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Source: Paleontological Research, 8(3) : 181-197

Published By: The Palaeontological Society of Japan

URL: https://doi.org/10.2517/prpsj.8.181

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Paleontological Research, vol. 8, no. 3, pp. 181–197, September 30, 2004
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Evolutionary trends and biostratigraphic significance of the ostracode genus *Stigmatocythere* in the Cenozoic succession of India

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Received February 2, 2004; Revised manuscript accepted July 8, 2004

Abstract. ***Stigmatocythere*** **Siddiqui is an important ostracode genus and occurs profoundly in sediments of marginal marine to shallow inner neritic origin in the Cenozoic succession of western India. Its species have short stratigraphic ranges and wide geographic distribution, which makes them good markers and helps in finer subdivision of the Cenozoic strata. Nineteen species including one new species *Stigmatocythere* (*Bhatiacythere*) *khoslai* have been recognized from Lower Eocene to Middle Miocene sediments of western India. Of these, *Stigmatocythere* (*S.*) *obliqua* Siddiqui is restricted to the upper part of the Lower Eocene. *Stigmatocythere* (*S.*) *lumaria* Siddiqui morphotype A and *S.* (*S.*) *portentum* Siddiqui are restricted to the upper part of the Middle Eocene (Bartonian) and *Stigmatocythere* (*S.*) *lumaria* Siddiqui morphotype B to the Upper Eocene. *Stigmatocythere* (*Bhatiacythere*) *khariensis* Khosla and Pant is restricted to the Lower Oligocene, while *S.* (*S.*) *bermotiensis* Khosla and Pant ranges from Lower Oligocene to Upper Oligocene and *Stigmatocythere* (*S.*) *reticulata* Khosla and Pant from Oligocene to Lower Miocene (middle part of Aquitanian). *Stigmatocythere* (*S.*) *khoslai* sp. nov. ranges from Aquitanian to lowermost Burdigalian, *S.* (*S.*) *chaasraensis* Guha ranges from uppermost Lower Oligocene to Lower Miocene (middle Burdigalian), and *S.* (*B.*) *reversa* Khosla, *S.* (*S.*) *quilonensis* Khosla and Nagori range from Aquitanian to middle Burdigalian, while *S.* (*S.*) *latebrosa* Lyubimova and Guha, *S.* (*B.*) *spinosa* Khosla and Nagori and *S.* (*B.*) *interrupta* Khosla and Nagori are confined to the Lower Miocene (lower to middle Burdigalian). *S.* (*B.*) *rete* Khosla and Nagori and *S.* (*B.*) *arcuata* Khosla and Nagori are confined to middle Burdigalian and *S.* (*S.*) *multicostata* Khosla and Nagori ranges from middle to upper Burdigalian. *S.* (*S.*) *colini* Bhandari is confined to the lowermost Middle Miocene and *S.* (*S.*) *keeni* Bhandari ranges up to the top of the Middle Miocene. The above species of the genus *Stigmatocythere* belong to five evolutionary lineages. They are: 1- *Stigmatocythere* (*S.*) *obliqua* – *S.* (*S.*) *portentum*, 2- *S.* (*S.*) *reticulata* – *S.* (*S.*) *latebrosa* – *S.* (*S.*) *multicostata* – *S.* (*S.*) *keeni*, 3- *S.* (*S.*) *bermotiensis* – *S.* (*S.*) *quilonensis* – *S.* (*S.*) *chaasraensis*, 4- *S.* (*B.*) *khariensis* – *S.* (*B.*) *khoslai* – *S.* (*B.*) *reversa* – *S.* (*B.*) *rete* – *S.* (*B.*) *arcuata*, 5- *Stigmatocythere* (*B.*) *reversa* – *S.* (*B.*) *interrupta*. These lineages are briefly discussed here.**

Key words: ***Stigmatocythere*****, Cenozoic, Evolutionary lineages, Ostracode, western India**

Introduction

The ostracode genus ''*Stigmatocythere*'' Siddiqui occurs abundantly in the Eocene to Recent sediments of India. This genus was established by Siddiqui (1971) for the highly ornamented Trachyleberididae. He designated *Stigmatocythere obliqua* from shales with Alabaster beds, Rakhi Nala section, Pakistan, as type species. The genus is characterized by having ''two ridges [that] spring from the eye tubercle, one to form a high anterior marginal rim, the other curving sharply round to join the subcentral tubercle''. This genus has normal overlap, i.e., left valve slightly larger than right valve, overreaches in the region of anterior cardinal angle and at the posterodorsal slope and hinge. In the right valve, the hinge consists of a strongly projecting anterior tooth followed by an anteromedian socket, a posteromedian groove and projecting reniform posterior tooth; the hinge in the left valve is complementary.

Subsequently, Khosla and Nagori (1988) established *Bhatiacythere* as a new subgenus within *Stigmatocythere*. They designated *Stigmatocythere (Bhatiacythere) reversa* Khosla (1976) as type species described

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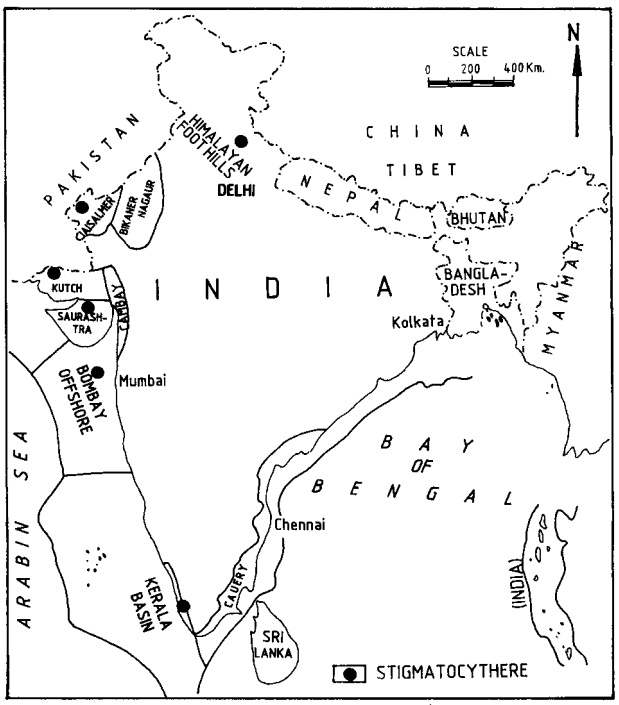


Figure 1. Map showing distribution of the genus *Stigmatocythere* in the Cenozoic succession of India.

from Lower Miocene beds of Jamnagar, Gujarat. This is characterized with reversal of overlap and hinge structure; right valve larger than left valve; hinge amphidont/heterodont; left valve consisting of projecting anterior tooth, a postjacent anteromedian socket, followed by a posteromedian groove and then a projecting reniform posterior tooth; hinge complementary in the right valve.

During the course of preparation of ostracode atlases from the West Coast of India, the author came across a rich assemblage of species of the genus *Stigmatocythere*. In all 19 species of the genus *Stigmatocythere* have been recognized from the Lower Eocene to Middle Miocene section of Rajasthan, Kachchh, Saurashtra, Bombay Offshore and Kerala basins of India (Figure 1). Stratigraphic ranges of these species were plotted and standardized with associated foraminifera (Figure 2). It was observed that some of these species have short stratigraphic ranges which can be used as zonal markers. In this paper an attempt has been made to establish evolutionary lineages in *Stigmatocythere* and to describe its biostratigraphic significance in finer subdivision of strata. Five distinct lineages have been established in the genus *Stigmatocythere* (Figures 3–7). The important taxa are illustrated in Figures 8–9 and described here briefly.

The specimens illustrated in this paper are deposited in the collection of Paleontology Laboratory, KDM Institute of Petroleum Exploration, Oil and Natural Gas Corporation Limited, Dehradun.

Previous work

Khosla (1976) for the first time described three species of the genus *Stigmatocythere* from the Lower Miocene beds of Saurashtra, India. These were *Stigmatocythere latebrosa* (Lyubimova and Guha), *Stigmatocythere chaasraensis* (Guha), and, in addition, *Stigmatocythere reversa*, which has reversed overlap of valve and hinge. Mehra (1980) recorded the above three species along with another new species of *Stigmatocythere* from the Lower Miocene beds of Kachchh.

Khosla and Pant (1988) recognised four species of the genus *Stigmatocythere* from the Eocene-Oligocene section of Kachchh. They are *Stigmatocythere* (*S.*) *portentum* Siddiqui from Babia, Middle Eocene section, Kachchh and *Stigmatocythere* (*S.*) *bermotiensis* Khosla and Pant, *S.* (*S.*) *reticulata* Khosla and Pant and *Stigmatocythere* (*Bhatiacythere*) *khariensis* Khosla and Pant from the Oligocene of Ramania and Waior sections of Kachchh. Later, Khosla and Nagori (1988) recorded nine species of *Stigmatocythere* from the Quilon beds (Lower Miocene) of Kerala. Of these, four species, namely *Stigmatocythere* (*S.*) *chaasraensis* (Guha), *S.* (*S.*) *latebrosa* Lyubimova and Guha, *Stigmatocythere* (*S.*) *multicostata* Khosla and Nagori and *S.* (*S.*) *quilonensis* Khosla and Nagori have normal overlap and hinge structure and are assigned to the subgenus *Stigmatocythere*, while the other five show a reversal of overlap and hinge structure. To accommodate this group Khosla and Nagori (1988) erected a new subgenus *Bhatiacythere* and put the following species in it: *Stigmatocythere* (*Bhatiacythere*) *arcuata*, *S.* (*B.*) *interrupta, S.* (*B.*) *rete, S.* (*B.*) *reversa* and *S.* (*B.*) *spinosa*.

Bhandari (1991) reported *Stigmatocythere lumaria* Siddiqui from the Upper Eocene of Kharatar well-A Jaisalmer Basin Rajasthan and subsequently, Bhandari (1995, 1996) reported *Stigmatocythere* (*S.*) *obliqua* Siddiqui from the Khuiala Formation (Lower Eocene) of Jaisalmer Basin, Rajasthan and Mathur and Juyal from Kakra and Subathu formations, Himalayan foothills.

