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Pliocene-Pleistocene Upper Siwalik Biota of the Outer Northwest Himalaya, Jammu and Kashmir, India: Palaeobiodiversity, Palaeoecology and Palaeoenvironment

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Abstract

Siwalik sediments of the Himalaya are famous worldwide for their rich biotic preservation comprising vertebrates, invertebrates, microfossils, and plant fossils. From time to time, various authors have been recovered, and described, fossil specimens from various Pliocene-Pleistocene fossiliferous sites of the Outer Northwest Himalaya, Jammu and Kashmir, India. The current work aims to present up-to-date Pliocene-Pleistocene fossil records from the Pliocene-Pleistocene Siwalik deposits. Based on this fossil record, a clear picture of palaeobiodiversity, palaeoecology, and palaeoenvironment of these deposits was reconstructed during the present study. Further, fossil record indicates that artiodactyls and charophytes were the highly diversified groups among the fauna and flora of these deposits. The fauna and flora suggest that two distinct palaeo-communities existed during the Pliocene-Pleistocene time *viz*. one terrestrial and another aquatic in the Outer Northwest Himalaya of Jammu and Kashmir.

Keywords: Pliocene-Pleistocene, Palaeobiodiversity, Palaeoecology, Palaeoenvironment, Jammu Province, India

Introduction

The Siwalik Group of rocks is the southernmost part of the Himalayan foreland basin and home of fossilised vertebrates, invertebrates, micro-vertebrates, microfossils, ichnofossils and plant fossils (Kundal, 2022). It is divided into three subgroups: the Lower Siwalik Subgroup, which comprises argillaceous sediments; the Middle Siwalik Subgroup, made up of arenaceous sediments; and the Upper Siwalik Subgroup, which consists of rudaeceous sediments. A comparative study indicates that the Upper Siwalik Subgroup has more biotic diversity than Lower and Middle Siwalik Subgroups. The Upper Siwalik Subgroup is divided into three formations *viz.* Tatrot Formation, Pinjor Formation and Boulder Conglomerate Formation. Among these three formations, Pinjor Formation contains a rich assemblage of fossil specimens (proboscideans, reptiles, artiodactyls, carnivores, perissodactyls, rodents, lizards, frogs, fishes, ostracodes, charophytes, gastropods, bivalves, plant impressions and trace fossils).The Siwalik Group of rocks is well exposed in Jammu region and lying between the Line of Actual Control (LAC) (border between Pakistan and Jammu & Kashmir) in the west and the Ravi River (boundary between Jammu and Kashmir and Punjab) in the east. The Upper Siwalik Subgroup of Jammu contains a rich assemblage of fossil specimens, which have been collected and described by various authors from time to time. The vertebrate specimens collected and described by various researchers over time (Wadia, 1925; De Terra and Teilhard, 1936; Verma *et al.,* 2002; Suneja and Kumar, 1979; Suneja and Sanjeev , 1983; Ganjoo, 1985; Ganjoo,1992; Gupta and Verma, 1988; Rage *et al.,* 2001; Gupta and Prasad, 2001; Prasad *et al.,* 2005; Kundal and Kundal, 2011; Kundal and Prasad, 2011; Kundal, 2018; Kundal *et al.,* 2017, 2019, 2022). Additionally, invertebrate fossils have been studied (Kundal, 2013), along with microfossils (Suneja *et al.,* 1980; Bhatia *et al.,* 2001; Bhandari and Kundal, 2008; Kundal, 2015, Kundal, 2022; Kundal *et al.,* 2023), ichnofossils (Kundal *et al.,* 2022) and plant fossils including algae (Kundal, 2022).

Geology and Stratigraphy Setting

The Outer Northwest Himalaya is bounded between two tectonic units viz. Main Boundary Thrust (MBT) and Himalayan Frontal Fault (HFF). The MBT separates the Lesser Himalaya from the Outer Himalaya in the north and HFF separating the Indo-Gangetic Plains from the Outer Himalaya in the south. The Outer Himalaya is divided into three subgroups and seven formations (Pilgrim, 1934) viz. Lower Siwalik Subgroup, Middle Siwalik Subgroup and Upper Siwalik Subgroup. Argillaceous rock units dominate Lower Siwalik Subgroup (Kamlial Formation and Chinji Formation), arenaceous rock units dominate the Middle Siwalik

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Subgroup (Nagri Formation and Dhokpathan Formation) and rudaceous rocks unit dominate the Upper Siwalik Subgroup (Tatrot Formation, Pinjor Formation and Boulder Conglomerate Formation). The Upper Siwalik Subgroup of the Jammu region was further divided into three formations (Rao *et al.*,1988) *viz.* Purmandal Formation (=Tatrot Formation), the Nagrota Formation (=Pinjor Formation) and Tawi Conglomerate (=Boulder Conglomerate Formation). The Purmandal sandstone formation is composed of friable sandstone, the Nagrota formation is composed of gray - coloured clay and some patches of sand and pebbles and a volcanic ash bed/marker horizon bed is exposed in the in this at twenty-six localities dipping towards the southwest. The origin and source of the marker horizon bed might be the Dashet-e-Nawar, Volcanic complex in eastern Afghanistan (Johnson *et al.,* 1982). Its continuity can see in Pakistan and Indian Siwalik. This volcanic ash bed has been dated by various authors from time to time. Rao *et al.* (1988) dated this volcanic ash bed (2.48 Ma) by applying fission track dating technique on zircon grains extracted from the ash bed and found that the recorded age date coinciding with the Gauss-Matuyama boundary. Bhat *et al.* (2008) carried out detailed study on volcanic ash beds of Jammu region and established four palaeolakes within 45km area and suggested an interfluvial-lacustrine depositional environment of the ash beds. Most of the fauna and flora presented in this study were recovered by the one of us (Som Nath Kundal) from the ash /marker beds and associated mudstone horizons present in the Outer Northwest Himalayan region of Jammu area. Earlier, The same author has recovered and published five species of charophytes, six species of gastropods and bivalves, sixteen species of ostracodes, one species of cyprinid fishes, two species of lizards, six species of rodents, two species of *Elephas* from mudstone horizon immediately underlying ash beds and fifteen species of ichnofossils within the ash beds and underlying mudstone horizon (Kundal *et al.,* 2022).The Tawi Conglomerate Formation composed of cobble, pebbles, boulder intercalated with mud and sand units. The present study is focused on the Upper Siwalik Subgroup of Jammu (Fig. 1). The comparative lithostratigraphic classification of the Siwalik of the Outer Northwest Himalaya of Jammu is given in Table 1.

