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PALAEOECOLOGICAL IMPLICATION OF OSTRACOD AND GASTROPOD ASSEMBLAGES OF THE HOLOCENE LAKE RECORDS FROM THE GANGA PLAIN

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ABSTRACT

Dispersed Sedimentary successions of two lakes, namely, Mesa Tal (Lat. 26°48' N; Long. 81°6' E) and Sanai Tal (Lat. 26°12' N; Long. 81°4' E) of upland interfluve surface of the Ganga Plain are studied for their microfaunal (ostracod and gastropod) content. From the Mesa Tal, 2.50 m thick sediment succession (dated ~8500 yrs BP - present) and from the Sanai Tal, 2.10 m thick succession (dated~15,000 yrs BP - present) were analyzed. In the Mesa Tal, the lower 1.5 m sequence is a marl horizon which has yielded rich and diversified microfaunal assemblage, whereas, in the Sanai Tal, the fauna is recorded from upper 1.05 m sequence. Total 36 sediment samples were collected from the lake profiles at different depth intervals. Ostracod assemblage includes 15 species belonging to 11 genera, of which *Candanopsis kingsleii, Strandesia weberi* (in Mesa Tal) and *Cyprinotus cingalensis* (in Sanai Tal) are the dominant. Gastropod assemblage includes 7 taxa, of which *Indoplanorbis* and *Gyraulus convexiusculus* are the most abundant in both the lakes. The inferred palaeoecology of ostracod and gastropod fauna in the Mesa Tal sediments suggest that in the early Holocene time, it was a relatively large lake with low supply of terrigenous clastics, in mid-late Holocene the lake shrank with increased supply of terrigenous sediments. In the Sanai Tal, ostracod and gastropod faunal assemblage suggest shallow, permanent water body since the onset of Holocene, and richness of fauna along with charophytes indicate enriched vegetation and climate amelioration during early-mid Holocene (10,120 to ~7,600 yrs BP) followed by gradual decline in lake size and water column during late Holocene.

Keywords: Ostracods, Gastropods, Palaeoecology, Lake sediments, Holocene, Ganga Plain

INTRODUCTION

The upland interfluve surface of the Ganga Plain sustains many lakes and ponds (locally referred to as 'Tal') of various shapes and sizes. Most of these lakes receive their water budget from monsoonal rainfall or as surface runoff from adjoining areas. These are very susceptible to local environmental changes and usually record quick responses of climate perturbations and anthropogenic activity which are well reflected in their sedimentological characteristics, microfaunal and floral assemblages, and changing hydrology. The use of microfaunal assemblage is significant for reconstructing the microenvironments of terrestrial lakes. Two lakes, viz. Mesa Tal (also written as Misa Tal) and Sanai Tal have been studied in detail for their chronology, pollen sequence and stable isotopic records (oxygen and carbon stable isotopes of gastropod aragonite) to infer their palaeohydrology and climatic variability (Singh, 1996; Sharma *et al.*, 2004, 2006). These lake sequences are further investigated herein for their microfaunal content and palaeoecology.

The microfaunal studies are helpful in deciphering the microenvironment of habitats. In the lake sediment records, the occurrence of diverse ostracod and gastropod species having different modes of life, help in reconstructing the microenvironments of lake. In the present paper, an attempt has been made to document the ostracod and gastropod fauna of the lake sediments of the Ganga Plain, and to infer palaeoecology on the basis of microfaunal assemblage.

Ostracods are small bivalved crustaceans, often referred to as 'non-marine foraminifers' of the continent. Their ubiquitous occurrence in the terrestrial water bodies and their response to environmental variability make them viable for ecological and climatic studies (Schwalb, 2003). Gastropods are the univalved (single shelled) molluscs, occupying a greater range of habitats than other molluscs. The majority is aquatic, inhabiting the marine habitats, especially shallow seas, and fresh water including running water, stagnant bodies (lake, ponds, ditches, swamps); and some are terrestrial also. Many ecological studies of living ostracods and gastropods have shown that the distribution of a particular species is determined primarily by salinity and temperature, though other factors such as water depth, water chemistry, hydrostatic pressure, turbidity and turbulence, nature of substrate, presence or absence of shelter, food supply and biologic competitions may also be important (Benson, 1961; Besonen, 1997; Curray, 1999; De Deckker and Forester, 1988; Lister, 1988). The importance of ostracod and molluscan assemblages in reconstructing the palaeoenvironment from the lake marl in Holocene has also been emphasized by Walker *et al.* (1993). The richness of ostracod fauna in permanent lakes or ponds is directly related to the presence of weeds which provide food and shelter for ostracodes. The importance of aquatic plants to the survival of ostracods has been demonstrated by many workers (Benzie, 1989; Kiss, 2002, 2004). A number of studies suggest that 'Charophytes' provide excellent shelter for ostracods. The ostracod fauna of both Mesa Tal and Sanai Tal is found associated with charophyte gyrogonites (Bhatia, 2006). A number of studies pertaining to fresh water ostracods of living and palaeorecords of Holocene time frame are available from Haryana-Punjab Plain (Bhatia and Singh, 1977; Bhatia and Khosla, 1967, 1977) and other parts of the country (Elumalai *et al.*, 2010; Hussain and Mohan, 2000); but records from the Indo–Gangetic Plain are meagre. Bhatia (1983) has reported some ostracod species from the Mesa Tal locality. Mathur (2001) has reported faunal assemblage of ostracods and molluscs along with other microfaunal remains from the Quaternary cliff sections of the Ganga Plain in Uttar Pradesh.

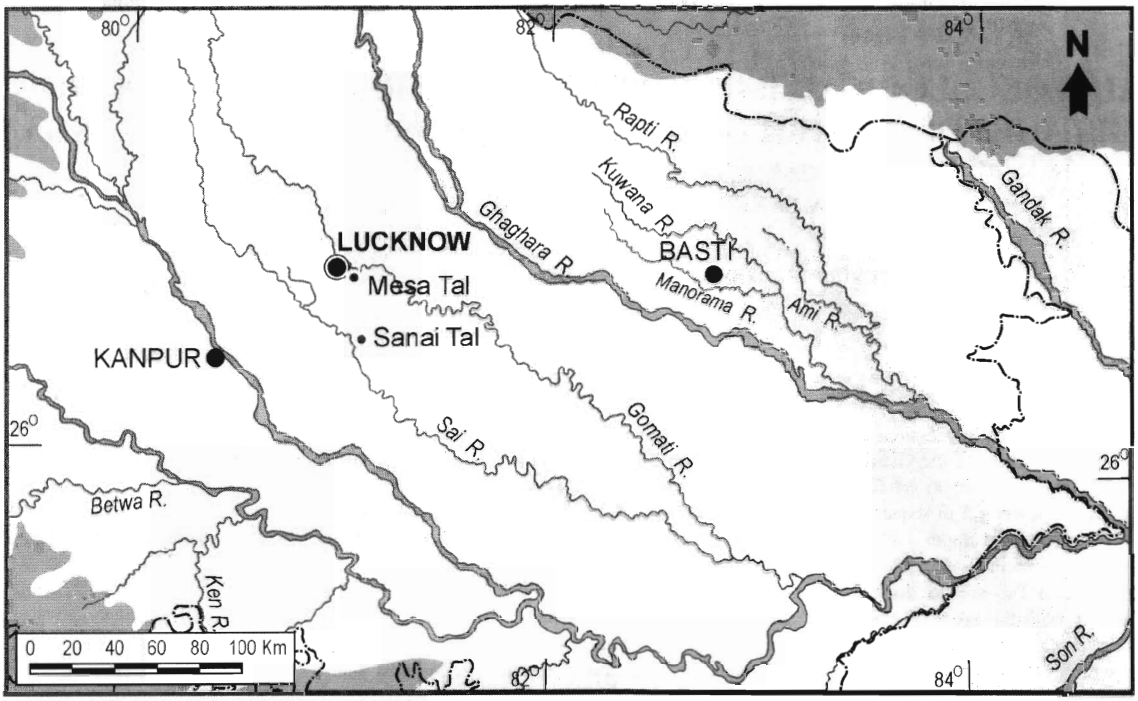


Fig. 1. Location of studied lakes in the Ganga Plain.

STUDY AREA: LAKE SETTING

Both the lakes, viz. Mesa Tal (Lat. 26°48' N; Long. 81°6' E) and Sanai Tal (Lat. 26°12' N; Long. 81°4' E) are located in the upland interfluve surfaces of the Central Ganga Plain (Fig. 1) and are 62 km apart.