Bhandari *et al.* (2001) described and illustrated eleven species of the genus *Stigmatocythere* from the Lower and Middle Miocene beds of West Coast of India. They include: *Stigmatocythere* (*Bhatiacythere*) *arcuata* Khosla and Nagori, *S.* (*B.*) *interrupta* Khosla

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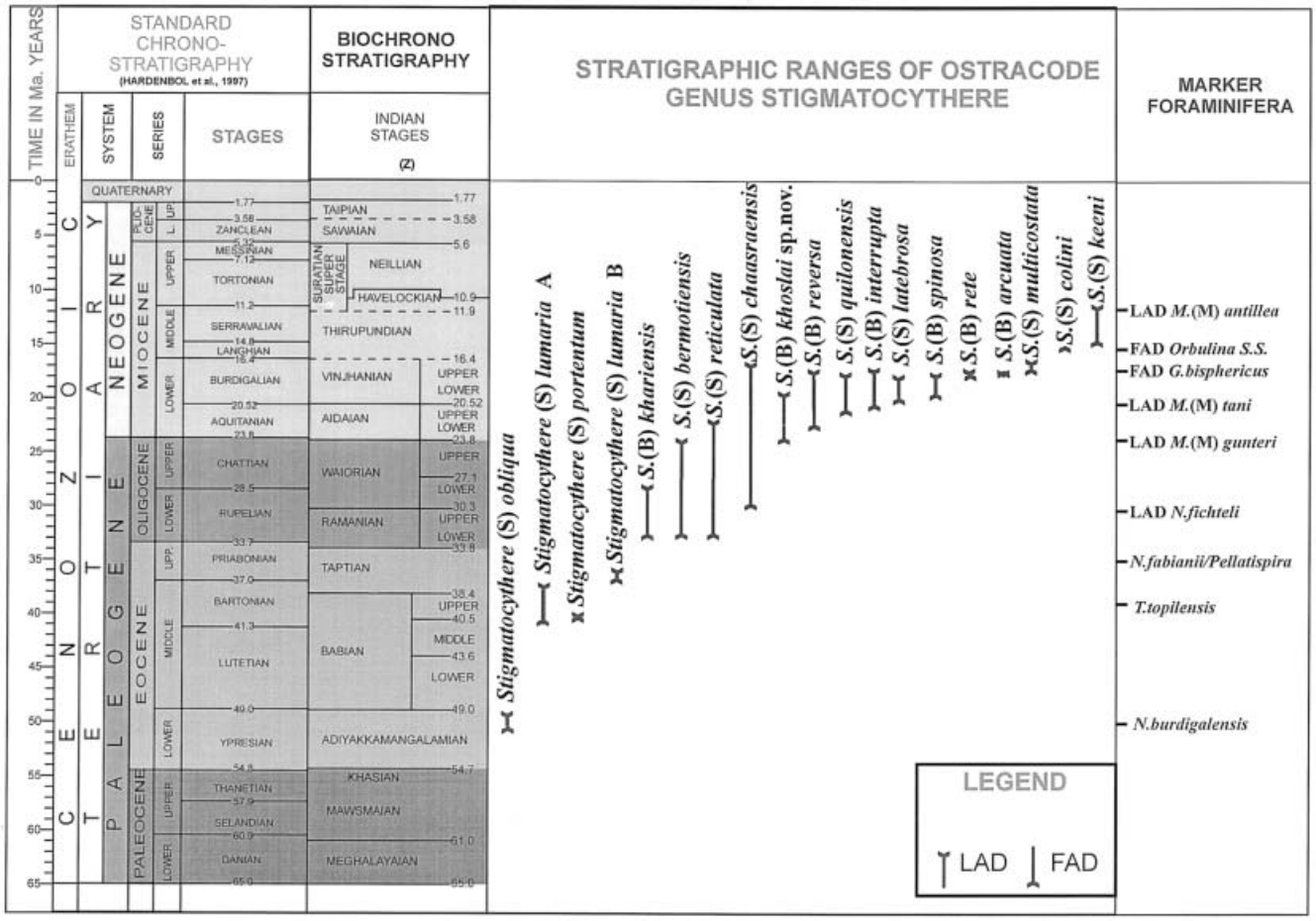


Figure 2. Stratigraphic ranges of ostracode genus *Stigmatocythere* during Cenozoic of India.

and Nagori, *S.* (*B.*) *rete* Khosla and Nagori, *S.* (*B.*) *reversa* Khosla, *S.* (*B.*) *spinosa* Khosla and Nagori, *Stigmatocythere* (*S.*) *chaasraensis* (Guha), *S.* (*S.*) *colini* Bhandari, *S.* (*S.*) *keeni* Bhandari, *S.* (*S.*) *latebrosa* (Lyubimova and Guha), *S.* (*S.*) *multicostata* Khosla and Nagori and *S.* (*S.*) *quilonensis* Khosla and Nagori.

Biostratigraphic significance

Nineteen species of the genus *Stigmatocythere* have been recognized from the Eocene-Middle Miocene sediments of India. Of these, one species each is confined to the Lower Eocene; Middle Eocene; Upper Eocene; Lower Oligocene and Lower Miocene (Aquitanian); six species to the Lower Miocene (Burdigalian) and two species to the Middle Miocene. A detailed biostratigraphic analysis is given below.

Lower Eocene

Stigmatocythere (*S.*) *obliqua* is the oldest known species of the genus *Stigmatocythere* recorded from the Cenozoic beds of India. This species is confined to the upper part of the Lower Eocene in Pakistan and India. However, Reyment (1963) reported the genus *Stigmatocythere* from West Nigeria and extended its range up to the Paleocene.

Middle Eocene

In the western part of India and Pakistan *Stigmatocythere* (*S.*) *portentum* and *S.* (*S.*) *lumaria* morphotype A are confined to the upper part of the Middle Eocene.

Remarks.—Siddiqui (1971) reported *Stigmatocythere* (*S.*) *delineate* and *S.* (*S.*) *calia* from the Middle Eocene of Zao River section, Pakistan. These species are restricted to Middle Eocene and so far it has not been reported from India.

Upper Eocene

Only *Stigmatocythere* (*S.*) *lumaria* morphotype B is restricted to Late Eocene of Pakistan and western part of Indian basins.

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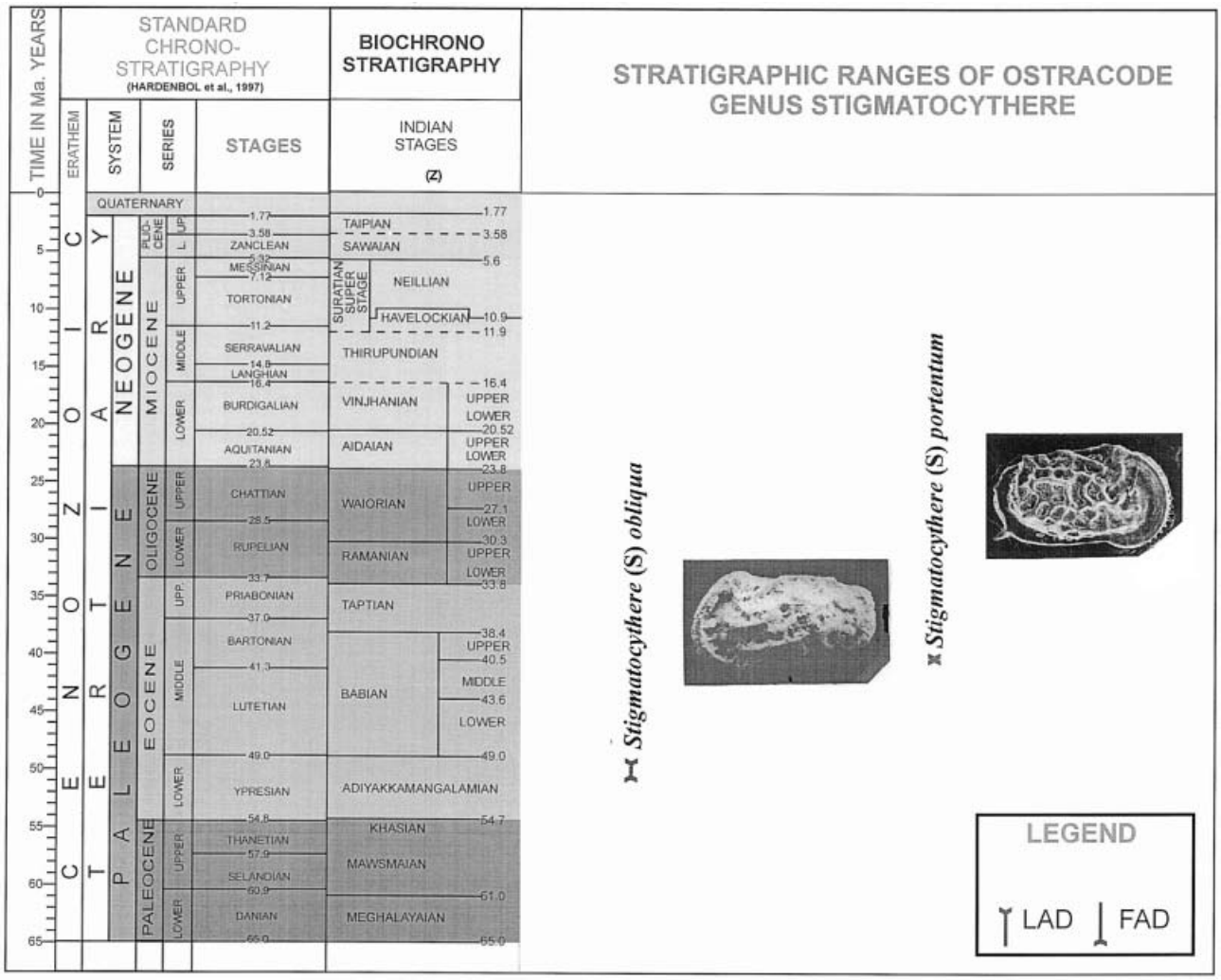


Figure 3. Stratigraphic ranges and distribution of *Stigmatocythere* (*S.*) *obliqua* – *S.* (*S.*) *portentum* lineage in the Cenozoic succession of India.

Oligocene

One species *Stigmatocythere* (*Bhatiacythere*) *khariensis* Khosla and Pant is restricted to the Lower Oligocene while *S.* (*S.*) *bermotiensis* Khosla and Pant ranges up to the Upper Oligocene, *S.* (*S.*) *reticulata* ranges to Lower Miocene (Aquitanian) and *S.* (*S.*) *chaasraensis* Guha ranges from uppermost Lower Oligocene to Lower Miocene (middle Burdigalian).

