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Evolutionary trends and biostratigraphic significance of the ostracode genus *Stigmatocythere* in the Cenozoic succession of India

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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.*) *multicosata* Khosla and Nagori range 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.*) *multicosata* – 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.
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 Waier 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 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...

**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.
Oligocene
One species *Stigmatocythere* (*Bhatiacythere*) *khar-iensis* 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.) kholai* sp. nov. is restricted to the Aquitanian, while *S. (S.) quilonensis* Khosla and Nagori and *S. (Bhatiacythere)* *reversa* Khosla range up to the Burdigalian.


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 3.** Stratigraphic ranges and distribution of *Stigmatocythere* (*S.*) *obliqua* – *S. (S.) portentum* 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 4.** Stratigraphic ranges and distribution of *Stigmatocythere* (S.) *reticulata* – *S. (S.) keeni* lineage in the Cenozoic succession of India.
the subgenus *Stigmatocythere* are recorded in the present work.

1. *Stigmatocythere* (*Stigmacythere*) *bermotiensis* Khosla and Pant, 1988
2. *S. (S.) chaasraensis* (Guha, 1961)
4. *S. (S.) keeni* Bhandari, 2001
5. *S. (S.) latebrosa* (Lyubimova and Guha, 1960)
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
4. *S. (B.) khalai* sp. nov.
5. *S. (B.) rete* Khosla and Nagori, 1988

Subgenus *Stigmatocythere* s.s.

The following species of this subgenus are described here briefly.
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.
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 sub-rectangular 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).
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.


*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 Chasra village upstream of Khari stream, Kachchh, Gujarat. Buff-color claystone, Chasra 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, Bandhah Formation, Middle Eocene.
**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.

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

*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.

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

*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 Khar 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/B02/04/6791), a male carapace, 0.58 mm long.

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

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**Stigmatocythere (Stigmatocythere) obliqua**

*Stigmatocythere obliqua* Siddiqui, 1971

*Stigmatocythere obliqua* Siddiqui, 1971, p. 70–71, pl. 35, figs. 1–10, pl. 36, figs. 1, 2; Bhandari, 1996, p. 138, 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 tubercule distinct. Valve surface strongly reticulate with three longitudinal ridges; dorsal ridge arched convexly upwards; median ridge starts from eye tubercule, 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.

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**Stigmatocythere (Stigmatocythere) portentum**

*Stigmatocythere portentum* Siddiqui, 1971

*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 Sarовар 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 tubercules are prominent. Surface reticulate with three longitudinal ridges; anterior margin ornamented with numerous spines.
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 5/10 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

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...
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 reticule 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 recures 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 dorsal 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).**

<table>
<thead>
<tr>
<th>Carapace</th>
<th>Length</th>
<th>Height</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holotype</td>
<td>0.68</td>
<td>0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>Paratype</td>
<td>0.68</td>
<td>0.42</td>
<td>0.42</td>
</tr>
</tbody>
</table>

**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
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**


**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 Reymert (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.


   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
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.) bornhardti 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.


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.


This lineage begins with S. (B.) khariensis and ends with S. (B.) arcuata, with middle members S. (B.) kholslai 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.) kholslai sp. nov. It is characterized by a right valve larger than left valve and three distinct longitudinal ridges: dorsal ridge originates above subcentral tubercule, making an arc overhanging margin and then turns downward at right angles in posterodorsal area; median ridge starts from subcentral tubercule and takes sharp turn around subcentral tubercule and continues posteriorly where it meets dorsal ridge; ventral ridge runs from anteroventral to posteroverntral 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.) kholslai 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 short inclined ridge extending towards subcentral tubercule from middle of dorsal ridge, other 2–3 ridges which were present in S. (B.) kholslai 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 dorso-median 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.

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Ostracode genus *Stigmatocythere* in Cenozoic of India

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References