Mesa Tal: It is a meander cut-off on the interfluve surface of Gomati and Sai rivers located near Gosaiganj town in Lucknow district. It is about 1500 m in length and 120-150 m in width with limited catchment area of 6.8 km^2 having the water depth of about 4-5 m. Total 12 samples (ME-1 to ME-12) were collected from a 2.50 m deep trench; the chronology of sediment succession is well established (Singh, 1996). The lake sediment of the lower part shows characteristic deposits of marl. The subsurface study of the Mesa Tal deposits shows lensoid nature of shell deposits (Agarwal *et al.*, 1992). The lithology and chronology (uncalibrated ^{14}C ages) of the lake succession is shown in Fig. 2A.

Sanai Tal: It is an arc-shaped depression lying on the Ganga-Sai interfluve surface and is a part of palaeochannel belt. It is a completely dried and silted water body having the area of 0.3 km^2 with the catchment area of 4.2 km^2. This lake has been studied in detail for reconstructing the palaeoclimate and palaeovegetation (C. Sharma *et al.*, 2001; Sharma *et al.*, 2004, 2006). The chronology (uncalibrated ^{14}C ages) and lithology of the lake profile is shown in Fig. 2B.

METHODOLOGY

For the separation of ostracods and gastropods, 50 g unit weight of each sediment sample was taken. All the samples were subjected to standard micropalaeontological techniques. The material was analyzed under the stereoscopic binocular

Table-1: Distribution of ostracod fauna in Mesa Tal sediments.

Name of species	ME-6	ME-7	ME-8	ME-9	ME-10	ME-11	ME-12
Strandesia weberi	R	F	F	A	VA	VA	A
Strandesia indica	-	R	R	F	A	A	F
Candonopsis kingsleii	A	F	VA	VA	A	VA	A
Cypris subglobosa	-	R	F	A	VA	VA	A
Gomphocythere sp.	-	-	R	R	-	R	R
Stenocypris major	-	-	-	R	-	R	-
Parastenocypris sp.	-	-	R	-	-	R	-
Darwinula stevensoni	-	R	-	F	R	F	R
Cypretta foveata	-	-	-	R	R	R	-
Cypridopsis vidua	-	R	A	-	VA	A	F
Candona fabaeformis	-	R	-	F	F	R	R
Candona sp.	R	R	-	R	R	R	-
Candona compressa	-	-	-	-	R	-	-

R- Rare (=5), F- Frequent (6-15), A- Abundant (16-35), VA- Very Abundant (>35).

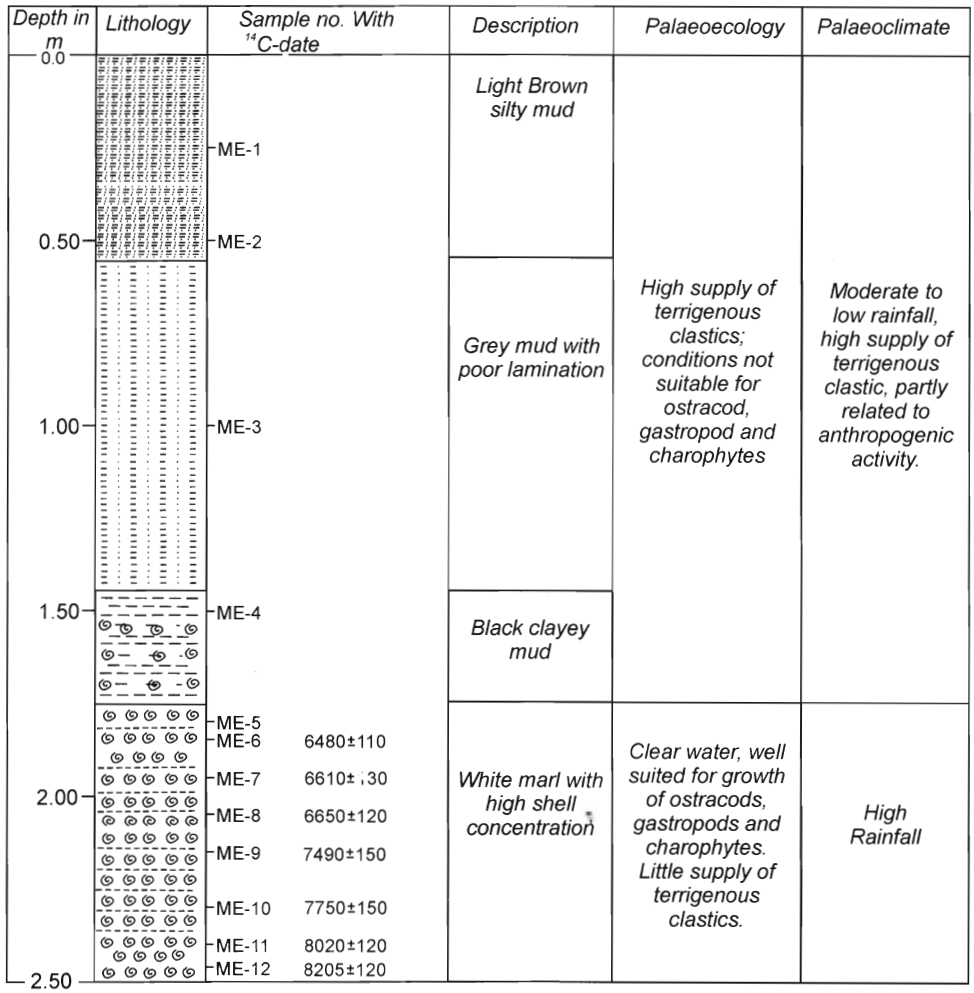


Fig. 2A. Litholog of Mesa Tal along with the ^{14}C dates (uncalibrated) and the inferred palaeoecology and palaeoclimate of the lake.

microscope for picking the ostracodes, and gastropods. Generic and species identification was made by detailed morphological study of carpaces/valve of ostracod and gastropod shell and referring to the literature. Some of the ostracods species were identified with the help of Prof. S.B. Bhatia (personal comm.). For clear illustrations, a few selected specimens were microphotographed using the Scanning Electron Microscope (SEM, model no. T-330), while the gastropod photographs were taken with Leica stereozoom SD6 microscope. The classification followed in the present work is that of Hartmann and Puri (1974) for ostracods; and for gastropods, the classification used herein is that of the Treatise part 1 (Mollusca 1) (1960). All the specimens are deposited in the Department of Geology, University of Lucknow.

OSTRACOD AND GASTROPOD ASSEMBLAGES

Mesa Tal Assemblages

From the 2.50 meter thick succession, 12 samples (ME-1 to ME-12) were collected at different intervals. However, only the lower 70 cm succession (ME-12 to ME-6) has yielded the fauna rich in gastropods and ostracods. Sediment samples ME-1 to ME-5 have not yielded any fauna and are barren, though in ME-5 broken shells of gastropods are present. From ME-6 to ME-12 ostracods and gastropods along with some charophyte gyrogonites and few bivalves are recorded in varying frequency. One noteworthy feature is gradual increase in size of the ostracod fauna from ME-6 to ME-11, though in ME-12 the size of the ostracod fauna is again reduced. In the lowermost part of the profile, in sediment sample ME-12, *Strandesia indica, Candonopsis kingsleii and Cypris subglobossa* (ostracods) and *Indoplanorbis*, *Gyraulus convexiculus* and *Planorbis* made the bulk of fauna. Likewise, in sediment samples ME-11, 10, and 9 the fauna is highly diversified in terms of abundance and individuals. Two species of bivalves, viz. *Pisidium mitchelli* and *Pisidium naevillium* are also recorded from ME-10 and ME-11. Towards the upper part of the marly horizon, the fauna gradually diminishes both in magnitude and species diversification.

From the ostracod assemblage of Mesa Tal, total 13 species are recorded. Some of the species are already reported by Bhatia (1983). Their qualitative distribution in each sample is given in Table 1. The gastropod assemblage includes seven genera, of which one is indeterminate. Their distribution is given in table 2.

Sanai Tal Assemblages

The ostracod and gastropod assemblages recovered from the Sanai Tal sediments are more or less similar to the fauna of Mesa Tal. Total 23 samples (SA-1 to SA-23) were collected at different depth intervals of the 2.10 m thick sediment profile (Fig. 3B). The lower 1.05 m succession (SA-1 to SA-10) is barren.