Lower Miocene

Aquitanian.—Only one species *S.* (*B.*) *khoslai* sp. nov. is restricted to the Aquitanian, while *S.* (*S.*) *quilonensis* Khosla and Nagori and *S.* (*Bhatiacythere*) *reversa* Khosla range up to the Burdigalian.

Burdigalian.—Six species are restricted to the Burdigalian. They are: *Stigmatocythere* (*S.*) *latebrosa* Lyubimova, Mohan and Guha, *S.* (*B.*) *spinosa* Khosla and Nagori, *S.* (*B.*) *rete* Khosla and Nagori, *S.* (*B.*) *arcuata* Khosla and Nagori, *S.* (*S.*) *multicostata* Khosla and Nagori and *S.* (*B.*) *interrupta* Khosla and Nagori.

Middle Miocene

Two species are confined to the Middle Miocene. They are *Stigmatocythere* (*S.*) *colini* Bhandari and *S.* (*S.*) *keeni* Bhandari.

Paleogeography

The geographic distribution of the genus *Stigmatocythere* has been discussed by Siddiqui (1982) and

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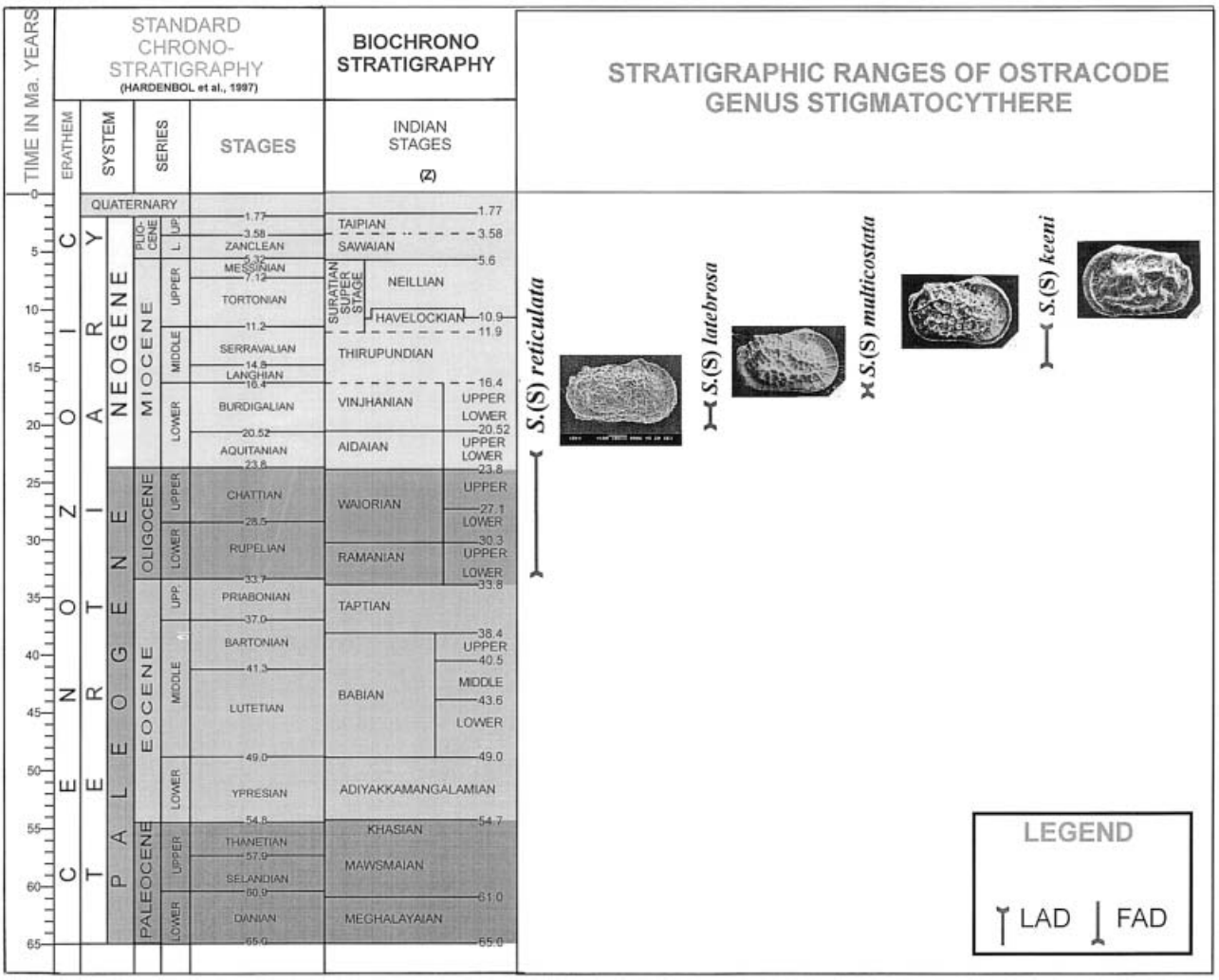


Figure 4. Stratigraphic ranges and distribution of *Stigmatocythere* (*S.*) *reticulata* – *S.* (*S.*) *keeni* lineage in the Cenozoic succession of India.

Khosla and Nagori (1988). In India this genus has been recorded from the Eocene of Kachchh (Khosla and Pant, 1988), Rajasthan (Bhandari, 1991, 1996); Oligocene of Kachchh (Khosla and Pant, 1988); Lower Miocene of Kachchh (Lyubimova *et al.*, 1960; Guha, 1961; Mehra, 1980; Bhandari *et al.*, 2001; Bhandari, 2002), Saurashtra (Khosla, 1976), Kerala (Khosla and Nagori, 1988), Cauvery Basin (Lyubimova *et al.*, 1960) and Middle Miocene of Bombay Offshore (Bhandari *et al.*, 2001). It occurs in the Paleocene of central Sahara and western Nigeria (Reyment, 1963), Eocene of Pakistan (Siddiqui, 1971, 1982), and offshore South Africa and Oligocene-Miocene of Tanzania (Ahmed *et al.*, 1991). The occurrence of the genus *Stigmatocythere* between western Asia and East Africa suggests that a sea connection existed during Cenozoic times.

Systematic paleontology

Subclass Ostracoda Latreille, 1806
Order Podocopida Muller, 1894
Suborder Podocopina Sars, 1866
Superfamily Cytheracea Baird, 1850
Family Trachyleberididae Sylvester-Bradley, 1948
Subfamily Trachyleberidinae Sylvester-Bradley, 1948
Tribe Costaini Hartmann and Puri, 1974
Genus ***Stigmatocythere*** Siddiqui, 1971

The genus *Stigmatocythere* was erected by Siddiqui (1971) and is divided into two subgenera. They are *Stigmatocythere* s.s. with normal overlap and hinge structure and subgenus *Bhatiacythere* with reversed overlap and hinge structure. The following species of

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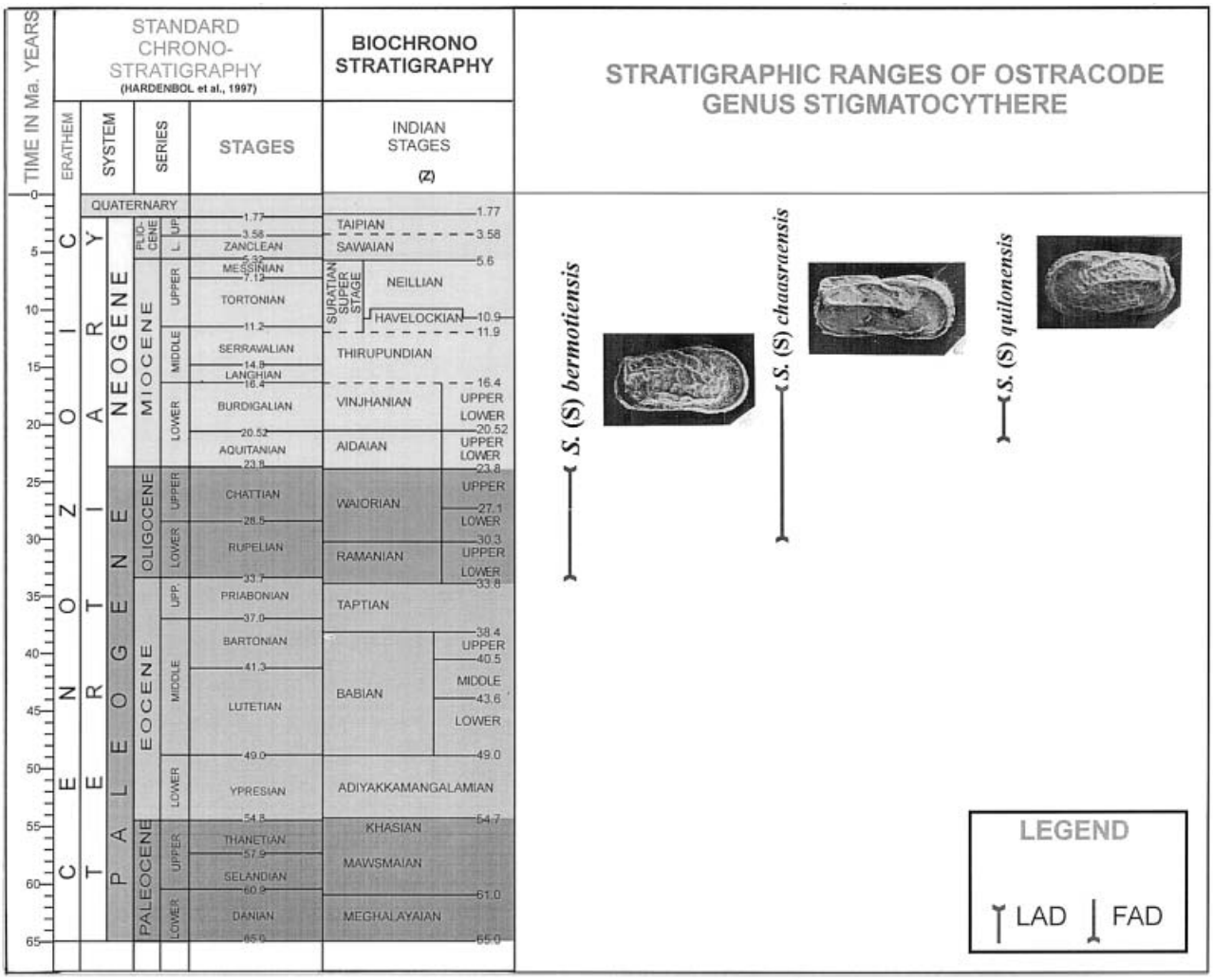


Figure 5. Stratigraphic ranges and distribution of *Stigmatocythere* (*S.*) *bermotiensis* – *S.* (*S.*) *quilonensis* lineage in the Cenozoic succession of India.

the subgenus *Stigmatocythere* are recorded in the present work.

