



Palaeobiogeographic implications of Ostracoda: A case study from Bagh Formation (Upper Cretaceous) of Narbada valley, Madhya Pradesh and Gujarat.

KEYWORDS

Ostracoda, Bagh Formation, Paleobiogeography.

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ABSTRACT

The Paleobiogeographic implications of Ostracoda from Cretaceous rocks of Narbada valley, Bagh Formation of Madhya Pradesh and Gujarat are discussed on the basis of the following genera: *Cytherelloidea*, *Rostrocytheridea*, *Makatinella*, *Majungaella*, *Sapucariella*, *Nigeroloxoconcha*, *Amphicytherura* and *Bythoceratina* and their relationship with nearby basins of Gondwana during Cenomanian-Turonian-Coniacian time.

SUMMARY: The Cretaceous rocks of Narbada valley occur as disconnected outcrop, extending for a distance of about 350 Kms. From Barwaha in the east to Rajpipla in the west. During course of study of ostracodes from these formation, present authors carried out detailed sampling in Narbada valley. Further it has been observed that the marine exposures in the eastern part are lithologically quite different to those of the western part of the Narbada river valley. Some of the ostracodes genera have paleobiogeographic implications, which are discussed in the paper.

INTRODUCTION:

The Cretaceous rocks of Narbada valley occur as disconnected outcrop, extending for a distance of about 350 Kms. from Barwaha (M. P.) in the east to Rajpipla (Gujarat) in the west (fig. 1). Narbada basin comprises the extreme western part of the "Narbada-Son-Damodar Graben". This first order structure is a major lineament with an ENE-WSW trend, and extends across the central part of the Indian subcontinent. Tectonically the basin may be classed as a "graben", which is filled up by Mesozoic sediments and is aligned roughly parallel to the present course of the Narbada River. The southern slope of the Malwa plateau, which marks the northern boundary of the echelon and step fault. The southern boundary of the graben is marked by a similar echelon fault system. It appears that the Narbada graben is the manifestation of tectonic forces operative over a zone of weakness in the Pre-Cambrian basement. The present study suggest that during the Upper Cretaceous time marine incursions took place either by progressive transgression or by eustatic changes of sea level due to emergence of new oceanic crust.

2. Western exposures: These extends from west of Alirajpur through Kawant upto Rajpipla (Gujarat).

The Bagh Formation include two distinct facies, a lower predominantly fresh water arenaceous facies with intercalated marine and/or brackish water bands towards the top, and an upper marine calcareous facies. The contact between the lower arenaceous and the upper calcareous facies is generally marked by the presence of a thin (0.3 to 1.5 mts. thick) Oyster band, which is either arenaceous or calcareous.

Table 1: Lithological succession of Bagh Formation

Bagh Area (Eastern Part)	Bilthana Area (Western Part)
Coralline Limestone	Marly Limestone
Marl	Siliceous Limestone
Nodular Limestone	Oyster beds
Oyster beds	Shale
Nimar Sandstone	Nimar Sandstone

PALEOBIOGEOGRAPHIC IMPLICATIONS

During Cenomanian period (about-100 Ma) marine transgression took place in the Bagh area as well in Jaisalmer Basin, Rajasthan and also in other basins of Peninsular India. This was the period when India and Madagascar was joined together and was also not much far away from Eastern and Southern part of Africa. Due to this reason many ostracode taxa which inhabits in these different basins migrated from one basin to another via through continental margins. The dispersion of ostracods in shallow-water marine environments is much more constrained by physical factors than it is far deep-water forms. Ostracodes can migrate latitudinally when temperature and other ecological parameters, such as bathymetry, remain stable within certain limits and continental margins can function as migration pathways (Babinot and Colin 1992).

Study on ostracode fauna of Bagh Formation reveals that these are very rich in *Cytherelloidea*, *Rostrocytheridea*, *Makatinella*, *Majungaella*, *Sapucariella*, *Haughtonileberis*, *Nigeroloxoconcha* and *Veeniacythereis*, of the above, some genera have paleobiogeographic implications.

