Tithonian to Lower Berriasian. The gastropod assemblage shows differential extinction and survival episodes. In the present endeavour, the temporal distribution of diversity patterns has been documented.

GEOLOGICAL BACKGROUND

During the Middle Jurassic (Bajocian–Bathonian), a pericratonic embayment developed at the northwestern margin of the Indian plate as the latter drifted from the African plate. The embayment is surrounded by African plate in the west and Kutch and Madagascar in the east. In the regional scenario, this embayment formed a pericratonic basin in Kutch. Structurally, it is a marginal graben bounded by Nagar Parker uplift in the north, Saurashtra uplift in the south and Radhanpur Arch in the East (for detail see Biswas, 1980, 1982, 1991). The regional slope of the Basin was towards WSW. This continental drift and the consequent regional tectonic events coincided with global marine transgression, especially during the Bathonian (see Haq *et al.*, 1987) which also flooded the newly emerged Kutch Basin. This sea, however, was land-locked towards the south between South Africa and the western part of India lying south of Kutch. Subsequently, during the Late Jurassic–Early Cretaceous time the southern part of the basin drifted further and resulted in the formation of a marine strait between India and South Africa, which paved way for faunal migration into the Pacific Realm and sub-Austral Antarctica and New Zealand (Rudra *et al.*, 2007).

Kutch experienced fluctuations in sea level due to many transgression-regression couplets and shore lines also show oscillatory patterns, sometimes strand shifted far east, i. e. up

to eastern Kutch (Deshpande and Merh, 1980; Fürsich and Heinze, 1998; Dutta, 1992). As a result of the repeated marine transgressions, thick piles of sediments developed (about 3000 meters) covering about half of the Kutch District. Initial deposition took place on a crystalline basement of the Archaean age and the contact is located in the Rann near Patcham Island (Biswas and Deshpande, 1968). The Mesozoic sediments at places, mainly in the western 'mainland' Kutch, are now overlain by the Deccan Trap volcanism of the Late Cretaceous.

Frequent spatiotemporal facies changes characterise the Kutch sediments. But faunal homogeneity and persistence of many marker horizons help correlate many isolated sections throughout Kutch (see also Fürsich *et al.*, 2001), which are now separated by vast alluvium track. The Mesozoic sediments of Kutch later were subjected to tectonic deformation which yielded three parallel anticlines which run roughly in NW-SE direction (Wynne, 1872; Poddar 1959). These anticlines have been again folded and resulted in a set of zones of culmination which stand out as structural as well as topographical domes offering best sections for study. The best fossiliferous sections are situated in the central anticline. Detail investigation has been made in Jara, Jumara, Keera, Jhura and Habo sections (Fig. 1). Besides these domes in the mainland, several sections have been studied in Wagad, Eastern Kutch, which is about 200 km from Jara and Ler-Samatra section, near Bhuj, located on the southern anticline. The northern anticline runs through the Rann area and crops out as the Patcham, Khadir, Bela and Chorar islands (Fig. 1) which are less fossiliferous and surprisingly contain rare archaeogastropods (personal observation and see Jaitly *et al.*, 2000). The low diversity of gastropods in these areas perhaps reflects the scarcity of fully marine conditions during the Bajocian and Lower Bathonian (personal communication, Fürsich, 2007).

The Mesozoic rocks of Kutch have been divided into four rock stratigraphic units which are the Patcham, Chari, Katrol and Bhuj formations, in ascending order (Waagen, 1873-75; Rajnath, 1932; Mitra *et al.*, 1979). The two older formations are particularly highly fossiliferous and include the main bulk of the

gastropod samples of the present study. All these formations are not exposed throughout Kutch, for example, the Patcham Formation is exposed only in the Jumara and Jhura areas in the 'mainland'. Its continuity beneath the alluvial soil of Rann to Patcham Island of the northern anticline has been recently recognised in Jhura where same beds (e.g. Golden Oolitic Bands and Raimarlo Limestone) are present in both the areas (Fürsich *et al.*, 1994; Mukherjee *et al.*, 2003). However, in Patcham Island the equivalent unit is named as the Kaladongar Formation. The Chari Formation on the other hand is exposed throughout the mainland of Kutch and gastropod fossils abound in this unit. The Katrol Formation, though extensively developed, is predominantly arenaceous and yields very rare fossils. However, in eastern Kutch, the equivalent rock, i.e. the Wagad Formation at places is highly fossiliferous and several gastropod specimens have been collected. The marine part of the Bhuj Formation is restricted only in the mainland Kutch and particularly well developed in the western fringe of the mainland along the Umia-Mundhan-Ghuner Road. The Bhuj Formation transcends the Jurassic-Cretaceous boundary and includes several fossiliferous bands. Several gastropods species have been collected from beds either side of the system boundary (see Das, 2002).

ARCHAEOGASTROPOD COMMUNITY

About 1350 specimens have been systematically collected with precise stratigraphic background (Jaitly *et al.*, 2000, 2002; Das, 2002, 2004; Das *et al.* 1998, 1999, 2005). There are 75 species spanning the Bajocian (i.e. Middle Jurassic) to Berriasian (i.e. Early Cretaceous). But the time interval of the present study is restricted within Bathonian to Oxfordian. 69 species belonging to 22 genera so far reported from this time interval (Fig. 2 and 3). Fifty species of them are new species.

Kutch archaeogastropod community is dominated by pleurotomariid gastropods throughout the studied interval. Salvini-Plawen (1980) redesignated the Archaeogastropoda as Vetigastropoda and included within it many primitive gastropods e.g. patellogastropod limpets and Neritopsina. However, Archaeogastropoda is well entrenched into the literature and widely used even by recent workers (e.g. Gründel, 2000, 2003;

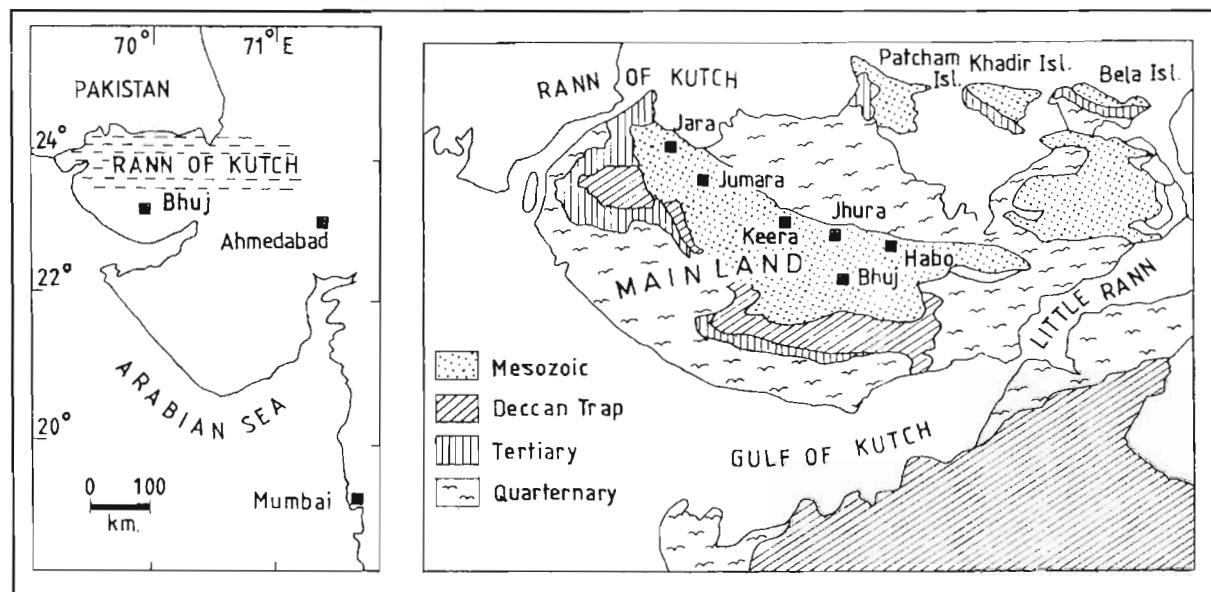


Fig. 1. Map showing geological distribution of the Mesozoic sediments.