1. *Stigmatocythere* (*Stigmatocythere*) *bermotiensis* Khosla and Pant, 1988
2. *S.* (*S.*) *chaasraensis* (Guha, 1961)
3. *S.* (*S.*) *colini* Bhandari, 2001
4. *S.* (*S.*) *keeni* Bhandari, 2001
5. *S.* (*S.*) *latebrosa* (Lyubimova and Guha, 1960)
6. *S.* (*S.*) *lumaria* Siddiqui, 1971
7. *S.* (*S.*) *multicostata* Khosla and Nagori, 1988
8. *S.* (*S.*) *obliqua* Siddiqui, 1971
9. *S.* (*S.*) *portentum* Siddiqui, 1971
10. *S.* (*S.*) *quilonensis* Khosla and Nagori, 1988
11. *S.* (*S.*) *reticulata* Khosla and Pant, 1988

The following species are recorded in the subgenus *Bhatiacythere*.

1. *Stigmatocythere* (*Bhatiacythere*) *arcuata* Khosla and Nagori, 1988
2. *S.* (*B.*) *interrupta* Khosla and Nagori, 1988
3. *S.* (*B.*) *khariensis* Khosla and Pant, 1988
4. *S.* (*B.*) *khoslai* sp. nov.
5. *S.* (*B.*) *rete* Khosla and Nagori, 1988
6. *S.* (*B.*) *reversa* Khosla and Nagori, 1988
7. *S.* (*B.*) *spinosa* Khosla and Nagori, 1988

Subgenus ***Stigmatocythere*** s.s.

The following species of this subgenus are described here briefly.

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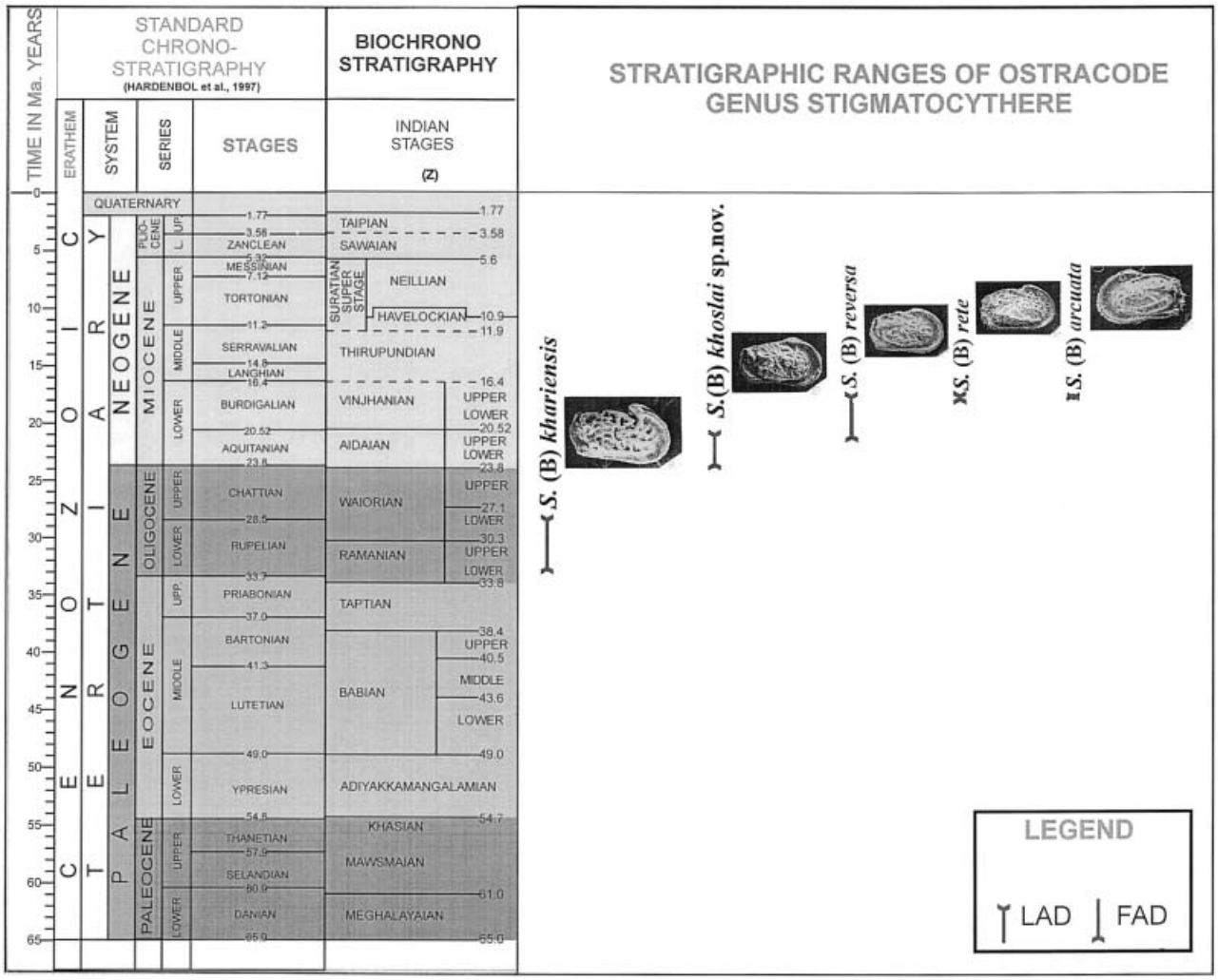


Figure 6. Stratigraphic ranges and distribution of *Stigmatocythere* (*B.*) *khariensis* – *S.* (*B.*) *arcuata* lineage in the Cenozoic succession of India.

Stigmatocythere (*Stigmatocythere*) *bermotiensis* Khosla and Pant, 1988

Figure 8.1

Stigmatocythere (*S.*) *bermotiensis* Khosla and Pant, 1988, p. 342–343, fig. 3D–E.

Locality and horizon.—Banks of the Waior-Charopadi stream, 0.3 km north-northwest of Waior village (sample W/1), section III (Khosla and Pant, 1988), yellowish brown limestone of Zone VI – *Actinocythereis ramaniaensis*.

Diagnostic characters.—Carapace subrectangular in lateral outline; dorsal margin straight, obscured posteriorly by overhanging ridge. Valve surface with broad reticulation marked by subcentral tubercle; two ridges originate from eye tubercle, characteristic of the genus; three longitudinal ridges, dorsal, median and ventral; first two joined posteriorly by a vertical ridge.

Figured specimen.—Male carapace, 0.63 mm long.

Distribution.—Lower and Upper Oligocene, Kachchh and Lower Oligocene, Bombay High.

Stigmatocythere (*Stigmatocythere*) *chaasraensis* (Guha, 1961)

Figure 8.2

Occultocythereis chaasraensis Guha, 1961, p. 4–5, figs. 8, 10, 13.

Stigmatocythere chaasraensis (Guha). Khosla, 1976, p. 136–137, pl. 1, figs. 7–9; Khosla, 1978, p. 271, pl. 5, fig. 2, pl. 6, fig. 16.

Stigmatocythere (*Stigmatocythere*) *chaasraensis* (Guha). Khosla and Nagori, 1988, p. 110–111, pl. 1, fig. 1; Khosla and Nagori, 1990, pl. 3, fig. 1; Bhandari *et al.*, 2001, p. 154, pl. 135, figs. 1, 2.

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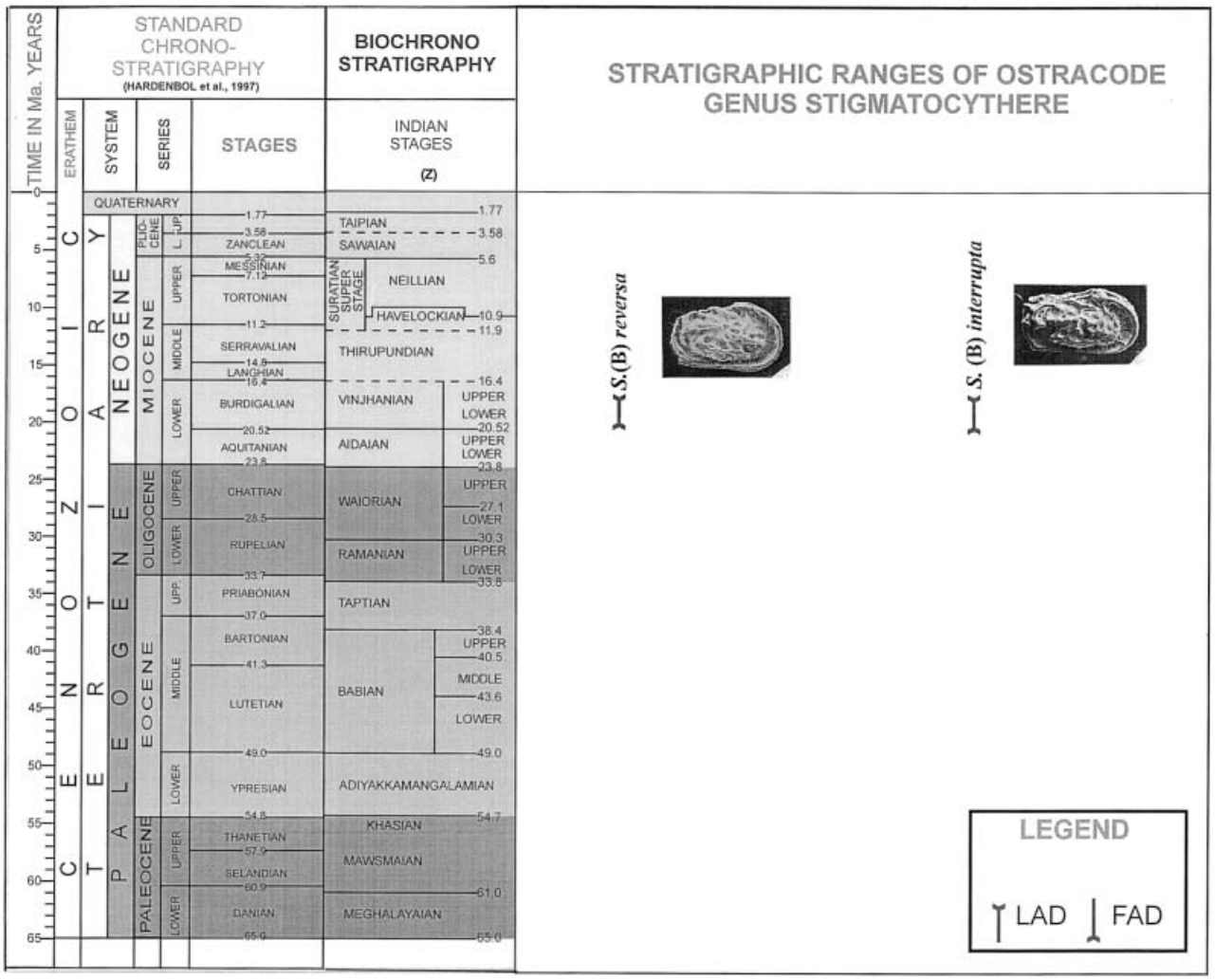


Figure 7. Stratigraphic ranges and distribution of *Stigmatocythere* (*B.*) *reversa* – *S.* (*B.*) *interrupta* lineage in the Cenozoic succession of India.