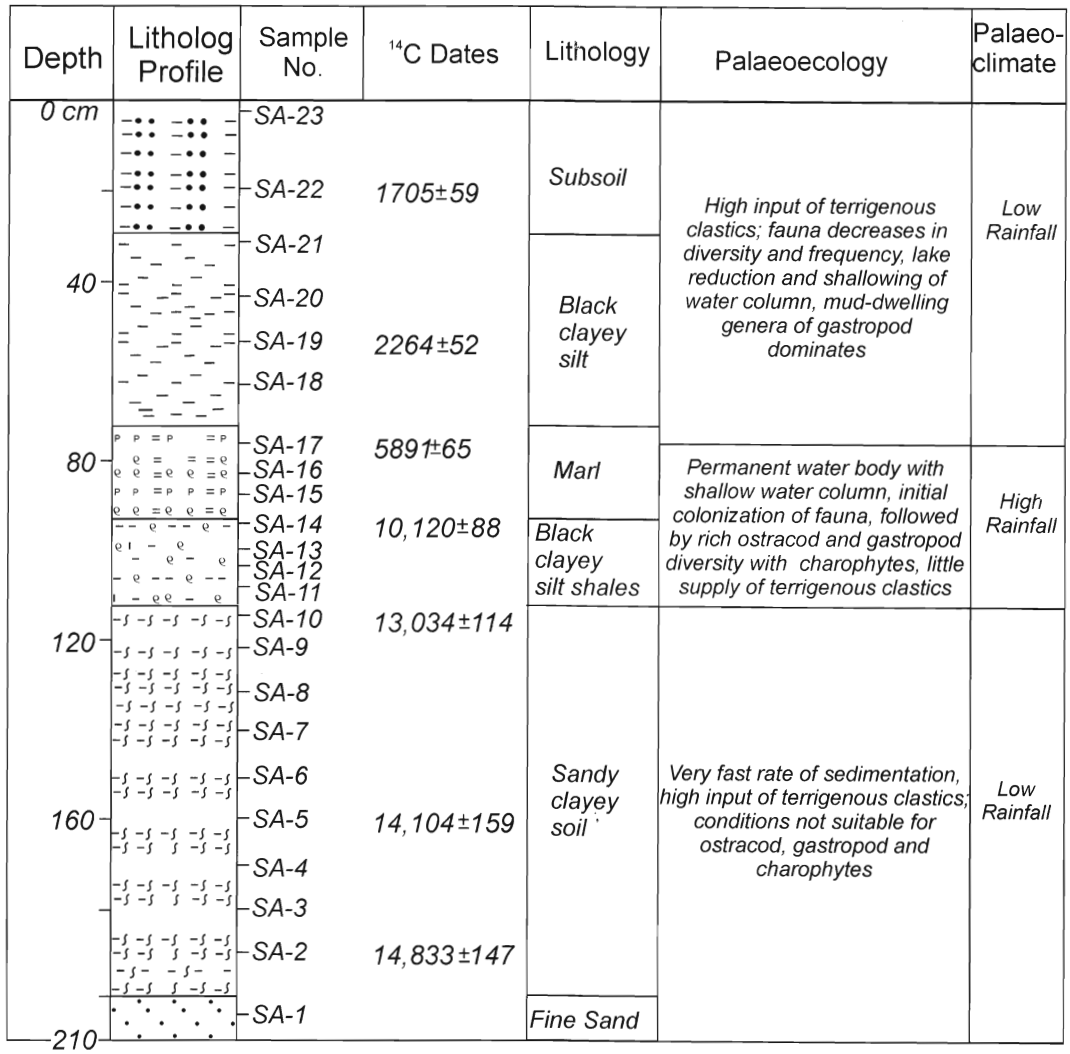


Fig. 2B. Litholog of Sanai Tal along with the ^{14}C AMS dates (uncalibrated) indicating the inferred palaeoecology and palaeoclimate of the lake.

The remaining upper part (1.05 m) has yielded good assemblages of ostracod and gastropod fauna. Samples SA-19 and SA-22 are also barren. The faunal abundance and diversification gradually increase from the base of the fossiliferous horizon (SA-11) up to SA-17 corresponding to the age bracket of ~13,000 yrs BP to 5891 yrs BP. From SA-18 to SA-23, the fauna shows decline in numbers and variety. The ostracod content includes six genera belonging to six species, of which *Cyprinotus cingalensis* and *Candanopsis kingsleii* are the most abundant. *Cyprinotus cingalensis* is not recorded in the Mesa Tal sediments. Distribution of ostracod fauna is given in Table 3. The gastropod fauna is represented by six taxa, of which *Indoplanorbis, Gyraulus* and *Viviparous* account for the bulk of the assemblage. *Melanoides tuberculata* is recoded here, which is absent in the Mesa Tal sediments. The gastropod distribution is represented in Table 4. A number of charophyte gyrogonites are also found associated with this assemblage.

SYSTEMATIC DESCRIPTION

Systematic classification and salient features of ostracod (Pl. I and II) and gastropods (Pl. III) assemblages obtained from the Mesa Tal and Sanai Tal are given.

Ostracod Assemblage

Class **Ostracoda** Latreille, 1806
Order **Podocopida** Müller, 1894
Suborder **Podocopina** Müller, 1894
Superfamily **Cypridacea** Baird, 1845
Family **Cyprididae** Baird, 1845
Subfamily **Cypricercinae** Mc Kenzie, 1971
Genus ***Strandesia*** Stuhlmann, 1888

Strandesia weberi (Moniez, 1892), (Keyser and Bhatia, 1989) (Pl. I, figs. 1-4)

Cypris weberi n. sp. Moniez 1892, Pl. 10, figs. 6-11. - Moniez and Müller, 1912, p. 233.

Cypris magnifica n. sp. Brehm, 1923, p. 222, figs. 1-3.

Eucypris weberi (Moniez) Klie, p. 459, *Strandesia spinifera* n. sp. Hartmann, 1964, figs. 63 a-c, 64 a-c.

Strandesia weberi (Moniez) Victor and Fernando, 1979, fig. 4. - Victor *et al.*, 1980, p. 730.

Strandesia spinifera (Hartmann) Bhatia, 1983, discussion in text p. 442-458, pl. 1, figs. 1-6.

Strandesia weberi (Moniez) Brood Bakker, 1983, fig. 9H. - Keyser and

Table 2: Distribution of gastropod fauna in the Mesa Tal sediments.

Name of species	ME-6	ME-7	ME-8	ME-9	ME-10	ME-11	ME-12
Indoplanorbis sp.	F	F	A	VA	VA	VA	VA
Gyraulus convexiusculus	F	F	A	VA	VA	VA	VA
Viviparous dubiosus	R	F	A	A	VA	VA	A
Lymnaea sp.	-	R	F	VA	A	VA	A
Succenia sp.	-	-	-	A	A	A	R
Helicorbis sp.	-	R	F	A	A	A	A
Unidentified	-	-	-	R	-	-	-
Pisidium mitchelii	-	-	-	R	R	-	-
Pisidium naevilleuum	-	-	-	-	R	-	-

R- Rare (=5), F- Frequent (6-15), A- Abundant (16-35), VA- Very Abundant (>35).

Bhatia, 1989, p. 129, 131, 135, Pl. 16, fig. 1-8.

Locality: Mesa Tal.

Size: Large, 1.0-1.5 mm in length, 0.5 to 0.7 mm in width, 0.3 to 0.4 mm in height.

Description: Carapace subelliptical in lateral view, tapering towards posterior end, anterior end rounded, and posterior end subrounded. In dorsal view carapace is biconvex, preplete, dorsal margin slightly curved (convex), ventral margin straight, greatest length in the middle, greatest height in the anterior half. The presence of a long hollow posterior spine, about half the length of the shell in the right valve and two short, curved anterior spine, $1/6^{th}$-$1/7^{th}$ of the length in left valve is a diagnostic feature of the species. Surface of valves is finely pitted with minute granules or intervening ridges. Muscle scar is typical of the genus.

Remarks: The species is charcaterized by subelleptical carapace, presence of a long hollow posterior spine in the right valve and two short, curved anterior spine, $1/6^{th}$-$1/7^{th}$ of the length in left valve. The species is originally described as belonging to Recent genera by Hartman (1964) from Kambodia, and by Victor and Fernando (1979). The Recent species is described as *S. weberi* (Keyser and Bhatia, 1989). The species was earlier reported from the marls of Mesa Tal by Bhatia (1983) as *S. spinifera*. It prefers shallow water and is a nekto-benthic species.

Strandesia indica (Moniez, 1892)

(Pl. I, fig. 5)

Cypris indica indica Moniez, 1892,

Strandesia indica Hartmann, 1964, fig. 62 a-b. - Victor and Fernando, 1979, fig. 6.