In Bagh Formation the genus *Cytherelloidea* represented by eight species, of which five were earlier described by Jain 1961 and 1975a, the recorded species are: *C. khoslai*, *C. oudiapurensis*, *C. raoi*, *C. subgranulosa* and *C. thuatensis*, further present authors recorded

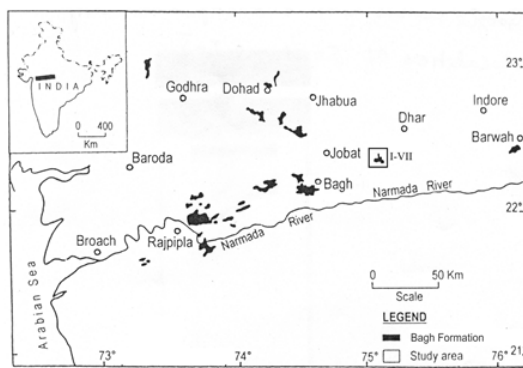


Fig. 1. Outcrops of Bagh Formation along Narbada Valley (Modified after Jain, 1975)

During course of study of ostracodes from these formation, present authors carried out detailed sampling in the eastern and western part of Narbada valley. Further it has been observed that the marine exposures in the eastern part of Narmada valley are lithologically quite different (Table- 1) to those of western part of the river valley. Hence the area has been broadly divided into two main regions.

1. Eastern exposures: Extending from Barwaha through Man valley (Jeerabad), Bagh, Jobat and Alirajpur.

two more new species and *C. oertelli* Singh from these beds. Singh, 1997 recorded five new species of the genus viz. *C. ghotaruensis*, *C. monomediocostata*, *C. onkareshwarensis*, *C. oertelii* and *C. reniformata* from Jaisalmer basin. Both the basins have their own endemic *Cytherelloidea* species except *Cytherelloidea oertelii* Singh, 1997. This was initially reported from lower part of Cenomanian, Manhera Tibba Well-I, Jaisalmer, Rajasthan, India. The same species has also been reported by Andreu *et al.*, 2007 from subsurface of Jaisalmer basin, Rajasthan, India and by Babinot *et al.*, 2009 from Albian-Middle Turonian of Antsiranana region (Northern Madagascar). The same species has also been reported by present authors from Bagh Formation of Narbada basin, M.P. India.

Similarly *C. ghotaruensis* Singh originally recorded from upper member (Cenomanian), Goru Formation, Manhera Tibba Well-I, Jaisalmer, India. Andreu *et al.*, 2007, also recorded same species, from same basin and Babinot *et al.*, 2009 from Albian-Cenomanian of Madagascar.

Cytherelloidea awaldaensis n. sp. (present authors) resembles closely with *C. agyroides*, initially described by Dingle, 1969 from Neocomian of South Africa. *C. tiginensis* Andreu *et al.*, 1998 described from Coniacian-Santonian of Essaouira basin, Atlantic Atlas, Morocco. *C. sp. 1* described by Piovesan *et al.*, 2013 from Upper Albian of Santos Basin, Brazil, *Cytherelloidea* sp. C. by Jain 1975b and ?*Cytherelloidea* sp. described by Sastry *et al.*, (1972) from Ariyalur Formation, Upper Cretaceous of South India.

Like wise *Cytherelloidea oudiapurensis* Jain 1975a, which was originally described from Bagh Formation resembles with *C. sp. 1* described by Rosenfeld and Raab, 1974 from Judea group (Upper Cenomanian) of Israel. Further *C. raoi* Jain 1975a resembles with *C. cf. C. bicostata* Crane from the same formation of Israel. So on the basis of *Cytherelloidea* it is evident that at least few species migrated from one basin to another via shallow sea route.

So far restricted occurrence of composition of Cenomanian ostracode assemblages from Austral Bioprovince, the genera *Arculicythere*, *Rostricytheridea*, *Makatinella*, *Majungaella* are remnants from the Early Cretaceous. During Cretaceous time several ostracode taxa occurred outside their area of origin. For example the genus *Sapucariella* (Previously known as *Brachycythere*), which probably evolved during the Aptian in Venezuela, is well represented in Africa, the Middle East, Brazil and in India, but it is absent from Europe. Similarly the genus *Rostricytheridea* which is strictly Gondwanian in its distribution (Ballent & Whatley, 2007).