Locality and horizon.—About 2.5 km northeast of Chaasra village upstream of Khari stream, Kachchh, Gujarat. Buff-color claystone, Chaasra Formation, Lower Miocene.

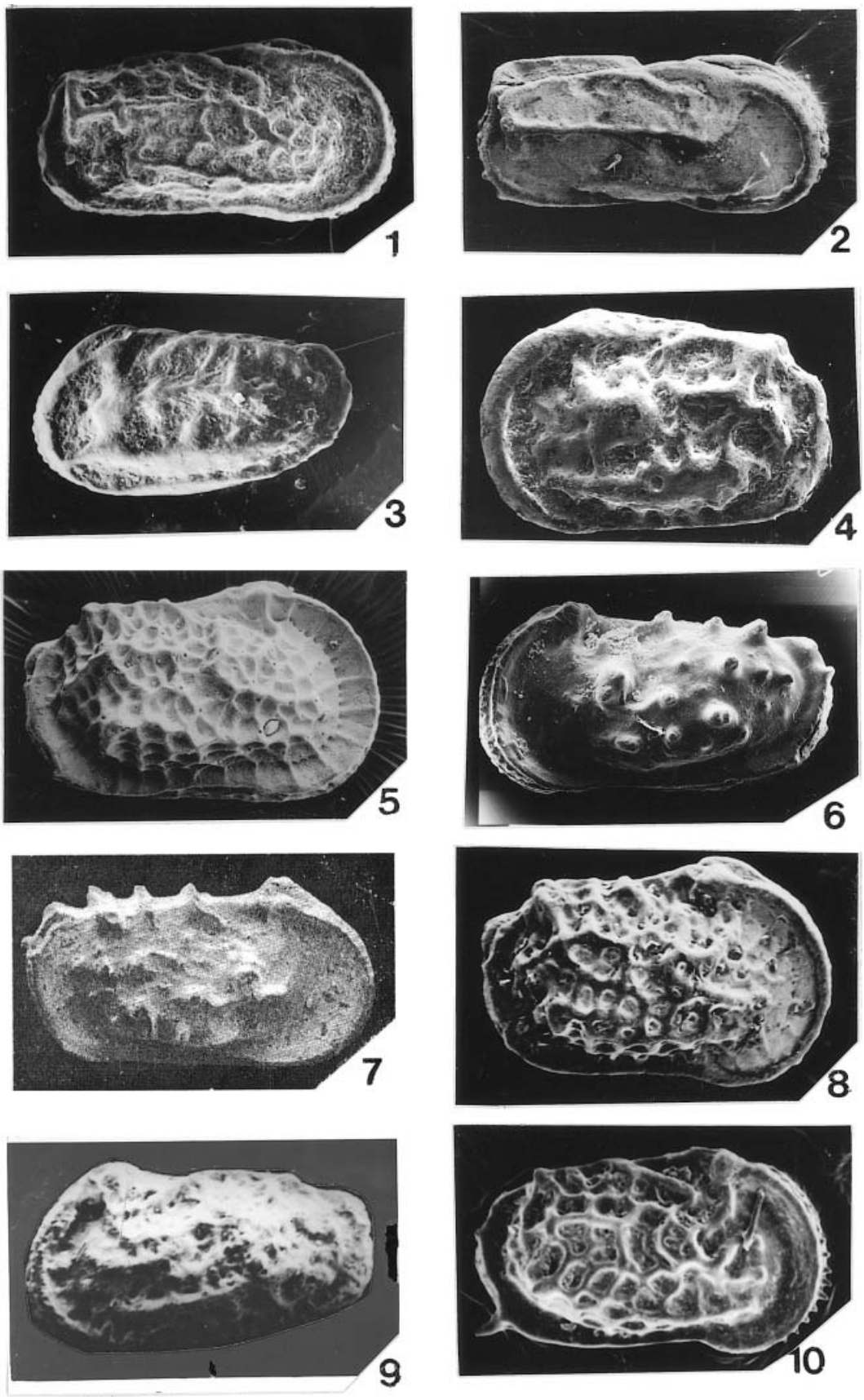
Diagnostic characters.—The species has a subrectangular carapace, compressed in lateral outline. Ventral margin slightly concave in middle; three longitudinal ridges, dorsal, median and ventral; dorsal and median ridges joined posteriorly by a vertical ridge; rest of area smooth.

Figured specimen.—Male carapace (IPE/BO2/04/9015), 0.55 mm long.

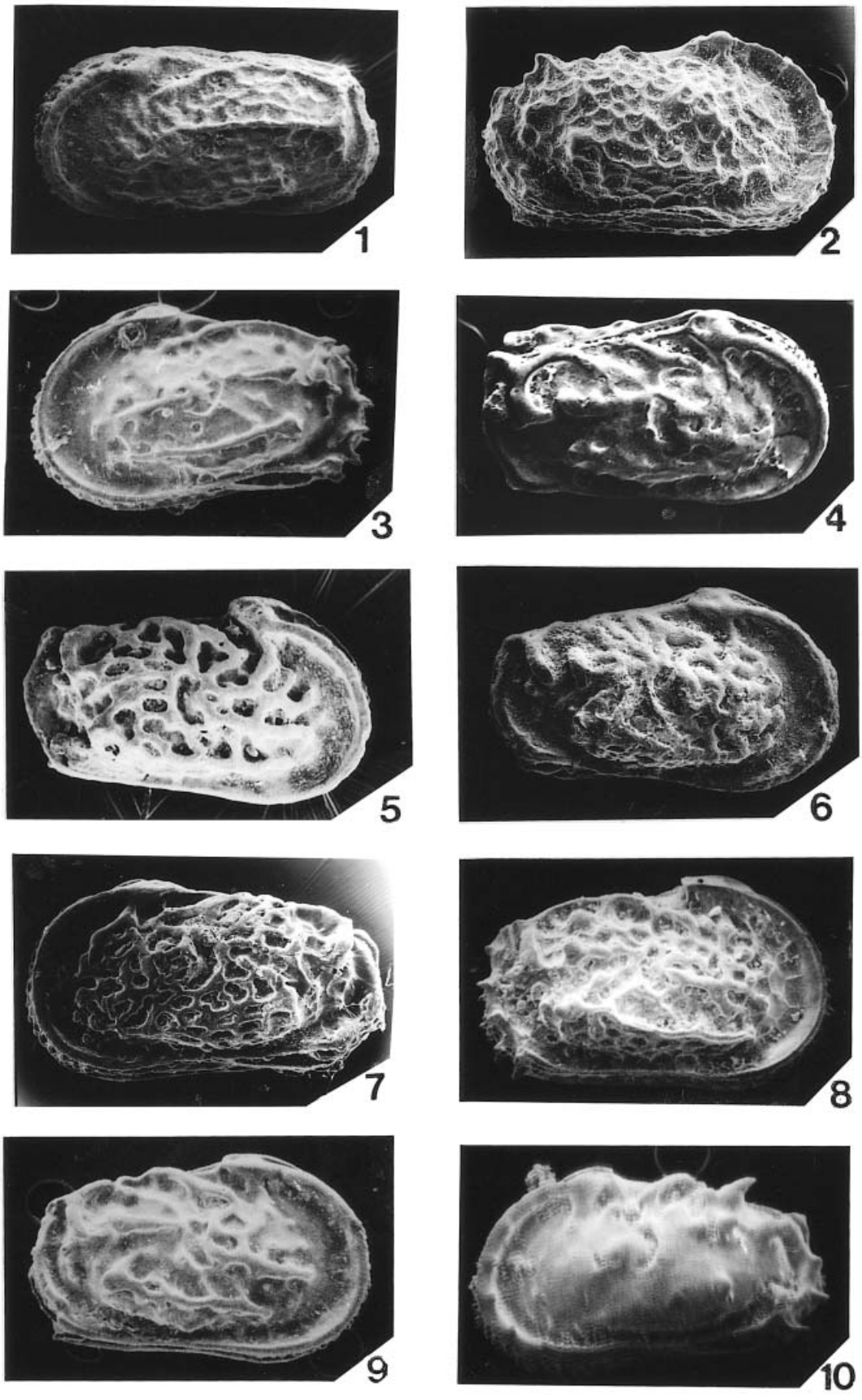
Distribution.—Upper Oligocene to Lower Miocene (middle Burdigalian), Lower Miocene (Aquitanian

➡ **Figure 8.** **1.** *Stigmatocythere* (*Stigmatocythere*) *bermotiensis* Khosla and Pant, male carapace, right valve view, ×86. **2.** *Stigmatocythere* (*S.*) *chaasraensis* (Guha), male carapace, (IPE/B02/04/915), right valve view, ×104. **3.** *Stigmatocythere* (*S.*) *colini* Bhandari, male carapace (IPE/H02/04/8055), right valve view, ×93. **4.** *Stigmatocythere* (*S.*) *keeni* Bhandari, male carapace, (IPE/H02/04/8057), left valve view, ×95. **5.** *Stigmatocythere* (*S.*) *latebrosa* (Lyubimova and Guha), female carapace, (IPE/B02/04/9017), right valve view, ×87. **6.** *Stigmatocythere* (*S.*) *lumaria* Siddiqui morphotype A, carapace (BOS No. 111), left valve view, ×86. **7.** *Stigmatocythere* (*S.*) *lumaria* Siddiqui morphotype B, carapace (IPE/B02/04/6790), right valve view, ×77. **8.** *Stigmatocythere* (*S.*) *multicostata* Khosla and Nagori, carapace (IPE/B02/04/9020), right valve view, ×94. **9.** *Stigmatocythere* (*S.*) *obliqua* Siddiqui, carapace (IPE/B02/04/6791) left valve view, ×77. **10.** *Stigmatocythere* (*S.*) *portentum* Siddiqui, carapace, left valve view, ×75.

