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Holocene Bioevents of Uttarakhand and Haryana, India and their application in environment evaluation

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ABSTRACT

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The concept of Bioevents envisages identification of biodiversity that helps in delineating short term environmental changes which may be due to population bloom, migration, mass mortality, extinction, etc. This concept was applied to already available information on microfossils by way of understanding the palaeoecology of Holocene deposits of Uttarakhand and Haryana. In Uttarakhand, the bioevents identified on the basis of biodiversity present in different sections in Bhagirathi, Mandakini and Alaknanda valleys are Arcellinids-*Heteropteris indicus* Bioevent, Arcellinids– Seeds Bioevent, Arcellinids Bioevent and Vegetal Matter Bioevent. The cold waterbody at low altitude of 1270 m amsl in Bhagirathi valley, remained undisturbed for long time is interpreted as long pause in tectonic activity in otherwise highly structurally disturbed region. In Haryana, the biodiversity has been affected by the quality of water from freshwater to hypersaline, which is represented by the bioevents *Darwinula stevensoni* Bioevent, in the earlier part of the Riwasa section to *Cyprideis torosa* Bioevent, *Pseudoeponides-Chara aspera-Indoplanorbis exustus* Bioevent representing increase in salinity. The flow of freshwater from perennial stream was disrupted by the shifting of channel due to reactivation of older faults in the area. The Bovid Bioevent, Seeds-Microvertebrates Bioevent and Seeds - *Chara aspera* Bioevent are interpreted to be the high ground with human culture close to freshwater body. Seeds-*Cyprideis torosa* (Reworked) Bioevent and *Cypridopsis vidua* (Reworked) Bioevent of Terraces represent the reworking of earlier sediments.

Keywords: Holocene, Bioevents, Uttarakhand, Haryana, Environment

INTRODUCTION

The concept of Bioevent was introduced by Kaufmann and Hart (1996) for short term extraordinary, environmental changes. They classified them as 'Diversification Bio-Events (punctuated evolution, population blooms, colonization and immigration bio-events), or Diversity Reduction Bio-Events (mass mortality, ecosystem shock, extinction and emigration bio-events)'. Bioevents represent biological response to rapid environmental changes and thus their identification is significant in understanding climatic fluctuations in the late Quaternary.

The Himalaya and the Indo-Gangetic plains present two important geomorphic domains where climatic variations in one affect the other. It is, therefore, pertinent to study the microbiota of the Late Quaternary of these two domains to understand climatic fluctuations and palaeoecology. Palaeontological studies on the

Quaternary deposits in parts of Haryana (Mathur 1998a, 1999a unpublished, 1999b, Mathur et al. 2004), Uttarakhand (Mathur 2004 a, b, Kacker 2006 unpublished), Himachal Pradesh (Mathur 1998b,), Uttar Pradesh (Mathur 2001) revealed that the biotic assemblages point to short term environmental changes represented by population bloom or mass mortality. Mathur and Mehrotra (2004) took initiative in identifying Holocene bioevents of Haryana and Uttarakhand, India. Recently, Bajpai et al. (2012) have discussed Phanerozoic Bio-Climatic events.

UTTARAKHAND

A number of workers have studied the Quaternary sediments of Uttaranchal (now Uttarakhand). Their studies were mainly confined to Quaternary geological and geomorphological investigations. The significant contributions are by Nambiar and Rai (1994), Nambiar and Rawat (1995) and Rawat and Gairola (1999a, b) who have demarcated various Terraces of Bhagirathi River on the basis of sedimentological studies and differentiated them as glacial, periglacial, fluvio-glacial and fluvial terraces. Nawani and Sanwal (1995) have studied the siltation problem of Tehri and Koteshwar reservoirs. Rai et al. (2001) have dated fluvio-glacial carbonaceous clay in Sarju Basin as 17310±450 years B.P. and similar sediments in Bhagirathi Valley have been dated at 11830±270 years B.P. They also observed glacial sediment at as low as 1040 m amsl.

In Alaknanda valley, Quaternary geological and geomorphological studies have been carried out by Deonath and Nambiar (1999, 2001), Rawat and Gairola (1999 a, b) and Rai and Kumar (1998 in Rai et al. (2001). Deonath and Nambiar (2001) have recorded evidences of palaeoglaciation in the form of lateral moraines, terminal moraines, solifluctional lobes, truncated spurs and high level glacial planation surfaces in the Mandakini and its major tributaries. In addition, glacial erosional features such as hanging valley, 'U' shaped valley, horns and aretes, striations, nivations, fossil cirques and remnant lakes have also been observed between Madhyamaheswar-Kedarnath and Kundchatti.

Geological set-up

Quaternary sediments unconformably overlie the rocks of Central Crystalline Group, Tethyan Group and Garhwal Group between Dharasu (30°37'59.99" N; 78°19'00" E) and Gangotri (30°58'48" N; 78°55'48" E) in Bhagirathi Valley. The general stratigraphic succession is given below in Table 1 (after Rawat & Gairola 1999a, b). The glacial/fluvio-glacial deposits have been observed in the section along Bhagirathi River between Uttarkashi (30°43'47.50" N; 78°26'36.31" E) and Gangotri townships whereas fluvial terraces are observed in the lower reaches below Uttarkashi. The glacial sediments are characterized by assorted angular to subangular rock fragments of heterogeneous composition derived from older metamorphics and oxidised silt-clay at places. The fluvial sediments in the lower reaches are characterized by thick sequences of well sorted conglomerates with subrounded to rounded boulders (sometimes more than 0.5m in diameter) over which rest 2–3 m thick silt–clay unit.

Table 1. Stratigraphic succession in Uttarakhand (after Rawat & Gairola 1999a).

Age	Stratigraphic units
Quaternary	Higher level Terraces T_4 to T_7 comprising glacial/ periglacial/Glacio -fluvial sediments Terraces T_1, T_2, T_3 comprising periglacial, glacio-fluvial, fluvial sediments
	Unconformity
Pre–Quaternary	Central Crystalline Group, Chandpur and Saknidhar formations

Along Alaknanda and Mandakini valleys, the Quaternary sediments unconformably overlie the rocks of Central Crystalline Group and Deoban Group. The stratigraphic succession is given below in Table 2.

Table 2. Stratigraphic succession along Alaknanda and Mandakini valleys, Uttarakhand (after Deonath & Nambiar 1999).

Age	Stratigraphic units
Holocene	Active plain/glacial/glacio-fluvial terrace GFT–1/lacustrine younger Terraces (Fluvial Terraces T_3–T_1)
	Disconformity
Middle to Upper Pleistocene	Older Terraces (Fluvial terraces T_6–T_4) Glacio-fluvial deposits (Glacio-fluvial Terrace GFT–3) Solifluction deposits Glacial till
	Unconformity
Pre– Quaternary	Deoban Group Central Himalayan Crystalline

The glacial deposits are characterized by unstratified, ill sorted, polished, faceted, angular to subangular clasts of heterogeneous composition, viz. quartzite, schist, phyllites, slates, gneisses and basic rocks, varying in size from fine particle to large boulders 2-5m across. They have been observed along Alaknanda valley in Mana (30°46'19" N; 79°29'43" E) area near Badrinath (30°43'48" N; 79°28'48" E) and along Mandakini valley around Kedarnath (30°48'31" N; 79°04'44" E). Remnant of glacial lake has been observed in Kedarnath area. Solifluction deposits derived from destruction of country rock caused due to repeated freeze and thaw action under periglacial environment constituting matrix dominated clasts have been observed in place like Joshimath (30°°33'01.98" N; 79°33'57.47" E)-Auli (30°19'12" N; 79°21'36" E) in Alaknanda valley. The glacio-fluvial sediments characterized by moderately sorted, poorly stratified, faceted/polished with local development of cross bedding and lamination have been observed near Helang (30°31'12" N; 79°30'38" E) along Alaknanda valley. The fluvial/alluvial deposits characterized by well sorted, well bedded sediments comprising rounded to subrounded clasts of quartzites, schists, gneisses, basics in sandy silt or silty sand/sand matrix have been observed in the lower reaches of the Alaknanda and Mandakini river valleys such as in Sumari (30°20'00" N; 78°06'00" E)-Tilwara (29°14'52" N; 79°40'13" E) area.

Holocene biodiversity and bioevents

The palaeontological studies carried out (Mathur 2004a, b, Kacker 2006 unpublished) so far reveal that although, 118 sections were systematically studied and sampled for their mega and microfossil content from Bhagirathi, Mandakini and Alaknanda valleys of Uttarakhand, only 18 sections were found to contain microfossils (Figure 1).

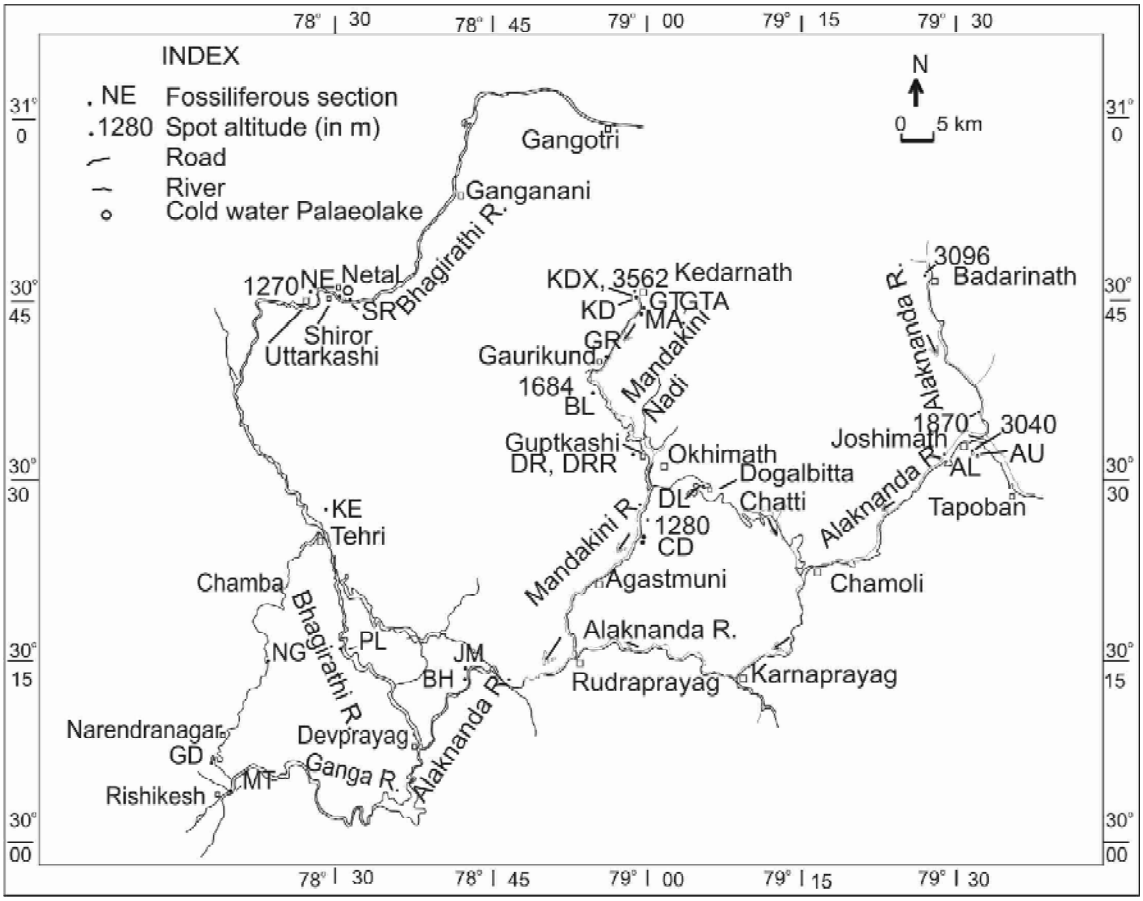

Figure 1. Locations of fossiliferous sections in Bhagirathi, Mandakini and Alaknanda valleys of Uttarakhand.