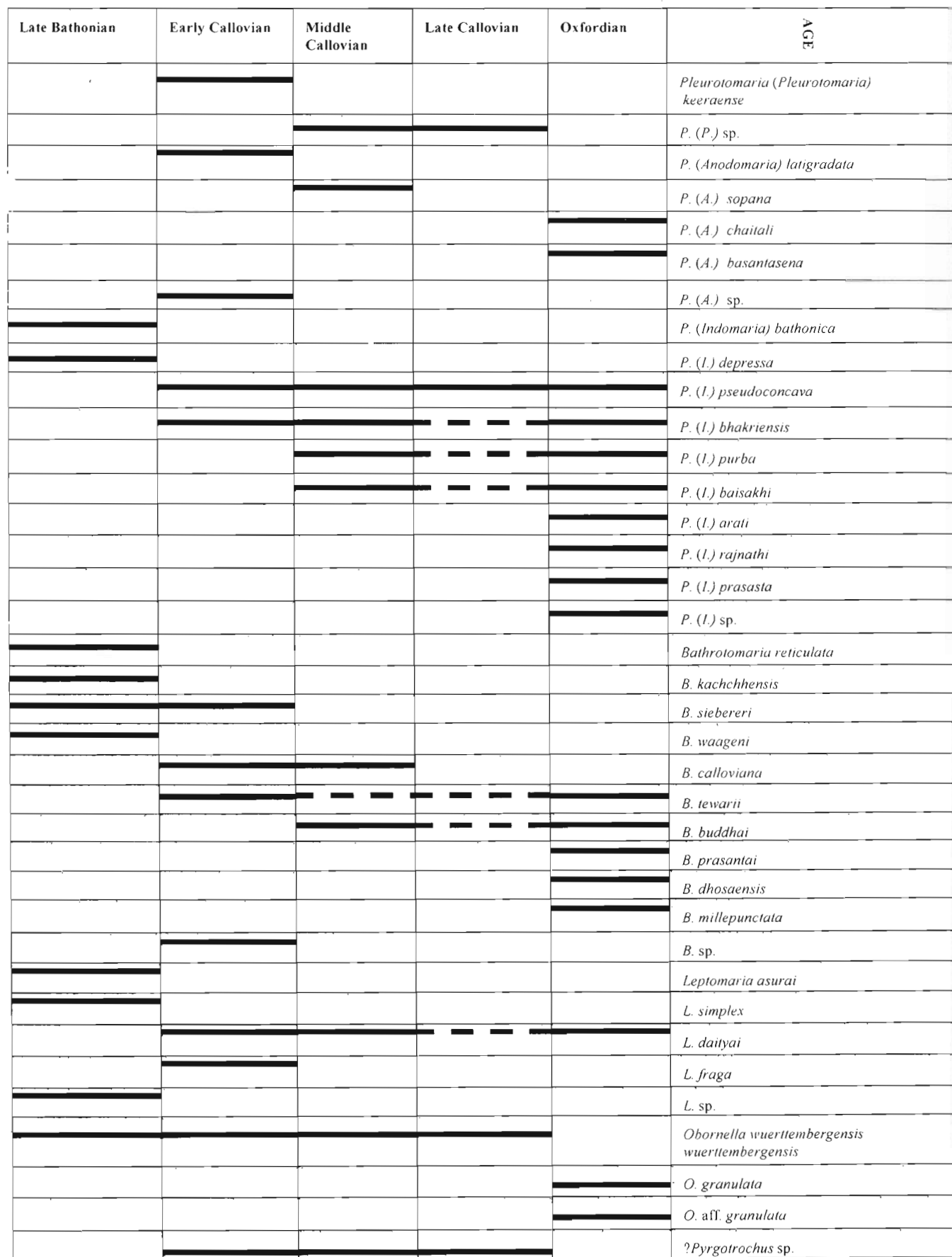


Fig. 2. Range chart of different pleurotomariid species of archaeogastropods within the time interval of the Bathonian to Oxfordian. For lithologic distribution see Fig. 5.

Late Bathonian	Early Callovian	Middle Callovian	Late Callovian	Oxfordian	AGE
					<i>Colpomphalus junarens</i>
					<i>Discohelix (Discohelix) rahi</i>
					<i>Emarginula (Tauschia) karuna</i>
					<i>Helicacanthus chanda</i>
					<i>Metriomphalus (Metrio.) vanu</i>
					<i>Amphitrochus angulatus</i>
					<i>Amphitrochus acutispira</i>
					<i>Amphitrochus orbis</i>
					<i>Eucyclus jadsaensis</i>
					<i>Eucyclus laevijugatus</i>
					<i>Riselloidea tagorei</i>
					<i>Riselloidea elongata</i>
					<i>Onkospira kutchensis</i>
					? <i>Onkospira praecursor</i>
					? <i>Onkospira</i> aff. <i>praecursor</i>
					<i>Buckmanina bhakriensis</i>
					<i>Proconulus jadavpuriensis</i>
					<i>Proconulus bhujensis</i>
					<i>Proconulus haboensis</i>
					<i>Proconulus wagadensis</i>
					<i>Proconulus jhikadiensis</i>
					<i>Proconulus</i> (? <i>Laeviconulus</i>) sp.
					<i>Ataphrus (A.) kaladongarensis</i>
					<i>Ataphrus (A.) belus</i>
					<i>Ataphrus (A.) acis</i>
					<i>Trochopsidea bajirensis</i>
					<i>Adeorbisina</i> sp.
					? <i>Calliostoma</i> sp.
					<i>Neritopsis (N.) patchamensis</i>
					<i>Neritopsis (H.) sankhamala</i>
					<i>Hayamia mitra</i>
					<i>Hayamia</i> sp.

Fig. 3. Range chart of different non-pleurotomariid species of archaeogastropods within the time interval of the Bathonian to Oxfordian. For lithologic distribution see Fig. 5.