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and Burdigalian) of Bombay Offshore, and Burdigalian of Saurashtra and Kerala basins.

Stigmatocythere (*Stigmatocythere*) *colini* Bhandari, 2001

Figure 8.3

Stigmatocythere (*Stigmatocythere*) *colini* Bhandari *in* Bhandari, Khosla and Nagori, 2001, p. 154, pl. 136, figs. 1, 2.

Diagnostic characters.—Carapace subrectangular in lateral outline; distinct overlap at anterior cardinal angle and at posterior margin. Eye tubercle low, depression posterior to it; subcentral tubercle distinct. Valve surface with three longitudinal ridges; dorsal ridge originates near eye tubercle and runs parallel to dorsal margin; median ridge originates from posterior to subcentral tubercle and dies out before reaching posterior margin; ventral ridge, concave down; rest of valve surface with about eight deep reticles.

Figured specimen.—Male carapace (IPE/H02/04/8055), 0.55 mm long.

Distribution.—Middle Miocene of Bombay Offshore.

Stigmatocythere (*Stigmatocythere*) *keeni* Bhandari, 2001

Figure 8.4

Stigmatocythere (*Stigmatocythere*) *keeni* Bhandari *in* Bhandari, Khosla and Nagori, 2001, p. 156, pl. 137, figs. 1–4.

Locality and horizon.—Murud Depression well A, Bombay Offshore. Sample 2250 m below surface; limestone with shale intercalation, Tapti Formation, Middle Miocene.

Diagnostic characters.—Carapace subquadrate in lateral outline. Dorsal and ventral margins straight; eye and subcentral tubercles distinct. Valve surface ornamented by broad reticulation and three thick longitudinal ridges; dorsal ridge originates just below eye tubercle, runs parallel to dorsal margin and then turns downward in posterodorsal region; median ridge originates posterior to subcentral tubercle and joins dorsal ridge; ventral ridge extends from anteroventral region backward and joins median ridge by a short vertical ridge.

Figured specimen.—Holotype (IPE/H02/04/8057), a male carapace, 0.60 mm long.

Distribution.—Middle Miocene of Bombay Offshore.

Stigmatocythere (*Stigmatocythere*) *latebrosa* (Lyubimova and Guha, 1960)

Figure 8.5

Cythereis latebrosa Lyubimova and Guha *in* Lyubimova, Guha and Mohan, 1960, p. 34–35, pl. 3, fig. 2.

Bradleya latebrosa (Lyubimova and Guha). Guha, 1968, p. 216, pl. 2, figs. 19, 21.

Stigmatocythere latebrosa (Lyubimova and Guha). Khosla, 1976, p. 137, pl. 1, figs. 10–11.

Stigmatocythere (*Stigmatocythere*) *latebrosa* (Lyubimova and Guha). Khosla and Nagori, 1988, p. 111, pl. 1, fig. 2; Khosla and Nagori, 1990, p. 91, pl. 3, fig. 2; Bhandari *et al.*, 2001, p. 156, pl. 138, figs. 1, 2.

Locality and horizon.—About 2.5 km northeast of Chaasra village upstream of Khari stream, Kachchh, Gujarat. Buff-color claystone, Chaasra Formation, Lower Miocene.

Diagnostic characters.—Carapace subquadrate in lateral outline. Ventral margin concave in the middle. Valve surface strongly reticulate and with three longitudinal ridges.

Figured specimen.—Female carapace (IPE/B02/04/9017), 0.60 mm long.

Distribution.—Lower Miocene beds of Cauvery Basin, Kachchh, Kerala, Bombay High and Saurashtra.

Stigmatocythere (*Stigmatocythere*) *lumaria* Siddiqui, 1971 morphotype A

Figure 8.6

Stigmatocythere lumaria Siddiqui, 1971, p. 75–77 (in part), pl. 37, fig. 11, pl. 38, figs. 1–10, pl. 39, fig. 11.

Locality and horizon.—Ghotaru Fort (GT-B), sample 320–325 m below surface; greenish grey argillaceous limestone, Bandah Formation, Middle Eocene.

⬅ **Figure 9.** **1.** *Stigmatocythere* (*S.*) *quilonensis* Khosla and Nagori, (IPE/B02/04/9021) male, left valve view, ×87. **2.** *Stigmatocythere* (*S.*) *reticulata* Khosla and Pant, (IPE/B02/04/9022), right valve view, ×87. **3.** *Stigmatocythere* (*Bhatiacythere*) *arcuata* Khosla and Nagori, male carapace (SU-82), left valve view, ×92. **4.** *Stigmatocythere* (*B.*) *interrupta* Khosla and Nagori, female carapace (IPE/B02/04/9623), right valve view, ×92. **5.** *Stigmatocythere* (*B.*) *khariensis* Khosla and Pant, male carapace (IPE/B02/049024), right valve view, ×51. **6.** *Stigmatocythere* (*B.*) *khoslai* sp. nov., carapace, holotype (IPE/H02/04/9025) right valve view, ×77. **7.** *Stigmatocythere* (*B.*) *khoslai* sp. nov., paratype (IPE/P02/04/9026), left valve view, ×75. **8.** *Stigmatocythere* (*B.*) *rete* Khosla and Nagori, carapace (SU-286), female, right valve view, ×87. **9.** *Stigmatocythere* (*B.*) *reversa* Khosla and Nagori, female carapace (SU290), right valve view, ×90. **10.** *Stigmatocythere* (*B.*) *spinosa* Khosla and Nagori, holotype carapace (SU 292), left valve view, ×93.

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Diagnostic characters.—Carapace subrectangular in lateral outline; dorsal margin straight, intricate due to surface ornamentation; ventral margin straight, concave near middle, prominent in right valve. Subcentral tubercle bilobate. Surface tuberculate, tubercles vary in size and number. There are three prominent tubercles in middorsal region. Eye tubercle joined to subcentral tubercle by a sharply curved ridge which is characteristic of the genus.

Figured specimen.—Hypotype (BOS No. 110), 0.70 mm long.

Distribution.—Middle Eocene, upper Chocolate Clays, Pakistan and Middle Eocene, Bandah Formation, subsurface, Jaisalmer Basin.

Stigmatocythere* (*Stigmatocythere*) *lumaria Siddiqui, 1971 morphotype B

Figure 8.7

Stigmatocythere lumaria Siddiqui, 1971, p. 75–77 (in part), pl. 39, figs. 1–8; Bhandari, 1991, p. 46, pl. 1, figs. 11, 12; Bhandari, 1996, p. 138, pl. 113, figs. 1, 2.

Locality and horizon.—Kharatar well-A, sample 335 to 340 m below surface glauconitic clays, Bandah Formation, Late Eocene.

Diagnostic characters.—It is similar to *Stigmatocythere* (*S.*) *lumaria* morphotype A, but it has surface ornamentation consisting of a combination of reticles and tubercles.

Figured specimen.—Hypotype (IPE/B02/04/6790), carapace, 0.70 mm long.

Distribution.—Upper Eocene, upper Chocolate Clays, Pakistan; Upper Eocene, glauconitic clays, Bandah Formation, subsurface of Jaisalmer Basin, Rajasthan.

Stigmatocythere* (*Stigmatocythere*) *multicostata Khosla and Nagori, 1988

Figure 8.8

Stigmatocythere (*Stigmatocythere*) *multicostata* Khosla and Nagori, 1988, p. 111–112, pl. 1, figs. 3–6; Bhandari *et al.*, 2001, p. 158, pl. 139, figs. 1–4.

Locality and horizon.—About 2.5 km northeast of Chaasra village upstream of Khari stream, Kachchh, Gujarat. Buff-color claystone, Chaasra Formation, Lower Miocene.

Diagnostic characters.—Carapace subquadrate in lateral outline. Ventral margin distinctly concave. Valve surface ornamented with broad reticulation and seven ridges, two originating from the eye tubercle, five longitudinal.

Figured specimen.—Hypotype (IPE/B02/04/9020), a male carapace, 0.58 mm long.

Distribution.—Lower Miocene of Kachchh, Kerala and Bombay High.

Stigmatocythere* (*Stigmatocythere*) *obliqua Siddiqui, 1971

Figure 8.9

Stigmatocythere obliqua Siddiqui, 1971, p. 70–71, pl. 35, figs. 1–10, pl. 36, figs. 1, 2; Bhandari, 1996, p. 138, pl. 114, figs. 1, 2; Mathur and Juyal, 2000, p. 110, pl. 21, figs. 5, 6, 15, 17, pl. 23, figs. 1–5.

Locality and horizon.—Ghotaru well-B, sample 580–585 m below surface, Khuiala Formation, Lower Eocene.

Diagnostic characters.—Carapace subrectangular in lateral view; dorsal margin straight, obscured by overreaching of dorsal ridge; ventral margin nearly straight; anterior margin broadly and obliquely rounded; posterior margin straight. Eye tubercle and subcentral tubercle distinct. Valve surface strongly reticulate with three longitudinal ridges; dorsal ridge arched convexly upwards; median ridge starts from eye tubercle, curves sharply round to join subcentral tubercle and continues posteriorly; ventral ridge slopes obliquely upward towards posterior.

Figured specimen.—Hypotype (IPE/B02/04/6791), a male carapace, 0.71 mm long.

Distribution.—Lower Eocene, Shales with Alabaster, Pakistan and Lower Eocene, Khuiala Formation, subsurface of Jaisalmer Basin, Rajasthan.

Stigmatocythere* (*Stigmatocythere*) *portentum Siddiqui, 1971

Figure 8.10

Stigmatocythere portentum Siddiqui, 1971, p. 72–73, pl. 36, figs. 3–6, 10; Khosla and Pant, 1988, p. 331.