Bhagirathi valley

At the bend of Bhagirathi River near Netal (30°44'35" N; 78°29'15" E) on Dharasu-Uttarkashi-Gangotri road (Figure 2.A, B) the biodiversity from samples NE 1–3 comprises fossil arcellaceans (the identification of which was undertaken with reference to Treatise by Loeblich Jr. and Tappan 1964 and Medioli and Scott 1988 and to the keys, including Kumar and Dalby1998) *Arcella vulgaris* Ehrenburg, *Diplochlamys leidyi* Goof, *Euglypha* sp. cf. *E. alveolata* Dujardin, *Pseudawerintzewia calcicola* Bonnet, *Centropyxis constricta* (Ehrenburg), *Centropyxis aculeata* "discoides" Ehrenburg, *Difflugiella* sp., *Trigonopyxis* sp. and *Heleopera* sp. aff. *H. sphagni* (Leidy), snow bug *Heteropteris indicus* Kumar and Mathur in a silt interbedded in a thick succession of unsorted angular to subangular pebbles and sporadic boulders. Further ahead of Netal near village Shiror (30°44'20" N; 78°29'15" E) the biodiversity from samples SR 1, SR 3 and SR 12 comprises Arcellaceans *Arcella vulgaris* Ehrenberg, *Centropyxis constricta* (Ehrenburg), *Diplochlamys leidyi* Goof, *Difflugiella* sp., *Trigonopyxis arcula* (Leidy) and seed of *Sabia* sp. cf. *S. campanulata* Wall. and indeterminate seeds. Sample SR 7 has been dated 6290–6000 (^{14}C) years BP by the Birbal Sahni Institute of Palaeosciences, Lucknow, India. The bioevents are recognised on the basis of climatically/ecologically significant biotic elements among the biodiversity related to particular time in geological history of the sediments. Since climatic, ecologic, tectonic events of the Holocene are of utmost significance in understanding variables which could affect humans in the immediate future, the thrust of the present work has been in identifying critical biota for such events.

I. Arcellinids-*Heteropteris indicus* Bioevent: Arcellinid assemblage comprising *Arcella vulgaris* Ehrenb. (Figure 3.a), *Diplochlamys leidyi* Greeff (Figure 3.b), *Euglypha* sp. cf. *E. tuberculata* Dujardin (Figure 3.c), *Pseudawerintzewia calcicola* Bonnet (Figure 3.d), *Centropixis constricta* Ehrenb. (Figure 3.e), *C. aculeata* "discoides" (Ehrenb.) (Figure 3.f), *Difflugiella* sp. (Figure 3.g), *Trigonopyxis arcula* Leidy (Figure 3.h–i), *Heleopera* sp. aff. *H. sphagni* (Leidy) (Figure 3.j), together with Hexapod insect *Hetropteropsis indicus* Kumar and Mathur (Figure 3.k–l), and seeds of Himalayan shrub *Sabia* sp. cf. *S. companulata* Wall. (Figure 3m–n) found in thick sediment pile comprising large unsorted heterogeneous boulders, angular to subangular clasts embedded in crushed rock flour (silty or clayey) material are exposed near Netal and Shiror, between Uttarkashi and Bhatwari (30°48'47.88" N; 78°37'12" E) townships, in Bhagirathi valley (Figure 2) in Uttarakhand. These Testate amoebae survive at as low temperature as –5°C to 16°C. *Arcella vulgaris* is known from Arctic lakes (Collins et al. 1990) and was also found in ice core from Antarctica (Mathur et al. 2006). The Hexapod

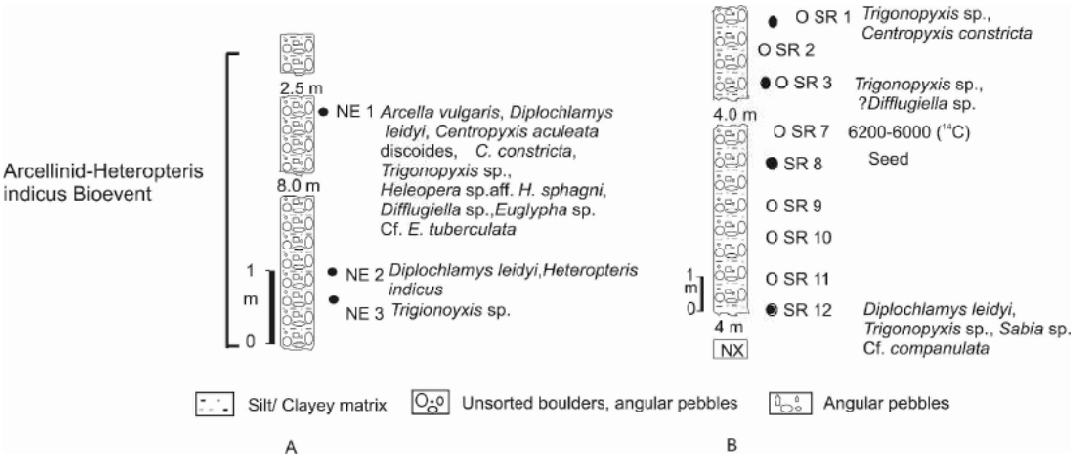

Figure 2. Bioevent based on biodiversity in sections of Holocene deposits in Bhagirathi Valley, exposed near A. Netal and B. Shiror, Uttarakhand.

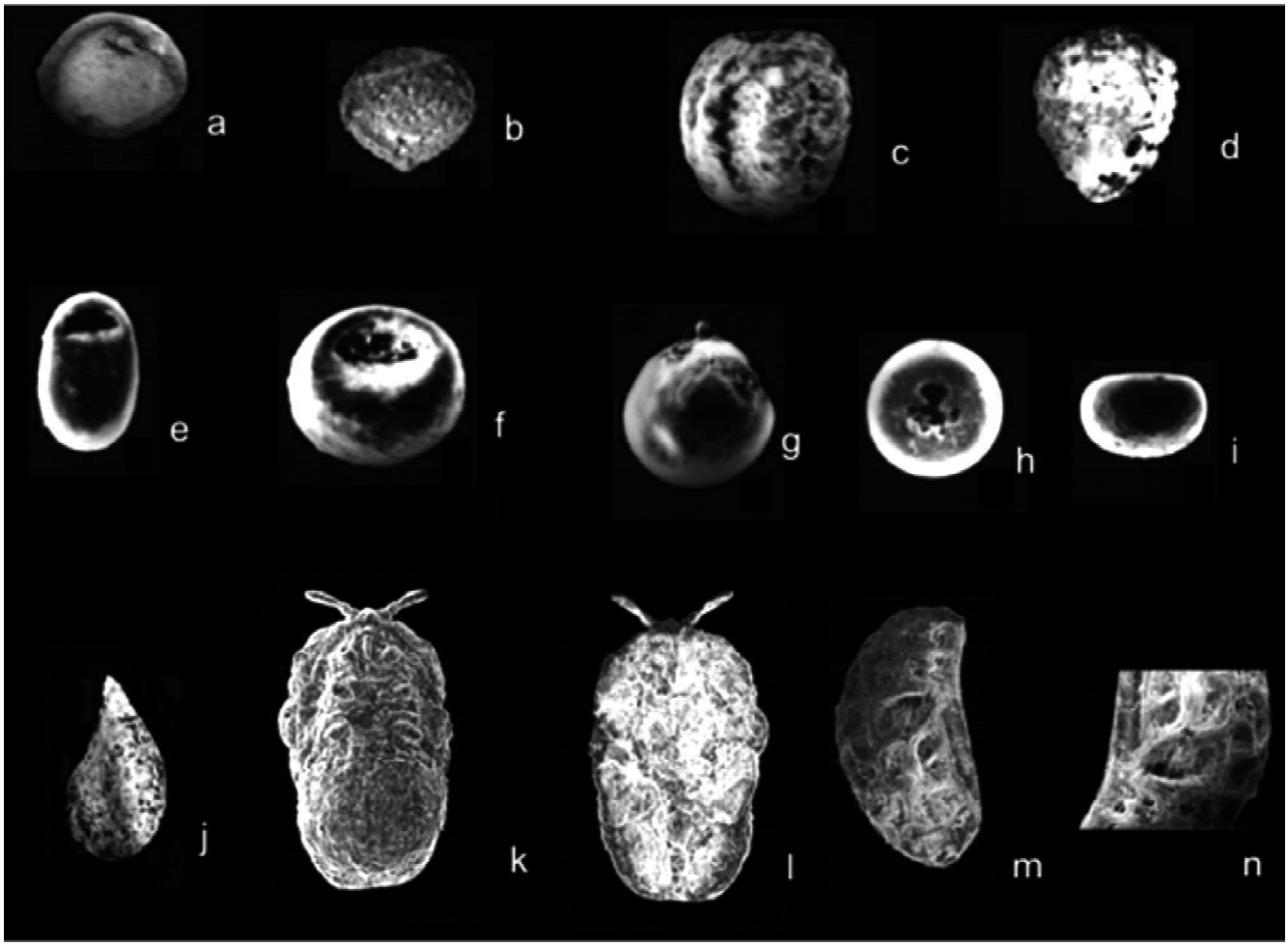

Figure 3. Significant microfossils from Holocene of Bhagirathi valley**.** Arcellinids: **a**. *Arcella vulgaris* Ehrenberg Diameter: 260 µm. **b**. *Diplochlamys leidyi* Greeff Diameter: 260 µm. **c**. *Euglypha* sp. cf. *E. tuberculata* Dujardin Diameter: 290 µm. **d**. *Pseudawerintzewia calcicola* Bonnet Diameter: 260 µm**. e**. *Centropyxis constricta* Ehrenberg Diameter: 100 µm. **f**. *Centropyxis aculeata* "discoides" (Ehrenberg) Diameter: 170 µm. **g**. *Difflugiella* sp. Diameter: 130 µm. **h, i**. *Trigonopyxis arcula* (Leidy) Diameter: 230 µm. **j**. *Heleopera* sp. aff. *H. sphagni* Leidy Diameter: 360 µm. **k, l**. Fossil Himalayan Bug: *Hetropteropsis indicus* Kumar and Mathur Length: 1.62 mm, Width: 0.62 mm. **m, n** Seed: *Sabia* sp. cf. *S. campanulata* Wall. Length: 1.85 mm, Width: 0.9 mm.

insect (a snow bug) *Hetropteropsis indicus* (Figure 3k–l) is well preserved with its antennae intact - possible only in extremely low temperatures as suggested by "rough surface of the cuticle in the fossil insect which may help absorb heat from outside and thus maintain its body warmth in the cold region" (Kumar & Mathur 2007, p. 172). The bioevent is characterized by dominance of Arcellinids such as *Arcella vulgaris*, *Trigonopyxis*, *Difflugia* species and Hexapod bug which indicate water body receiving continuous flow of cold water, possibly from glaciers at higher altitudes permitting survival and proliferation of Arcellinids at low altitudes of 1270 m amsl around 6290–6000 (^{14}C) years BP. Arcellinids-*Heteropteris indicus* Bioevent represents water body formed at low altitude due to impounding of the river around 6ka year BP.

