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CYTHERELLOIDEA (OSTRACODA) FROM THE UPPER CRETACEOUS BAGH FORMATION OF MADHYA PRADESH, INDIA: ITS AFFINITY AND PALAEOGEOGRAPHIC IMPLICATIONS

MAYA CHAUDHARY, M. L. NAGORI* and NIDHI BHANAT

DEPARTMENT OF GEOLOGY, MOHANLAL SUKHADIA UNIVERSITY
51, SARASWATI MARG, UDAIPUR – 313 002, INDIA
* E-mail: madan.nagori@gmail.com

ABSTRACT

Cytherelloidea is a cosmopolitan Ostracoda genus having worldwide distribution. It occurs commonly in the Cretaceous shallow marine marginal basins of the erstwhile Gondwanaland *viz*. South America, Africa, Middle East, Madagascar, Australia and India. In the present work eight species of the genus have been recorded from the Bagh Formation (Upper Cretaceous) of Madhya Pradesh, India. Of these, two species- *Cytherelloidea awaldaensis* and *C. rosebaidaensis* are new. The other reported species are *Cytherelloidea oertelii* Singh, *C. oudiapurensis* Jain, *C. raoi* Jain, *C. subgranulosa* Jain, *C. thuatiensis* Jain, and *Cytherelloidea* sp. Affinity and palaeogeographic implications of the genus *Cytherelloidea* are discussed.

Keywords: Madhya Pradesh, Bagh Formation, Upper Cretaceous, Ostracoda, Palaeogeographic implications.

INTRODUCTION

The exposures of Bagh Formation occur as isolated patches, extending about 350 kms. in length from Barwaha (M.P.) in the east to Rajpipla (Gujarat) in the west. This rift/graben basin of central India is roughly ENE-WSW trending, in which marine/ fluviatile sediments of Cretaceous ages are deposited (Fig.1). During the course of study of Ostracoda from these beds, present authors came across many species of the genus *Cytherelloidea*, of which few species are endemic and rest are either common or resembling with other basins of then Gondwanas.

Genus *Cytherelloidea* was erected by Alexander (1929), which has worldwide distribution from Liassic? to Recent sediments of shallow, warm marine waters; it is occasionally also found in brackish (mesohaline) environments. The species of the genus occur quite abundantly in the Cretaceous marine basins of Peninsular India, particularly Jaisalmer, Narbada and Cauvery. Surprisingly all the basins have their endemic *Cytherelloidea* species, with some exceptions.

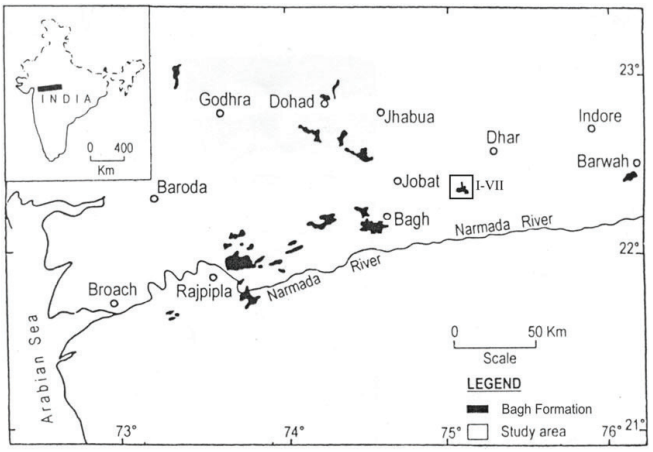


Fig. 1. Outcrops of the Bagh Formation along Narbada Valley (Modified after Jain, 1975)

PREVIOUS WORK

Ostracodes from the Bagh Formation were first recorded by Jain (1961), who reported the occurrence of twenty-two species, including ten new. Of these, only the new species were briefly described without any illustration. Subsequently Roy Chowdhury and Sastri (1962) listed four ostracode taxa from the Deola-Chirakhan marl. Thereafter Guha and Ghosh (1970) reported seventeen ostracode taxa, including eight new species and a new variety, without any description and illustration.

The only comprehensive work on this group is by Jain (1975a), who described thirty ostracode taxa, including nine new species. In that paper, Jain described and illustrated five species of the genus *Cytherelloidea*. Of these, two species: *Cytherelloidea khoslai* and *C. oudiapurensis* were new, while the other three species were *Cytherelloidea raoi* Jain, *C. subgranulosa* Jain, and *C. thuatiensis* Jain, which were earlier briefly described by Jain (1961). (*C. thuatiensis* was then designated as *C. indica* Jain, 1961).