Kiel and Bandel, 2001, 2002). We also therefore provisionally retain this well familiar term, Archacogastropoda in the present endeavour. The type genus *Pleurotomaria* is highly variable that prompted many workers to subdivide it into several subgenera. For example, Cox (1960) grouped them as *Pleurotomaria* s.s. and some problematic forms under *Pleurotomaria* s. l. Szabó (1980) described *Anodomaria* and Fischer and Weber (1997) created *Talantodiscus*. Recently I (Das, 2002) proposed *Indomaria* as a new subgenus. *Anodomaria* is a non-tuberculated group, otherwise identical to *Pleurotomaria* s.s., *Talantodiscus* has similar ornamental elements like *Pleurotomaria* s.s. but has a discoidal shell and selenizone that is situated above the mid-whorl. *Indomaria* is characterised by its non-nodose, phaneromphalous and depressed trochiform to low turbiniform shell with the selenizone situated on the mid-part of relatively broader outerface. So far 37 pleurotomariid species belonging to five genera have been reported from Kutch (Jaitly *et al.*, 2000; Das, 2002, 2004, 2007; Das *et al.*, 1998, 2005). They are: *Pleurotomaria* DeFrance, 1826, *Bathrotomaria* Cox, 1956, *Leptomaria* E. Eudes-Deslongchamps, 1864, *Obornella* Cox, 1959 and ? *Pyrgotrochus* P. Fischer, 1885.

Other than pleurotomariids, rest of the archacogastropods are represented by eight families in the Late Bathonian to Oxfordian. They are: Helicotomidae Wenz, 1938, Fissurellidae Fleming, 1822, Turbinidae Rafinesque, 1815, Trochidae Rafinesque, 1815, Ataphridae Cossmann, 1918, Neritopsidae Gray, 1847 and Neritidae Rafinesque, 1815. We here follow the classification by Knight *et al.*, 1960 and Fischer and Weber (1997). Paraturbinidae Cossmann 1916 is the only family recorded from the Middle to the latest Tithonian. It is represented by two new species of the same genus, *Chartronella* (see Das, 2004).

Family Helicotomidae is represented by two new species, i.e. *Colpomphalus jumarensis* Das *et al.*, 1999 and *Discohelix* (*Discohelix*) *rabi* Das, 2004. *Emarginula* (*Tauschia*) *karuna* Das *et al.*, 1999 is the solitary representative of the family Fissurellidae. Family Turbinidae represented by two species, *Helicacanthus chanda* Das *et al.*, 1999 and *Metriomphalus* (*Metriomphalus*) *vanu* Das, 2004.

In terms of diversity, the family Trochidae comes after family Pleurotomariidae; but so far as the relative abundance is concerned, they are the highest contributors to Kutch archacogastropod community. Jaitly *et al.* (2000) have tentatively placed some species under the Superfamily Eucycloidea Koken, 1896 instead of placing them under the Superfamily Trochoidea. We, however, consider Trochoidea in broad sense following Hickman and McLean (1990) and think that eucycloid species described by Jaitly *et al.* (2000) should be included under Family Trochidae (see also Das *et al.*, 1999). This family is represented by seven endemic species (Das *et al.*, 1999; Das, 2004). They are: *Eucyclus jadsaensis* Das, 2004, *Riselloidea tagorei* Das *et al.*, 1999, *R. elongata* Das *et al.*, 1999, *Onkospira kutchensis* Das *et al.*, 1999, *Buckmanina bhakriensis* Das, 2004, *Proconulus jadavpuriensis* Das *et al.*, 1999 and *P. jhikadiensis* Das, 2004. *Riselloidea tagorei* is present in such a great abundance that it even formed a trophic nucleus (Das *et al.*, 1999).

Ataphridae has three species in Kutch. Two species have previously been identified by János Szabó along with others (Jaitly *et al.*, 2000). These include *Ataphrus* (*Ataphrus*) *belus* (d'Orbigny, 1853), an immigrant species from Europe, and

Ataphrus (*Ataphrus*) *kaladongarensis* Jaitly *et al.*, 2000. Das (2004) has recently described another species, *Trochopsidea bajirensis*.

Family Neritopsidae is represented by four species which are *Neritopsis* (*Neritopsis*) *patchamense* Das *et al.*, 1999; *N. (Hayamiella) sankhamala* Das *et al.*, 1999; *Hayamia mitra* Das *et al.*, 1999 and *Hayamia* sp. A new genus, *Bhujnerita*, has been described by Jaitly *et al.* (2002) under the family Neritidae from northern Khadir Island. The type species of this genus is *Bhujnerita bhattii* Jaitly *et al.*, 2002. This has not been included in the present study because its occurrence lies outside the 'mainland'.

DIVERSITY PATTERNS AND EVOLUTIONARY TEMPO

It has already been mentioned that the Kutch Basin experienced sea level changes on a continental platform. Initially, the deposition took place on a carbonate ramp where benthic community was dominated by coral-sponge association. The oldest bed exposed in Jumara within the Patcham Formation in the mainland of Kutch is a palaeontological storehouse. Over 130 species of different taxa unravel life's bounty during the Late Bathonian time (Das *et al.*, 1998). This is a coral biostrome (packstone/grainstone) deposited in an agitated shallow shelf as a skeletal banks. It includes diverse hermatypic corals, bivalves, echinoids and brachiopods. Out of 71 species of corals, 65 were found to be new (Pandey and Fürsich, 1993). Besides, many nautiloids (Halder, 2002), ammonites (Jana, 2002), bivalves (Jaitly *et al.*, 1995) and brachiopods (Mukherjee *et al.*, 2003) were enriched by speciation events. Among these the archacogastropods constitute one prominent group. The present study has brought into light a rich haul of gastropods from the 'mainland' of Kutch.

The assemblage shows strong Tethyan affinity, particularly with Europe at generic level. Species level analysis during the same time interval from other parts of the world shows that gastropods, like ammonites, are also provincialized and Kutch gastropods belong to the Indo-Madagascan Faunal Province (Das, 2004). Different provinces and faunal regions of the Tethyan Realm during the Jurassic are shown in Fig. 4. However, at specific level out of 27 species, 23 are endemic. In order of abundance (number of specimens is 793), they are *Riselloidea tagorei* (52.71%), *Proconulus jadavpuriensis* (8.57%), *Leptomaria asurai* (7.31%), *Proconulus bhujensis* (6.3%), *Bathrotomaria reticulata* (3.78%), *Onkospira kutchensis* (3.27%), *Metriomphalus* (*Metriomphalus*) *vanu* (2.26%), *Emarginula* (*Tauschia*) *karuna* (2.01%), *Ataphrus* (*Ataphrus*) *belus* (2.01%), *Obornella wuerttembergensis* (1.63%), *Helicacanthus chanda* (1.26%), *Neritopsis* (*Hayamiella*) *sankhamala* (1.26%), *Riselloidea elongata* (1.008%), *Ataphrus* (*Ataphrus*) *kaladongarensis* (1.008%), *Neritopsis* (*Neritopsis*) *patchamensis* (1.008%), *Pleurotomaria* (*Indomaria*) *bathonica* (0.75%), ?*Onkospira praecursor* (0.75%), *Colpomphalus jumarensis* (0.5%), *Bathrotomaria siebereri* (0.5%), *Amphitrochus angulatus* (0.5%), *Bathrotomaria kachchensis* (0.37%), *Pleurotomaria* (*Indomaria*) *depressa* (0.25%), *Bathrotomaria waageni* (0.25%), *Hayamia mitra* (0.25%), *Leptomaria simplex* (0.12%), *Leptomaria* sp (0.12%), and *Buckmanina bhakriensis* (0.12%).