Locality and horizon.—Escarpment 2 km north of Harudi village (23°20′30″ N: 68°41′10″ E) along banks of Rakhdi stream, south of Harudi from its crossing with Nalia-Narayan Sarovar road to the south of Rakhdi Dam, Olive-green shale, *Acanthocythereis bhujensis* Zone IV.

Diagnostic characters.—Carapace subrectangular in lateral outline; dorsal margin straight but looks irregular because of overreaching dorsal ridge; ventral margin straight; anterior and posterior cardinal angles well developed. Eye tubercle and subcentral tubercles are prominent. Surface reticulate with three longitudinal ridges; anterior margin ornamented with numerous spines.

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Figured specimen.—Carapace, right valve view, 0.71 mm long.

Distribution.—So far recorded from Middle Eocene of Kachchh.

Stigmatocythere* (*Stigmatocythere*) *quilonensis
Khosla and Nagori, 1988

Figure 9.1

Stigmatocythere (*Stigmatocythere*) *quilonensis* Khosla and Nagori, 1988, p. 112–114, pl. 1, figs. 7–10; Bhandari *et al.*, 2001, p. 158, pl. 140, figs. 1–4.

Locality and horizon.—Bombay High well-A, Bombay Offshore, sample CC#18 (1621–1639 m), Box 13/18 Bottom (1632 m), below surface argillaceous limestone, Bombay Formation, Aquitanian (Lower Miocene).

Diagnostic characters.—Carapace subrectangular in lateral outline. Ventral margin slightly concave in the middle. Valve surface ornamented by distinct reticulation and five ridges, two springing from eye tubercle and three longitudinal; dorsal ridge making an arc overhangs part of margin and then turns downward at right angles in the posterodorsal region; median ridge meets dorsal ridge at posterodorsal and ventral ridge slopes up posteriorly.

Figured specimen.—Hypotype (IPE/B02/04/9021), a male left valve view, 0.63 mm long.

Distribution.—Lower Miocene of Kerala and Bombay High.

Stigmatocythere* (*Stigmatocythere*) *reticulata
Khosla and Pant, 1988

Figure 9.2

Stigmatocythere (*Stigmatocythere*) *reticulata* Khosla and Pant, 1988, p. 343–344, fig. 3C; SG-H.

Locality and horizon.—Bombay High well SW#F, Bombay Offshore, sample CC#4 (1921–1930 m), Box 6/11 Bottom, calcareous limestone, Mukta Formation, Lower Miocene.

Diagnostic characters.—Carapace subquadrate in lateral outline. Valve surface strongly reticulate and three faint longitudinal ridges.

Figured specimen.—Hypotype (IPE/B02/04/9022), carapace, right valve view, 0.63 mm long.

Distribution.—Oligocene of Kachchh and Lower Miocene (Aquitanian), Bombay High.

Subgenus ***Bhatiacythere*** Khosla and Nagori, 1988

Stigmatocythere* (*Bhatiacythere*) *arcuata Khosla and Nagori, 1988

Figure 9.3

Stigmatocythere (*Bhatiacythere*) *arcuata* Khosla and Nagori, 1988, p. 115, pl. 1, figs. 11–13; Bhandari *et al.*, 2001, p. 148, pl. 130, figs. 1–4.

Locality and horizon.—Sankaramanglam well 4, Kerala. Sample S/19, 40.54–46.63 m below the surface, bluish-grey sticky clay, Quilon beds, Lower Miocene.

Diagnostic characters.—A species of the subgenus *Bhatiacythere* with reversed overlap and hinge structure. Valve surface ornamented by two ridges that spring from eye tubercle; three longitudinal ridges, dorsal, median and ventral; dorsal ridge making a broad arc and overhanging margin; two small oblique ridges; rest of area with indistinct reticulation.

Figured specimen.—Holotype (SU282), a male left valve view, 0.60 mm long.

Distribution.—Lower Miocene of Kerala.

Stigmatocythere* (*Bhatiacythere*) *interrupta
Khosla and Nagori, 1988

Figure 9.4

Stigmatocythere (*Bhatiacythere*) *interrupta* Khosla and Nagori, 1988, p. 115–117, pl. 2, figs. 1–4; Bhandari *et al.*, 2001, p. 150, pl. 131, figs. 1–4.

Locality and horizon.—Bombay High well SN#F, Bombay Offshore, sample CC#3 (1405–1423 m), Box 5/10 Bottom, calcareous limestone, Bombay Formation, Lower Miocene.

Diagnostic characters.—Valve surface ornamented by four longitudinal ridges, of which two are dorsal, one median and one ventral; upper dorsal ridge originates below eye tubercle and runs up to dorsal margin; lower dorsal ridge extends from posterodorsal corner to subcentral tubercle to dorsal margin, where it overhangs at right angles in the posterodorsal region; median ridge runs posterior to subcentral tubercle and does not join lower dorsal ridges; ventral ridge starts from anteroventral region and rises posteriorly; rest of area either smooth or with indistinct reticulation.

Figured specimen.—Holotype (SU284), a male right valve view, 0.60 mm long.

Distribution.—Lower Miocene of Kachchh, Kerala and Bombay High.

Stigmatocythere* (*Bhatiacythere*) *khariensis
Khosla and Pant, 1988

Figure 9.5

Stigmatocythere (*Bhatiacythere*) *khariensis* Khosla and Pant, 1988, p. 344–345, fig. 5BF.

Locality and horizon.—Escarpment 2 km north of

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Harudi village (23°20′30″ N, 68°41′10″ E) along banks of the Rakhdi stream, south of Harudi from its crossing with the Naliya – Narayan Sarovar road to the south of Rakhdi dam, section II (Khosla and Pant, 1988). Pale yellow sandy limestone of Zone VI – *Actinocythereis ramaniaensis* Zone (sample H-17).

Diagnostic characters.—Carapace subrectangular in lateral outline; valve surface with prominent subcentral tubercle and deep reticulation, raised edges of recticle meshes look like ridges; three distinct longitudinal ridges; dorsal ridge originates above subcentral tubercle making an arc and overhanging margin and turns downward at right angles in posterodorsal area; median ridge extends posterior to subcentral tubercle and meets dorsal ridge posteriorly; ventral ridge sloping upward to posteroventral.

Figured specimen.—Holotype, a female carapace, 0.64 mm long.

Distribution.—Lower Oligocene, Kachchh and Bombay Offshore.

Stigmatocythere* (*Bhatiacythere*) *khoslai sp. nov.

Figures 9.6–7

Name.—The species is named in honor of the retired ostracodologist Prof. S.C. Khosla, Department of Geology, M.L. Sukhadia University, Udaipur, Rajasthan.

Material.—Twenty-six carapaces from well BH#A.

Type locality and horizon.—Bombay High well-A, Bombay Offshore. Sample CC#14 (1559–1577 m) Box 5/18 (1564 m), below surface, argillaceous limestone, Bombay Formation, Aquitanian (Lower Miocene).

Description.—Carapace subrectangular in lateral view, with greatest height at anterior cardinal angle; right valve slightly larger than left valve, overlapping at anterodorsal and posterodorsal margins; dorsal margin straight, obscured by dorsal ridge; ventral margin concave in the middle; anterior margin broadly rounded; anterior marginal area smooth; posterior margin subrounded. Eye and subcentral tubercles distinct. Valve surface ornamented by two ridges which spring from the eye tubercle, one forms a high rim along the anterior, ventral and posterior margins, other turns and joins subcentral tubercle, where it recurves and runs anteriorly; three prominent longitudinal ridges; a dorsal ridge originates below subcentral tubercle, runs parallel to dorsal margin and overhangs it posteriorly; median ridge smaller, runs posterior to subcentral tubercle and does not join dorsal ridge posteriorly; a short inclined ridge starts from dorsomedian to subcentral tubercle, there are 2–3 short inclined ridges in the anterodorsal region; ventral ridge starts near anteroventral to posteroventral. Valve surface ornamented by deep reticles.

Dimensions (mm).—

	Length	Height	Width
Holotype (IPE/H02/04/9025), carapace	0.70	0.42	0.40
Paratype (IPE/P02/04/9026), carapace	0.68	0.42	0.42

Discussion.—The species resembles *Stigmatocythere* (*Bhatiacythere*) *reversa* Khosla (1976), in overall shape and surface ornamentation. It differs, however, in having 2–3 short inclined ridges in anterodorsal region. The species seems to have evolved from *S.* (*B.*) *reversa*.

Occurrence.—Lower Miocene (Aquitanian) of Bombay High.

Stigmatocythere* (*Bhatiacythere*) *rete Khosla and Nagori, 1988

Figure 9.8

Stigmatocythere (*Bhatiacythere*) *rete* Khosla and Nagori, 1988, p. 117–118, pl. 2, figs. 5–8; Bhandari *et al.*, 2001, p. 150, pl. 132, figs. 1–4.

Locality and horizon.—Paravur, Kerala, sample PR/4, bluish-grey calcareous clay, Quilon beds, Lower Miocene.

Diagnostic characters.—Valve surface ornamented by strong reticulation, meshes arranged concentrically; dorsal ridge originates below eye tubercle, making an arc overhanging posterior part of the margin, turns downward at right angles in the posterodorsal region and bear three nodes; median ridge less distinct and does not join the dorsal ridge; ventral ridge prominent.

Figured specimen.—Holotype (SU286), a female right valve, 0.63 mm long.

Distribution.—Lower Miocene of Kerala.

Stigmatocythere* (*Bhatiacythere*) *reversa Khosla, 1976

Figure 9.9

Stigmatocythere reversa Khosla, 1976, p. 137–138, pl. 1, figs. 1–6; Khosla, 1978, p. 271, pl. 5, figs. 3–5, pl. 6, fig. 17.

Stigmatocythere (*Bhatiacythere*) *reversa* Khosla and Nagori, 1988, p. 118, pl. 2, figs. 9, 10; Bhandari *et al.*, 2001, p. 152, pl. 133, figs. 1, 2.

Locality and horizon.—Near kilometer stone 186/6 on Jamnagar-Dawarka State Highway No. 25, about

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midway between Nandana and Bhatia villages, Jamnagar District, Gujarat, Light-yellow marlstone (sample III/1), Lower Miocene.

Diagnostic characters.—Valve surface ornamented by sparse reticulation, edges of reticulation meshes raised to low ridges giving rugged appearance; two ridges spring from eye tubercle; three longitudinal ridges, dorsal, median and ventral, the first two do not join posteriorly; a short inclined ridge extending towards subcentral tubercle from middle of the dorsal ridge.