Mandakini and Alaknanda valleys

Arcellenids have been found in several sections (Figures 4, 6) in Mandakini valley such as at Gauri Kund (30°39'00" N; 79°01'00" E) (samples GR 4, 6), Mana Ghat (29°22'09.60" N; 79°28'23.45" E) (samples MA1, 2), Guptkashi (30°31'45" N; 79°05'05" E)-Dewar (27°43'06" N; 78°21'51" E) (samples DR 1; DRR 1, 2), Badalpur (Sersi) (29°44'18" N; 78°47'07" E) (sample BL 4), Chandrapuri (30°27'00" N;

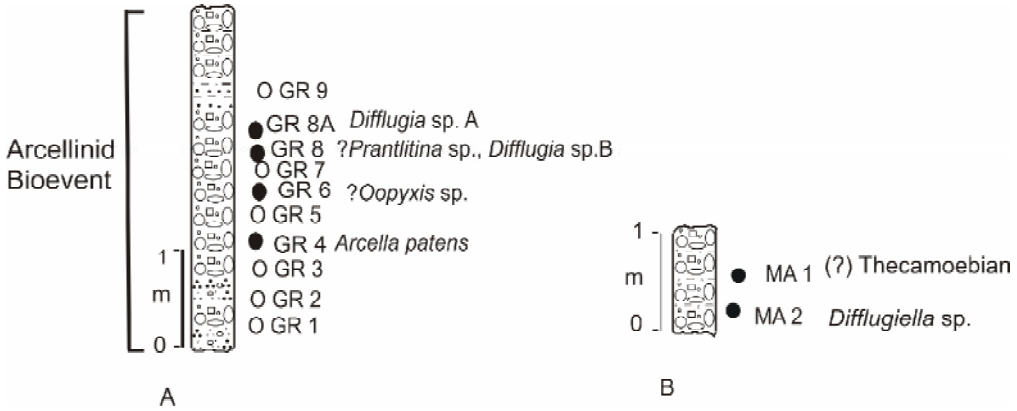

Figure 4. Bioevent based on Biodiversity from Holocene deposits along Gaurikund - Kedarnath foot-track in Mandakini valley, Uttarakhand.

79°04'00" E) (sample CD 5) random samples at Kedarnath (samples KD 2, 3) as also in the waterbody north of the Kedarnath Temple (sample KDX). In addition, seeds have been found in sections at Dewar (sample DR 2; DRR 1, 2) Badalpur (sample BL 4), Garur Chatti (29°54'3.92" N; 79°36'44.93" E) (sample GTA) and Chandrapuri (sample CD 5). The fossils identified so far include Arcellinids *Arcella vulgaris*

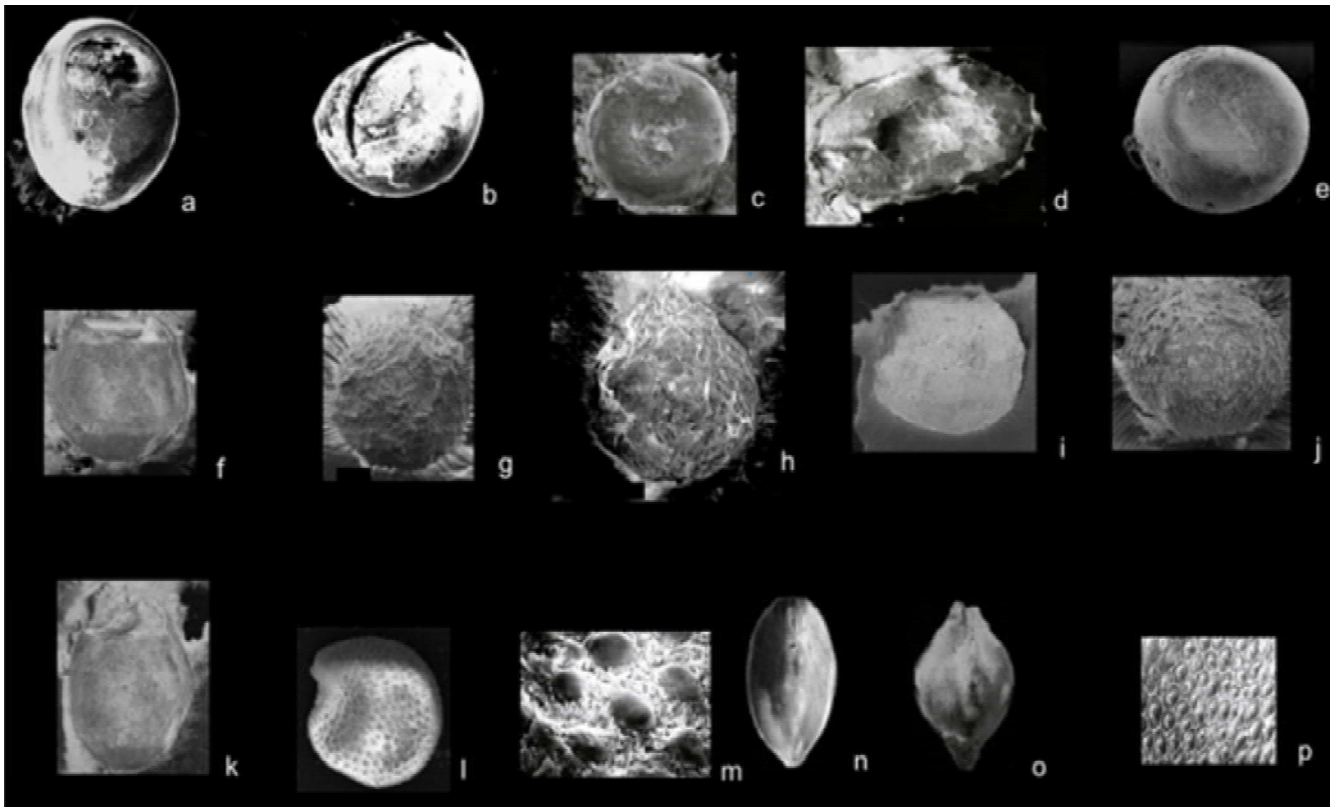

Figure 5. Significant microfossils from Holocene of Mandakini valley. **a.** *Centropyxis constricta* (Ehrenberg) Diameter :170 µm. **b**. *Arcella patens* Claparede & Lachmann Max. Diameter :260 µm. **c**. *Trigonopyxis arcula* (Leidy) Diameter :230 µm. **d**. *Prantlitina* sp. cf. *P. sturi* Vas]íek & Rmžièka Max. Diameter: 287 µm. **e**. *Cyclopyxis* sp. cf. *C. arcelloides* (Penard) Diameter: 408 µm. **f.** *Difflugia urceolata* Carter "urceolata" Diameter: 225 µm. **g**. *Phryganella* sp. cf. *P. nidulus* Penard Diameter: 116 µm. **h**. *Euglypha* sp. cf. *E. alveolata* Dujardin Diameter: 235 µm. **i**. *Cucurbitella* sp. cf. *C. tricuspis* (Carter) Diameter: 235 µm. **j**. *Phryganella* sp. Diameter: 203 µm. **k**. *Difflugia* sp. Diameter: 175 µm. **l**. Indet Seed DR 1 Diameter: 0.45 mm. **m**. enlarged view of surface of Indet Seed DR1. **n**. Indet. Seed BH 2 Diameter: 0.75 mm. **o**. Indet Seed BH 1 Diameter: 0.58 mm. **p**. enlarged view of surface of Indet Seed BH 1.

Ehrenb., *Arcella patens* Claparede & Lachmann, *Trigonopyxis* sp., *Cyclopyxis* sp., *Pseudawerintzewia* sp., ?*Phryganella* sp., ?*Prantlitina* sp., *Diplochlamys* sp., *Euglypha* sp. cf. *E. tuberculata* Dujardin, *Difflugia protaeiformis* Lamark, *Difflugia protaeiformis* "*amphoralis*" Reinhart et al., *Difflugia oblonga* Ehrenberg, *Difflugia oblonga* glans Reinhart et al., ?*Nebela* sp., *Lagenodifflugia vas* (Leidy) and at least ten forms of *Difflugia*, fragment ostracods of Ilyocyprid, *Cypridopsis* sp. *Candona* spp. Among ostracods and several types of seeds.

II. Arcellinids-Seeds Bioevent: The significant Arcellinid assemblage in sections (Figure 4) in Mandakini valley comprises of *Arcella patens* Claparede & Lachmann (Figure 5.b), *Centropyxis constricta* (Ehrenberg) (Figure 5.a), *Trigonopyxis arcula* (Leidy) (Figure 5.c), *Prantlitina* sp. cf. *P. sturi* Vas]íek & Rmžièka (Figure 5.d), *Cyclopyxis* sp. cf. *C. arcelloides* (Penard) (Figure 5.e), *Difflugia urceolata* Carter "urceolata" (Figure 5.f), *Phryganella* sp. cf. *P. nidulus* Penard (Figure 5.g), *Euglypha* sp. cf. *E. alveolata* Dujardin (Figure 5.h), *Cucurbitella* sp. cf. *C. tricuspis* (Carter) (Figure 5.i), *Phryganella* sp. (Figure 5.j), *Difflugia* sp. (Figure 5.k) together with seeds: Indet Seed DR 1 (Figure 5.l, m), Indet Seed BH 1 (Figure 5.o–p), Indet. Seed BH 2 (Figure 5.n). *Centropyxis aculeata* "discoides" is recorded from lakes near Cobalt, Ontario, Canada (Reinhardt et al. 1998). The centropyxids thrive in cold temperatures, low salinity regimes (Scott and Medioli 1980) but may also dominate shallow vegetation covered substrates (Reinhardt et al. 1998). Krashevska et al. (2007) while studying morphological variations of genus *Trigonopyxis* especially *T. arcula* s.l. which is found among mosses along altitudinal transect at 1000, 2000 and 3000 m amsl in a tropical montane rainforest in southern Ecuador reflect changing environmental conditions on different altitudes such as humidity, precipitation and temperature. According to Schulz et al. (2018) the size variation of *T. arcula* in Ecuador is between 60 and 210 µm whereas the present specimen is 230 µm suggesting suitable ecologic parameters. The influx of seeds along with Arcellinids further suggests that the coldwater bodies were surrounded by well grown shrubs. The dominance of Arcellinids in the Quaternary sections is similar to the assemblage from the modern waterbody at an altitude of 3562 m amsl north of Kedarnath Temple (sample KDX) indicative of cold water bodies at the time of deposition. Arcellinids - Seeds Bioevent represents continuity in biodiversity at different altitudes due to favourable environmental conditions.