The oldest records of *Rostricytheridea* seem to be *Rostricytheridea* sp. mentioned by Dingle (1982) from the Protlandian of South Africa and *R. opisthorhynchus* Ballent and Whatley (2007) from the late Tithonian-Berriasian of Argentina. These constitutes the only Jurassic records of the genus, and their almost simultaneous appearances clearly confirm the short distances of the marine migration routes along the Southern margins of Gondwana at that time. During the latest Jurassic-Berriasian the opening of a shallow intermittent epicontinental seaway between southern South Africa and Southern Argentinian Patagonia favoured faunal interchange.

Some palaeoceanographical and palaeogeographical changes, such as opening pole change at 105 Ma (early Albian), probably led to the deep water passages forming along the line of the Falkland Plateau-Southern Africa fracture zone, allowing the dysaerobic temperate South Atlantic to be flushed by oxygenated waters, which favored the appearance of new taxa (Ballent and Whatley, 2006). At the same time, some old or original elements of the South Gondwana fauna such as *Majungaella* and *Rostricytheridea* made their way to Madagascar, India, and Australia. The genus *Rostricytheridea* was erected by Dingle 1969. The genus *Rostricytheridea*, which is represented by six species in Narbada Basin, of which two are new.

This is forming very important constituents in the upper part of Bagh Formation. In Jaisalmer basin, genus is represented by only one species i.e. *R. jaisalmerensis*, which also occurs in the Bilthana (Rajpipla) section of Bagh Formation. *Rostricytheridea* arrived in Madagascar, Jaisalmer and Narbada basins, India. In the India, the genus appears in Jaisalmer basin during the Albian-Turonian (Singh, 1997, Andreu *et al.*, 2007), and in Narbada basin during Cenomanian-Turonian and probably Coniacian time.

Rostricytheridea arrived in Australia in the Albian-Cenomanian (*R. ?allaruensis* Krommelbein) and continued up into the Upper Cretaceous with *R. westraliensis* (Chapman) and *R. canaliculata* Bate (Santonian-Campanian). The record of *Rostricytheridea* in Antarctica (*R. hamiltonensis* Fauth and Seeling) from Middle-Upper Campanian of Southeastern James Ross Island shows that the Ross Sea area was connected faunally to Southeastern Australia.

With respect to palaeoenvironmental preferences, all records of *Rostricytheridea* are from similarly warm and normal saline, shallow water environments. The presence of *Rostricytheridea* in Antarctic, together with that of *Majungaella* Grekoff, which has a typically tropical distribution in the Cretaceous as well as the co-occurrence of the thermophile *Cytherelloidea* Alexander, supports once again the idea of warm climates in high-latitude regions in late Cretaceous. Also the records of *Rostricytheridea* and other ostracodes taxa provide clear evidence of links between Western Australia, Argentina, and Antarctic Peninsula in one hand to South Africa, Madagascar and India during the late Cretaceous time.

Genus *Nigeroloxoconcha* is a typically a South Tethyan origin (Gondwanian). This is an African and South American genus; it appears in the Aptian of Morocco and develops from Albian to Miocene in Morocco, Algeria, Tunisia, Gabun, Niger, Ivory Coast, Nigeria, Egypt, Libya. Some species are also known in the Cenomanian-Santonian from Brazil. In India from Jaisalmer basin Andreu *et al.*, 2007 reported *Nigeroloxoconcha* sp. from Turonian. Similarly from Bagh Formation of Madhya Pradesh present authors reported two new species of the genus.

Another important genus *Majungaella* Grekoff which is only member of the once dominant ostracode family Progonocytheridae to survive the Jurassic and also to survive the Cretaceous-Tertiary boundary event. In the Jurassic, *Majungaella* had a northeastern Gondwanine distribution, occurring only in India, Africa and Madagascar. However, during the Neocomian it appears in South America where it extends to the Maastrichtian, while in Australia it first appears in the Aptian and ranges up to the Campanian. Its last records in Africa are in the Cenomanian of South Africa and the Santonian of South Western Africa. Three species of the genus reported by Singh (1997) from Cenomanian-Turonian of Jaisalmer basin, few more species of the genus reported by Andreu *et al.*, 2007 from late Albian to Coniacian of Same basin. Similarly present species from Bagh Formation of the genus also range from Cenomanian-Turonian. This southward shift of genus into higher latitudes was probably due to an increasing cryophilia and, although this may have also been prompted by competitive exclusion by better adapted, newly evolved taxa, it is difficult to demonstrate this due to the universal distribution of most Late Mesozoic ostracode genera. Whatever the reason, *Majungaella* seems to have become, during the Cretaceous, increasingly adapted to living in high latitude shallow seas and this adaptation is advanced as the prime reason why the genus, alone among the Progonocytherids was able to survive both the post-Cretaceous global cooling.