Besides above, from Jaisalmer Basin Singh (1997) recorded five new species of *Cytherelloidea viz.* C. *ghotaruensis, C. monomediocostata, C. onkareshwarensis, C. oertelii* and *C. reniformata.* Further Sastry *et al.* (1972), described six species of the genus from Ariyalur Group (Upper Cretaceous), Tiruchirapalli District, Tamilnadu. They are: *C. ozanana* Sexton, *C. naraiyurensis* Sastry and Mamgin, *C. sillakkudiensis* Sastry and Mamgain, *C. tricarinata* Sastry and Mamgain, ? *C.* sp., and *Cytherelloidea* sp. Thereafter Jain (1975b) recorded seven species of the genus from Ariyalur Formation (Upper Cretaceous). The species are *C.* sp. cf. *C. dubia* Veen, *C. kallankurichiensis* Jain, *C. vimalai* Jain, *C.* sp. A, *C.* sp. B, *C.* sp. C and *C.* sp. D. Recently Singh and Porwal (1989) recorded *C. bicostata* Crane from Sillakkudi Formation (Late Cretaceous) of Cauvery basin, Tamilnadu. This species was previously reported by Govindan (1969) from Upper Cretaceous of Vridhachalam, South India.

STRATIGRAPHY

The Bagh Formation has long been known to the Indian geologists. It was initially classified by Blanford (1869) and later on Bose (1884) proposed definite names to its subunits. In subsequent years considerable work has been carried out on the stratigraphy of these beds. Among these, important contributions were made by Rode and Chiplonkar (1935); Roy Chowdhury and Sastri (1962); Sahni and Jain (1966); Sastry and Mamgain (1971); Chiplonkar *et al.,* (1975); Dassarma and Sinha (1975); and Guha (1976). The generalized stratigraphy of the region is given in table 1.

Table 1. The generalized stratigraphy of the Bagh region:

Age	Formation	Lithology
Uppermost Cretaceous	Deccan Traps Lameta Formation	Basalts Cherty Limestone, Calcareous Sandstone
Upper Cretaceous	Bagh Formation	Coralline Limestone Deola-Chirakhan Marl Nodular Limestone
Lower Cretaceous		Nimar Sandstone
Archean	Bijawar Formation	Metamorphics

With the intention of revising the ostracode fauna of the Bagh Formation, authors collected samples from six different localites near Jeerabad village in Man Valley, Dhar District. The locations of these localities are given in the sequel and also in fig. 2. The stratigraphic successions at localities 1 to 6 are given in figs. 3-4.

Locality 1: Around 500mts. SW from Rosebaida village, in a nala section, (N 22°26': E 74° 56')

Locality 2: Around 2 kms. from Rosebaida village, in a stream section (N 22° 26': E 75° 05')

Locality 3: Near Ratitalai village, 6 kms. SW from Jeerabad Town (N 22° 24': E 75° 03')

Locality 4: Near Hanumanpura village (N 22° 22': E 75° 04')

Locality 5: 1 km SW of Jeerabad village (N 22° 05': E 74° 54')