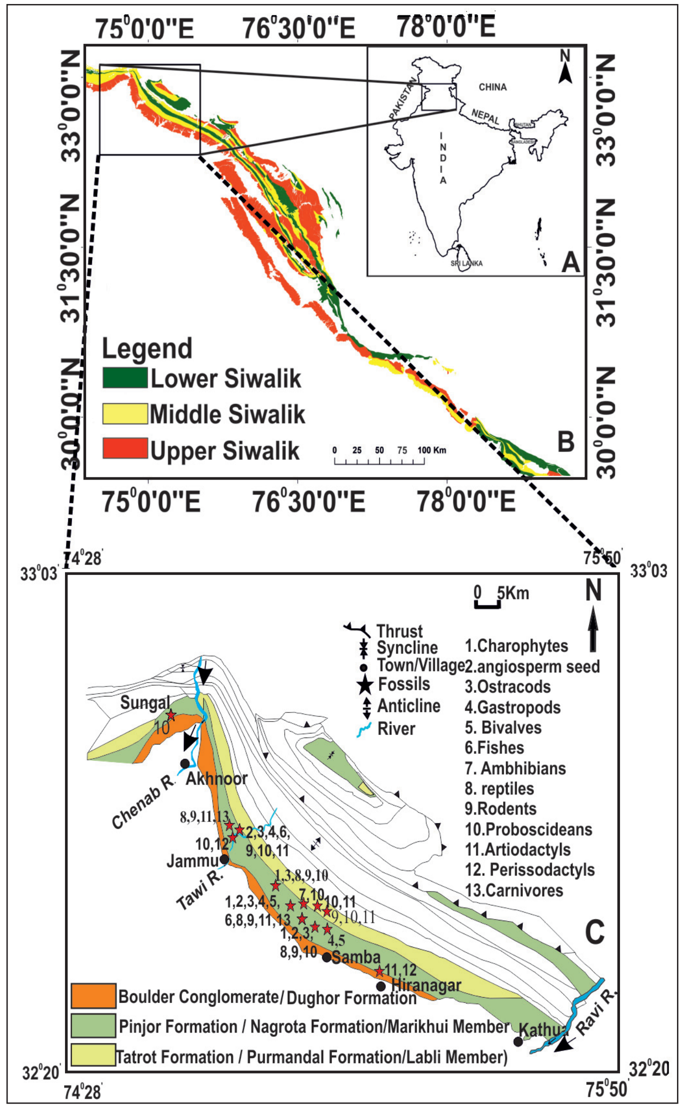

Fig.1. Showing map of India and adjoining countries (1a), Range of Northwest Siwalik Hills, India (1b) and fossil yielding sites in the of study area (1c).

Table 1: Comparative lithostratigraphic classification of the Siwalik Group, Outer Northwest, Himalaya, India

Group	Siwalik Subgroup	Potwar Plateau (Pilgrim,1934) Pakistan		Jammu and Kashmir: Gupta and Verma 1988		Jammu and Kashmir: Rao *et al.*, 1988	Jammu and Kashmir: Agarwal *et al.*, 1993	Jammu and Kashmir: Eliyas *et al.*, 2017	Himachal Pradesh (GSI 2002)	Age (After Johnson *et al.*, 1985; Ranga Rao *et al.*, 1988)
Siwalik	Upper Siwalik	Soan Formation	Lower Boulder Conglomerate	Dughor Formation		Tawi Conglomerate		Dughor Formation	Kalar	Lower-Middle Pleistocene (1.7Ma to 0.6Ma)
			Pinjor Formation	Uttarbaini	Marikhui Member	Nagrota Formation	Nagrota Member A Nagrota Member B Nagrota Member C	Marikhui Formation	Pinjor Formation	Pliocene (5.3 Ma to 1.7 Ma)
			Tatrot Formation		Labli Member	Parmandal Sandstone		Labli Formation	Saketi Formation	
	Middle Siwalik	Dhokpathan Formation		Mohargarh Formation				Mohargarh Formation	Mohargarh Formation	Upper Miocene (11.2 Ma to 5.3Ma)
		Nagri Formation		Dewal Formation				Dewal Formation	Dewal Formation	
	Lower Siwalik	Chinji Formation Kamlial Formation		Mansar Formation				Mansar Formation	Nahan Formation	Middle Miocene (18.3Ma to 11.2 Ma)