III. Arcellinids Bioevent: The sections between Gaurikund and Kedarnath (Figure 4) show continuity in Arcellinid biodiversity *Prantlitina* sp. cf. *P. sturi* Vas]íek & Rmžièka (Figure 5.d), *Arcella patens* Claparede & Lachmann (Figure 5.b) in temporary water bodies. Nainwal at el (2007) have identified three phases of glaciation in the Quaternary on the basis of relict periglacial features and presence of lateral moraines in the area. According to Srivastava et al. (2017) 'the Kedarnath record provides compelling evidence for a reorganization of the global climate system taking place at ~5.5 ka BP possibly after sea level stabilization and the advent of interannual climate variability governed

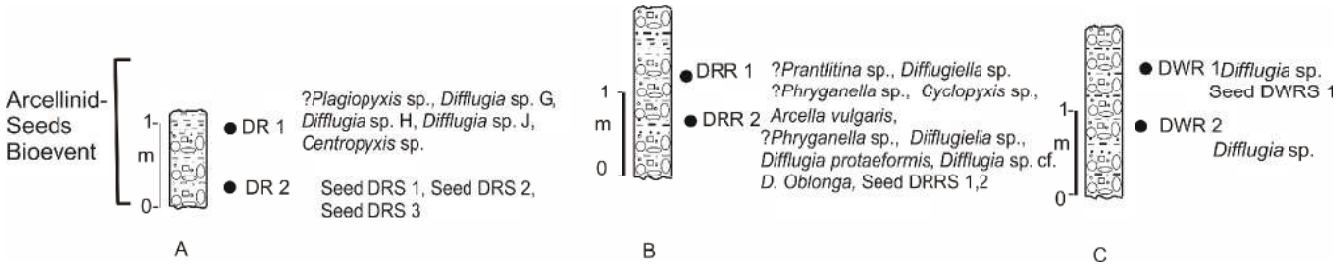

Figure 6. Bioevent based on Biodiversity of Holocene sediments in Mandakini valley on Guptkashi - Dewar foot-track

by the modern El-Nino Southern Oscillation (ENSO) phenomenon.' Arcellinid Bioevent represents continuity in environmental conditions to allow population growth of Arcellinids.

IV. Vegetal Matter Bioevent: In Alaknanda valley the exposed Holocene sediments were mostly disturbed and sections at Dogalbitta (30°07'55" N; 79°12'19" E) (Figure 7.A) and at Auli Hill (30°33'19.37" N; 79°33'16.56" E) (Figure 7.B) could be measured and sampled for microfossil content. These contained vegetal matter and no identifiable microfossil was found. However, selected samples from these sections (Figure 1) were subjected for ^{14}C dating at the Birbal Sahni Institute of Palaeosciences, Lucknow, India. In section opposite Dogalbitta 0 km stone, sample DL 1 provided date of 4640 years BP (Cal Age 4458–4830 years BP) and the section about 300 m west of Garhwal Vikas Mandal Nigam setup at Auli Hill the sample AU 2 has been dated 8180–7970 years BP. The poor response to biodiversity shows that the conditions for a water body to support biodiversity were not congenial due to frequent disruptions on account of climate and/or structural instability. Vegetal Matter Bioevent represents unstable conditions of climate preventing the growth of biodiversity.

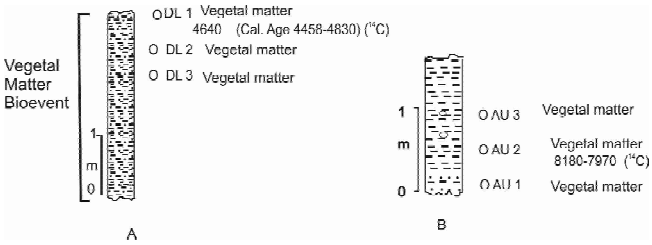

Figure 7. Bioevent based on absence of identifiable biodiversity in Holocene deposits in Alaknanda valley.

HARYANA

The Quaternary deposits of Haryana have been studied for microfossils by Bhatia and Khosla (1967, 1977), Bhatia and Singh (1988), palaeoecology and fossils by Mathur (1998a, b, 1999a unpublished, b). The geological investigations were also carried out by Dasgupta et al. (1994), Thussu et al. (1994), Razdan and Raina 1996 (Unpublished), Thussu (2004). A total of 64 sections of the Quaternary have been measured and systematically sampled. The geological and geomorphological map compiled by Razdan and Raina (1996 unpublished) forms the basis of sections studied (Figure 8).

Geological set-up

In Haryana, the oldest rocks exposed are Delhi Supergroup which provides the basement to most of the Quaternary sediments in its southern part. In the northern part, Siwalik Group (chiefly Upper Siwalik) sediments are exposed as foot hills. The generalised stratigraphy given in Razdan and Raina (1996 unpublished) has been adopted here (Table 3). The Holocene deposits in the southern Haryana comprise

Table 3. Generalised stratigraphic succession in Haryana (after Razdan & Raina 1996, unpublished).

Age	Formation	Unit	Lithology
Holocene	Newer Alluvium	Younger Alluvium of Yamuna, Ghaggar, Saraswati, Markanda. Terrace Alluvium of Yamuna, Ghaggar	Fine to medium grained sand, pebble bed, coarse grit, dark grey sand, silt and clays. Grey fine to medium grained sand coarse grit with pebbles and grey green and purple sandstone
		Disconformity	
Middle to Upper Pleistocene		Older Alluvium	Ambala Older Polycyclic sequence of sand, silt, Clay with nodular/ bedded 'kankar' calc sandstone Alluvium Piedmont/ a) Boulder, Pebble, grit Fan deposits b) Sandstone, clay, sandy clay
		Disconformity	
Middle Miocene to Middle Pleistocene	Siwalik Group	Siwalik Group Undifferentiated	Boulder conglomerate, green grey sandstones, purple/ green/ red/ yellow clay, etc.
		Unconformity	
Proterozoic	Delhi Supergroup	Alwar and Ajabgarh Groups with intrusives	Pegmatites, quartzites, granite, quart-biotite schists, quartz veins, phyllites, slates, crystalline Limestone, marble, etc.

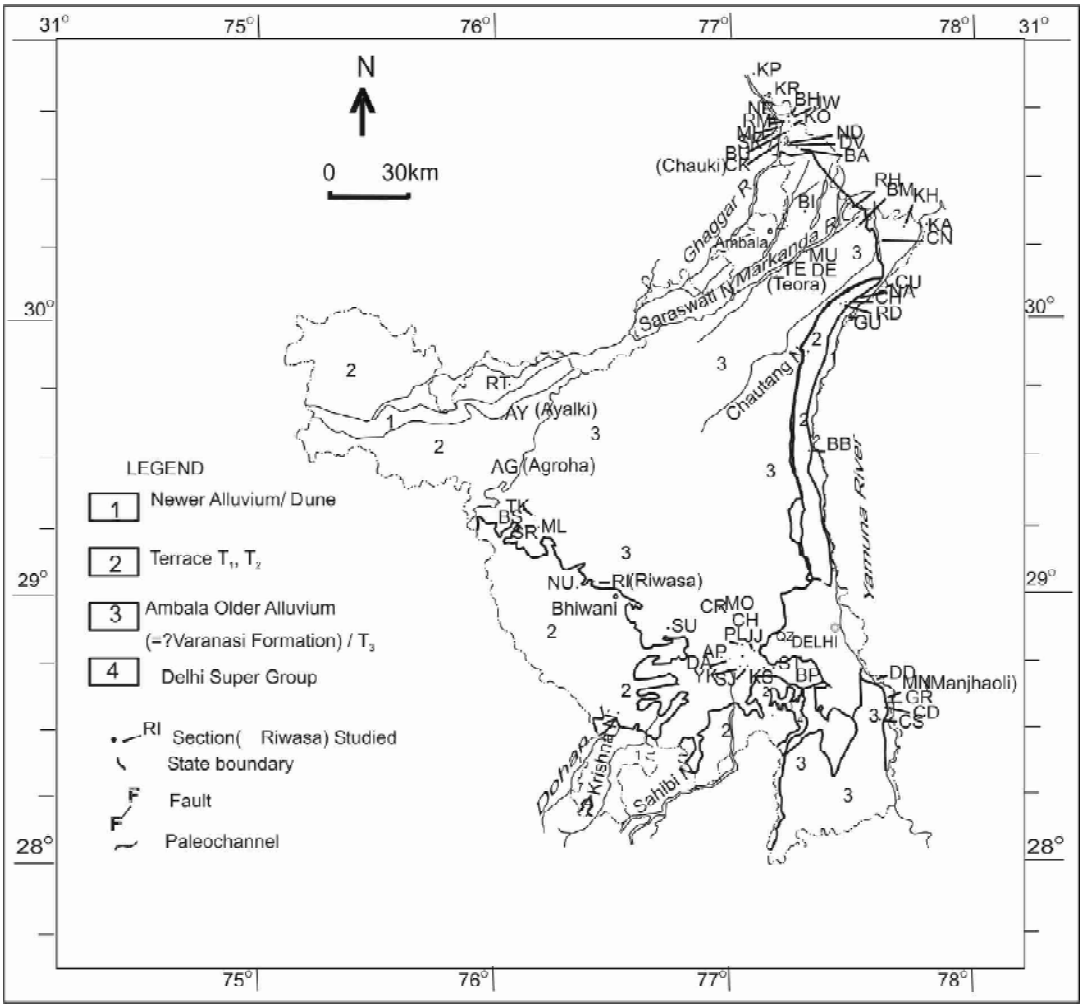

Figure 8. Locations of sections studied for palaeoecological changes in the Quaternary of Haryana (based on geological and geomorphological map of Haryana compiled by Razdan and Raina 1996).

of fossils which are sensitive to ecological variations. Biodiversity in these sediments is given in the sequel.

Holocene biodiversity and bioents

The biodiversity of Ambala Older Alluvium and Terraces T_2, T_3 and T_4 of Ghaggar and Yamuna River sections exposed in Central and southern Haryana comprise the molluscs *Gyraulus singularis* (Mousson), *G. convexiusculus* (Hutton), *Hydrobioides avarix* Annandale, *G. stewarti* Germain, *Indoplanorbis exustus* (Deshayes), *Melanoides tuberculata* (Mueller), *Lymnaea* sp. cf. *L. (Galba) andersoniana* Nevill, *?Philalanka nannophya* Rensch, *Gulella* (*Huttonella*) *bicolor* (Hutton), *Caecilioides* (*Geostilbia*) *bensoni* Gude, *Viviparus* sp. cf. *V. bengalensis* (Lamark) (juvenile), *Ena* (*Subzebrinus*) sp., *Succinea* sp. *Gyraulus* sp., *Polypylis* sp. cf. *P. kennardi* Bullen, *Lymnaea* sp., *Succinea* (*Fossaria*) sp.; the ostracodes *Cyprideis westi* Bhatia and Khosla, *Cyprinotus* (*Heterocypris*) *cingalensis* Brady, *Cyprideis torosa* Jones, *Hemicypris* sp., *Cypris subglobosa* Sowerby, *Candona* (*Candona*) *neglecta* Sars, *C.* (*C.*) *marengoensis* Klie, *C.* (*Candona*) sp. cf. *C.* (*C.*) *paionica* Petkovski, *C. lactea* Baird, *Strandesia* sp., *Darwinula stevensoni* (Brady and Robertson), *C.* (*Hetrocypris*) *incongruens* (Ramdohr), *Ilyocypris bradyi* Sars, *I. gibba* (Ramdohr), *Cyprideis* sp., *Cypridopsis vidua* (Mueller), *Candona* sp., ?*Strandesia* sp., *Hemicypris arorai* (Battish) ?*Limnocythere* sp., *Hemicypris* sp.,