Locality 6: Near Awalda village

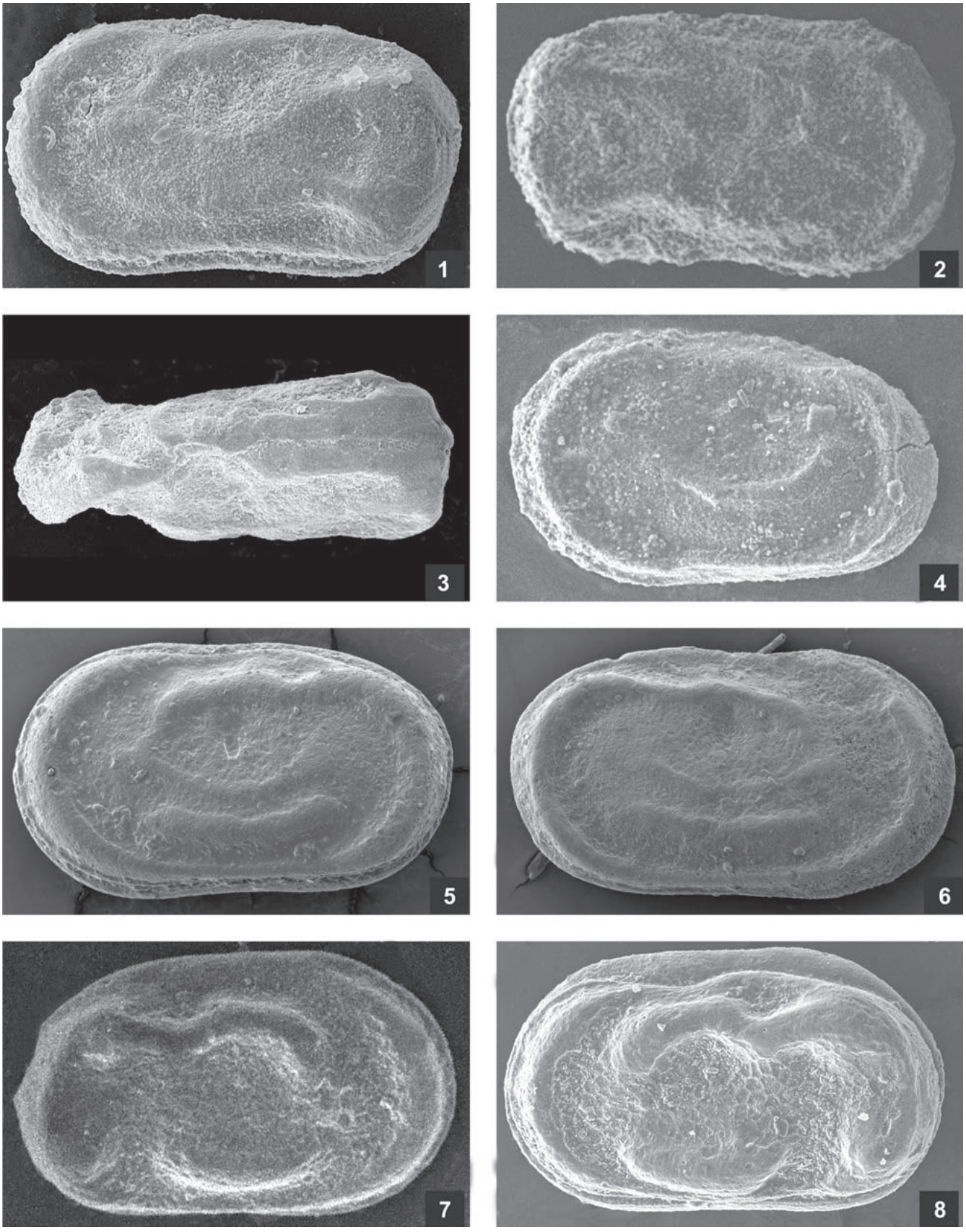
Repository: All the described specimens are deposited in the micropaleontology laboratory, Department of Geology, M. L. Sukhadia University, Udaipur and are designated by SUGDMF Nos. 1264-1279.

Fig. 2. Google earth map showing sampling localities of Sections I-VI

EXPLANATION OF PLATE I

1-3. ***Cytherelloidea awaldaensis*** n.sp. 1, holotype, (SUGDMF No. 1264), a carapace, left valve view, X 166 ; 2, paratype I (SUGDMF No. 1265), right valve, lateral view, X 142 ; 3, paratype II (SUGDMF No. 1266), a carapace, dorsal view, X 144 . 4. ***Cytherelloidea oertelli*** Singh. A carapace (SUGDMF No. 1267), left valve view, X 216. 5-6. ***Cytherelloidea oudiapurensis*** Jain. 5, carapace (SUGDMF No. 1268), left valve view, X 152 ; 6, carapace (SUGDMF No. 1269), right valve view, X 173. 7-8. ***Cytherelloidea raoi*** Jain. 7, right valve (SUGDMF No. 1270), lateral view, X 130 ; 8, carapace (SUGDMF No. 1271), left valve view, X 148 .

Plate I



SYSTEMATIC PALAEONTOLOGY

Subclass **Ostracoda** Latreille, 1806
Order **Podocopida** Müller, 1894
Suborder **Platycopid** Sars, 1866
Family **Cytherellidae** Sars, 1866
Genus ***Cytherelloidea*** Alexander, 1929

Cytherelloidea awaldaensis n. sp.
(Pl. I, figs. 1-3)

Name: After village Awalda.

Material: 6 carapaces and 2 valves from locality 6.

Type level and locality: Sample B4/AM1, creamish marl (full of echinoids), Bagh Formation, Upper Cretaceous, Awalda village, Madhya Pradesh, India.

Diagnosis: Carapace elongate-subrectangular in lateral view and nearly wedge-shaped in the dorsal; right valve larger than left valve, overlapping along dorsal and ventral margins, more conspicuously along the latter. Dorsal margin nearly straight; ventral margin concave in middle, anterior margin rounded, and fringed with about 7 denticles; posterior margin truncated in lower half. Maximum length in middle, and height in the anterior.

Surface of each valve marked with a prominent anterior and a posterior marginal rib; three prominent longitudinal ribs; dorsal rib obliquely disposed in posterodorsal and middorsal area, not joining anterior or median ribs; median rib more prominent and linked to posterior rib at posterodorsal margin, runs forward for a short distance and in median region it takes a curve, convex towards the venter, rising slightly up again and dying out in dorsomedian area; ventral rib linked to posterior rib at posteroventral margin and at 1/4 length it takes a curve, convex towards the dorsal, runs slightly down and then parallel to median rib.