Data Collection and Methodology

The primary purpose of the study is to collect the data of fossil specimens recovered and, described by various authors from Pliocene-Pleistocene deposits of Jammu. This has been done through published literature on the Upper Siwalik Subgroup of Jammu. Secondly, the corresponding author (Som Nath Kundal) recovered a good number of fossil specimens including mega vertebrates, micro vertebrates, invertebrates, microfossils, ichnofossils, and plant fossils from the various sections (Dora, Karju Nalla, Teri, Kherdi, Uttarbehani, Mandal, Badakhetar, Anand Pur, Khanpur, Jagti, Kamini, Dhami). The mega vertebrates were directly collected from the sections/fields and for microfossils, micro vertebrates, and plant fossils (Chara), the following methodology was employed. Samples of mudstone were collected from fossil ferrous mudstone horizons. The mudstone samples acquired for the study were of two distinct types: soft and hard. The soft samples underwent a sun-drying process followed by a soak in a plastic tub of water for 5-6 hours. After this, the samples were screened and washed using a 60-mesh (ASTM) sieve. In contrast, the hard samples were treated using the kerosene technique. Initially, the samples were broken down to a few inches in size using a hammer and then dried in an oven to remove any residual moisture. The samples were then submerged in kerosene for a span of seven to eight hours. Subsequently, water was added to the plastic tub. Since water has a higher specific gravity than kerosene, it displaced kerosene from the samples. The samples were then broken down into millimeters and washed and screened using tap water. The material obtained from the water and kerosene methods was then dried in sunlight and sorted under a binocular microscope for microfossils, vertebrates, and plant charophytes. After that photomicrography and identification of specimens were carried out.

Results

By employing the fossil retrieval methodology described above, a diverse range of vertebrates, micro-vertebrates, invertebrates, microfossils, and micro-floral species have been identified and analyzed. A list of the fauna and flora recovered by the current authors and various palaeontologists over time is given in Table 2.

Table 2: List of taxa recovered from the Upper Siwalik Subgroup of Jammu, Jammu and Kashmir, India

Flora and Fauna Group	Taxa	Authors name and Year
Charophytes	*Hornichara maslovi*	Bhatia *et al.*, 2001; Kundal *et al.*, 2008
	Chara contraria	Kundal *et al.*, 2008; Kundal, 2022
	Chara rantzieni	Kundal *et al.*, 2008, Suneja *et al.*, 1980
	Chara rantzieni sivalensis	Kundal *et al.*, 2008; Suneja *et al.*, 1980
	Chara globularis globularis	Kundal *et al.*, 2008; Kundal, 2022
	Lychnothamnous breviovatus	Kundal *et al.*, 2008; Kundal, 2022
	Lamprothamnium papulosum	Kundal *et al.*, 2008; Kundal, 2022
	cf. *Lamprothamnium*	Kundal *et al.*, 2008; Kundal, 2022
	Lychnothamnus barbatus	Bhatia *et al.*, 2001; Kundal, 2022
Angiosperms seed	*Boraginocarpus lakhanpalii*	Bhatia *et al.*, 2001; Kundal et al., 2008
Ostracods	*Hemicypris* sp.	Sujneja *et al.*, 1980
	Hemicypris megalops sars	Bhatia *et al.*, 2001
	Hemicypris pyxidata	Bhatia *et al.*, 2001; Bhandari and Kundal, 2008
	Candona lactea Baird	Bhatia *et al.*, 2001; Bhandari and Kundal, 2008
	Sclerocypris? sp.	Bhatia *et al.*, 2001; Bhandari and Kundal, 2008
	Cypridopsis sp.	Bhatia *et al.*, 2001; Bhandari and Kundal, 2008
	Cypris subglobosa Sowerby	Bhandari and Kundal, 2008
	Cypris cf. C. decaryi	Bhandari and Kundal, 2008
	Cypridopsis sp.A	Bhandari and Kundal, 2008
	? Cypridopsis sp.	Bhandari and Kundal, 2008
	Candona sp.A	Bhandari and Kundal, 2008
	Candona sp.B	Bhandari and Kundal, 2008
	Eucypris sp.A	Bhandari and Kundal, 2008
	Eucypris sp.B	Bhandari and Kundal, 2008
	Stenocypris major (Baird)	Bhandari and Kundal, 2008
	Stenocypris sp.	Bhandari and Kundal, 2008
	Zonocypris barakhetarensis sp. nov.	Bhandari and Kundal, 2008
	Ilyocypris bradyi Sars	Bhandari and Kundal, 2008
	Ilyocypris sp.	Bhandari and Kundal, 2008
	Darwinula sp.	Bhandari and Kundal, 2008
	Darwinula jammuensis sp. nov.	Bhandari and Kundal, 2008
	Potamocypris sp.	Bhandari and Kundal, 2008
Gastropods	*Gastrocopta* sp.	Kundal, 2013
	Gyraulus sp.	Kundal, 2013
	Viviparus sp.	Kundal, 2013
	Viviparus bengalinsis	Kundal, 2013
	Bellamya celispirals	Kundal, 2013
Bivalves	*Lamellidens lewisi*	Kundal, 2013
	Oxynaia sp. indet	Kundal, 2013
Fishes	*Cyprnid* fishes -Gen. sp. Indet.	Suneja and Kumar, 1979, Kundal *et al.*, 2017
Amphibians	*Anurans* (Frogs)	Suneja and Kumar, 1979
Reptiles	*Varanus* sp. (varanide)- Lizards	Rage *et al.*, 2001
	Lacertilia indet.	Kundal *et al.*, 2011

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.... Table 2: Contd.