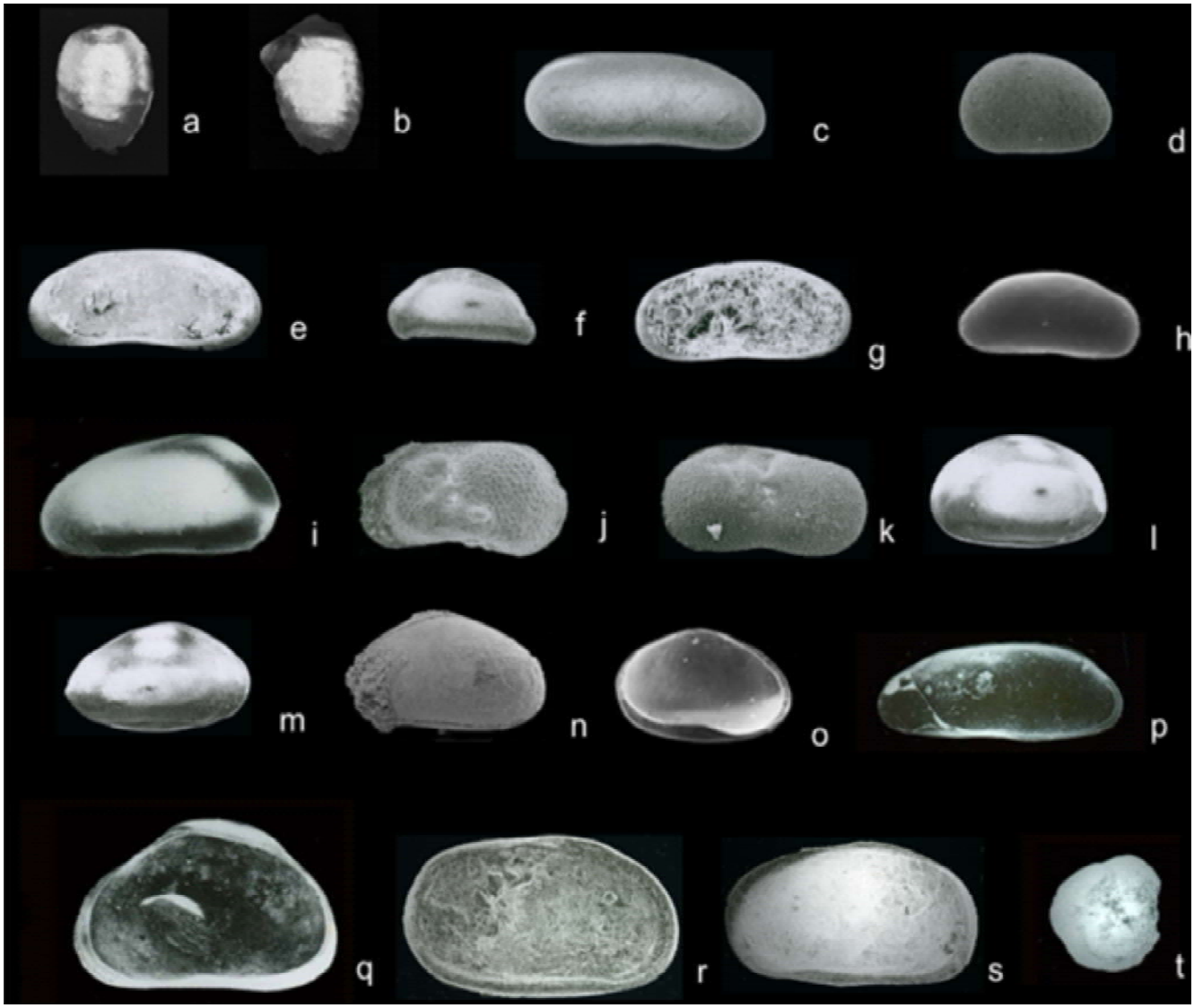

Figure 9. Selected microfossil biodiversity from Holocene of Haryana. **a.** *Lamprothamnium* sp. LED: 925 µm; **b.** *Chara aspera* Willd. LED: 430 µm; **c** *Darwinula stevensoni* (Brady & Robertson) L: 0.840 mm; **d** *Cyclocypris* sp. L: 0.42 mm; **e.** *Candona compressa* (Koch) L:0.760 mm; **f.** *Potamocypris* sp. L: 0.525 mm; **g.** *Candona fabaeformis* (Fischer) L: 0.520 mm; **h.** *Candona paionica* Petkovski L:1.30 mm; **i.** *Candona candida* (O.F. Müller) L: 0.835 mm; **j.** *Ilyocypris gibba* (Ramdohr) L: 0.615 mm; **k.** *Ilyocypris bradyi* Sars 0.725 mm; **l.** *Hemicypris arorai* (Battish) L: 0.730 mm; **m.** *Cypris subglobosa* Sowerby L: 1.15 mm; **n.** *Cyprideis westi* Bhatia & Khosla L: 0.61 mm; **o.** *Cypridopsis vidua* (O.F. Mueller) L: 0.425; **p.** *Stenocypris major* (Baird) L:1.25 mm; **q.** *Cyprinotus cingalensis* Brady L: 0.945 mm; **r.** *Cyprideis torosa* Jones (reworked) L:0.85 mm; **s.** *Cyprideis torosa* Jones L: 0.820 mm; **t.** *Pseudoeponides whittakeri* Bhatia L: 0.22 mm.

Stenocypris major (Baird), *Potamocypris* sp. and reworked ostracod *Cypridopsis vidua*, *Cyprideis torosa* (reworked), *Ilyocypris* sp., Charophytes *Chara aspera* Willdenow, *Lamprothamnium* sp. cf. *L. populosum* (Wallroth), Foraminifer *Pseudoeponides whittakeri* Bhatia, Premolar P 2 of Bos sp., Molar of small bovid, Indeterminate Seeds such as Seed TE 2B/1, Seed AY 4/1, Seed MN 1/1 and many more seeds which being indeterminate have not been included here.

I. *Darwinula stevensoni* Bioevent: The ostracode *Darwinula stevensoni* (Figure 9.c) in the marls (dated ^{14}C 5363 and ^{14}C 3640 years BP, Bhatia and Singh 1988) near Riwasa (28°47'30" N; 75°44'15" E) in the plains of southern Haryana indicates presence of freshwater bodies. According to Külköylüoðlu and Vinyard (2000) and Van Doninck et al. (2003) the survival of *D. stevensoni* declines with increase in salinity and it prefer less saline water. The works of Meisch

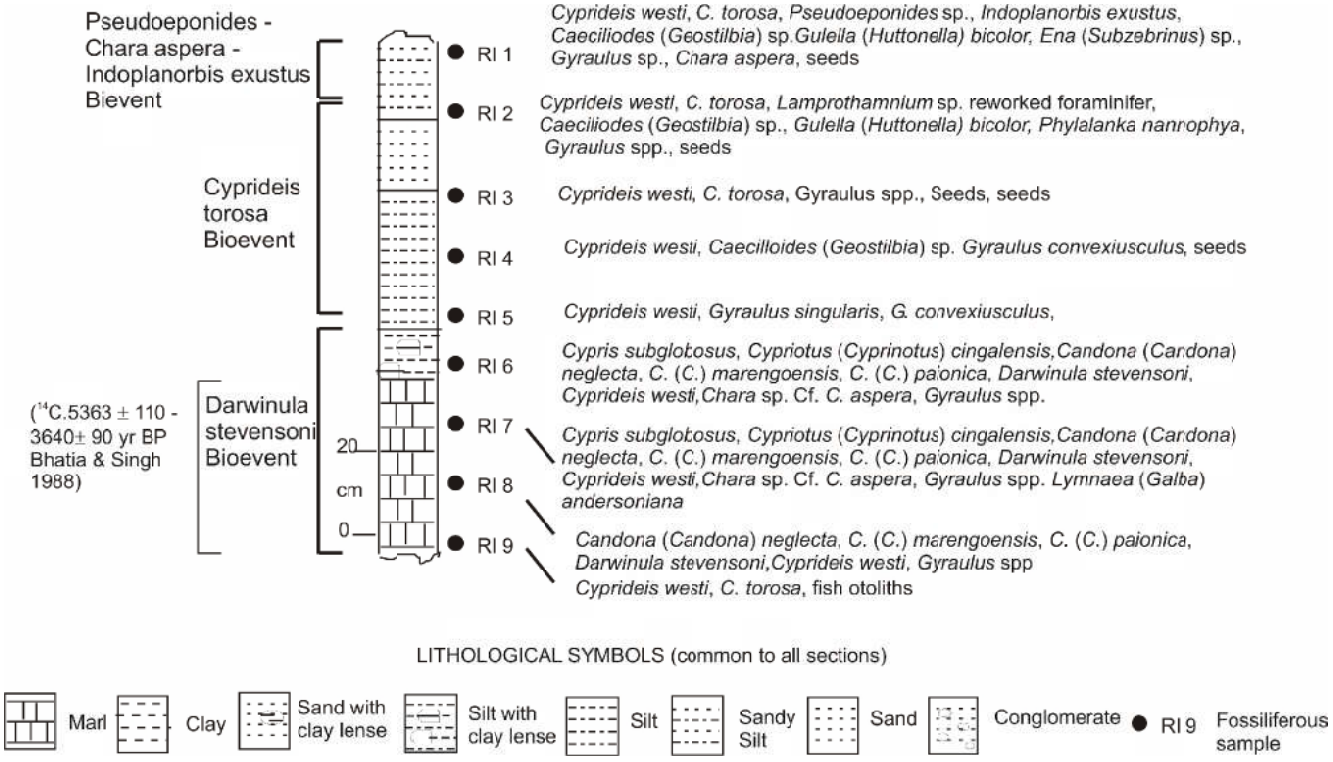

Figure 10. Section of Older Alluvium exposed near Riwasa. Bioevents based on biodiversity recorded. Lithological symbols common to all sections.

(2000), Pérez et al. (2011) Lorenschat and Schwalb (2013) Lorenschat et al. (2014) quoted in Yavuzatmaca and Külköylüoðlu (2019) suggest that although the depth range of *D. stevensoni* is up to 20 m in a stabilised water body, its optimum depth is 2.3 m. In addition, there are other microfossils *Cypris subglobosa* (Figure 9.m), *Candona* (*Candona*) *candida* (Figure 9.i), *Chara aspera* (Figure 9.b) which are also freshwater habitants. Thus *D. stevensoni* Bioevent (Figure 10) is interpreted as representing shallow freshwater body in the lower part of section which existed in southern Haryana up to 3.6 ka and to maintain low salinity for survival of *D. stevensoni*, it received water from a perennial source.

II. *Cyprideis torosa* Bioevent: Vladimir et al. (2001) while dealing with the ecology of Lake Elton (Volgograd Region, Russia) found that this hypersaline lake is dominated by *Cyprideis torosa.* The saline rivers in arid region are highly productive with *C. torosa* as its bottom dweller element. *Cyprideis torosa* (Figure 9.s) in the middle part of the section (Figure 10) also points towards high salinity. *Gulella (Huttonella) bicolor* (Figure 11.b) present among biodiversity is a land predator pulmonate gastropod which is found in sandy mud (Castillo-Rodriguez et al. 2018). The *Cyprideis torosa* Bioevent thus represents hypersaline temporary water body which had blown sand in the middle part of the section.