Dimensions (mm):

	Length	Height	Width
Holotype (SUGDMF No.1264), carapace	0.51	0.28	0.19
Paratype I (SUGDMF No.1265), Right valve	0.57	0.32	-
ParatypeII(SUGDMF No.1266), carapace	0.56	0.32	0.20

Remarks: This species closely resembles with the *Cytherelloidea agyroides* Dingle, 1969 originally described from Neocomian of South Africa and later on by Brenner and Oertli, 1976 from Algoa Basin, South Africa in over all shape and rib pattern. However, in *C. agyroides* posterior rib is situated slightly away from the margin, median rib having a gentle curve, convex towards the venter, and a more or less straight ventral rib. The present species also differs with *C. tigignitensis* Andreu *et al.,* 1998 described from Coniacian- Santonian of Essaouria Basin, Atlantic Atlas, Morocco. In the latter species posterior rib is away from the margin, dorsal oblique rib joins median ribs at 1/4 length in back of anterior rib and ventral rib nearly straight and parallel to ventral margin. The present species also differs with *Cytherelloidea* sp. 1 described by Piovesan *et al.,* (2013) from the Upper Albian of Santos Basin, Brazil. In the latter species dorsal oblique rib is short and median rib nearly straight and parallel to ventral rib.

Cytherelloidea oertlii Singh
(Pl. I, fig. 4)

Cytherelloidea oertlii Singh, 1997, pp. 23-24, pl. 14, figs. 8-9, 13-14, 16, 20-22. – Andreu *et al.,* 2007, pl. 2, figs. 3-7. - Babinot *et al.,* 2009, pp. 6-7, pl. 1, figs. 9-14.

Material: One carapace from locality 5.

Dimensions (mm):

	Length	Height	Width
A carapace (SUGDMF No.1267)	0.37	0.24	0.07

Remarks: The species has so far been recorded from the Parth Formation, Turonian– Coniacian, (Upper Cretaceous) of Manhera Tibba well-I, Jaisalmer, Rajasthan by Singh (1997), Coniacian-Santonian of subsurface of Jaisalmer Basin by Andreu *et al.,* (2007), and from Albian-Turonian of the Antsiranana region, Northern Medagascar by Bibinot *et al*., (2009). The present specimen is identical with *C. oertlii* Singh. Surface ornamentation of the species comprises a thin rib running all along the margin, and a curved, comma-shaped median rib, its posterior end is thick, whereas anterior end is thin.

Cytherelloidea oudiapurensis Jain
(Pl. I, figs. 5-6)

Cytherelloidea oudiapurensis Jain, 1975a, pp. 193-194, pl. 1, figs. 6 a-b; text-fig. 1.

Material: 48 carapaces and 18 valves from localities 1, 2, 3, 4 and 5.

Dimensions (mm):

	Length	Height	Width
A carapace (SUGDMF No.1268)	0.54	0.31	0.18
A carapace (SUGDMF No.1269)	0.53	0.29	0.17

Remarks: The present specimens are identical with the *Cytherelloidea oudiapurensis* Jain (1975a) described from the Coralline Limestone (Coniacian), Oudiapur, Dhar District.

The species is ornamented by a strong anterior and a posterior rib; posterodorsally the posterior rib continues into an inner sinuate rib below the dorsal margin, this inner rib makes a hair pin bend somewhat behind the anterior rib slightly above the mid height and a very short rib from the dorsal part of the inner loop bends downwards; one more short, thick longitudinal rib present in between the ventral part of the inner loop and the ventral margin.

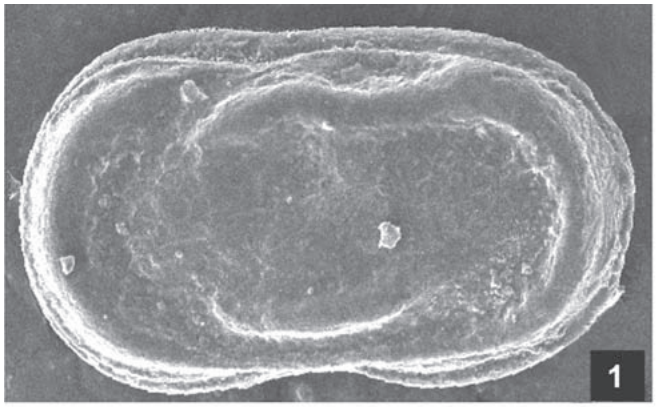
Cytherelloidea raoi Jain
(Pl. I, figs. 7-8)