Flora and Fauna Group	Taxa	Authors name and Year
	Acrochordus dehmi (snakes)	Rage *et al.*, 2001
	Crocodilia	Suneja and Kumar, 1979
	Colossochelys atlas	Gupta and Verma, 1988
	Crocodilus sp.	Gupta and Verma, 1988; Verma *et al.*, 2002
	Geoclemys hamiltoni	Gupta and Verma, 1988
	Gavialis sp.	Gupta and Verma, 1988
	Trionyx sp.	Gupta and Verma, 1988
Rodents	*Parapelomys robertsi*	Gupta and Prasad, 2001
	Golunda kelleri	Gupta and Prasad, 2001; Prasad *et al.*, 2005
	Golunda sp.	Gupta and Prasad, 2001; Kundal and Prasad, 2009
	Dilatomys pilgrim	Gupta and Prasad, 2001
	Millardia sp. indet.	Gupta and Prasad, 2001; Kundal and Prasad, 2009
	Abudhabia cf. *A. kabulense*	Gupta and Prasad, 2001
	Rhizomyides sivalensis	Gupta and Prasad, 2001
	cf. *Rattus*	Kundal and Prasad, 2009
	Mus sp.	Kundal and Prasad, 2009
	Mus jacobsi	Kundal and Prasad, 2009
	Dilatomys sp.	Kundal and Prasad, 2009
	? Tatera pinjoricus	Kundal and Prasad, 2009
	? Cremnomys blanfordi	Kundal and Prasad, 2009
	Mus flynni	Kundal and Prasad, 2009; Gupta and Prasad, 2001
Proboscideans	*Anancus falconeri*	Verma *et al.*, 2002; Verma et al., 2002
	Gomphotherium sp.	Verma *et al.*, 2002
	Stegolophodon sp.	Verma *et al.*, 2002; Ganjoo, 1985
	Stegolophodon latidens	Kundal *et al.*, 2021
	Stegodon ganesa	Wadia,1925; Ganjoo, 1985; Gupta and Verma,1988; Verma *et al.*, 2002
	Stegodon insignis	Ganjoo, 1985; Gupta and Verma, 1988; Verma *et al.*, 2002, Kundal *et al.*, 2017
	Elephas planifrons	De Terra and Teilhard, 1936; Ganjoo, 1985; Gupta and Verma, 1988; Kundal *et al.*, 2017, 2019; Verma *et al.*, 2002
	Elephas hysudricus	Gupta and Verma, 1988; Verma *et al.*, 2002 Kundal, 2022
	Elephas maximus indicus	Kundal and Kundal, 2011
Artiodactyls	*Antilope* sp.	Gupta and Verma, 1988
	Boselaphus tragocamelus	Verma *et al.*, 2002
	Boselaphus sp.	Verma *et al.*, 2002
	Bos namadicus	Gupta and Verma, 1988
	Bos sp.	De Terra and Teilhard 1936; Verma *et al.*, 2002
	Cervus sp.	Gupta and Verma 1988; Verma *et al.*, 2002
	Cervus sivalensis	Gupta and Verma, 1988; Verma *et al.*, 2002
	Camelus sivalensis	Gupta and Verma, 1988
	Cervus triplidens	Verma *et al.*, 2002
	Cervus punjabiensis	Verma *et al.*, 2002
	Doracatherium minus	Verma *et al.*, 2002
	Dicoryphochoerus sp.	Verma *et al.*, 2002
	Gazella sp.	Gupta and Verma, 1988
	Gazella gen. indet	Verma *et al.*, 2002
	Gazella superba	Verma *et al.*, 2002
	Giraffa sp.	Verma *et al.*, 2002
	Hemibos sp.	Verma *et al.*, 2002
	Hemibos acuticornis	Gupta and Verma, 1988
	Hemibos triqutricornis	Gupta and Verma, 1988
	Hexaprotodon sp.	Verma *et al.*, 2002; Gupta, 1982-83
	Hexaprotodon sivalensis	Verma *et al.*, 2002; Gupta, 1981-82
	Hippopotamus sp.	Verma *et al.*, 2002; Gupta, 1984-85
	(?)Listriodon sp.	Verma *et al.*, 2002; Gupta, 1984-85
	? Potamochoerus sp.	Verma *et al.*, 2002; Gupta, 1982-83
	Sus giganteus	Verma *et al.*, 2002; Gupta and Verma, 1988
	Sus sp.	Verma *et al.*, 2002; Gupta and Verma, 1988
	Sus. scrofa	Verma *et al.*, 2002; Gupta, 1981-82
	Sivacapra sivalensis	Verma *et al.*, 2002; Gupta, 1981-82
	Sus falconeri	Verma *et al.*, 2002; Gupta and Verma, 1988
Perissodactyls	*Aceratherium* sp.	Verma *et al.*, 2002; Gupta, 1985-86
	Coelodonta sivalensis	Gupta and Verma, 1988
	Coelodonta sp.	Gupta and Verma, 1988
	Equus sivalensis	Verma *et al.*, 2002, Gupta and Verma, 1988
	Hipparion antilopinum	Verma *et al.*, 2002
	Hipparion sp.	Verma *et al.*, 2002
	Hipparion theobaldi	Verma *et al.*, 2002
	Rhinoceros sp.	Verma *et al.*, 2002
Carnivores	*Crocuta.mordax*	Verma *et al.*, 2002
	Crocuta feline	Gupta and Verma 1988
	Ictitherium sivalense	Verma *et al.*, 2002
	Panthera cristata	Gupta and Verma, 1988
	Ursus sp.	Verma *et al.*, 2002

Palaeobiodiversity

The research area under study is home to a diverse range of organisms, such as charophytes, angiosperm seeds, ostracods, gastropods, bivalves, fishes, amphibians, reptiles, rodents, proboscideans, artiodactyls, perissodactyls, and carnivores. The most prevalent group is the artiodactyls, which constitute 25% of the total population. This is followed by ostracods at 19% and rodents at 12%. Charophytes, reptiles, and proboscideans each contribute approximately 8%, while perissodactyls make up 7%. Gastropods and carnivores each represent 4%, bivalves make up about 2%, and angiosperm seeds, fishes, and amphibians each represent around 1% each of the total population (Kundal, 2015). The biotic diversity is given in Figure 2 and some of specimen is given in Figure 3.