III. *Pseudoeponides-Chara aspera-Indoplanorbis exustus* Bioevent: The increase in salinity of water body is well indicated by the presence of benthic foraminifer *Pseudoeponides whittakeri* (Figure 9.t), charophyte *Lamprothamnium* sp. (Figure 9.a) in the upper part of the section (Figure 10). *Chara aspera* (Figure 9.b) prefers shallow water environments and usually occurs at depths of about 6 m (Blindow & Schütte 2007). The proliferation of oospores of *Chara aspera* indicates low germination due to level of light penetration (Van den Berg 2001). *Indoplanorbis exustus* (Figure 9.b) is able to populate in small

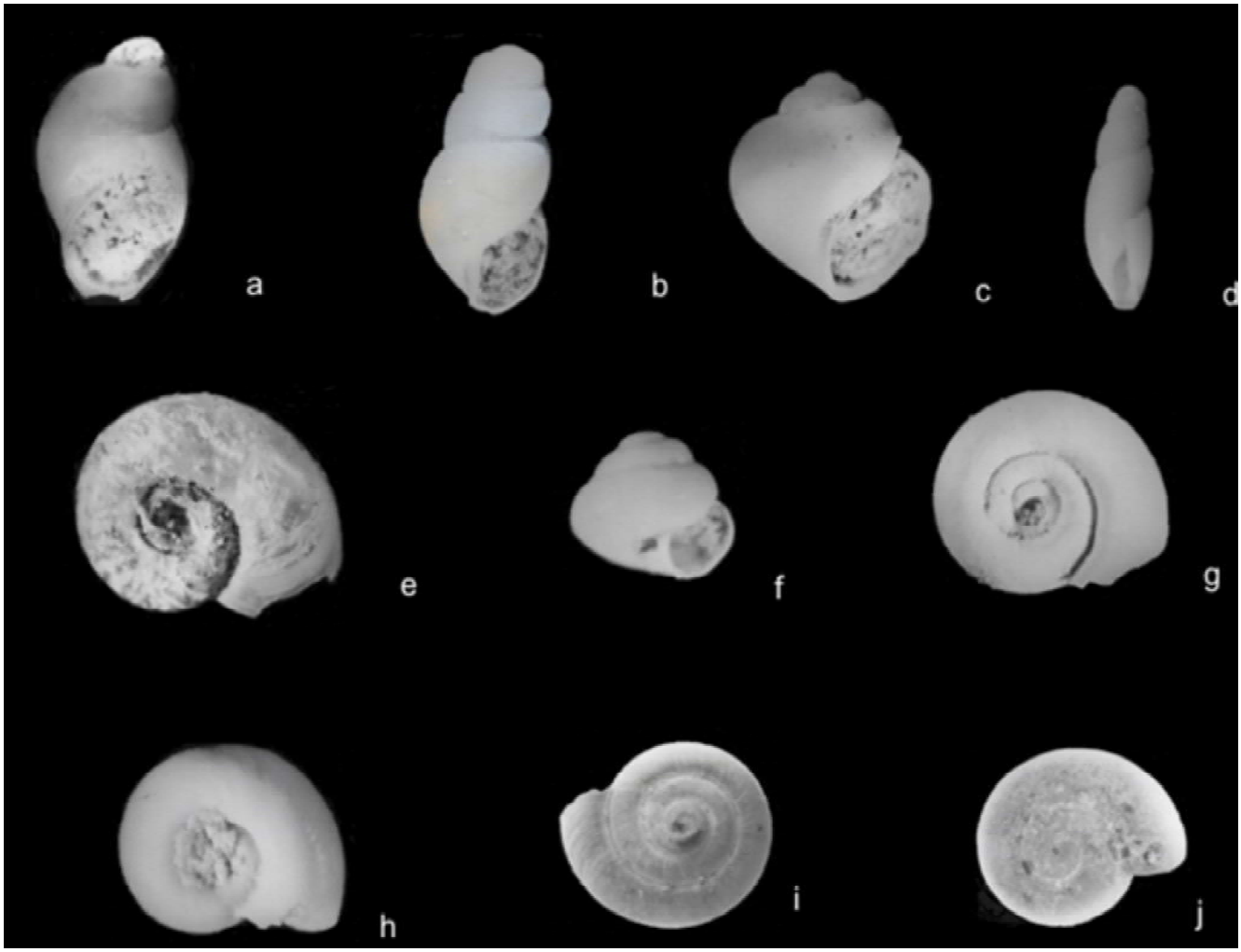

Figure 11. Selected molluscan biodiversity from Holocene of Haryana. **a.** *Succinea* (*Fossaria*) sp. H: 7.0 mm; **b.** *Gulella* (*Huttonella*) *bicolor* Gude; H: 2.2 mm; **c.** *Viviparus* sp. cf. *V. bengalensis* (Benson) (juvenile) H: 6.5 mm; **d.** *Caecilioides* (*Geostilbia*) *bensoni* Gude H: 2.5 mm; **e.** *Indoplanorbis exustus* (Deshayes) Dia: 2.8 mm; **f.** *Pyramidula javana* (Moellendorf) H: Dia. 2.25 mm; **g.** *Gyraulus convexiusculus* (Hutton) Dia. 2.0 mm; **h.** *Gyraulus singularis* (Mousson)Dia. 2.0 mm; **i.** *Philalanka micromphala* Benthem Jutting Dia: 1.60 mm; **j.** *Philalanka nannophya* Rensch Dia. 0.73 mm.

freshwater bodies with other pulmonate gastropods and can occur in semi-permanent pools in flood plains. During dry season it can survive in the mud (Liu et al. 2010). The overall biodiversity indicates presence of shallow water semi-permanent waterbody with variable salinity where *Cyprideis torosa* (Figure 9.s) and *C. westi* (Figure 9.n) also inhabited. *Pseudoeponides-Chara aspera-Indoplanorbis exustus* Bioevent thus represents a shallow water body with high salinity and the presence of foraminifer further indicates hypersaline condition.

IV. Bovid Bioevent: The entire section exposed near Agroha (29°20'00" N; 75°34'00" E) (Figure 12) has dominance of bovid teeth. The presence of gastropods *Gyraulus singularis* (Figure 11.h), *G. convexiusculus* (Figure 11.g) is well marked in the middle of the section. *G. convexiusculus* is highly restricted to ponds and rivers or confluence (Choubisa & Sheikh 2013). In addition, the presence of premolar P_2 of *Bos* sp, (Figure 13.d) and molar of small bovid (Figure 13.e) together with pottery pieces and burnt vegetal matter at different levels indicates existence of human culture between 7050±130 to 4180±140 years BP. Thus, the Bovid Bioevent represents high ground close to the permanent water source of Riwasa as observed in *Darwinula stevensoni* Bioevent.

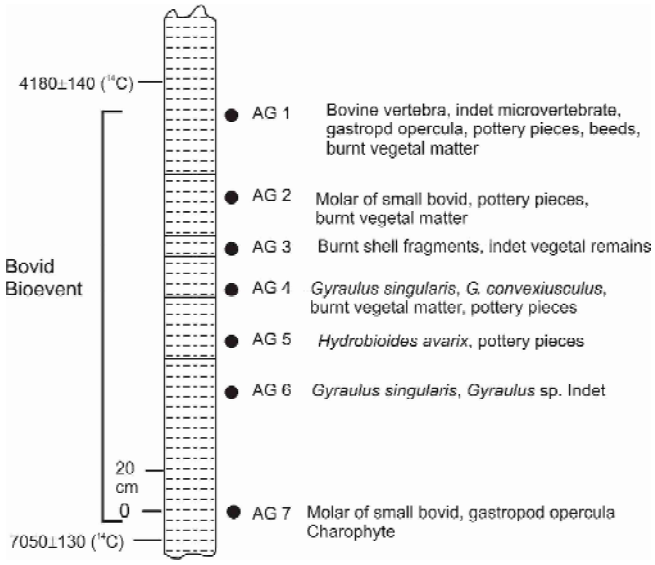

Figure 12. Section of Older Alluvium exposed near Agroha. Bioevent based on biodiversity recorded.

V. Seeds - Microvertebrates Bioevent: The dominance of indeterminate seeds such as Seed TB 2/1 (Figure 13.a) and others in the Section near Teora (30°07'00" N; 76°52'15" E) (Figure 14) along with the microvertebrates which were mostly fish vertebra that could not be identified and the mammalian remains together with pottery pieces indicate existence of human culture. Seeds-Microvertebrates Bioevent thus also represents a high ground in the area.

VI. Seeds-*Chara aspera* Bioevent: The section near Ayalki (29°34'00" N; 75°30'00" E) (Figure 15) is also dominated by seeds. Indet Seed AY 4/1 (Figure 13.b) and many other types of seeds which could not get germinated due to ecological conditions of temperatures and moisture to germinate. The seeds could not be identified. The presence of *Chara aspera* (9 b) and closely associated *Chara* sp. indicates impermanent water body in the middle of the section. Pottery pieces in the upper part of section indicate human settlement. Seeds-*Chara aspera* Bioevent also represents high ground.

VII. Seeds-*Cyprideis torosa* (Reworked) Bioevent: There is dominance of different varieties of seeds, such as Indet Seed MN 1/1 (Figure 13.c) in the section of Terrace T_2 of Yamuna River. The presence

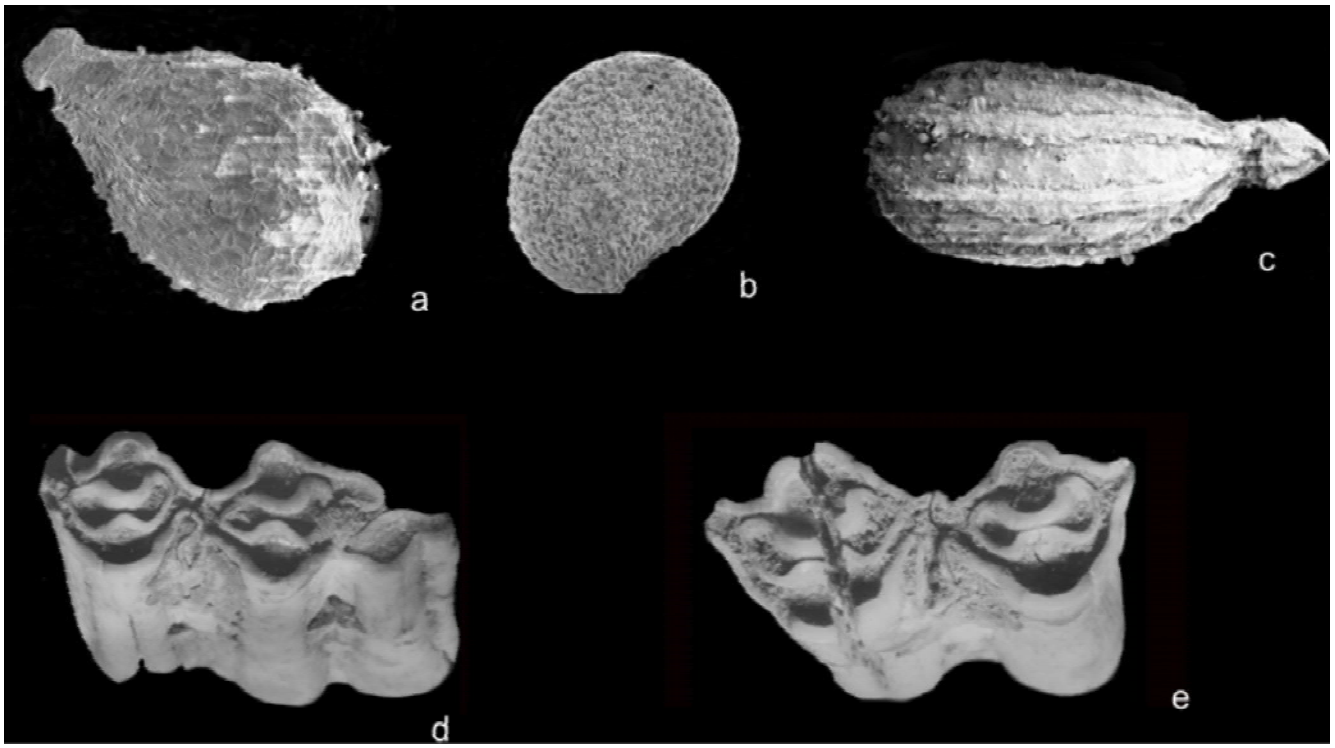

Figure 13. Selected megafossil biodiversity from Holocene of Haryana. **a.** Indet. Seed TE 2B/1 Max Diameter: 0.525mm; **b.** Indet Seed AY 4/1 Max Diameter: 1.54mm; **c.** Indet Seed MN 1/1 Max Diameter: 0.95 mm; **d.** Premolar P2 of *Bos* sp. Width of the crown: 5.5cm; **e.** Molar of small Bovid Width of the Crown: 6.3 cm.