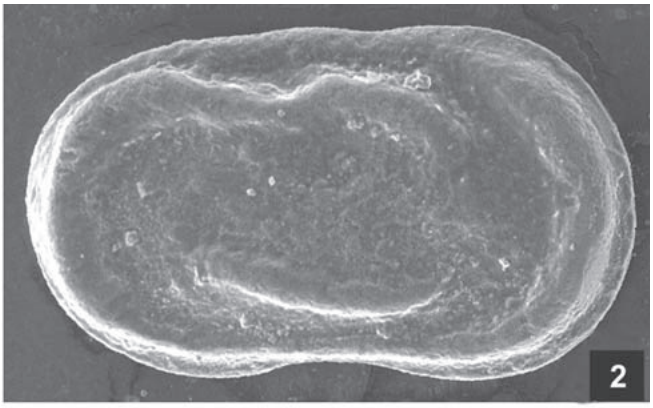
Cytherelloidea raoi Jain, 1961, p. 342. – Jain, 1975a, pp. 194-195, pl. 1, figs. 3a-b; text-fig. 2.

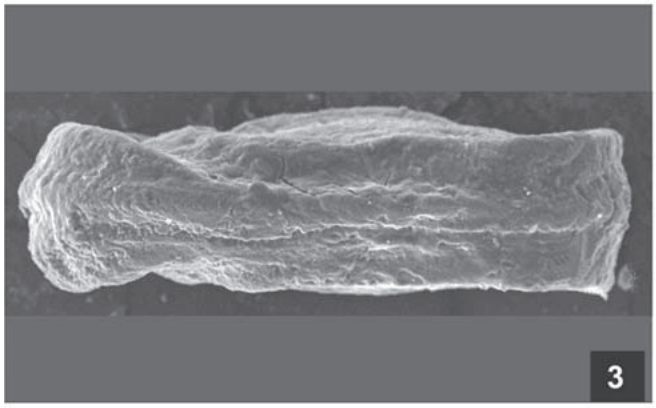
EXPLANATION OF PLATE II

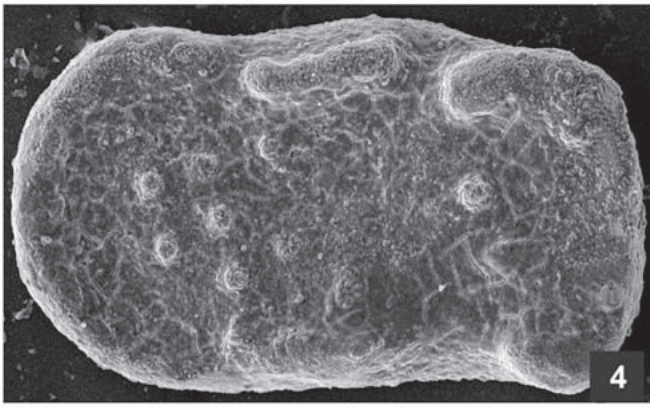
1-3. ***Cytherelloidea rosebaidaensis*** n.sp. 1, holotype, (SUGDMF No. 1272), a carapace, left valve view, X 134 ; 2, paratype I (SUGDMF No. 1273), carapace, right valve view, X 132 ; 3, paratype II (SUGDMF No. 1274), a carapace, dorsal view, X 134. 4-5. ***Cytherelloidea subgranulosa*** Jain. 4, left valve (SUGDMF No. 1275), lateral view, X 124 ; 5, carapace (SUGDMF No. 1276), right valve view, X 118 . 6-7. ***Cytherelloidea thuatiensis*** Jain. 6, carapace (SUGDMF No. 1277), right valve view, X 128 ; 7, carapace (SUGDMF No. 1278), left valve view, X 128. 8. ***Cytherelloidea*** sp. A. Carapace (SUGDMF No. 1279), left valve view, X 125.