Charophytes and Angiosperms

Charophytes are represented by ten species (*Chara contraria,Hornichara maslovi*, *Chara rantzieni, Chara rantzieni sivalensis, Chara globularis globularis, Lamprothamnium populosum,* cf. *Lamprothamnium, Lamprothamnium barbatus*, and *Lychnothamnous breviovatus)* and there is one species of angiosperm seed (*Boraginocarpus lakhanpalii)*. Within the charophyte community, *Chara contraria* is the most prevalent species, accounting for approximately 29% of the population. *Hornichara maslovi* follows, making up 25% of the population. The other species, including *Chara rantzieni, Chara rantzieni sivalensis, Chara globularis globularis, Lamprothamnium populosum,* cf. *Lamprothamnium, Lamprothamnium barbatus*, and *Lychnothamnous breviovatus*, contribute 13%, 11%, 9%, 9%, 7%, 3%, 2%, and 1% respectively (Bhatia *et al.,* 2001; Kundal, 2023). The angiosperm seed *Boraginocarpus lakhanpalii* represents about 1% of the total population.

Ostracods

Ostracods make up 19% of the total biotic diversity and represented by *Hemicypris megalops* sars, *Candona lactea* Baird, *Hemicypris pyxidata, Sclerocypris?* sp., *Cypridopsis* sp., *Cypris subglobosa* Sowerby, *Cypris subglobosa* Sowerby, *Cypris* cf. *C. decaryi, Cypridopsis* sp.A, *? Cypridopsis* sp*., Candona* sp.A, *Candona* sp.B, *Eucypris*sp.A, *Eucypris* sp.B, *Stenocypris major* (Baird), *Stenocypris* sp., *Zonocypris barakhetarensis* sp. nov.,

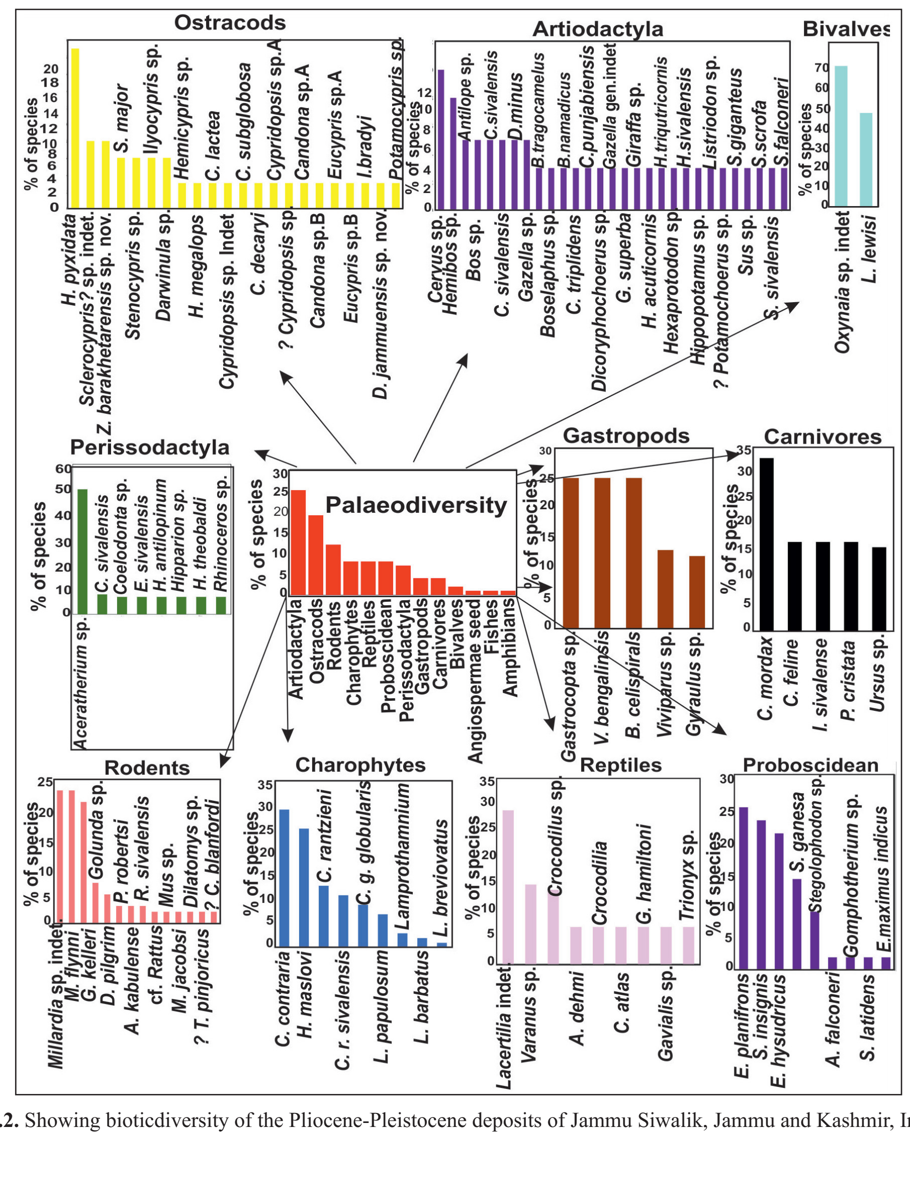

Fig.2. Showing bioticdiversity of the Pliocene-Pleistocene deposits of Jammu Siwalik, Jammu and Kashmir, India.