Another ostracode family Brachycytheridae is one of the most common taxa of Late-Cretaceous shallow marine microfossil, and occurs in the marginal basins of Africa, Madagascar, India, Middle East, South and North America. Although the Late-Cretaceous Brachycytheridae are very widely distributed, their use for correlation has been hampered due to their conservative external

morphology, with all of them having a posteriorly-sloped dorsal margin and a swollen ventrolateral carapace, and all of them were long assigned to a single genus *Brachycythere*. Puckett (2002) observed that members of the family from Gondwana were distinct in having a single (unsplit) second adductor muscle scar whereas all of those from North America had a split second scar, on this ground Puckett *et al.*, 2016 erected a new genus for Gondwana i.e. *Sapucariella* and *Brachycythere* restricted to North America only. The genus *Sapucariella* were described by Andreu, 1991 as *B. sp.1* and *B. sp.2* from Late-Albian of Morocco, part of Gondwana; the genus is typically a South American and African one from the Albian to the Turonian (Puckett, 2002). In the eastern part of Gondwana, the genus *Sapucariella* represented by several species, appears in the Albian and spreads out during the Turonian. *Sapucariella jodhpurensis* (Singh, 1997) is probably a synonym of both *S. aff. S. sapucariensis* Krombelbein, in Bate and Bayliss (1969), from the Turonian of Brazil and Tanzania and *S. gr. S. sapucariensis* Andreu, 1991, from the Cenomanian of Morocco and the same species, along with *S. angulata* (Singh and Porwal, 1989) have also been reported from Bagh Formation, M.P., India. All these observations of Indian material tend to clearly demonstrate that the Indian "*Sapucariella*" and the South American-African "*Sapucariella*" sensu Puckett 2002 belongs to same lineage.

The genus *Makatinella* was until known considered to be endemic in South Africa (inshore and offshore) and known from the Aptian to Cenomanian (Dingle, 1984, 1996). The species of genus has also been reported by Andreu *et al.*, 2007 from Turonian of Jaisalmer basin. Similar species, along with two other forms also present in the Bagh Formation (Turonian-Coniacian).

The genus *Amphicytherura* is known both in Laurasia and Gondwana, in the Albian-Campanian of North America and Gulf Coast (Crane, 1965; Moysey and Maddocks, 1992); in Europe in the Hauterivian of Germany (*Amphicytherura arcuata* Luppold, 2001) and in the Cenomanian of France (*Amphicytherura berbiguierensis* Colin, 1974; *A. falloti* Donze and Thomel); from the Portlandian to the Cenomanian in East Gondwana: Morocco, Algeria, Tunisia, South Africa, Israel, Mozambique (Babinot and Colin, 1988, Andreu, 1991) and in the Albian-Cenomanian of West Africa and Brazil. *Amphicytherura aff. A. yakhiniensis* Rosenfeld, 1974 (in Rosenfeld and Raab, 1974) from Coniacian, is morphologically close to *Amphicytherura (Sondagella) gigantodistincta* Andreu, 1991 from the Aptian-Cenomanian of Morocco and probably to *Fissocarinocythere? Hexagona* Singh, 1997 from the Cenomanian of the Jaisalmer basin. *A. aff. A. yakhiniensis* Rosenfeld, 1974 has also been recorded from Cenomanian-Turonian of Bagh Formation.

One more species *Bythoceratina tewarii* (Jain) described from Turonian-Coniacian of Bagh Formation, Madhya Pradesh by Jain, 1975a. The present species has also been reported from late Cenomanian of Jaisalmer basin (Andreu *et al.*, 2007) and also been reported by present authors from Bagh Formation.