Locality: Mesa Tal.

Size: Large, 1.0-1.4 mm in length, 0.5-0.6 mm in width, 0.3 to 0.4 mm in height.

Description: Carapace ovate to subelliptical in outline, both the valves are convex. All other characters are similar to *S. weberi* except the absence of spines in both valves. The species is quite similar to *S. hartmanni*, but the latter has relatively broad inner lamella and compressed ventral margin.

Remarks: The species is reported by Hartman (1964) from Kerala and other localities of South India. Bhatia and Singh (1977) have reported this species from the Punjab Plain. Later, Bhatia (1983) recorded its occurrence from the Holocene deposits of the Mesa Tal.

Subfamily **Cypridopsinae** Kaufmann, 1900

Genus ***Cypridopsis*** Brady, 1868

Cypridopsis vidua Müller, 1876

(Pl. I, fig. 11)

Cypris vidua (Müller), 1876 p. 119; *Cypridopsis vidua* (Muller) Brady, 1867, p.117. - Staplin, 1963, p. 1183, 1184 (et. syn.). - Bhatia, 1968; - Bhatia and Singh, 1971 p. 217. pl. 1, fig. 1. - Bhatia and Singh, 1977, p. 407, pl. 1, fig. 1. - Jain, Gupta and Bhatia, 1969, p. 34, pl. 1, fig. 1.

Locality: Mesa Tal.

Size: Medium, 0.9 to 1.0 mm in length and 0.5 to 0.6 mm in width.

Description: Carapace thin shelled, elongate to ovate, both ends rounded, valves inflated but laterally compressed, ventral margin slightly concave, inner lamella wide anteriorly and posteriorly, narrow in middle, numerous straight and simple marginal pore canals, hinge adont. Muscle scar pattern is typical of the genus.

Remarks: This species is reported and described by Bhatia (1968) from the Pleistocene deposits of Kashmir and by Jain *et al.* (1969) from Spiti Valley. This species is reported from the Mesa Tal, Central Ganga Plain (Bhatia, 1983). The modern analogues of this species usually occur in the weed rich ponds

Table 3: Distribution of ostracod fauna in Sanai Tal sediments.

Name of species	SA-11	SA-12	SA-13	SA-14	SA-15	SA-16	SA-17	SA-18	SA-19	SA-20	SA-21	SA-22	SA-23
Cyprinotus cingalensis	VA	VA	A	A	F	F	F	R		R	R		-
Candona sp.	F	F	F	F	R	R	R	F		-	-		F
Candonopsis kingsleii	F	A	A	F	F	F	R	-		-	A		F
Cypridopsis vidua.	-	-		F	R	-		R		-	-		-
Stenocypris major	-	R	R	-	-	R	-	-		-	-		-
Darwinula stevensoni	-	R	R	R	-	-	-	-		-	-		-

BARREN

R- Rare (=5), F- Frequent (6-15), A- Abundant (16-35), VA- Very Abundant (>35).

Table 4: Distribution of gastropod fauna in the Sanai Tal sediments.

Name of species	SA-11	SA-12	SA-13	SA-14	SA-15	SA-16	SA-17	SA-18	SA-19	SA-20	SA-21	SA-22	SA-23
Indoplanorbis sp.	F	F	R	F	F	F	R	F		-	-		F
Gyraulus convexiusculus	A	A	A	F	A	A	F	F		F	F		F
Viviparous dubiosus	A	F	A	A	A	F	F	F	BARREN	A	A	BARREN	F
Lymnaea sp.	F	R	R	F	F	R	-	R		R	-		R
Succenia sp.	-	-	R	-	-	-	-	R		-	R		-
Melanoides tuberculata	-	F	R	R	-	-	R	R		-	R		R

R- Rare (=5), F- Frequent (6-15), A- Abundant (16-35), VA- Very Abundant (>35).

and swim actively in open water.

Subfamily **Cypridinae**

Genus ***Cypris*** Müller 1776

Cypris cf. subglobosa Sowerby, 1840)

(Pl. I, figs. 6, 7)

Cypris subglobossa Sowerby, 1840, in Malcomson, 1840, p. 537-575.- Baird, 1859, p. 232. - Bhatia, 1968 p 470-471 (et syn).

Locality: Mesa Tal.

Size: Large, 1.0 to 1.6 mm in length, 0.5-0.8 mm in width, carapace height about 0.5 mm.

Description: Carapace ovate, bulging and globose, surface punctuated, dorsal margin convex, ventral margin straight, posterior margin elongated, carapace ends are angulated, greatest height in the middle and more than half of the length, anterior margin is rounded and provided with anterior lip, inner lamella narrow, hinge adont. Muscle scar typical of the genus.

Remarks: The species was first described by Sowerby (1840) and later, by Baird (1859). Bhatia (1968) reported it from the Pleistocene deposits of Upper Karewas of Kashmir. Bhatia (1983) has described it from the Mesa Tal. This species occurs in abundance in Mesa Tal.

Subfamily **Cyprinotinae** Bronshtein, 1947

Genus ***Cyprinotus*** Brady, 1886

Cyprinotus cingalensis Brady, 1886

(Pl. II, figs. 1, 2)

Cyprinotus cingalensis Brady 1886, p. 302, pl. 38, figs. 28-30. - Bhatia and Khosla, 1967, p. 508, fig. 1. - Bhatia and Khosla, 1977, p. 334, fig. 2, figs. G-J.

Locality: Sanai Tal.

Size: Medium to large, 0.8 to 1.1 mm in length, 0.5 to 0.7 mm in width, carapace height about 0.5 mm.

Description: Carapace subtriangular, in dorsal view carapace biconvex, surface smooth left valve slightly larger than right, overlapping distinctly all along the margins except the dorsal where the right valve is conspicuously higher than the left, greatest height slightly posterior to middle, maximum width posterior to middle, anterior and posterior margins denticulate, inner lamella with moderate width, muscle scar typical of the genus.

Remarks: Subtriangular shape and denticulate anterior and posterior margins are the characteristic features of this species. It has been reported from the sub-recent marl bed in southern Haryana by Bhatia and Khosla (1977).

Subfamily **Cyprinotinae** Bronshtein, 1947

Genus ***Stenocypris*** Baird, 1859

Stenocypris major Baird, 1859

(Pl. II, fig. 4)

Cypris cylindrica Sowerby var. *major* Baird 1859, p. 23, pl. 63, fig. 4. *Stenocypris major* (Baird) Ferguson, 1969, fig. 1.1; figs. 3, 1-3. - Singh 1977, p. 369, Pl. VII, figs. 6-9. - Bhatia and Singh, 1977. p.405, pl. 2, fig. 1; pl. 3, figs. 3-4, pl/ 4, fig. 2; pl. 5, fig. 2; - Ravi *et al.* 2007, p. 123, pl. 1, figs. k,l.

Locality: Mesa Tal and Sanai Tal.

Size: Large, 1.3 to 1.7 mm in length, 0.35-0.4 mm width.

Description: Carapace elongate-ovate, laterally compressed, height always less than half the length; anterior and posterior ends are rounded, ventral margin concave at the anterior end. Surface almost smooth, inner lamella very wide anteriorly, narrow in ventral and posterior part. Hinge adont, muscle scar typical of the genus.

Remarks: This cosmopolitan species is reported from the late Pleistocene of Punjab (Bhatia and Singh, 1977; Bhatia, 1983). However, this is the first report of species from the Holocene marl deposits of the Ganga Plain.

Subfamily **Herpetocypridinae**

Genus ***Parastenocypris*** Hartmann, 1964

Parastenocypris sp. Hartmann, 1964

Locality: Mesa Tal.

Size: Large, 1.3 mm in length, 0.35 mm width.

Description: Carapace elongate with subelliptical outline, laterally compressed, slightly sinuous ventral margin, moderately convex dorsal margin, both ends rounded, inner lamella very wide and oblique, adont hinge.