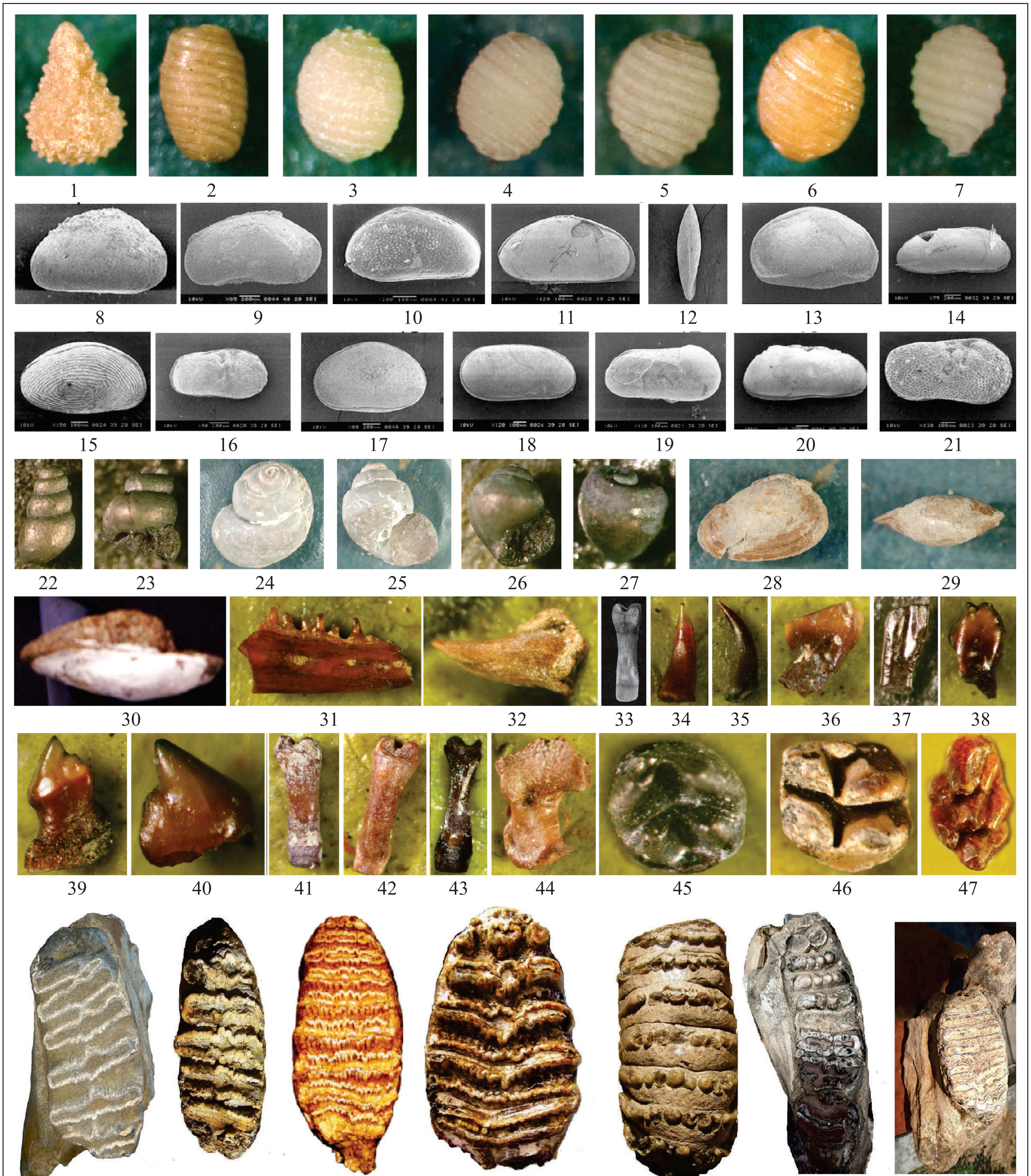

Fig.3. Showing photographs of 1. *Boraginocarpus lakhanpalii*, 2. *Chara globularis aspera*, 3. *Chara globularis globularis*, 4. *Chara rantzieni*, 5. *Lamprothamnium papulosum*, 6. *Lychnothamium brebiovatus*, 7. *Hornichara maslovi*, 8. *Cypridopsis* sp. A, 9. *Cypridopsis* sp. B, 10.*Candona* sp. A, 11. *Eucypris* sp. A, 12. *Hemicypris pyxidata* (deformed), 13. *Hemicypris pyxidata*, 14. *Stenocypris* sp., 15. *Zonocypris barakhetarnesis* nov. sp., 16. *Illyocypris bradyi*, 17. *Hemicypris pyxidata* (female), 18. *Hemicypris pyxidata* (male), 19. *Vestalenula jammuensis* sp. nov., 20. *Stenocypris* sp., 21. *Illyocypris* sp., 22. *Gastrocopta* sp.apertual view, 23. *Bellmiya celispiralis*, 24-25 *Viviparus bengalinesis*, 26. *Viviparus* sp., 27. *Gyraulus* sp., 28-29.*Oxyonia* sp., 30. *Lamellidens lewisi*, 31. Fish teeth, lateral view, 32. Isolated mammalian claw, 33. Phlanges of mammalian indet., 34-40. Fish teeth (different morphotypes), 41-43. Phlanges of mammalian indet., 44. Astragalus of cf. *Rattus,* 45. *Mus* sp., 46. *Goluna Kellerii*, 47. *Mus Flynni*, 48-49. *Elephas planifrons,* 50. *Elephas maximus indicus*, 51. *Elephas planifrons,* 52. *Stegodon insignis*, 53. *Steglophodon latidens,* 54. *Elephas hysudricus* (Kundal and Bhandari, 2008; Kundal and Prasad, 2011; Kundal, 2013; Kundal *et al.,* 2017; Kundal, 2018, 2019; Kundal *et al.,* 2023)

Ilyocypris bradyi Sars, *Ilyocypris* sp., *Darwinula* sp. *Darwinula jammuensis* sp. nov. *Potamocypris* sp. Ostracodes are highly useful for determining palaeoenvironment conditions. Among ostracods species, the most dominant species is *Hemicypris pyxidata* which contributes about 19%, followed by *Sclerocypris*? sp. indet. and*Zonocypris barakhetarensis* sp. nov. contributes 8% equally. *Stenocypris major*, *Stenocypris* sp., *Ilyocypris* sp. and *Darwinula* sp. each contributes 6% of the ostracodes population. The rest of the species *Hemicypris megalops* sars, *Candona lactea* sp. Indet., *Cypris subglobosa* Sowerby, *Cypris subglobosa* Sowerby, *Cypris* cf. *C. decaryi, Cypridopsis* sp.A , *? Cypridopsis* sp*., Candona* sp.A, *Candona* sp.B, *Eucypris* sp.A, *Eucypris* sp.B, *Ilyocypris bradyi* Sars, *Darwinula jammuensis* sp. nov. and *Potamocypris* sp. each one contributes 3% of the ostracods diversity.