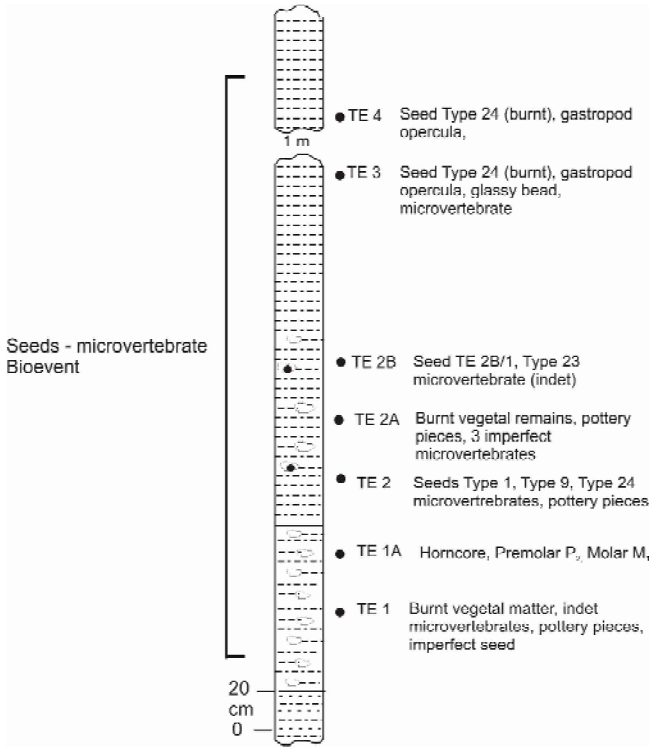

Figure 14. Section of Older Alluvium exposed near Teora. Bioevent based on biodiversity recorded.

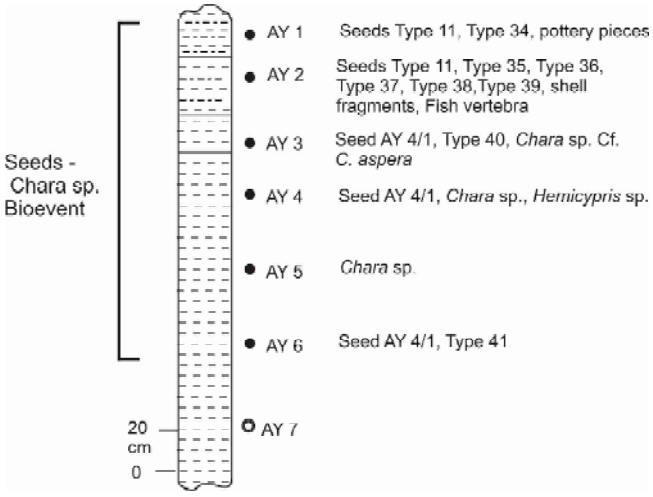

Figure 15. Section of Older Alluvium exposed near Ayalki. Bioevent based on biodiversity recorded.

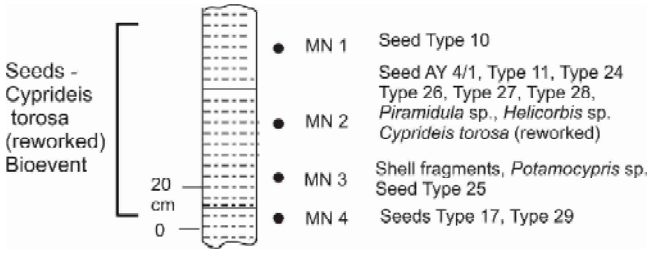

Figure 16. Section of Terrace T_2 of Yamuna River near Manjhaoli. Bioevent based on biodiversity recorded.

of gastropod *Pyramidula* sp. (Figure 11.f), ostracode *Potamocypris* sp. (Figure 9.f) indicate fresh water pool. The reworked *Cyprideis torosa* (Figure 9.r) in the biodiversity indicates denudation of Older Alluvium in the near vicinity and its redeposition in the Terrace T_2. Seeds-*Cyprideis torosa* (Reworked) Bioevent represents overbank sediments of Yamuna River near Manjhaoli (28°22'15" N, 76°28'00" E) (Figure 16) with water pool.

VIII. *Cypridopsis vidua* (Reworked) Bioevent: The biodiversity comprising gastropods *Gyraulus singularis* (Figure 11.h), *G. convexiusculus* (Figure 11.g), ostracodes *Stenocypris major* (Figure 9.p) are indicative of a semi-permanent freshwater body formed as an overbank. The reworking of *Cypridopsis vidua* (Figure 9.o) in the section is interpreted as due to denudation of older sediments in near proximity. Ghaggar River actively cut across the sediments of Older Alluvium and deposited near Chauki (30°42'30" N; 76°53'30" E) (Figure 17). *Cypridopsis vidua* (Reworked) Bioevent of Terrace T_2 of Ghaggar River thus represents overbank sediments.

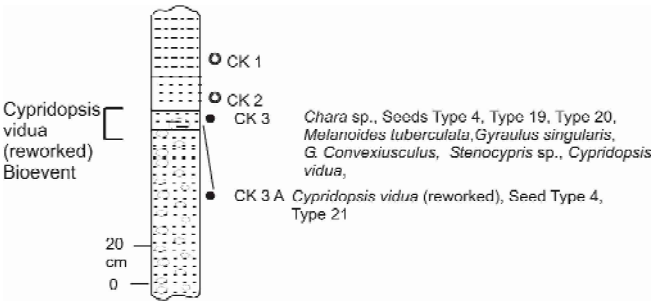

Figure 17. Section of Terrace T_2 of Ghaggar River near Chauki. Bioevent based on biodiversity recorded.

APPLIED ASPECT OF BIOEVENTS

Kaufmann and Hart (1996) introduced the term Bioevents for short term extraordinary, environmental changes. They classified the bioevents as 'Diversification Bio-Events (punctuated evolution, population blooms, colonization and immigration bio-events), or Diversity Reduction Bio-Events (mass mortality, ecosystem shock, extinction and emigration bio-events)'. The uncommon (exotic) fossils or peak of common biotic elements in the strata recorded over short stratigraphic

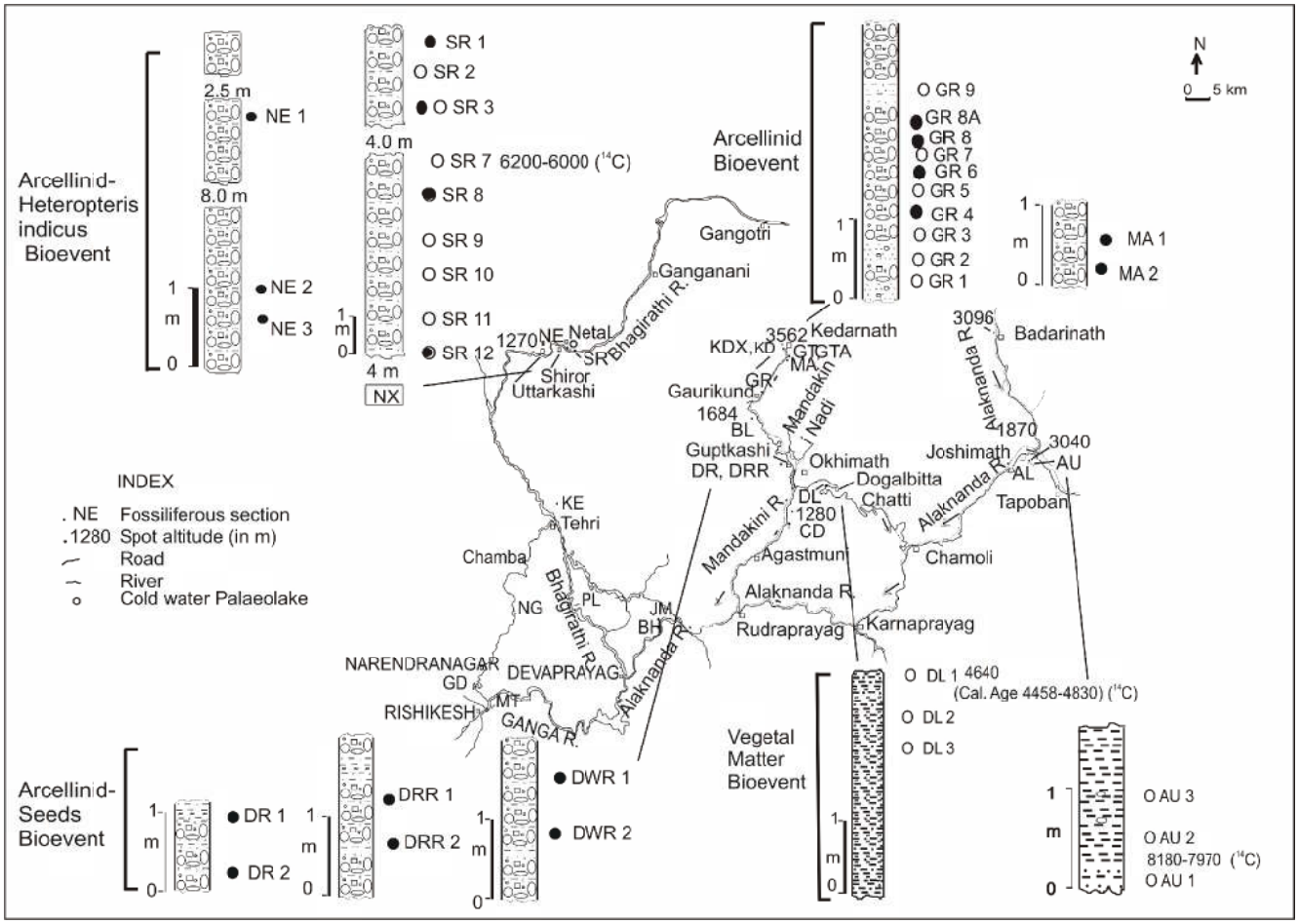

Figure 18. Relative position of bioevents in Bhagirathi, Mandakini and Alaknanda valleys.

interval are a characteristic feature of bioevent (Wilmsen 2012). These criteria have been found useful in identifying bioevents in the Holocene of Uttarakhand and Haryana (Mathur and Mehrotra 2004). They are an important tool in building the past environments and geomorphology. This application is discussed below.