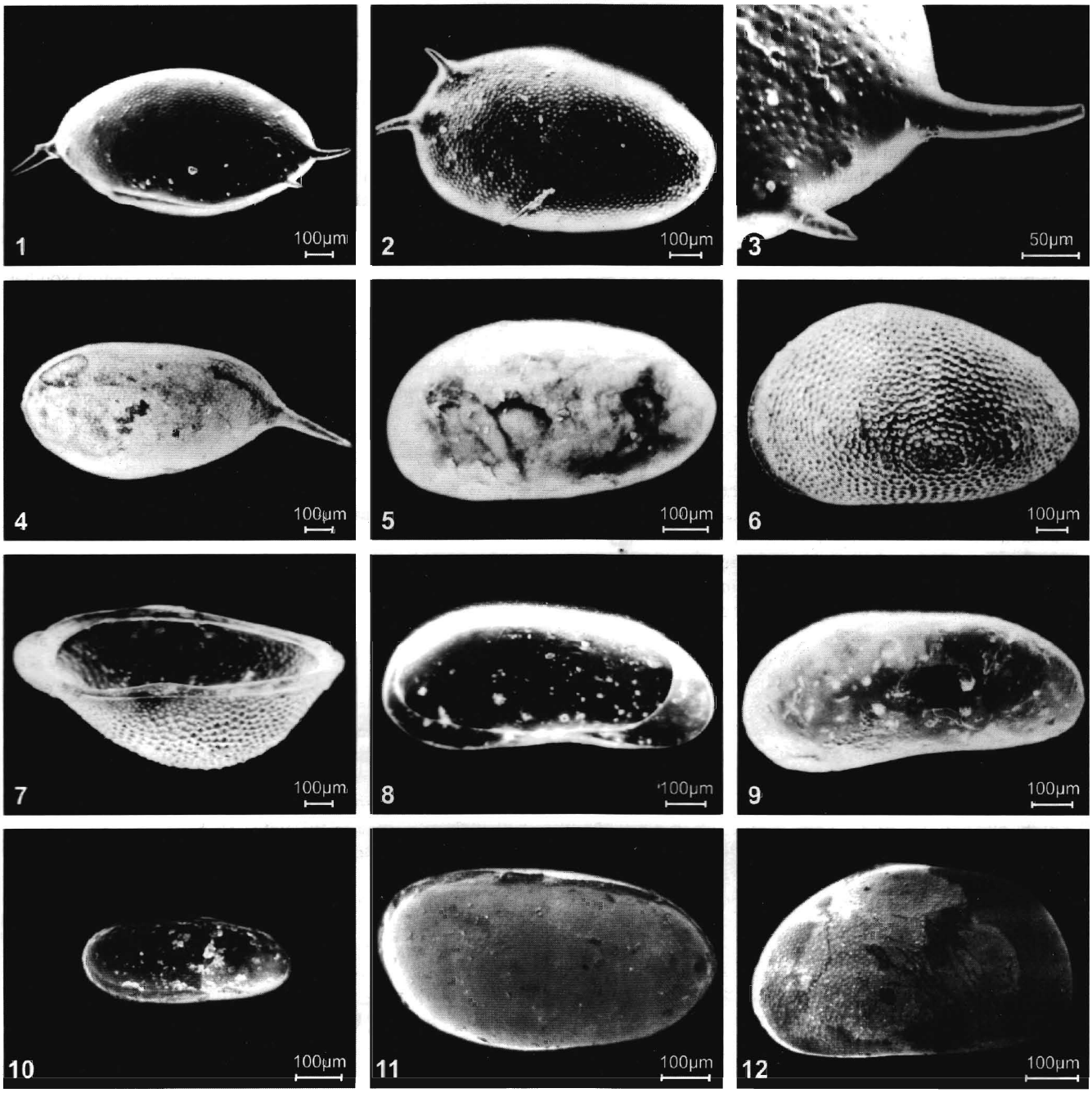
Remarks: This genus is described from fresh water recent fauna of southern India by Mannikeri and Vaidya (1990), questionable occurrence from the late Pleistocene fauna of Punjab (Bhatia and Singh, 1977) and from the Mesa Tal deposits (Bhatia, 1983).

EXPLANATION OF PLATE I

SEM microphotographs of Ostracod fauna recovered from Mesa Tal and Sanai Tal.

1. carapace of ***Strandesia weberi***
2. left valve of ***S. weberi***
3. enlarged view of spines of left valve of ***S. weberi***
4. right valve of ***S. weberi***
5. right valve of ***S. indica***
6, 7. carapace and valve of ***Cypris subglobossa***
8. external view of valve of ***Candonopsis kingsleii***
9. carapace of ***Candonopsis kingsleii***
10. internal view of valve of ***Darwinula stevensoni***
11. internal view of valve of ***Cypridopsis vidua***
12. carapace of ***Cypridopsis*** sp.

Plate I



SAXENA, SINGH AND AGARWAL

Family **Cyprididae** Baird, 1845
Genus ***Cypretta*** Vavra, 1895
Cypretta foveata (Hartmann, 1964)

Cypretta foveata n. sp. Hartmann, 1964, fig. 37.

Locality: Mesa Tal.

Size: Medium, 0.7 to 0.9 mm in length, 0.3 to 0.4 mm width.

Description: Carapace subtriangular in outline, both ends subrounded, dorsal margin convex, ventral margin slightly concave, valves inflated, inner lamella narrow. Muscle scar typical of the family.

Remarks: Hartmann (1964) first described it form Kathiavar peninsula, Northwestern India.

Family **Candonidae** Kaufmann, 1900
Subfamily **Candoninae** Dday
Genus ***Candonopsis***, Vavra, 1891
Candonopsis kingsleii (Brady and Roberstson, 1870)
(Pl.I figs.8, 9)

Candonopsis kingsleii Brady and Robertson, 1870 p. 17, pl. 9 figs. 9-12. - Varva, 1891, p. 54, fig. 16 (1-10). - Muller, 1900, p. 38, pl. 6; figs. 5,6, 23-28; pl. 7, figs. 22, 25. - Sars, 1928, p. 38, pl. 41. - Swain, 1963, Pl. 96; fig. 4, p. 806. - Bhatia and Singh, 1977, pl. 3, figs. 1-2; p. 407. - Malik and Singh, 1994, p. 6, pl. 1, figs. d, e; fig. 3. VI, VII, VIII, IX.

Locality: Mesa and Sanai Tal.

Size: Medium, 0.6 to 1.0 mm in length, 0.3 - 0.4 mm width.

Description: Lateral outline sub-reniform, carapace smooth and highly calcified, thin and hyaline; greatest height near or just behind the middle and equal to approximate half the length, valves compressed laterally, greatest width is less than the height, both the ends rounded. Inner lamella is rather wide anteriorly, narrower in ventral and posterior parts. marginal zone is narrow anteriorly and posteriorly. Marginal pore canals numerous, straight and simple, normal pores are small open, few in central part of the valves and numerous in anterior and posterior ends. Hinge adont. Muscle scars basically that of the Candoninae, with a small supplementary scar in front.

Remarks: In the north central India, this ubiquitous species in fossil is reported and described by Bhatia (1968) from the Upper Karewa of Kashmir, recent fauna of fresh water lakes of Kashmir (Bhatia and Singh, 1970, 1971), the recent fauna of Mansar lake, Jammu (Malik and Singh, 1994). Bhatia (1983) has also reported this species from Mesa Tal. Its modern representatives are common in permanent small freshwater bodies with abundant vegetation and the bottom rich in organic mud.

Subamily **Candoninae** Kaufmann, 1900
Genus **Candona** Baird, 1845
Candona fabaeformis (Krstié, 1972)
(Pl. II, figs. 9)

Cypris fabaeformis n. sp. Fischer, 1851, p. 146, table 3, figs. 6,7,9,10.
Candona fabaeformis Krstié, 1972, p. 5, fig.12.

Locality: Mesa Tal and Sanai Tal.

Size: Medium, 0.7 to 0.9 mm in length, 0.3 to 0.4 mm width.

Description: Carapace bean shaped, ovate-elongate, thin shelled, valves moderately inflated: surface very smooth, hyaline and punctuated, marginal zone narrow, numerous short marginal pore canals, adont hinge. Muscle scar typical of candoninae with a small supplementary scar.

Remarks: It is characterized by thin, smooth and transparent shell. Its modern representatives are benthic epifaunal and occur on muddy substrate.

Subamily **Candoninae** Kaufmann, 1900
Genus **Candona** Baird, 1845
Candona sp.
(Pl. II, figs. 6, 7)

Locality: Mesa Tal.

Size: Medium, 0.8 to 0.9 mm in length, 0.3 to 0.4 mm width

Description: Carapace bean shaped, ovate-elongate, thin shelled, valves moderately inflated, surface very smooth, hyaline and punctuated, marginal zone narrow, numerous short marginal pore canals, adont hinge. Muscle scar typical of Candoninae with a small supplementary scar.

Remarks: It is characterized by thin and smooth shell with prominent inner lamella.

Subamily **Candoninae** Kaufmann, 1900
Genus **Candona** Baird, 1845
Candona compressa Koch, 1837
(Pl. II, figs. 8)

Cypris compressa Koch, 1837, p.16.
Candona compressa Bhatia and Singh, 1971 p. 217, pl. 1 fig. 2.