The Cenomanian-Turonian species common to the Jaisalmer and Narbada basins and the Southern margin of the Tethys enable us to link up the Jaisalmer Basin, West Rajasthan shelf and Narbada Basin to the "North African-Middle East paleobiogeographical province, established during the early Cretaceous and extending to the South-Tethyan margin in the Cenomanian, as defined by Andreu, 1993, or to the South-Tethyan ostracode province proposed by Luger, 2003. Andreu *et al.*, 2007, name it as new province the Cenomanian-Turonian "South Tethyan ostracode Province", incorporating at one time the North African, Middle East Province, India, Madagascar, South Africa and South America (fig. 2). This South Tethyan ostracode Province extends also to the eastern border of the Tethys, with the presence in the Cenomanian of Ecuador of the genera *Sapucariella* and *Nigeroloxoconcha*.



Fig. 2: Location of the Cenomanian-Turonian "South Tethyan Ostracod Province", on the paleobiogeographic map proposed, for the Cenomanian (after Andreu, 1993)

Previous work of Jain (1975a, 1975b, 1975c, 1976) on Late Cretaceous ostracodes of Southern and Central India provides conflicting data except for the occurrence of a few "African" genera, such as *Ovocytheridea* and *Sapucariella*. In his work he has shown a very close similarity with those from Limburg, Holland (Jain, 1975d), especially at genus level. Previously Sastry *et al.*, (1972) also noticed strong similarities between Late Cretaceous ostracode species from Southern India and Northern Europe. This is all because "major uncertainties do exist in the maps, particularly in the positions of Madagascar and India" (Lloyd, 1982). Reconstructions of Smith and Briden (1977) and Bernoulli and Lemoine (1980) show India located east of central Africa during the early Late Cretaceous. Briggs (1987) places India in contact with northeastern Africa during Late Cretaceous, whereas Barron *et al.*, (1981) places it in a more southern position.

Recent paleogeographic reconstructions are based on GPlates open source software (GPlates, 2013), with rotational poles and coastal outlines those of Seton *et al.*, (2009). It is clear from these maps that the centre of their evolution was in the African realm, with the species at the end of Early Cretaceous already spread across the margins of Gondwana from Madagascar, India and North Africa to Venezuela. Hence available data from plate tectonics, paleogeography and taxonomy to interpret how the breakup of Pangea affected the evolution and migration of ostracode fauna of Late-Cretaceous time. In the early stages of the breakup of Pangea, Gondwana rifted away from North America and Europe beginning in the Triassic and northerly continental masses were too far or too deep for genetic communication. Although Madagascar and India rifted away from Africa during the Late Jurassic (about 158 Ma), movement was almost directly south and nearly parallel to the African coastline, so genetic communication was still possible in the shallow marine environments until atleast the earliest Cenomanian (about 100 Ma).

As Africa and South America rifted away from each other continental-scale stresses caused rifting in the North Africa Rift Zone (Creating the Trans-Saharan Seaway), the Central African Shear Zone, and several fracture zones in South America. During late Cenomanian, the combination of down drop due to rifting in North African rift zone and high sea level due to the high production of oceanic crust in the South Atlantic caused a shallow seaway to form connecting the Benue Trough region to the northern margin of Gondwana and Tethyan Seaway (Trans-Saharan Seaway). This brief seaway enabled ostracode taxa to migrate to large regions in North and West Africa and Arabia, when sea level dropped in early

Turonian, these faunas were cut off and evolved separately. The relatively high sea levels of the Campanian and Maastrichtian further aided migration and evolution of ostracode taxa (Puckett *et al.*, 2016). An actualistic approach emphasizing the main parameters that control the distribution of ostracode genera and species, allow us to understand past processes and in particular, the effect of migration pathways, especially along continental margins. The presence and the role of factors such as bathymetry (Deep-water Zones) and Deep-ocean width seem to be very important for the occurrence of palaeobiogeographic barriers.

The recognition of examples of generic convergence or homeomorphy between different bioprovince, brings evidence for the existence of latitudinal zones. This seems to reflect climatic zones; but the distribution can be disturbed by oceanic currents, eustasy, and global tectonics, which can restrict or enhance latitudinal and longitudinal migrations.

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