Gastropods

The present collection includes five species of gastropods, which collectively represent 4% of the total diversity. The species are *Gastrocopta* sp., *Gyraulus* sp., *Viviparus* sp., *Viviparus bengalensis*, and *Bellamya bengalensis.* The predominant species are *Gastrocopta* sp., *Bellamya bengalensis* and *Viviparus bengalensis, each* accounting for approximately 25%, 13% and 12% (Kundal, 2013, 2015).

Bivalves

Bivalves are represented by two species: *Lamellidens lewisi* and *Oxynaia* sp. indet.and contributed 2% of biotic composition. Among the bivalves, *Oxynaia* sp. indet makeup 60% and *Lamellidens lewisi* make up 40% the bivalve's compositions (Kundal, 2013, 2015).

Fishes

Fishes is represented by three morphotypes *viz.* cyprinid fish morphotype I, cyprinid fish morphotype II and cyprinid fish morphotype III that contribute 1% of the total biotic diversity (Kundal and Prasad, 2011).

Reptiles

Reptiles contributed about 8% of the total diversity and the most dominant species among Reptilia are Lacertilia indet. (29%) followed by *Varanus* sp. (15%) and *Crocodilus* sp. (14%). *Acrochordus dehmi,Colossochelys atlas*, *Geoclemys hamiltoni*, *Gavialis* sp., and *Trionyx* sp. each contributes equally about 7% of the reptilian population (Rage *et al*., 2001; Verma *et al.,* 2002).

Rodents

A significant variety of rodent species has been documented from the Upper Siwalik Subgroup of the Jammu province. Rodents constitute 12% of the total biotic population. The rodent population is most dominated by *Millardia* sp. at 23% and *Mus flynni* at 23%, followed by *Golunda kelleri* 21%, *Golunda* sp. 7%, *Dilatomys* 5%, *Parapelomys robertsi 3%*, *Abudhabia* cf. *A. kabulense* 3%, *Rhizomyides sivalensis* 3%, and the rest including cf. *Rattus, Mus* sp., *Mus jacobsi*, *Dilatomys* sp.,? *Tatera pinjoricus*, ?*Cremnomys blanfordi*, each accounting for 2% (Gupta and Prasad, 2001).

Proboscideans

Upper Siwalik proboscideans represented by nine species *viz. Anancus falconeri, Gomphotherium* sp., *Stegolophodon latidens, Stegolophodon* sp., *Stegodon insignis, Stegodon ganesa, Elephas planifrons, Elephas hysudricus* and *Elephas maximus indicus.* This makes up 8% of the total biotic population. Among proboscideans, *Elephas planifrons* was a dominant extinct species and contributed 25% of the proboscidean population and is followed by *Stegodon insignis* which is contributed 23% of the total populations of proboscideans (Verma *et al*., 2002; Kundal *et al.,* 2011, 2017, 2019, 2021). Next dominant species are *Elephas hysudricus, Stegodon ganesa*, and *Stegolophodon* sp. which contributed 21%, 14% and 9% respectively. *Anancus falconeri, Stegolophodon latidens, Gomphotherium* sp., *Elephas maximus indicus* each contributed 2% of the *proboscidean* fauna.

Artiodactyls

Artiodactyls is the most dominant group among vertebrates and contributed 25% of the total biotic diversity. Artiodactyls are represented by 29 number of species, which includes *Cervus* sp. (10%) contributed major part of Artiodactyla and followed by *Hemibos* sp. (8%). *Antilope* sp., *Bos* sp., *Cervus sivalensis*, *Camelus sivalensis*, *Doracatherium minus,* and *Gazella* sp., each makeup about 5% of the Artiodactyla population, the remaining species *Sus falconeri, Boselaphus tragocamelus, Boselaphus* sp., *Bos namadicus*, *Cervus triplidens*, *Cervus punjabiensis*, *Dicoryphochoerus* sp., *Gazella* gen. indet., *Gazella superba*, *Giraffa* sp., *Hemibos* sp., *Hemibos acuticornis*, *Hemibos triqutricornis*, *Hexaprotodon* sp., *Hexaprotodon sivalensis*, *Hippopotamus* sp., ?*Listriodon* sp., ? *Potamochoerus* sp., *Sus giganteus*, *Sus* sp., *Sus scrofa, Sivacapra sivalensis,* each contributes equally about 3% of the total Artiodactyla population.

Perissodactyls

Perissodactyla contributed 7% of the total biotic diversity and representing by eight species *viz. Equus sivalensis, Aceratherium* sp., *Coelodonta* sp., *Hipparion antilopinum*, *Hipparion* sp., *Hipparion theobaldi,Coelodonta sivalensis.Equus sivalensis* contributes 50%, making it the most dominant species among perissodactyla. *Aceratherium* sp. *at 8%, Coelodonta* sp., *Hipparion antilopinum*, *Hipparion* sp., *Hipparion theobaldi*, and *Coelodonta sivalensis* each contribute about 7% of Perissodactyla population.

Carnivores

Carnivores makeup 4% of the total biotic diversity and are represented by five species. The most dominant species is *Ictitherium sivalense,* which contributed 33% of the carnivore's population, followed by *Crocuta feline, Panthera cristata* and *Ursus* sp., each contributing 17% and *Crocutamordax* contributed 16% of the Carnivores population (Verma *et al.,* 2002).