Locality: Mesa Tal.

Size: Large, 0.8 to 1.0 mm in length, 0.4 to 0.6 mm width

Description: Carapace bean shaped, ovate-elongate, thin shelled, valves moderately inflated, surface very smooth, hyaline and punctuated, marginal zone narrow, inner lamella wide, numerous short marginal pore canals, adont hinge. Muscle scar typical of candoninae with a small supplementary scar.

Remarks: The inner lamella is very wide which is prominent along the anterior margin and is relatively narrow along ventral and posterior margins. It is the characteristic feature of this species. Modern analogues are common in marshes, ponds and lakes and unable to swim. They prefer epifaunal and seminfaunal modes of life on muddy or muddy-sandy substrates.

Superamily **Darwinulacea** Brady and Norman, 1889
Family **Darwinulidae** Brady and Norman, 1889
Genus ***Darwinula*** Brady and Robertson, 1885
Darwinula stevensoni Brady and Robertson, 1885
(Pl.1 fig.10)

Polycheles stevensoni Brady and Robertson 1870, p. 25-26, pl. 7, figs. 1-7, p. 10, figs. 4-14.
Darwinula stevensoni (Brady and Robertson) Brady and Norman, 1889, pp. 122-123, pl. 10, figs. 7-13, figs. 1-9; 23, figs. 5. - Bhatia, 1968, pl. 13, figs. 5 a-b, pl. 5, fig. 13. - Malik and Singh, 1994, p 5-6, pl. 1, figs. a,b,c; fig. 3, I, II and III. - Ravi *et al.* 2007, p. 124, pl. I, fig m.

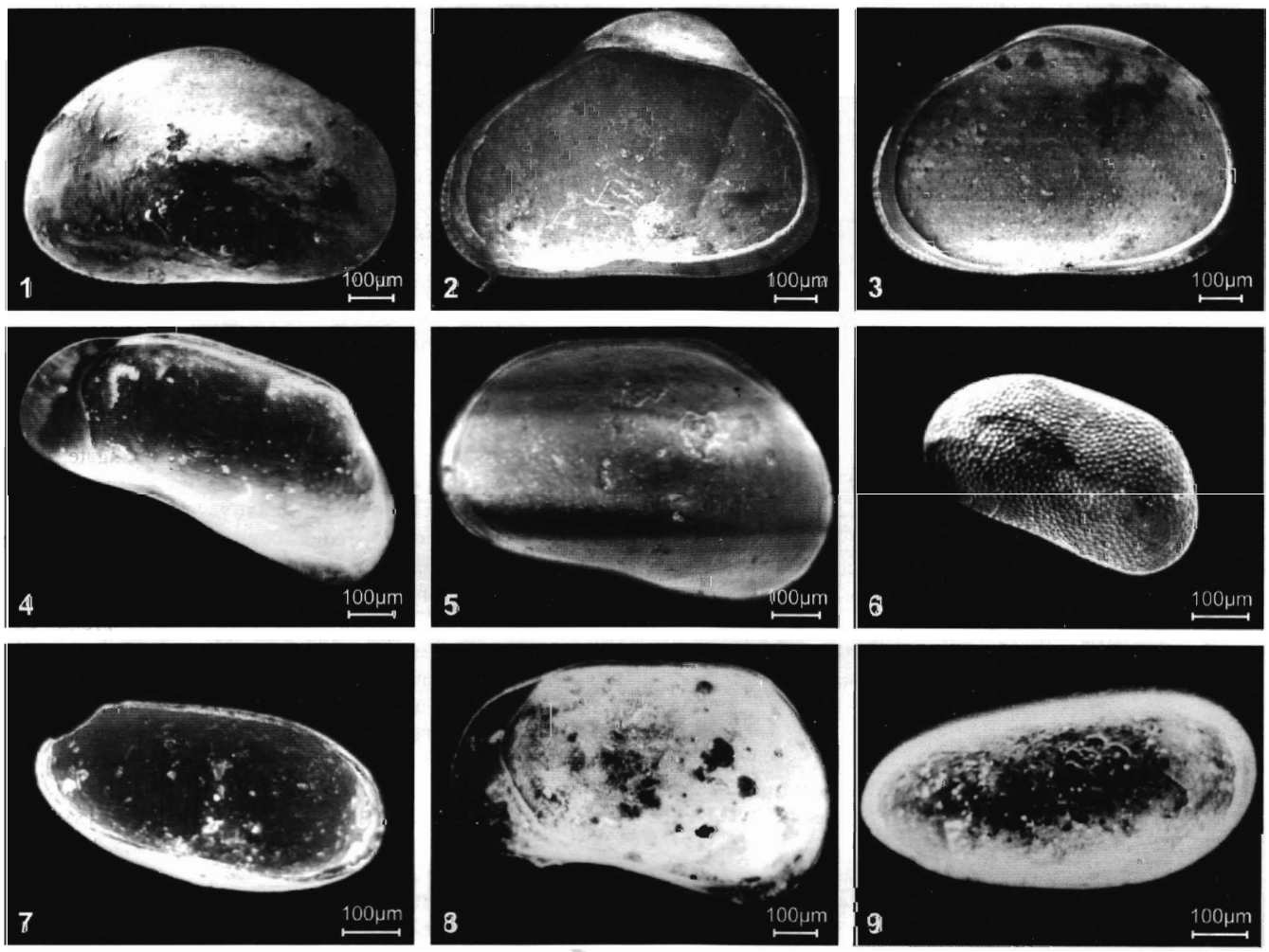
Locality: Mesa Tal and Sanai Tal.

EXPLANATION OF PLATE II

SEM microphotographs of Ostracod fauna recovered from Mesa Tal and Sanai Tal.

1. carapace of ***Cyprinotus cingalensis***
2. right valve of ***C. cingalensis***
3. left valve of ***C. cingalensis***
4. internal view of valve of ***Stenocypris major***
5. internal view of valve of ***Gomphocythere*** sp.
6. external view of valve of ***Candona*** sp.
7. internal view of valve of ***Candona*** sp.
8. internal view of valve of ***Candona compressa***
9. external view of valve of ***Candona faebeformis***

Plate II



SAXENA, SINGH AND AGARWAL

Size: Small to medium, 0.7 to 0.9 mm in length, 0.3 to 0.5 mm width.

Description: Carapace elongate, subcylindrical, tapering towards the anterior end, both ends rounded, thin-shelled, greatest height, behind the middle. Smooth and shiny surface, inner lamella very narrow, adont hinge. Muscle scars in typical 'rosette' arrangement.

Remarks: The species is reported from the Mesa Tal sediments by Bhatia (1983). The present day representatives of the species are unable to swim, epibenthonic. In lakes or ponds, it is often found along the lake margins with abundant vegetation (Malik and Singh, 1994.

Superamily **Cytheracea** Baird, 1850,
Family **Limnocytheridae** Klie, 1938
Subamily **Timiriaseviinae** Mandelstam, 1960
Genus ***Gomphocythere*** Sars, 1924
Gomphocythere sp. Sars, 1924
(Pl.II, fig. 5)

Locality: Mesa Tal and Sanai Tal.

Size: Medium, 0.9 to 1.0 mm in length, 0.4 to 0.6 mm width.

Description: Subovate carapace, surface pitted with sieve pores, lateral margin slightly curved with notch and fine reticulation, anterior and posterior end subrounded, distinctive inverse lophodont hinge; Left valve has anterior and posterior cardinal teeth that fit into corresponding sockets of right valve, muscle scar typical of the family.

Remarks: The species is described from Mesa Tal by Bhatia (1983). Its modern analogues live in shallow ponds or lakes and are epibenthonic walkers/crawlers.

Gastropod Assemblage

Phylum **Mollusca**
Class **Gastropoda**
Subclass **Pulmonata**
Order **Basomnatophora**
Family **Planorbidae**
Subfamily **Planorbinae** Rafinsque, 1815
Genus ***Gyraulus*** Agassiz, 1837
Gyraulus convexiusculus Hutton, 1849
(Pl. III, figs. 1, 2)

Planorbis (Gyraulus convexiusculus) Hutton, 1849, p. 657. - Preston, 1915, pp. 118-119; *Gyraulus convexiusculus* (Hutton) Annadale *et al.*, 1921, p. 631. -Prashad, 1922, p. 15. - Rao, 1928, p. 457. - Rao, 1929, p. 297. - Prashad, 1937, p. 279.

Anisus convexiusculus (Hutton) Butot, 1955, p. 112, fig. 22.