Though, in terms of diversity, gastropods come after corals (71 species) and bivalves (32 species), their relative abundance is almost equally high. The gastropod species are repre-

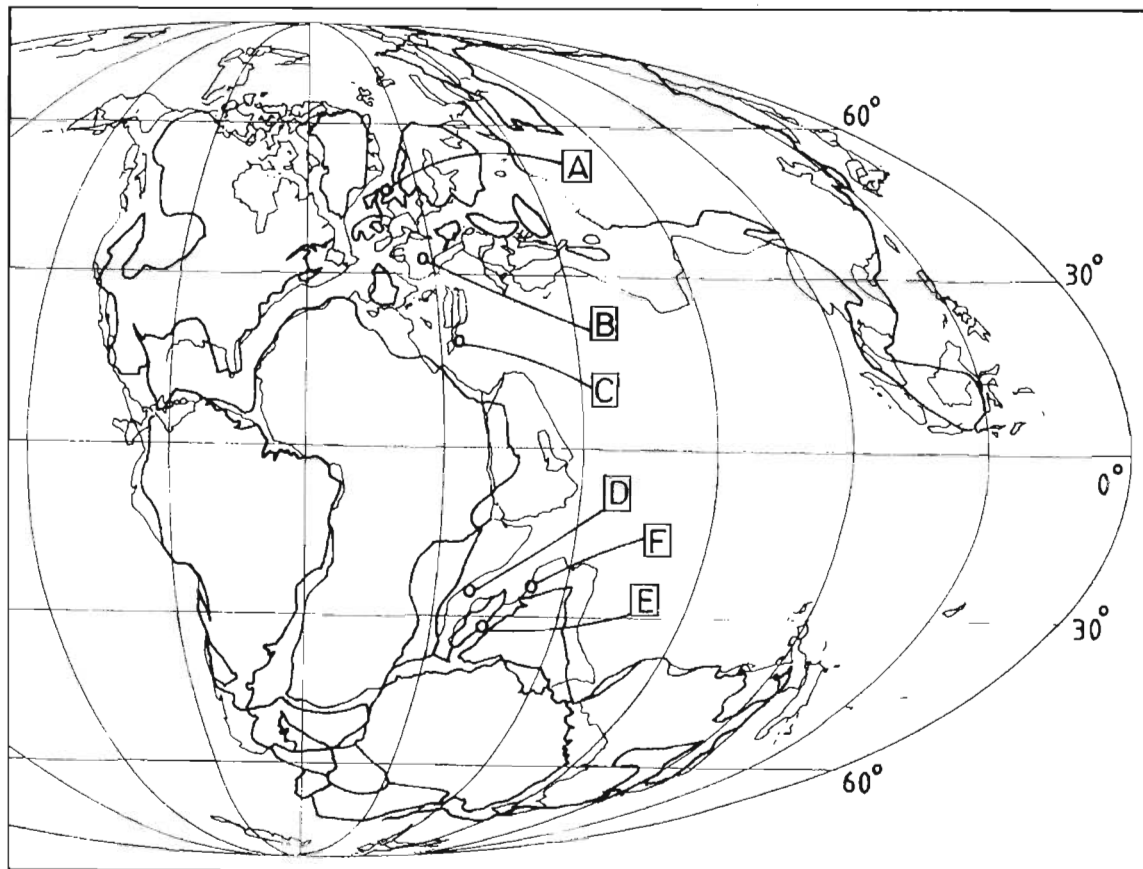


Fig. 4. Palaeolatitudinal positions during the Middle Jurassic of different subprovinces based on gastropod fauna within the Tethyan Realm (base map is modified after Smith *et al.*, 1994). Bold lines demarcate the land areas and thin lines submerged areas. Key: A. Neumayrian, B. Alpine, C. Sicilian, D. East Africa, E. Madagascar, F. Kutch. Sources are: Szabó, 1994; Das, 2004; Jaitly, 2000.

sented by different morphotypes, where trochiform to conical is a dominant morphotype represented by 11 species (40.74%) [*Bathrotomaria reticulata*, *B. waageni*, *B. kachchhensis*, *B. siebereri*, *Leptomaria asurai*, *L. simplex*, *Leptomaria* sp., *Riselloidea tagorei*, *R. elongata*, *Proconulus jadavpuriensis* and *P. bhujensis*]. In terms of relative abundance, trochiform gastropods are also the major faunal constituents (81.08%). Other morphotypes, in order of abundance, are depressed trochiform to depressed turbiniform (25.92%) [*Colpomphalus jumarensis*, *Pleurotomaria* (*Indomaria*) *bathonica*, *P. (I.) depressa*, *Obornella wuerttembergensis*, *Ataphrus* (*Ataphrus*) *kaladongarensis*, *A. (A.) belus* and *Amphitrochus angulatus*], turbiniform (18.51%) [*Helicacanthus chanda*, *Metriomphalus* (*Metriomphalus*) *vanu*, *Onkospira kutchensis*, ?*O. praecursor* and *Buckmanina bhakriensis*], neritiform (11.11%) [*Neritopsis* (*Neritopsis*) *patchamensis*, *N. (Hayamiella)* *sankhamala* and *Hayamia mitra*] and limpet (3.7%) [*Emarginula* (*Tauschia*) *karuna*]. Trochiform gastropods are mostly epifauna except *R. elongata* which perhaps has an infaunal mode of life. On the other hand, another morphotype, i.e. limpet, solitary *E. (E.) karuna*, appears to be an encruster on hard substrate, may be on corals, having suspension mode of feeding. They, however, constitute only 2.01% of community population and trophically are not very important. Neritiform gastropods were non-carnivores, other epifauna mainly pleurotomariids used to graze in coral meadows and were herbivores and scavengers like the present-day deep-sea population (Yonge, 1973).

One of the most significant gastropod species is restricted

to this carbonate ramp, which continues across the Patcham-Chari boundary (Fig. 5). Out of seven families, which first entered the Kutch Sea, only one family, was restricted within this carbonate substrate. Bathonian-Callovian boundary in Kutch is marked by further deepening of the basin resulting in an offshore setting which further triggered the large-scale change in substrate lithology (dominated by argillaceous facies). The boundary witnessed major faunal turnover both at the genus and species level. Recently, Fürsich *et al.* (2005) have also reiterated this view based on palaeoecological and geochemical data.