Uttarakhand: The three valleys of Uttarakhand that have been studied for biodiversity and the consequent bioevents, present unique bioevent for each valley. In Bhagirathi valley, Arcellinid-*Heteropteris indicus* Bioevent represents water body created at low altitude of 1270 m amsl. A water body in otherwise high rising Himalayan terrain at low altitude is possible only by impounding of the stream carrying turbulent water which also carried large boulders. The impounded water which occupied large area was cold enough to permit proliferation of Arcellinids and supported snow bug *Heteropteris indicus* (Mathur et al. 2005, Kumar and Mathur 2007). From Himalayan Quaternary, fossil Arcellinids which are rare to find, were first reported by Mehra et al. (2003). The morphology of quartz grains from these sediments also suggests cold water (Mathur et al. 2009) conditions. The thick succession of glaciated deposits with this thriving biodiversity indicates undisturbed sedimentation which could be possible in the absence of any tectonic activity in Bhagirathi valley around 6 ka BP. In Mandakini valley, the sections between Gaurikund and Kedarnath and other sections of the Arcellinid Bioevent, the biodiversity includes variety of cold water Arcellinids, indicating their continuity in successive impermanent water bodies formed by the receding glaciers. The quick shifting of water bodies in younger sediments of successive higher altitudes indicate relatively more tectonic activity than

in Bhagirathi valley. In Alaknanda valley, there were no identifiable biodiversity and only vegetal matter was found which provided ^{14}C dates of 4640 years BP (Cal Age 4458–4830 years BP) for sediments exposed near Dogalbitta and ^{14}C dates of 8180–7970 years BP at Auli Hill. Also, the earlier sediments appear to be masked by relatively younger sediments which is interpreted as due to higher tectonic activity as compared to Bhagirathi and Mandakini valleys thereby releasing the loose sediments.

Haryana: The bioevents (Figure 19) derived from the biodiversity in Holocene of Haryana throws up variability in the environment which affected the chemistry of water bodies through time. In Riwasa area *Darwinula stevensoni* Bioevent identified in the exposed lower part of the section represents permanent freshwater body. Bhatia and Singh (1988) have assigned the marl an age between 5363 and 3640 years BP. The geomorphological studies (Razdan and Raina 1996 Unpublished) show palaeochannels of the streams Saraswati and Chautang which were discharging freshwater in the lake. The younger sediments represented by *Cyprideis torosa* Bioevent show proliferation of hypersaline *Cyprideis torosa* which points to degradation of environment and consequently the rise in total dissolved solids to turn the water body hypersaline. The further younger *Pseudoeponides-Chara aspera-Indoplanorbis exustus* Bioevent points to narrowing of the waterbody to ponds where shallow water gastropods like *Indoplanorbis exustus* survived with other pulmonate gastropods. The Charophytes also found congenial ecology. Section near Agroha has gastropods like *G. convexiusculus* which is highly restricted to ponds and rivers in Bovid Bioevent

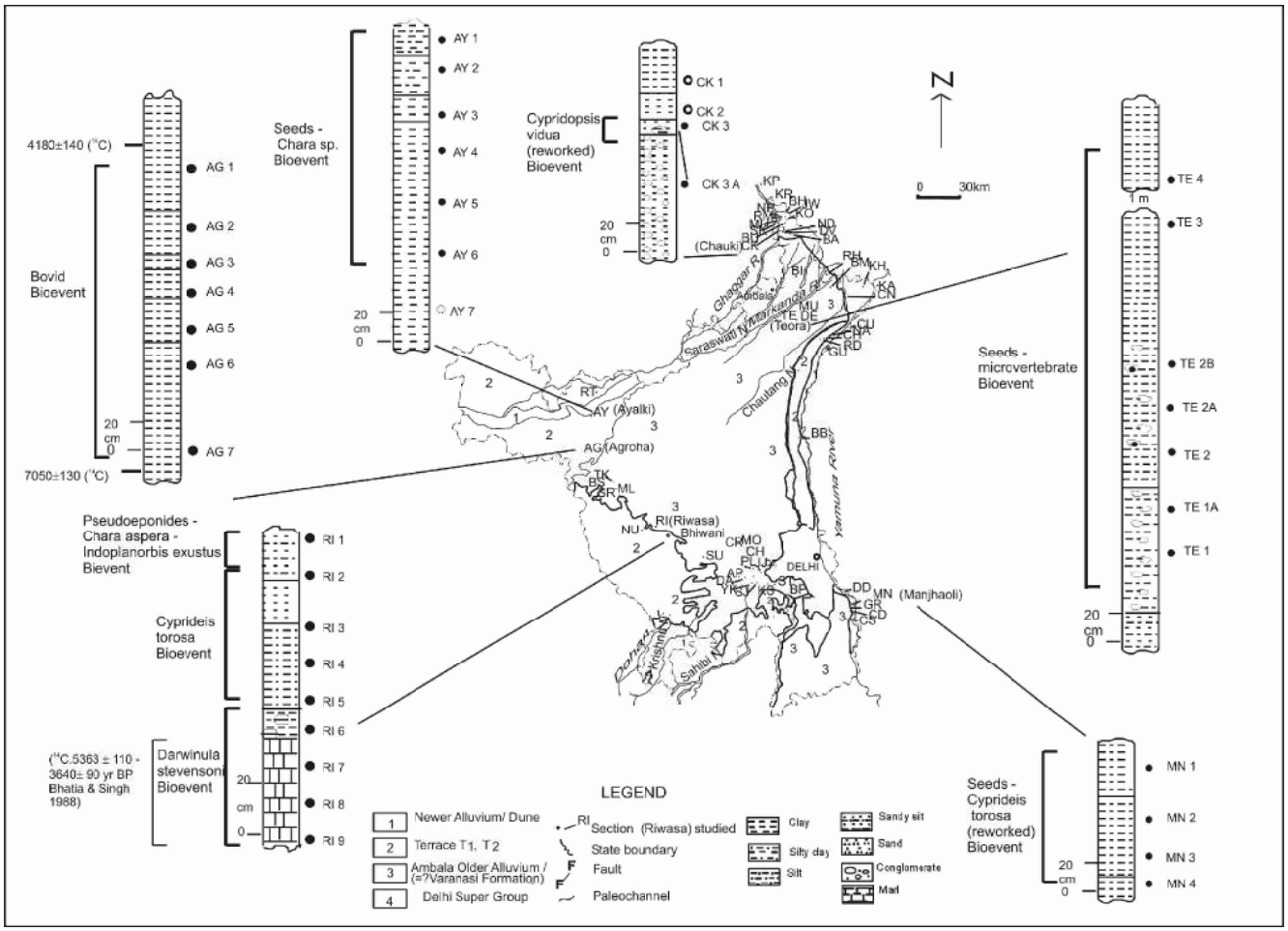

Figure 19. Distribution of bioevents in southern Haryana.

indicating development of pools of water due to overbanking. The appearance of bovids in section indicates stable land. The pottery pieces also found in this section indicates human culture which occupied this high ground. The exposed section has time range of 7050±130 to 4180±140 years BP during which this culture existed. The area near village Teora close to Ambala, Seeds - Microvertebrates Bioevent represents high ground where vegetation contributed seeds which did not germinate perhaps due to unfavourable conditions. The burnt nature of seeds together with pottery pieces and remains of land mammals point to the existence of human culture. The microvertebrate remains such as fish vertebra which could not be identified suggest presence of small pools of water for sustainability of human culture. The biodiversity of Seeds-*Chara aspera* Bioevent suggests presence of semi-permanent pools of fresh water where Charophytes could survive. The presence of pottery pieces in the upper part of exposed section near Ayalki village can be interpreted as high ground where human culture was thriving. The high grounds observed as above, had been subjected to erosion as seen in Seeds-*Cyprideis torosa* (Reworked) Bioevent. The reworked ostracodes are present in section near Manjhaoli locality which is Terrace T_2 of Yamuna River. The abundance of seeds is, as stated earlier, suggests uncongenial conditions for germination. The reworking of *Cyprideis torosa* from earlier deposited sediments points either to neotectonic activity or shifting of river channels or both. The *Cypridopsis vidua* (Reworked) Bioevent represents T_2 of River Ghaggar, exposed near village Chauki. A semi-permanent freshwater body, which supported ostracodes like *Cypridopsis vidua* and *Stenocypris major*, had formed. The presence of reworked *Cypridopsis vidua* in the sediments indicates quick erosion of earlier sediments, which could be due to neotectonic activity.

DISCUSSION

In Uttarakhand, the most striking feature is the impounding of a high energy river Bhagirathi, by large, more than 2–3 meters across polished boulders derived from higher altitude glacial waste around 6 ka to form a large water body. The waterbodies supported cold water biodiversity interpreted from Arcellinid-*Heteropteris indicus* Bioevent. Such boulders have been observed by Rai et al. (2001, p. 9, photo 2) in Sarju valley. The stability of the waterbodies at low altitude of 1270 m amsl further indicates that no tectonic activity of main central thrust (MCT) north of Netal and Shiror would have occurred, as otherwise, a waterbody with varied biodiversity could not have existed. On the other hand, in Mandakini River, the waterbodies formed were short lived as interpreted from Arcellinid Bioevent which may be due to short tectonic activity. The Alaknanda valley seems to be tectonically more active as inferred from the absence of identifiable biodiversity.

In the plains of southern Haryana, Bioevents, *Darwinula stevensoni* Bioevent to *Cyprideis torosa* Bioevent to *Pseudoeponides-Chara aspera-Indoplanorbis exustus* Bioevent in Riwasa section, exhibit change in water quality from freshwater to hypersaline on the basis of contained biodiversity. For this, two possibilities can be postulated, i.e., change in environment or abandoning of channel due to hinderance in the continuous flow of perennial stream. According to Valdiya (2002), 'the geomorphogical evidence shows beyond doubt that the older faults were reactivated time and again during the last 10000 years of the Holocene epoch. The movement along the fault are accompanied by earthquakes, ground subsidence, land upliftment and drainage deflection or diversion'. Thus, it is surmised that the perennial channel of Saraswati was hindered by upliftment in the north of Agroha-Teora-Ayalki land and resulted in stagnant water in the water body thereby changing the water quality to hypersaline, unsuitable for human consumption. Puri (2001) and subsequently, Valdiya (2013) have emphasized with respect to the ancient river Saraswati, whose palaeochannel have been shown (Figure 8, 18) in Razdan and Raina (1996 unpublished) that climate alone was not responsible for continuity of this river but also glacial water fed to the streams at its origin. The Bovid Bioevent in Agroha whose exposed section has been dated between

7050±130 and 4180±140 years BP, Seeds-Microvertebrates Bioevent from Teora section and Seeds-*Chara aspera* Bioevent at Ayalki where, beside the biodiversity including bovid remains, pottery pieces are also present. This shows the existence of human culture at high ground close to the Riwasa water body that fulfilled the requirement of water. Valdiya and Chatterjee (2018) while reviewing palaeochannels of Northwest India found large number of Harappan settlements on the banks of the channels which 'lead to the unequivocal surmise that these channels were once the water course of a large river having discharge' sufficient enough for the culture to flourish. This discharge supported the permanence of Riwasa waterbody.

CONCLUSIONS

1. In Uttarakhand, impounding of high energy Bhagirathi River formed waterbody at low altitude.
2. The permanent cold waterbody around 6 ka with rich biodiversity was possible due to long pause in tectonic activity of MCT in higher altitude in the area.
3. The frequent shift in waterbodies indicated in Mandakini valley by biodiversity is interpreted as due to tectonic activity at short intervals which did not permit permanent waterbodies for biodiversity to flourish.
4. The change in water quality from freshwater to hypersaline in Riwasa waterbody is interpreted from bioevents, which shows that the abandoned channels gradually stopped receiving water and not due only to environment reasons.
5. The high ground around the Riwasa waterbody supported human culture as interpreted from biodiversity of the bioevents.

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