Gyraulus convexiusculus (Hutton) Benthem Jutting, 1956, pp. 463-466. figs. 127, 129-130. Wright, 1963, p. 262, pl. 1, figs. 9-17. — Bhatia and Mathur, 1973, pp. 24-58, fig 4 (8-9). — Bhatia, 1974, pp. 371-395, fig. 2k.

Locality: Mesa Tal and Sanai Tal.

Description: The adult shells with maximum diameter up to 4.50 mm, distinctly compressed, composed of 5 and a half to 6 gradually opening whorls, height of body whorl equal across the whorl, dorsal side concave, ventral side flat, periphery obliquely rounded, aperture elongate-oval in outline.

Remarks: This is a widely distributed species in North India, and reported from many late Pleistocene successions of the Himalaya (Bhatia and Mathur, 1973; Bhatia, 1974; Mathur and Kotlia, 1999). They tend to occur in bodies of water with a firm mud bottom, with high levels of decaying organic matter. Their usual habitat is the subaqueous portion of the rooted vegetation of lakes and swamps.

Genus ***Indoplanorbis*** Annadale and Prashad, 1920
Indoplanorbis sp. Annadale and Prashad, 1920

Locality: Mesa Tal and Sanai Tal.

Description: Shell is planispirally coiled, discoidal in shape; whorls are 3 and a half to 4, convex and rapidly opening, large elongate-oval aperture. The surface is ornamented with faint striations.

Remarks: The species is very abundant in both Mesa Tal and Sanai Tal. This snail is preferably distributed in ponds and pools of temporary nature, which remain dry for 3-6 months each year, during which period it undergoes dormancy.

Genus ***Helicorbis*** Benson, 1855
Helicorbis sp. Benson, 1855
(Pl. III, figs. 3, 4)

Locality: Mesa Tal.

Description: Small shell, planispirally coiled, in lateral view trapezoidal in outline, in apical view outline slightly concave to flat. Spire clearly visible in apical view while only partly visible through umbilicus in basal view, umbilicus open, moderately wide, inner margin of persitome slightly arched near the umbilicus, whorls 2 to 2 and 3/4 rapidly opening, width of the spiral whorls exposed dorsally varies and does not increase gradually, nuclear whorl comparatively much broader than the first whorl, basal periphery of body whorl slightly acute to rounded, sides of the ultimate whorl steeply sloping.

Superamily **Lymnaeacea**
Family **Lymnaeidae**
Subfamily **Lymnaeinae**
Genus ***Lymnaea*** Lamarck, 1799
Lymnaea sp. Lamarck, 1799
(Pl. III, figs. 7, 8, 9)

Locality: Mesa Tal and Sanai Tal.

Description: Shell thin, fragile, oligogyral, with acute apex and inflated last whorl, whorls with distinct but rounded shoulder, spiral angle about 30°, aperture about half total height, body whorl larger than spire, columnar lip with a distinct fold passing forwards into the peristome, labral profile slightly parasigmoidal and the lower reversal of curvature forming an anterior embayment of peristome. Surface sculpture consists of microscopic raised periostracal striae.

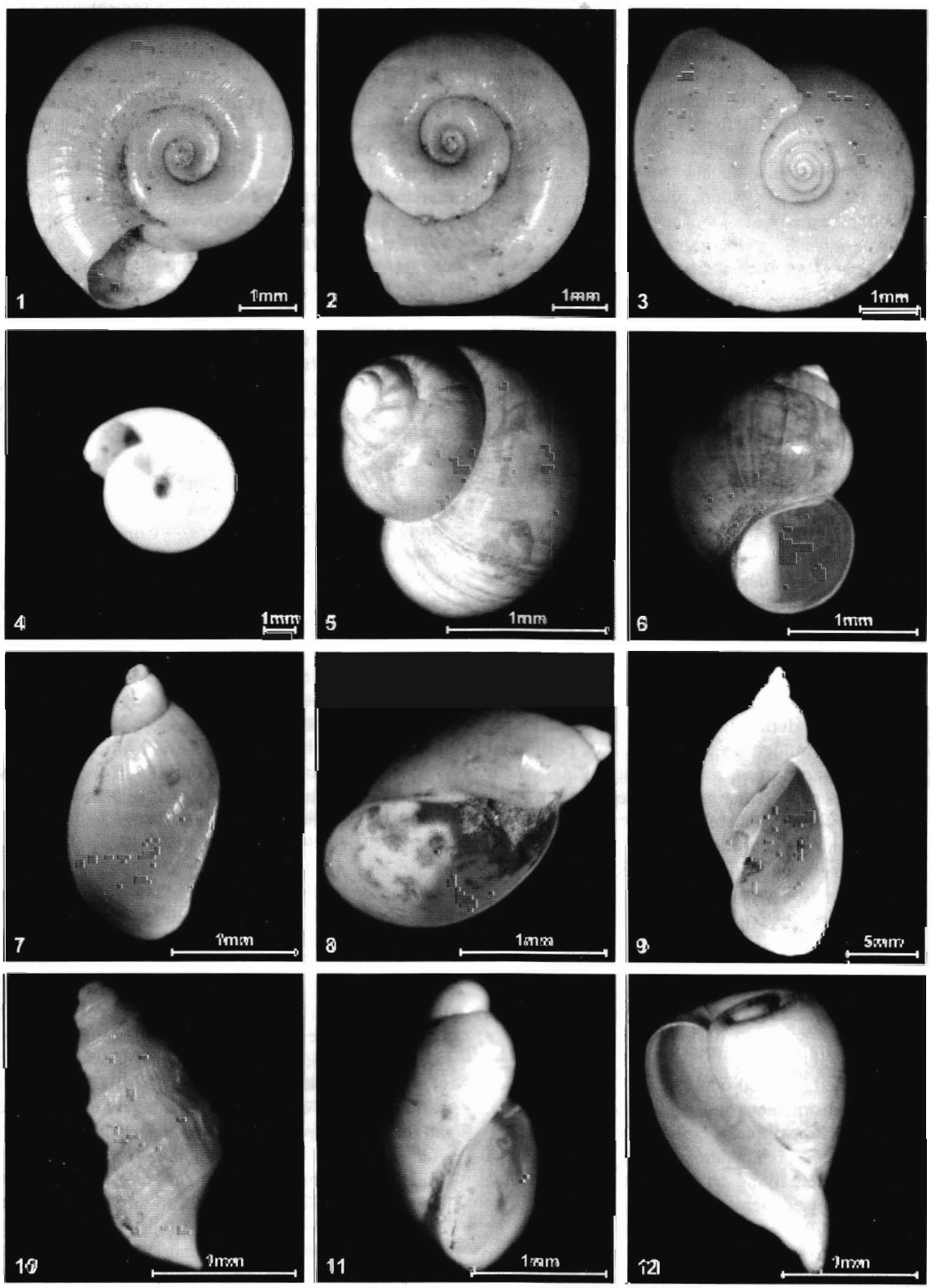
Remarks: The species is common in the marl of Mesa Tal, but rare in the sediments of Sanai Tal. It is reported from several localities of the Himalaya and peninsular India. One or two

EXPLANATION OF PLATE III

Microphotographs of Gastropod fauna recovered from Mesa Tal and Sanai Tal.

1 apertural view of ***Gyraulus convexiusculus***
2 dorsal view of ***G. convexiusculus***
3 dorsal view of ***Helicorbis*** sp.
4 apertural view of ***Helicorbis*** sp.
5 dorsal view of ***Viviparous dubiosus***
6 apertural view of ***V. dubiosus***
7 dorsal view of ***Lymnaea*** sp.
8 apertural view of ***Lymnaea*** sp.
9 apertural view of ***Lymnaea*** sp. (large specimen)
10 dorsal view of ***Melanoides tuberculata***
11 apertural view of ***Succinea*** sp.
12 apertural view of undetermined species

Plate III



SAXENA, SINGH AND AGARWAL

specimens have very large size of about 1.8 cm length and 0.9 cm in width.

Order **Stylommatophora**
Family **Succineidae**
Genus ***Succinea*** Draparnaud, 1801
Succinea sp. Draparnaud, 1801
(Pl. III, fig . 11)

Locality: Mesa Tal and Sanai Tal.

Description: Shell thin, elongate and ovate, paucispiral with short spire and large last whorl, apex and base rounded, aperture oval and more than half of the total height, thin labrum, very thin callus on inner lip of the peristome.