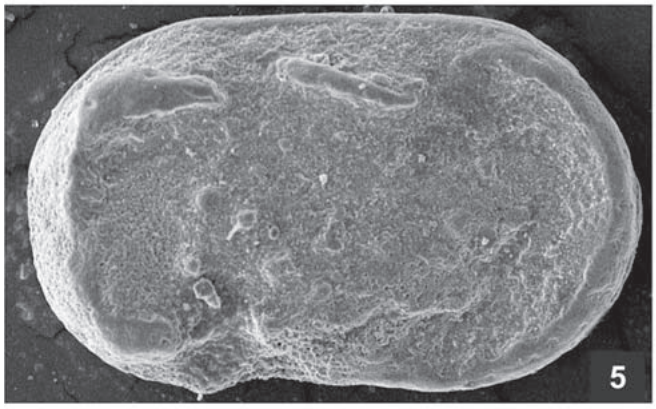
Plate II

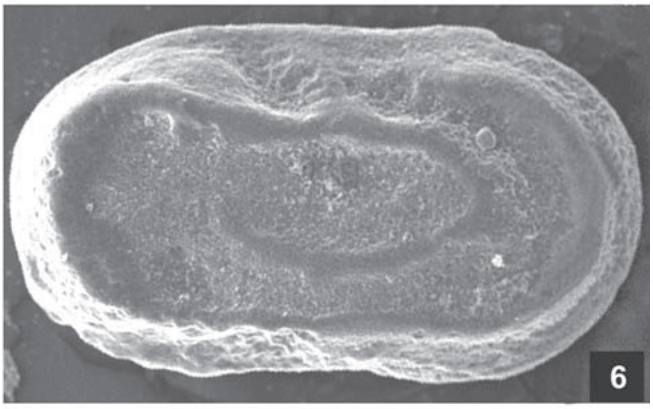


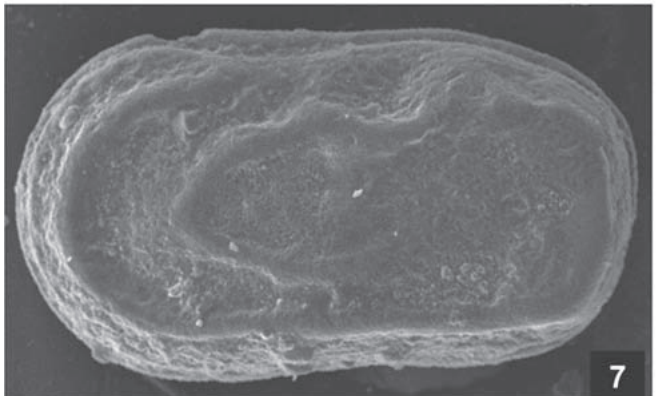


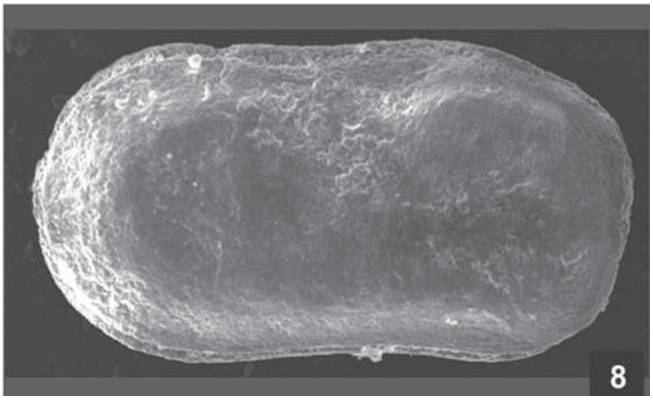












Material: 78 carapaces and 116 valves from localities 1, 2, 3, 4, 5 and 6.

Dimensions (mm):

	Length	Height	Width
A right valve (SUGDMF No.1270)	0.63	0.39	–
A Carapace (SUGDMF No.1271)	0.56	0.35	0.24

Remarks: The specimens recorded herein are identical with the *Cytherelloidea raoi* described by Jain (1961 & 1975a) from the Coralline Limestone (Coniacian), Thuati, Dhar District. In *C. raoi* surface ornamentation consists of a thick anterior rib, two nodes in posterior region, joined posteriorly by a vertical rib, a thickened dorsal rib inside the dorsal margin which is joined posteriorly by a posterodorsal node and anteriorly curves round, another short but thick longitudinal rib is present in the ventral part above the main upturned part of the ventral margin, ventral rib is not joined with poteroventral node. Surface smooth/finely reticulate.

Cytherelloidea rosebaidaensis n. sp.
(Pl. II, figs. 1-3)

Name: After village Rosebaida.

Material: 50 carapaces and 55 valves from localities 1, 2, 3, 4, 5 and 6.

Type level and locality: Sample No. RB 1/5, Nodular Limestone, Bagh Formation, Upper Cretaceous. Rosebaida, Madhya Pradesh, India.

Diagnosis: Carapace elongate-subrectangular in lateral outline; dorsal margin nearly straight, ventral margin concave in middle; anterior margin broadly rounded; posterior margin less so; right valve larger than left valve, overlapping all along margin, more pronounced along the dorsal. Maximum length in the middle, height at anterodorsal corner. Surface marked by a prominent anterior and a posterior marginal rib; besides, two more longitudinal ribs; dorsal rib more pronounced and linked to posterior rib at posterodorsal corner, runs a short distance and takes a down curve and up again and continued in the back of anterior rib; ventral rib short, horizontal to curved, somewhat comma shaped, situated in ventromedian region. Rest of valve surface smooth.