Datta (1992) placed a regional extinction boundary based on pelagic ammonites and other benthic taxa. He used gastropods at generic level, but in the present study which involves species, the first appearance and last appearance graphs (Fig. 6a and 6b) reconfirm Datta's view about the presence of an extinction level at Bathonian-Callovian boundary. Sedimentary facies changes may sometimes accompany changes in biofacies also but may not necessarily indicate an extinction level (see Kaim, 2001). But the change in gastropod assemblage is evident throughout the 'mainland' of Kutch. All the major Callovian sections (Jara, Jumara, Keera Jhura and Habo; see Fig. 1) have been studied. In every section, regardless of the sedimentary facies, the Lower Callovian gastropod assemblage is quite different from that of the Upper Bathonian assemblage. Significant background extinction of gastropod species at Bathonian-Callovian boundary, therefore, appears to be real and regional in nature. Fürsich *et al.* (2005)

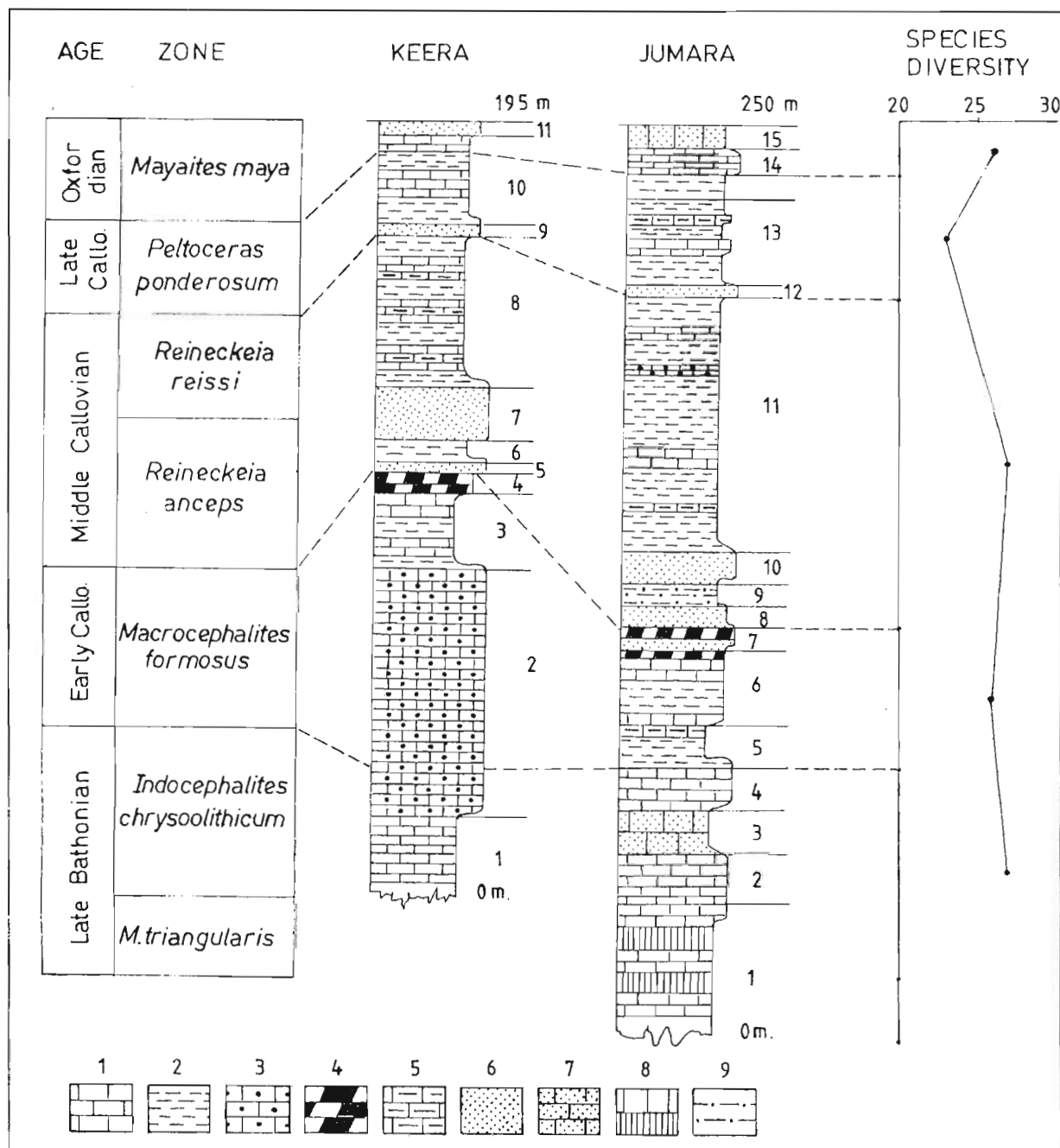


Fig. 5. Diversity pattern of different archaeogastropod species shown against regional ammonite biozonation (modified after Bardhan *et al.*, 1994 and Mukherjee *et al.*, 2003) and lithostratigraphic sections of Keera and Jumara (modified after Bardhan *et al.*, 1994 and Mukherjee *et al.*, 2003), from where maximum specimens of the present study have been collected (Data sources: Das *et al.* 1998, 1999, 2005; Jaitly *et al.*, 2000, 2002; Das, 2002, 2004). Key: 1 Lime stone, 2. Shale, 3. Golden oolitic limestone, 4. Coquina bed, 5. Ironstone, 6. Sandstone, 7. Green oolitic limestone, 8. Coral biostrome, 9. Siltstone. Vertical Scale proportional with thickness.

have also documented the extinction or rarity of the typical Bathonian corals, sponges and some bivalves in the Callovian in the Kutch Basin. They have attributed this faunal change to change in palaeoenvironment. Species level turnover is very high; out of 27, only ten species were able to overcome the boundary crisis (63% extinction)(see Fig. 6c). But at generic level, taxa have been less affected, where, out of 16 genera present in the carbonate facies of Bathonian, 11 genera (68.75%) have straddled the boundary and majority of them have new species in the Callovian. Pleurotomariid gastropods are represented by five genera in Kutch. Other than *Pyrgotrochus*

which was restricted within Callovian, all the four (genera, i.e. *Pleurotomaria*, *Bathrotomaria*, *Leptomaria* and *Obornella* recorded from the Bathonian) crossed the Bathonian-Callovian boundary. But of the ten Bathonian species present, 20 % were able to cross the boundary (see Fig. 2). The nature of extinction pattern reveals that the most dominating lineage of the Bathonian, i.e. pleurotomariids, show only species-level extinction in spite of the fact all the genera were species rich. Only two species of the older community could cross the boundary. On the other hand, seven nonpleurotomariid genera, such as *Colpomphalus*, *Onkospira*, *Buckmanina*, *Proconulus*,