Remarks: This genus is reported from the late Pleistocene succession of the Ladakh Himalaya (Mathur and Kotlia, 1999), and from the Upper Siwalik succession of Punjab (Bhatia and Mathur, 1973). This species lives in very damp places, such as on vegetation on river banks and marshes.

Order **Mesogastropoda**
Family **Viviparidae**
Genus ***Viviparous*** Montfort, 1810
Viviparous dubiosus Annadale, 1924
(Pl. III, figs. 5, 6)

Viviparous dubiosus Annadale, 1924, p. 100-101, pl. 7, figs. 4, 4a.- Bhatia and Mathur, 1973, p. 42, fig. 5 (12).

Locality: Mesa Tal and Sanai Tal.

Description: Shell thin, dextrally coiled, medium to large in size with rounded whorls, spire consisting of 4-5 whorls, body whorl is globose, deeply impressed sutures and a closed umbilicus, shell aperture and operculum nearly circular.

Remarks: This species is widely distributed in the Indian subcontinent. It lives on the bottom muds of ponds, marshes and marsh channels but during flood high waters, the empty shells float and are stranded up to the edge of peripheral emergent reliefs in marsh areas, thus delineating high water marks. It is also present in estuarine shore deposits.

Order **Prosobranchia**
Superfamily **Cerithiacea**
Family **Thiaridae (Melanoiidae)**
Genus ***Melanoides*** Oliver, 1807
Melanoides tuberculata Müller, 1774
(Pl. III, fig. 10)

Nerita tuberculata Müller, 1774, p. 191 (non vidi).

Melanoides tuberculata (Müller) Prashad, 1921, p. 224, 225.- Benthem Jutting, 1966, p. 412-418, text figs. 69,73,91 (et syn.).- Brown, 1965, p.46.

Locality: Sanai Tal.

Description: Shell turreted-conical, with feebly convex whorls bearing spiral ornament and gently concave collabral costellae with crenulations, oval-elongate aperture.

Remarks: The species is ubiquitous in the lakes of Ganga Plain. It is mud dweller; living on subaquatic soft bottoms, often concealed in the sediments.

DISCUSSION

Both the lakes are located on the interfluve surfaces of Central Ganga Plain and are only 62 km apart; therefore, it can be assumed that they had shared a similar climatic regime. The architectural framework and chronology of both the lakes also suggest that their origin and evolution had taken place in analogous manner. The faunal assemblages of both the lakes are autochthonous; as evidenced by the fine texture of sediments, good number of carapaces in ostracod assemblage and more or less consistent ecological conditions. Ample fauna and smooth and pristine nature of preservation of ostracods and gastropods indicate largely stable and stagnant depositional environment. However, the species variability of ostracods and gastropods along with occasional presence of bivalves in vertical profile is suggestive of changing lake hydrology in the past.

The marly succession of 70 cm thickness in Mesa Tal, ranging in age between 9100 to 6000 years BP was deposited in a relatively large lake with low supply of terrigenous clastic sediments. It corresponds to the early Holocene climate maxima when rainfall was high due to more intense SW monsoon system (Singhvi *et al.*, 2010). During this period, the area around lake was also vegetated and rate of soil erosion (hence the supply to terrigenous clastic sediment) was low. During this time period, water chemistry was suitable for precipitation of $CaCO_3$ which was mostly consumed by shell-secreting organisms, and ostracods and gastropods flourished. The base of the fossiliferous horizon (marl deposit) (ME-12) of Mesa Tal which corresponds to the age of ~9100 yrs BP (estimated), records very high abundance of ostracods and gastropods along with plenty of charophyte gyrogonites. It suggests that the fauna was existing even before this time. The high population of *Strandesia, Candanopsis kingsleii, Indoplanorbis* and *Gyraulus* is indicative of large permanent water body with shallow water column. The ostracod assemblage of *Strandesia-Candonopsis kingsleii-Darwinula stevensoni* is characteristic of water depth of < 15 m (Perez *et al.*, 2010). *Candonopsis kingsleii* which is present in all the sediment samples, prefers the lake margins with paludal substrate to thrive in water bodies (Sohar and Meidla, 2010). The occasional presence of *Cypridopsis vidua* (a phytophyllic genus) with charophytes in the lower horizon (ME-12 to ME-9) is suggestive of increasing density of vegetation with water column less than 5 m. The faunal assemblage continues to proliferate till around 7490 yrs BP. After 7490 yrs BP to nearly about 5700 yrs BP (estimated), from ME-9 to ME-5, the decline in lake-level can be inferred from the gradual reduction in size of ostracod and gastropod fauna along with decrease in species diversity. The occurrence of broken shell fragments in the uppermost horizon of the marl succession (ME-5) with intercalations of the black clayey mud indicates increased supply of terrigenous clastic material and simultaneous decrease in carbonate secreting organisms. This trend continues till the present time. The absence of ostracod and gastropod fauna, subsequent to the deposition of sediment interval ME-6 and ME-5 (~ 5700 yrs BP) can be explained by the reduction of carbonate concentration in the water column and increased supply of terrigenous clastics from nearby areas with reduced rainfall. The increased supply of terrigenous clastic may be partly due to anthropogenic activity in the area. The change in sedimentation rate also supports the above inference. The available dates suggest that prior to 7490 yrs BP, sedimentation rate was 46 mm/100 yrs which reduced to 44 mm/100 yrs after 7490 yrs BP till 6480 yrs BP; later it again reduced to about 29 mm/100 yrs till recent.

The fossiliferous horizon of Sanai Tal is limited to top 1.05 m succession corresponding to the age bracket of ~13000 yrs BP- Recent. The extreme paucity or absence of microfauna in the lower 1.05 m profile (~15000 yrs BP to 13000 yrs BP, SA-1 to SA-11) could be attributed to very fast rate of sedimentation and occasional influence of flowing stream, therefore, input of

soft water with low calcium carbonate (as Sanai Tal is a part of palaeochannel belt). Nevertheless, the above inference is supported by the multiproxy study of the Sanai Tal deducing that the channel was abandoned during 15,000-13,000 yrs BP witnessing comparatively arid conditions and was converted into the swamps (Sharma *et al.*, 2004). The initial colonization of the fauna began around 12,000 yrs BP corresponding to sediment sample SA-11 with low abundance and diversity of ostracod fauna. Though the gastropod fauna is represented by the frequent occurrence of ecologically tolerant genera *Indoplanorbis* and *Gyraulus*, fauna exhibits proliferation and diversification since the onset of Holocene up to late-mid Holocene (around 7,600 yrs BP, SA-15). The presence of *Cyprinotus cingalensis*, *Candanopsis kingsleii* and *Darwinula stevensoni* in ostracod assemblage and *Viviparous, Indoplanorbis* and *Gyraulus* in gastropod assemblage suggest shallow but permanent lake. The frequent presence of *Cypridopsis vidua* around 10,120 to ~7,600 yrs BP (SA-14 and SA-15) and abundant charophytes suggests enriched vegetation indicating climate amelioration. After 7,600 yrs BP, the faunal assemblage gradually decreases in terms of quantity and diversity signifying lake reduction and further shallowing of water column. Further upward in the profile, paucity of ostracod fauna is encountered owing to deposition of clayey silt succession highly rich in organic matter. However, the gastropod fauna continues with mud-dwelling genera e.g. *Viviparous*, *Indoplanorbis* and *Melanoides tuberculata* which are more resistant to changing ecological conditions. These variations in the faunal assemblage suggests climate deterioration towards the late Holocene with increased rate of siltation, leading to complete drying of water body, as is the present-day scenario. The increased supply of terrigenous clastic sediments can be partly attributed to anthropogenic activity. These findings are in corroboration with stable isotopic study of ä^{18}O and ä^{13}C recorded from aragonite shells of gastropods from this lake. It shows enrichment in heavier ä^{18}O, potentially reflecting reduced monsoonal activity and/or enhanced evaporation during 13,000 to 10,000 yrs BP followed by shift towards lighter values as a result of enhanced monsoonal precipitation during 10,000-5,800 yrs BP (Sharma *et al.*, 2004). The analysis of sedimentological framework and available pollen records (Sharma *et al.*, 2001) also support the above inferences.

CONCLUSIONS

The ostracod and gastropod faunal records of the lake-fill successions provide evidences for the changes in the microenvironment of the lakes. The pattern and responses of lake-level fluctuations, ecological changes, variation in sedimentation rates and lithological changes are very well reflected in the specific associations of ostracod and gastropod assemblages. In corroborations with the other proxy records such as chronology, palynology and stable isotopic records, the faunal assemblages prove to be excellent tool to add more information pertaining to the regional scenario of palaeoenvironment of the Ganga Plain.

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