Figured specimen.—Female carapace (SU290), 0.60 mm long.

Distribution.—Lower Miocene of Kachchh, Kerala, Bombay High and Saurashtra.

Stigmatocythere* (*Bhatiacythere*) *spinosa Khosla and Nagori, 1988

Figure 9.10

Stigmatocythere (*Bhatiacythere*) *spinosa* Khosla and Nagori, 1988, p. 118–119, pl. 2, figs. 11–13; Bhandari *et al.*, 2001, p. 152, pl. 134, figs. 1–4.

Locality and horizon.—Sankaramanglam well-4, Kerala. Sample S/15, 64.92–68.88 m below the surface, bluish-grey clay with limestone, Quilon beds, Lower Miocene.

Diagnostic characters.—Valve surface ornamented by two ridges springing from eye tubercle; dorsal and median lines of ornamentation composed of spines/nodes, and a low ventral ridge terminating in a spine; a crescent-shaped depression posterior to subcentral tubercle; rest of area smooth.

Figured specimen.—Holotype (SU 292), left valve, 0.59 mm long.

Distribution.—Lower Miocene of Kerala and Bombay High.

Evolutionary lineages

The evolutionary trends in the genus *Stigmatocythere* were discussed by Khosla and Pant (1988) and Khosla and Nagori (1988). The origin of the genus is not known but the oldest species of this genus is reported from the Paleocene of West Nigeria by Reyment (1963). However, in India and Pakistan the oldest species of the genus is recorded from the Lower Eocene. In all nineteen species of *Stigmatocythere* are recorded from India. On the basis of their shape, size, overlap, ornamentation and internal hinge structure, five probable evolutionary lineages have been worked out. They are described here briefly.

1. *Stigmatocythere obliqua* – *S.* (*S.*) *portentum* lineage

This lineage begins with *S.* (*S.*) *obliqua* and ends with *S.* (*S.*) *portentum*. The lifespan of this lineage is about 10.5 Ma spanning from 51 to 40.5 Ma. The oldest known species of the genus *Stigmatocythere* is represented by *S.* (*S.*) *obliqua*. It appears in the Lower Eocene as recorded for the first time by Siddiqui (1971) from the Shales with Alabaster, Rakhi Nala section, Pakistan. This species is characterized by having strongly reticulate valve surface with two ridges springing from eye tubercle, one ridge forms high anterior ridge along anterior margin and another ridge joins less developed subcentral tubercle and three well developed longitudinal ridges including an oblique ventral ridge. It evolves at higher stratigraphic levels and gives rise to *Stigmatocythere* (*S.*) *portentum*, which is large in size, carapace characterized by having shallow reticulation and a prominent subcentral tubercle. It has been recorded from the uppermost part of the Middle Eocene (Figure 3).

Occurrence.—*Stigmatocythere* (*S.*) *obliqua* has been recorded from the Lower Eocene of Pakistan and the uppermost part of the Lower Eocene, Jaisalmer Basin Rajasthan and *S.* (*S.*) *portentum* from the upper part of Middle Eocene of Pakistan and Kachchh.

Remarks.—The intermediate forms of this lineage has not been recorded.

2. *Stigmatocythere* (*S.*) *reticulata* – *S.* (*S.*) *latebrosa* – *S.* (*S.*) *multicostata* – *S.* (*S.*) *keeni* lineage

This lineage begins with *S.* (*S.*) *reticulata* and ends with *S.* (*S.*) *keeni*, with *S.* (*S.*) *latebrosa* and *S.* (*S.*) *multicostata* as middle members (Figure 4). This lineage spans about 33.0 Ma to 11.2 Ma. *Stigmatocythere* (*S.*) *reticulata* seems to be the ancestral form to *S.* (*S.*) *latebrosa*, which was recorded by Khosla and Pant (1981) from the Lower Oligocene of Kachchh. This species continues up to the middle part of the Aquitanian in the Bombay Offshore Basin. It is characterized by strongly reticulate valve surface with three faintly developed longitudinal ridges. This species evolved during the early Burdigalian and gave rise to *S.* (*S.*) *latebrosa* (Lyubimova and Guha). It has a larger-size carapace compared to the ancestral *S.* (*S.*) *reticulata* and strongly developed longitudinal ridges. This species continued up to the middle Burdigalian (N6 Middle) and further evolved and gave rise to *S.* (*S.*) *multicostata* by development of two additional longitudinal ridges between median and ventral. It continues up to the end of the Burdigalian (16.4 Ma) and further evolved to gave rise to *S.* (*S.*) *keeni* during the early Middle Miocene and went extinct near the end of the Middle Miocene. It is characterized by having a

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thick anterior marginal ridge, three thick longitudinal ridges and broad reticulations and a prominent subcentral tubercle.

Remarks.—The intermediate form between *S.* (*S.*) *reticulata* and *S.* (*S.*) *latebrosa* has not been recorded in this work. However, the form similar to *S.* (*S.*) *bormharditi* Ahmed, Neale and Siddiqui (1991) recorded from the Oligo-Miocene of Tanzania is expected to occur in the Indian material. A more detailed work on the Oligocene-Miocene of the Indian basins is in progress.

3. *Stigmatocythere* (*S.*) *bermotiensis* – *S.* (*S.*) *chaasraensis* – *S.* (*S.*) *quilonensis* lineage

This lineage begins with *S.* (*S.*) *bermotiensis* and ends with *S.* (*S.*) *quilonensis*, with *S.* (*S.*) *chaasraensis* as an intermediate member (Figure 5). This lineage spans about 33.0 Ma to 17.5 Ma. *Stigmatocythere* (*S.*) *bermotiensis* is the oldest taxa of this lineage and was described by Khosla and Pant (1981) from the Lower Oligocene sediments of Kachchh. It is characterized by three longitudinal ridges: dorsal, median and ventral. Dorsal and median ridges joined posteriorly by vertical ridge and rest of valve surface coarsely reticulate. This species continued and it evolved to *Stigmatocythere* (*S.*) *chaasraensis* (Guha) in the latest Late Oligocene. The species continued up to early Miocene (middle Burdigalian). This species is characterized by smooth valve surface. In the lower part of the Aquitanian this species further evolved and gave rise to *S.* (*S.*) *quilonensis*, which has a fine reticulate valve surface and continued up to upper Burdigalian.

4. *Stigmatocythere* (*Bhatiacythere*) *khariensis* – *S.* (*B.*) *khoslai* sp. nov. – *S.* (*B.*) *reversa* – *S.* (*B.*) *rete* – *S.* (*B.*) *arcuata* lineage

This lineage begins with *S.* (*B.*) *khariensis* and ends with *S.* (*B.*) *arcuata*, with middle members *S.* (*B.*) *khoslai* sp. nov., *S.* (*B.*) *reversa* and *S.* (*B.*) *rete*. This lineage spans about 33.0 Ma to 17.5 Ma. The oldest member of this lineage *Stigmatocythere* (*B.*) *khariensis* Khosla and Pant (1988) appeared during the earliest Oligocene and seems to be ancestral to *S.* (*B.*) *khoslai* sp. nov. It is characterized by a right valve larger than left valve and three distinct longitudinal ridges: dorsal ridge originates above subcentral tubercle, making an arc overhanging margin and then turns downward at right angles in posterodorsal area; median ridge starts from subcentral tubercle and takes sharp turn around subcentral tubercle and continues posteriorly where it meets dorsal ridge; ventral ridge runs from anteroventral to posteroventral areas; valve surface deeply reticulate, raised edges of reticulate muri appear like ridges and a distinct marginal ridge. This species continues toward the end of the Early Oligocene and evolves at a higher stratigraphic level near the base of the Aquitanian to give rise to *S.* (*B.*) *khoslai* sp. nov. In this species the median ridge does not join posteriorly; the dorsal ridge is posterodorsal and there is an additional development of 2–3 inclined ridges between middorsal and anterodorsal; valve surface reticulate and other characters are more or less the same as *S.* (*B.*) *khariensis*. This species continues toward the end of the Aquitanian, where it further evolves to give rise to *S.* (*B.*) *reversa*. This species has only a hort inclined ridge extending towards subcentral tubercle from middle of dorsal ridge, other 2–3 ridges which were present in *S.* (*B.*) *khoslai* sp. nov. disappear and valve surface is sparsely reticulate. It continues to near the end of the Burdigalian. This species further evolved and gave rise to *S.* (*B.*) *rete* Khosla and Nagori (1988), which is characterized by strong reticulation and other characters of the previous species. It further evolved to *S.* (*B.*) *arcuata* in the later Burdigalian. In this species the dorsal ridge become more arcuate and the rest of the valve surface is characterized by indistinct reticulation.

5. *Stigmatocythere* (*B.*) *reversa* – *S.* (*B.*) *interrupta* lineage

Stigmatocythere (*B.*) *reversa* Khosla (1976) evolved during the early Burdigalian and gave rise to *S.* (*B.*) *interrupta* Khosla and Nagori (1988) (Figure 7). In this species the dorsal ridge is interrupted at the dorsomedian region. Valve surface is more or less smooth and rest of characters are same as for *S.* (*B.*) *reversa*.

Conclusions and scope for future research

1. Nineteen species of the genus *Stigmatocythere* have been recorded from the Lower Eocene to Middle Miocene succession of India.
2. 12 species belong to the subgenus *Stigmatocythere* s.s. and 7 species to the subgenus *Bhatiacythere*.
3. Five evolutionary lineages have been identified.
4. A beginning only has been made in tracing evolutionary lineages. Intermediate forms between evolving species are to be traced.

Acknowledgements

The author wishes to thank Shri Y. B. Sinha, Director (Exploration) and D. Ray, Executive Director and Head, KDMIPE for giving permission for presentation and publication of this paper in the XIX Indian Colloquium on Micropaleontology and Stratigraphy at

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Banaras Hindu University, Varanasi. Sincere thanks are due to S. C. Khosla (Retd. Professor) and M. L. Nagori, Reader, Department of Geology, M. L. Sukhadia University, Udaipur for allowing me to use some of their SEM photographs and topotype material in this publication. The author is also grateful to N. J. Thomas (GRG) and Shri James Peters, Head, Geology Division for providing necessary facilities during preparation of this paper and to Shri Bharat Singh for computer assistance. The views expressed in this paper are those of the author only and do not necessarily reflect the views of the organization.

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