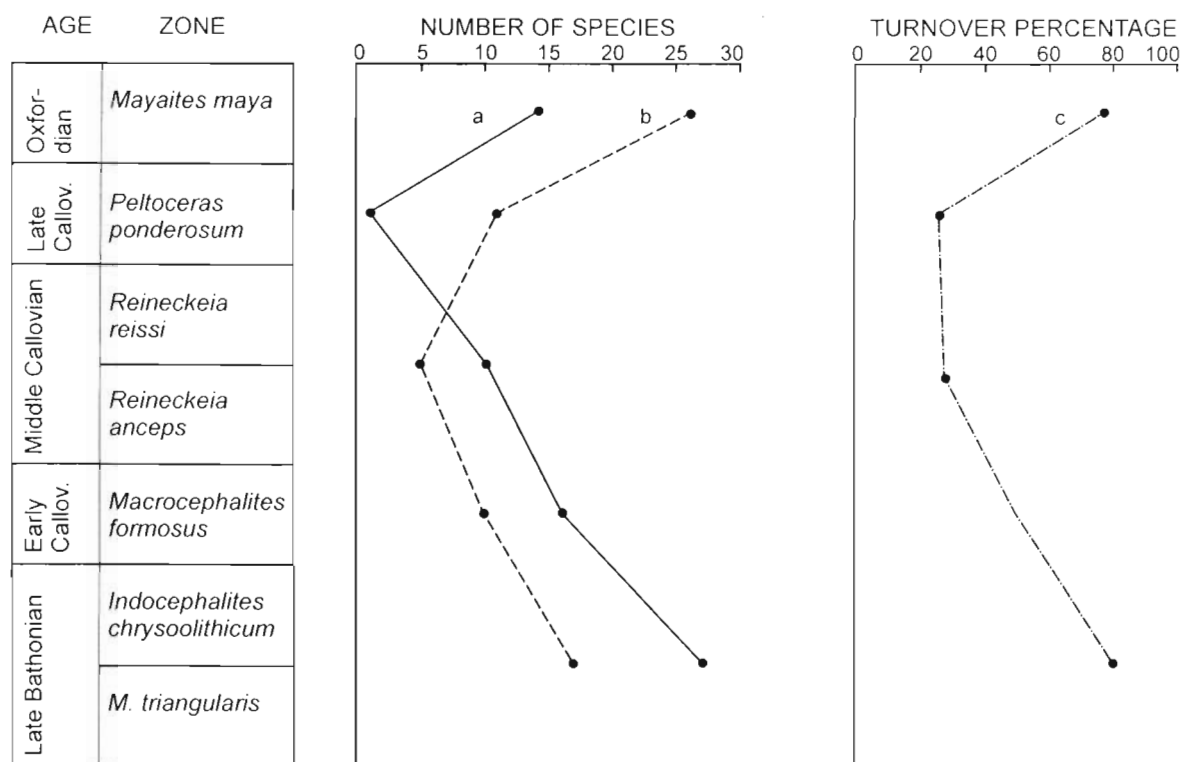


Fig. 6a-c: First appearance [Solid line] (a), Last appearance [broken line] (b), and Turnover [broken line with dots] (c) graphs of all Kutch archaeogastropod species during the Late Bathonian to Oxfordian. Turnover (average number of first and last appearance divided by total number of taxa) expressed in percentage (After Hallam, 1987). The graphs are shown against regional ammonite biozonation (modified after Bardhan *et al.*, 1994 and Mukherjee *et al.*, 2003)

Ataphrus, *Amphitrochus* and *Hayamia* which were species poor, passed the boundary without showing any perturbation even at species level. This clearly defies Jablonski's (1986) observation that species-poor taxa are more prone to background extinction than species-rich ones. Bivalves which, like gastropods, are benthic and have similar planktotrophic larval stage, also show a decrease in species-level diversity. Fürsich *et al.* (2000) recently revised Jurassic bivalves of Kutch. They show that out of 34 Bathonian species only 19 crossed the Bathonian-Callovian boundary (44% became extinct).

The Formosus Zone of the Lower Callovian is entirely represented by argillaceous sequence. According to Datta (1992), deposition took place on a rimmed platform of the offshore region. He showed that ammonite diversity regained quickly following the Bathonian-Callovian boundary crisis. But marked faunal turnover at Bathonian-Callovian boundary and subsequent appearance of new gastropod species clearly suggest that the clayey substrate was inimical to the pleurotomariid and other non-pleurotomariid species which are present on the carbonate ramp (Figs. 2 and 3). Twenty six species inhabit this environment, of which sixteen species appear for the first time. They belong to different genera of diverse families, most of them having small size. Close facies analysis reveals that they actually occur in the thin limestone bands within the basic motif of argillaceous facies. Frequency and thickness of limestone bands increase during the upper part of the Lower Callovian and likewise the number of species also increases. The Lower and Middle Callovian sub stage boundary also marks another extinction level of ammonites and other taxa as indicated by Datta (1992), which was soon

followed by increase in diversity of fauna. Out of 33 ammonite species, 23 went extinct at this boundary (70% extinction). Gastropods also suffer background extinction at this level but extinction intensity is relatively weaker; out of 26 species only 10 disappeared (38.5% extinction, see Figs. 2 and 3).

The Middle Callovian rocks are mainly arenaceous and consist mainly of sandstone and siltstone. The thickness and coarseness of these sandy facies increase towards the eastern basin margin. The facies is commonly multistoried and characterized by large scale cross stratification, representing a shoaling upward phase (Fürsich and Oschmann, 1993). It perhaps formed during storm surges. Virtual absence of any bioturbation possibly indicates rapid deposition. This interval is dominated by pleurotomariid genera (5 out of 13 genera) and species (12 out of 27 species). During the Late Callovian, sea again became deeper and the Kutch Basin witnessed deposition of argillaceous facies similar to B like that of the Early Callovian. Gastropod diversity drops and only one new species appears. Out of 23 gastropod species, 11 went extinct at this boundary (48% extinction). Extinction intensity of bivalves is still higher (87.5% extinction; data source: Fürsich *et al.*, 2000).

Maximum diversity of gastropod community again coincides with a stage boundary between Callovian and Oxfordian. Oxfordian in Kutch is characterized by a oolitic carbonate facies which is regionally persistent and locally known as the Dhosa Oolite. The depositional environment has been interpreted as the product of the transgression of sea. The conglomeratic top which hosts diverse gastropods, represents a transgressive lag of the latest Oxfordian (Singh, 1989; Fürsich

et al., 1992; Datta, 1992). The community is particularly dominated by diverse and abundant pleurotomariid gastropods, e.g. 4 out of 9 genera and 18 out of 26 species of this group are present. Both species diversity and first appearance graphs (Figs. 5 and 6a) support the general pattern as depicted by the other taxa (see Datta, 1992). Here, species-level turnover is also very high like the Late Bathonian assemblage (Fig. 6c). The assemblage also shows strong Tethyan affinity, particularly with Europe at generic level. But at specific level, out of 26 species 21 are endemic. In order of abundance, the species (number of specimens is 260) are *Eucyclus jadsaensis* (21.53%), *Pleurotomaria* (*Indomaria*) *bhakriensis* (12.69%), *Leptomaria daityai* (12.69%), *Pleurotomaria* (*I.*) *purba* (10%), *Pleurotomaria* (*I.*) *pseudoconcava* (8.84%), *Bathrotomaria buddhai* (5.76%), *Discohelix* (*Discohelix*) *rabi* (5%), *Bathrotomaria prasantai* (3.46%), *Pleurotomaria* (*I.*) *arati* (3.07%), *Bathrotomaria dhosaensis* (2.69%), *Obornella granulata* (2.3%), *Pleurotomaria* (*Anodotomaria*) *basantasena* (1.92%), *Pleurotomaria* (*I.*) *rajnathi* (1.53%), *Pleurotomaria* (*A.*) *chaitali* (1.15%), *Ataphrus* (*Ataphrus*) *belus* (1.15%), *Hayamia mitra* (1.15%), *Pleurotomaria* (*I.*) *baisakhi* (0.76%), *Eucyclus laevijugatus* (0.76%), *Proconulus bhujensis* (0.76%), *Pleurotomaria* (*I.*) *prasasta* (0.38%), *Pleurotomaria* (*I.*) sp. (0.38%), *Bathrotomaria millepunctata* (0.38%), *Bathrotomaria tewarii* (0.38%), *Obornella* aff. *granulata*, (0.38%), *Proconulus jadavpuriensis*, (0.38%), and *Hayamia* sp. (0.38%).