Dimensions (mm):

	Length	Height	Width
Holotype (SUGDMF No.1272), carapace	0.61	0.35	0.21
Paratype I (SUGDMF No.1273), carapace	0.62	0.35	0.20
Paratype II (SUGDMF No.1274), carapace	0.61	0.34	0.19

Remarks: *Cytherelloidea rosebaidaensis* n. sp. closely resembles *Cytherelloidea oudiapurensis* Jain 1975a, described from Oudiapur, Dhar District. However in the latter species posterodorsally the dorsal rib continues into an inner sinuate rib below the dorsal margin, this inner rib makes a hair pin bend somewhat behind the anterior rib, above midheight and a short sinuate rib, from dorsal part of the inner loop bends downward and continued upwardly. Present new species also resembles with *C. raoi* Jain, 1975a, in overall shape. However in latter species two nodes in posterior region, joined posteriorly by a vertical rib and a very thick dorsal rib. Present species also resembles with *C. austinensis* Sexton, 1951 in overall shape and to some extant surface rib pattern. However in *C. austinensis* dorsal rib is nearly straight and parallel to dorsal margin.

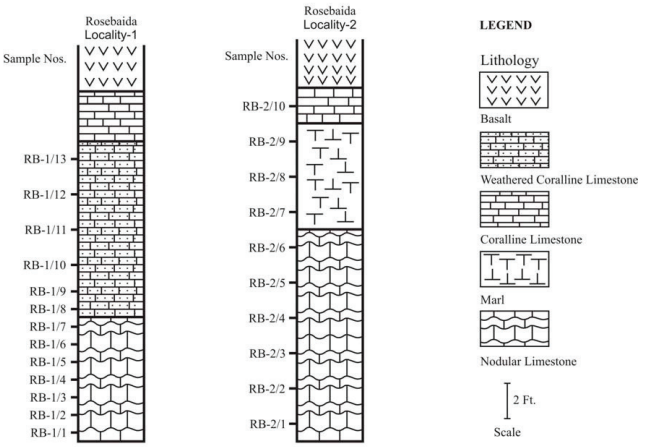


Fig. 3. Stratigraphic columnar sections of Upper Cretaceous, Bagh Formation at locality 1 and 2

Cytherelloidea subgranulosa Jain
(Pl. II, figs. 4-5)

Cytherelloidea subgranulosa Jain, 1961, p. 341. – Jain, 1975a, pp. 195-196, figs. 4ab, 5; text-fig. 3.

Material: 9 carapaces and 6 valves from localities 1, 4, and 6.

Dimensions (mm):

	Length	Height	Width
A left valve (SUGDMF No.1275)	0.69	0.39	–
A carapace(SUGDMF No.1276)	0.70	0.45	0.33

Remarks: Specimens recorded herein are identical with *Cytherelloidea subgranulosa* described by Jain (1961 & 1975a) from the Coralline Limestone (Coniacian), Thuati, Dhar District. *Cytherelloidea* species characterized by a discontinuous marginal rib; the posterior part of the rib is thick and prominent; the anterior part of the rib is thinner than the posterior; a short oblique rib in dorsomedian region; rest of the valve surface ornamented with 14-16 granules.

Cytherelloidea thuatiensis Jain
(Pl. II, figs. 6-7)

Cytherelloidea indica Jain, 1961, p. 341.

Cytherelloidea thuatiensis Jain, 1975a, p. 196, pl. 1, figs. 10a-c, text-fig.4.

Material: 110 carapaces and 41 valves from localities 1, 2, 3, 4, and 5.

Dimensions (mm):

	Length	Height	Width
A carapace (SUGDMF No.1277)	0.66	0.35	0.20
A carapace (SUGDMF No.1278)	0.67	0.35	0.21

Remarks: The present specimens are identical with *Cytherelloidea thuatiensis* described by Jain (1961 & 1975a), from the Coralline Limestone (Coniacian), Thuati, Dhar District. The species has following characteristics: valve surface ornamented with a spiral rib with nearly equally strong anterior, ventral and posterior parts of the outer loop and dorsal and ventral parts of the inner loop; the rib starts from the anterodorsal margin.

Cytherelloidea sp.
(Pl. II, fig. 8)

Material: 3 carapaces from locality 1.

Remarks: Carapace elongate-subrectangular in lateral outline; dorsal margin straight; ventral margin sinuate in the middle; anterior and posterior margins subrounded; surface ornamented with an anterior and a high posterior marginal rib, posterior rib in lower part curves anteriorly and continue parallel to ventral margin at half the distance. Rest of the surface area smooth. The species is left under open nomenclature for want of more material.

Dimensions (mm):

	Length	Height	Width
A carapace (SUGDMF No.1279)	0.64	0.33	0.27

AFFINITY AND PALAEOGEOGRAPHIC IMPLICATION

Rifting of India and Madagascar from Africa initiated in the Late Jurassic (about 155 Ma); the movement was almost directly south and nearly parallel to the African coastline, so genetic communication was still possible in the shallow marine environment until at least the earliest Cenomanian (about 100 Ma).