The archaeogastropod community represents four morphotypes, of which the depressed trochiform to depressed turbiniform is the dominating morphotype and it is represented by 14 species (53.84%) [*Pleurotomaria* (*Indomaria*) *bhakriensis*, *Pleurotomaria* (*I.*) *purba*, *Pleurotomaria* (*I.*) *pseudoconcava*, *Bathrotomaria buddhai*, *Bathrotomaria prasantai*, *Pleurotomaria* (*I.*) *arati*, *Obornella granulata*, *Pleurotomaria* (*I.*) *rajnathi*, *Ataphrus* (*Ataphrus*) *belus*, *Pleurotomaria* (*I.*) *baisakhi*, *Pleurotomaria* (*I.*) *prasasta*, *Pleurotomaria* (*I.*) sp., *Bathrotomaria tewarii* and *Obornella* aff. *granulata*]. In terms of relative abundance, the depressed trochiform to depressed turbiniform gastropods are also the major faunal constituents (51.15%). The other morphotypes in order of abundance are trochiform to conical (34.61%) [*Eucyclus jadsaensis*, *Leptomaria daityai*, *Bathrotomaria dhosaensis*, *Pleurotomaria* (*A.*) *basantasena*, *Pleurotomaria* (*A.*) *chaitali*, *Eucyclus laevijugatus*, *Proconulus bhujensis*, *Bathrotomaria millepunctata* and *Proconulus jadavpuriensis*], naticiform (7.69%) [*Hayamia mitra* and *Hayamia* sp.] and discoidal (3.8%) [*Discohelix* (*Discohelix*) *rabi*].

Besides change in diversity patterns, there is also evolutionary change of gastropod morphotypes. During the Late Bathonian, Kutch sea witnessed dominance of trochiform to conical morphotypes (40.74%). Majority of the species show high translation rate and low expansion rate (T and W of Raup, 1966). During the Oxfordian, it provides a different picture. Species with depressed trochiform to depressed turbiniform morphotypes (53.84%) dominate the community, which means that they had low translation and high expansion rates.

ACKNOWLEDGEMENTS

I am grateful to Prof. S. Bardhan, Department of Geological Sciences, Jadavpur University for overall supervision and constant guidance, to the Indian Statistical Institute, Kolkata

for providing infrastructural facilities and to two reviewers Prof. F. T. Fürsich, Institut für Paläontologie der Universität Würzburg, Pleicherwall 1, D 97070 Würzburg, Germany and Prof. Andrzej Kaim, Instytut Paleobiologii PAN, Twarda 51/55, 00-818 Warszawa, Poland who have critically reviewed the manuscript and provided valuable suggestions. I am most grateful to Mr. A. K. Das for drawing the figures and to all other members of Palaeontology Laboratory of Jadavpur University who helped at various stages both in the field and the laboratory. The Department of Geological Sciences, Jadavpur University granted access to the type material.

REFERENCES

- Bardhan, S., Datta, K., Jana, S. K. and Pramanik, D. 1994. Dimorphism in *Kheraicerus* Spath from the Callovian Chari Formation, Kutch, India. *Journal of Paleontology*, **68**: 287-293.
- Biswas, S. K. 1980. Structure of Kutch – Kathiawar region, Western India, p 255-272. In: *Proc. 3rd Ind. Geol. Congr. Poona*.
- Biswas, S. K. 1982. Rift basins in western margin of India and their hydrocarbon prospects with special reference to Kutch basin. *Bulletin of the American Association of Petroleum Geologists*, **66**(10): 1497-1513.
- Biswas, S. K., 1991. Stratigraphy and Sedimentary Evolution of Mesozoic Basin of Kutch, Western India, p. 74-103. In: *Sedimentary basins of India, Tectonic Context* (Eds. Tandon, S. K., Pant, C. C. and Casshyap, S. M.), Gyanodaya Prakashan, Nainital.
- Biswas, S. K. and Deshpande, S. V. 1968. Basement of the Mesozoic sediments of Kutch, Western India. *Bulletin Geological, Mining and Metallurgical Society of India*, **40**: 1-7.
- Cox, L.R. 1960. The British Cretaceous Pleurotomariidae. *Bulletine British Museum Natural History*, **4**: 387-423.
- Das, S. S. 2002. Two new pleurotomariid (Gastropoda) species, including the largest *Bathrotomaria*, from the Berriasian (Early Cretaceous) of Kutch, western India. *Cretaceous Research*, **23**: 99-109.
- Das, S. S., Lahiri, T.C. and Bardhan, S. 1998. A life's window from the Middle Jurassic of Kutch, Gujarat - a new assemblage of gastropods. *Geological Survey of India News*, **29**: 21-22.
- Das, S. S., Bardhan, S. and Lahiri, T.C. 1999. The Late Bathonian gastropod fauna of Kutch, western India – a new assemblage. *Paleontological Research*, **3**: 268-286.
- Das, S. S. 2004. New assemblage of the Mesozoic gastropod faunas of Kutch, western India – a study of systematics, palaeobiogeography and evolution. *Unpublished Ph. D. dissertation, Jadavpur University, Kolkata*.
- Das, S. S., Bardhan, S. and Kase, T. 2005. A new pleurotomariid gastropod assemblage from the Jurassic sequence of Kutch, western India. *Paleontological Research*, **9**: 329-346.
- Das, S. S., 2007. Record of a new species of *Obornella* Cox 1959 (Gastropoda) from the Tithonian of Kutch, Western India. *Journal of Asian Earth Sciences*, **30**: 207-212.
- Datta, K. 1992. Facies, fauna and sequence: an integrated approach in the Jurassic Patcham and Chari Formations, Kutch, India. *Unpublished Ph. D. dissertation, Jadavpur University, Calcutta*.
- Davis, G. M. 1978. The origin and evolution of the gastropod family Pomatiopsidae, with emphasis on the Mekong River Triculinae. *Academy of Natural Science, Philadelphia, Monograph*, **20**: 1-120.
- Deshpande, S. V. and S. S. Merh. 1980. Mesozoic sedimentary model of Wagad Hills, Kutch, western India. *Journal of the Geological Society of India*, **21**: 75-83.
- Fischer J. C. and Weber, C. 1997. Gastropodes jurassiques. Vol. 11, 300 p. In: *Révision critique de la Paléontologie Française d' Alcide d'Orbigny* (Ed. Fischer, J. C.), Masson, Paris.
- Fürsich, F. T., Oschmann, W., Singh, I.B. and Jaitly, A.K. 1992. Hardgrounds, reworked concretions levels and condensed horizons in the Jurassic of Western India: Their significance for basin analysis. *Journal of the Geological Society of London*, **149**: 313 – 331.
- Fürsich, F. T. and Oschmann, W. 1993. Shell beds as tools in basin analysis: the Jurassic of Kutch, Western India. *Journal of the Geological Society of London*, **150**: 169-185.
- Fürsich, F. T., Pandey, D. K., Callomon, J. H., Oschmann, W. and Jaitly, A. K. 1994. Contribution to the Jurassic of Kutch, western India. II. Bathonian stratigraphy and depositional environment of the Sadhara Dome, Panchtham Island. *Beringeria*, **12**: 95-125.