This timing is important because there are ostracodes that occur in Madagascar and India quite early in their evolutionary history, early Cenomanian (Babinot *et al.*, 2009) and shallow water migration pathways must have been open.

Rifting ceased after only a few million years, it again initiated about 130 Ma and resulted in the movement of India, Madagascar and Africa away from Antarctica. During the next 50 Ma (until about 82 Ma), India remained close to Madagascar, but during the Campanion, sea floor spreading initiated between India and Madagascar via the Carlsberg ridge, resulting in rapid movement of India away from Madagascar (Puckett *et al.*, 2016).

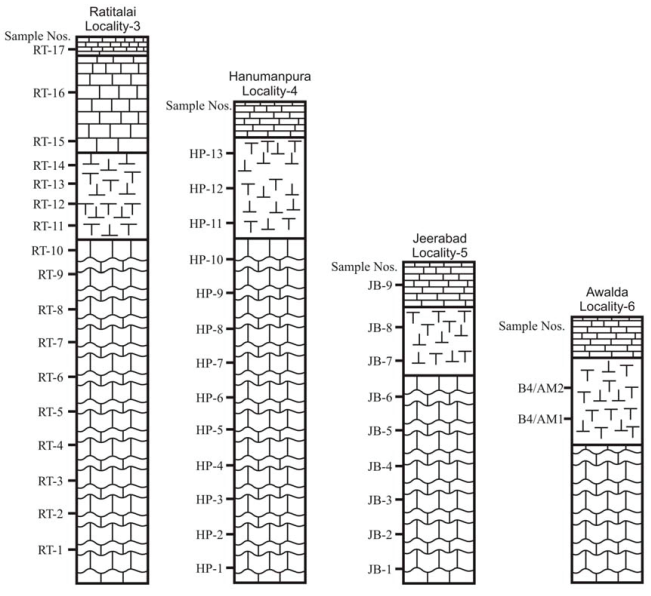


Fig. 4. Stratigraphic columnar sections of Upper Cretaceous, Bagh Formation at locality 3 and 6

Puckett *et al*. (2016) stated that "As Africa and South America rifted away from each other, continental–scale stresses caused rifting in the North Africa Rift Zone (creating the Trans–Sahara Seaway), the Central African Shear Zone, and several fracture zones in South America. During the Late Cenomanian, the combination of down drop due to rifting in the 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 the Tethyan seaway (Trans–Saharan Seaway). This brief seaway enabled ostracode species to migrate to large regions in North and West Africa and Arabia; when sea level dropped in the early Turonian, these faunas were cutoff and evolved separately".

Singh (1997) recorded five new species of the genus *Cytherelloidea viz.* C. *ghotaruensis, C. monomediocostata, C. onkareshwarensis, C. oertelii* and *C. reniformata* from Jaisalmer Basin. While from Bagh Basin Jain (1961, 1975a) had earlier recorded another five new species *viz. C. khoslai, C. oudiapurensis, C. raoi, C. subgranulosa* and *C. thuatiensis*, further present authors have now recorded two more new species and *C. oertelli* Singh from this basin. Both the basins have their own endemic *Cytherelloidea* species, except for *Cytherelloidea oertelii* which was originally described from the lower part of Cenomanian, Manhera Tibba Well-I, Jaisalmer, Rajasthan, India. This 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).

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

Cytherelloidea awaldaensis n. sp. shows close affinity with *C.* a*gyroides,* initially described by Dingle, (1969) from Neocomian of South Africa, *C. tigignitensis* 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 1(975b) and ? *Cytherelloidea* sp. described by Sastry *et al.* (1972) from Ariyalur Formation, Upper Cretaceous of South India.

Cytherelloidea oudiapurensis Jain 1975a originally described from Bagh Formation shows affinity with *C*. sp. 1 described by Rosenfeld and Raab (1974) from Judea group (Upper Cenomanian) of Israel, similarly *C. raoi* Jain 1975a shows close affinity with *C*. cf. *C. bicostata* Crane from the equivalent horizon of Israel. It is evident from above that at least few species migrated from one basin to another via shallow sea route.

From above distribution of ostracodes it is concluded that during rifting of South America from Africa and Madagascar and India from Africa, a new oceanic crust emerges, with opening of South part of Atlantic ocean and similarly northern part of Africa via Israel and Saudi Arabia and northern part of Madagascar with Jaisalmer and Narbada Basins of India has atleast shallow sea for movement of ostracode species. That is the reason many *Cytherelloidea* species shows close affinity with Brazil, Morroco, Israel, South Africa, Tanzania, Madagascar and to some extent with South India.

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