- Fürsich, F.T. and Heinze, M. 1998. Contributions to the Jurassic of Kutch, Western India. VI. The bivalve fauna. Part III. Subclass Palacoheterodonta (Order Trigonioidea). *Beringeria*, **21**: 151-168.
- Fürsich, F.T., Heinze, M. and Jaitly, A.K. 2000. Contributions to the Jurassic of Kutch, western India. VIII. The bivalve fauna. Part IV. Subclass Heterodonta. *Beringeria*, **27**: 63-146.
- 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. *Journal of the Palaeontological Society of India*, **46**: 173-198.
- Fürsich, F.T., Singh, I. B., Joachimski, M., Krumm, S., Schlirf, M. and Schlirf, S. 2005. Palaeoclimate reconstructions of the Middle Jurassic of Kachchh (western India): an integrated approach based on palaeoecological, oxygen isotopic, and clay mineralogical data. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **217**: 289-309.
- Gründel, J. 2000. Archaeogastropoda aus dem Dogger Norddeutschlands und des nordwestlichen Polens. *Berliner geowissenschaftliche Abhandlungen* **34**: 205-253.
- Gründel, J. 2003. Gastropoden aus dem Bajocium und Bathonium von Sengenthal und Kinding, Franken (Süddeutschland). *Zitteliana*, **43**: 45-91.
- Halder, K. 2002. Jurassic nautiloids of Kutch, western India: a study on their systematics, palaeoecology and evolution. *Unpublished Ph. D. dissertation, Jadavpur University, Kolkata*.
- Haq, B. U., Hardenbol, J. and Vail, P. R. 1987. Chronology of fluctuating sea levels since the Triassic. *Science*, **235**: 1156-1166.
- Hickman, C. S. and McLean, J. H. 1990. Systematic revision and suprageneric classification of trochacean gastropods. *Science Series Natural History Museum of Los Angeles County*, **35**: 1-169.
- Jablonski, D. 1986. Background and mass extinctions: The alternation of macroevolutionary regimes. *Science*, **231**: 129 – 133.
- Jaitly, A.K., Fürsich, F.T. and Heinze, M. 1995. Contributions to the Jurassic Kachchh, western India. IV. The bivalve fauna. Part I. Subclass Palacotaxodonta, Pteriomorpha, and Isofilibranchia. *Beringeria*, **16**: 147-257.
- Jaitly, A.K., Szabó, 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., and Szabó, J. 2002. *Bhujnerita* (Neritidae), a new gastropod genus from the Kachchh Jurassic (western India), *Fragmenta Palaeontologica Hungarica*, **20**: 49-52.
- Jana, S. K. 2002. Macrocephalitinae and Eucycloceratinae of the Family Sphaeroceratidae (Ammonoidea) and other ancillary taxa from the Middle Jurassic of Kutch, western India: Systematics, Phylogeny and Evolution. *Unpublished Ph. D. dissertation, Jadavpur University, Kolkata*.
- Jana, S.K., Bardhan, S. and Halder, K. 2005. Eucycloceratin ammonites from the Callovian Chari Formation, Kutch, India. *Palaeontology*, **48**(4): 883-924.
- Kaim, A. 2001. Faunal dynamics of juvenile gastropods and associated organisms across the Valanginian transgression-regression cycle in central Poland. *Cretaceous Research*, **22** (3): 333-351.
- Kiel, S and Bandel, K. 2001. Trochidae (Archaeogastropoda) from the Campanian of Torallola in northern Spain. *Acta Geologica Polonica*, **51**: 137-154.
- Kiel, S and Bandel, K. 2002. Further Archaeogastropoda from the Campanian of Torallola, northern Spain. *Acta Geologica Polonica*, **52**: 239-249.
- Knight, J. B., Cox, L. R., Keen, A. M., Batten, R. L., Yochelson, E. L. and Robertson, R. 1960. Systematic description, 1169-324. In: *Treatise on Invertebrate Paleontology, Part 1, Mollusca 1* (Ed. Moore, R. C.), The University of Kansas Press and the Geological Society of America.
- Mitra, K. C., Bardhan, S. and Bhattacharya, D. 1979. A study of Mesozoic stratigraphy of Kutch, Gujarat with special reference to rock stratigraphy and biostratigraphy of Keera dome. *Bulletin of Indian Geologists' Association*, **12**: 129-143.
- Mukherjee, D., Bardhan, S. Datta, K. and Ghosh, D.N. 2003. The terebratulid *Kutchiathyris* (Brachipoda) from the Jurassic sequence of Kutch, western India – revisited. *Paleontological Research*, **7** (2): 111-128.
- Pandey, D. K. and Fürsich, F. T. 1993. Contributions to the Jurassic of Kachchh, western India. I. The coral fauna. *Beringeria*, **10**: 3-69.
- Poddar, M. C. 1959. Stratigraphy and oil possibilities in Kutch, Western India. *Proceedings, Symposium on the development of Petroleum Resources of Asia and the Far East, Mineral Research and Development*, **10**: 146 – 148.
- Rajnaath. 1932. A Contribution to the stratigraphy of Cutch. *The Quarterly Journal of the Geological, Mining and Metallurgical Society of India*, **4**: 161-174.
- Raup, D. M. 1966. Geometric analysis of shell coiling: general problems. *Journal of Paleontology*, **40**: 1178-1190.
- Rudra, P., Bardhan, S., Shome, S. 2007. Phylogeny of the three species of the existing subgenus 'Eselaeovitrigonia' from the Late Jurassic – Early Cretaceous of Kutch, India and palaeobiogeographic significance. *Journal of Palaeontology*, **81**: 1066-1079.
- Salvini-Plawen, L. von. 1980. A reconsideration of systematics in the Mollusca (Phylogeny and higher classification). *Malacologia*, **19**: 249-278.
- Simpson, G. G. 1944. *Tempo and Mode in evolution*. Columbia University Press, New York.
- Simpson, G. G. 1953. *The major features of evolution*. Columbia University Press, New York.
- Singh, I. B. 1989. Dhosa Oolite – A Transgressive Condensation Horizon of Oxfordian age in Kachchh, western India. *Journal of Geological Society of India*, **34**: 152-160.
- Spath, L. F. 1927-33. Revision of the Jurassic Cephalopod fauna of Kachchh (Cutch). *Memoirs of the Geological Survey of India, Palaeontologia Indica, New Series 9*, **2**: 1-945.
- Stanley, S.M. 1978. Aspects of the adaptive morphology and evolution of the Trigonidae. *Philosophical Transactions of the Royal Society of London, Series B*, **284**: 247-258.
- Szabó, J. 1980. Lower and Middle Jurassic gastropods from the Bakony Mountains (Hungary). Part II., Pleurotomariacea and Fissurellacea (Archaeogastropoda). *Annales historico- naturae Musei nationalis Hungarici*, **72**: 49-71.
- Valentine, J. W. and Moores, E. M. 1970. Plate-tectonic regulation of faunal diversity and sea level: a model. *Nature*, **228**: 657-659.
- Waagen, W. 1873-75. Jurassic fauna of Kutch. The Cephalopoda, *Memoirs of the Geological Survey of India Palaeontologia Indica*, ser. 9, **1**: 1-247.
- Wynne, A. B. 1872. Memoir on the Geology of Kutch, to accompany a map compiled by A. B. Wynne and F. Fedden, during the seasons 1867-68 and 1868-69. *Memoir of Geological Survey of India*, **9**(1).
- Yonge, C.M. 1973. Observation of pleurotomariid *Entemnotrochus adansoniana* in its natural habitat. *Nature*, **241**(5384): 66-68.