Discussion

Palaeoecological and Palaeoenvironmental Significance

During the Miocene to Pleistocene epochs, the Siwalik region was characterised by various ecosystems. Majority of the taxa collected from the Upper Siwalik strata of the Jammu region have their living representatives. Using Huttonian's principle "Present is the Key to the Past" a reasonably acceptable palaeoecological and palaeoenvironmental reconstruction of the area can be made. Since the physical, chemical, and biological factors influencing the ecological distribution of a particular taxon might have changed over time, it would be prudent to use all the members of an assemblage or different fossil assemblages so that the palaeoecological and palaeoenvironmental interpretations based on one taxon can be tested with that of others. The fossil evidence for the palaeoecological and palaeoenvironmental inferences are derived from several important sources, including plant, microfossils, invertebrate and vertebrate fossils. The combined information from the fauna and flora suggests a mosaic landscape, with sections of bush land and wooded grassland interspersed with mostly wooded grassland in the Tatrot region and mostly grassland with bush land and grassland in the Pinjor area (Gaur and Chopra, 1984). A palaeocummunity structure of the fauna and flora of Upper Siwalik Subgroup of Jammu province is given in Table 3.

Charophytes and Angiosperms

Charophytes and angiosperms inhabit a wide range of aquatic environments, including the periphery of deep lakes that receive spring-fed tuffaceous deposits, or deep, cold freshwater lakes that are similar to their shallow counterparts. Charophytes also flourish in saline inland waters, tropical lakes, and ephemeral ponds with fresh or brackish water bodies (Soulie-Märsche, 1993; Khosla *et al.,* 2022; Kania *et al.,* 2022; Khosla *et al.,* 2023). Their distribution is greatly influenced by factors like salinity, water hardness, and climate (Corillion, 1975). Charophytes cannot grow in acid or neutral environments and are not found in non-calcareous sediments. Generally, they occur in alkaline water bodies, such as lakes and ponds with pH varying between7.5 and 8. They are superficially fixed on a substratum which may be mud, sand or silt-covered peat and sand (Moore, 1986). All the species of charophytes of present collection indicate freshwater, shallow lacustrine / pond environment except for the species *Lamprothamnium populosum* and *cf. Lamprothamnium*, which prefer saline conditions. *Lamprothamnium* is generally found in shallow waters up to a depth of 1-1.5m. *L. papulosum* and *cf. Lamprothamnium* are active and fructify in between 20-40% of salinity. Short period of low salinity down to 10% for germination is also tolerated (Dubois, 1968). This genus occurs neither in permanent freshwater nor in permanently high saline environments. This characteristic makes it particularly valuable as a marker for seasonal rainfall. But its occurrence in the freshwater fluvial / lacustrine sediments poses ecological questions. Soulie-Marsche (1989) has demonstrated that abundance of gyrogonites suggests no transport or reworking during deposition. As transport during deposition would result in homogenous distribution, different distribution patterns or frequencies at different levels would indicate lack of reworking. In the present study, it is noticed that the distribution of charophyte taxa is not homogenous at different sites thus giving little credence to reworking.

Ostracods

Ostracods may adapt to different aquatic conditions, such as fresh, brackish, and marine waters (Khosla *et al.,* 2023). They are essential for reconstructing palaeoenvironment and can adapt to their aquatic realm. In the Jammu and Kashmir, India, Upper Siwalik deposits, ostracods were a part of the freshwater aquatic ecosystem throughout the Late Pliocene epoch. They thrived in wet habitats like lakes and rivers (Kundal, 2015). *Hemicypris pyxidata* has previously been obtained from freshwater ponds in Kutch (Jain, 1977; 1979, Battish, 1981), rock pools in Madurai (Victor and Fernando, 1979), and rice fields in Sri Lanka (Neale, 1977). This species may also be found in Karnataka and Dharward's freshwater lakes and ponds, where it prefers typical temperatures of 25 degrees Celsius and depths of 1 to 3 meters. *Hemicypris* can withstand diverse water conditions in permanent or semi-permanent bodies, from fresh to brackish, according to Bhatia et al. (2001). Bhatia and Khosla (1967) described *Darwinula* sp. as *D. stevensoni* from Chandigarh (Upper Siwalik beds) and Riwasa, Tehsil Bhiwani (limestone beds). *Darwinula* sp. and the newly identified *Darwinula jammuensis* sp. nov. also collected from Barakhetar section (Palaeolake) of Upper Siwalik (Bhandari and Kundal, 2008). *Stenocypris,* a key species in this collection, lives in shallow warm-water lakes and ponds (Singh, 1977) and swims across the muddy floors of standing water pools (Sars, 1924). *Ilyocypris bradyi* Sars is seen occasionally in Kashmir valley rice fields (Singh, 1973). *Stenocypris major* (Baird) inhabits rice fields, ponds, and shallow-water lakes. *Ilyocypris* is represented in the current collection by *Ilyocypris* sp. and *Ilyocypris bradyi* Sars. *Ilyocypris* sp. inhabits rice fields and small shallow water ponds, but *Ilyocypris bradyi* thrives in rice field conditions. The presence of *Ilyocypris* in water bodies indicates either transitory or persistent running water, or at least some current action (Holmes, 1937; Staplin, 1963a-b). It also reveals wind-induced water turbulence near the margins of water bodies (Kendeigh, 1975). Palaeoecological data on *I. bradyi* show both transient and permanent running water conditions with abundant vegetation (Holmes, 1937; Hoff, 1942; Bhatia,1968). Petovski (1964) reports finding *Cypris subglobosa* in rice fields, in its native freshwater ponds and shallow lakes, gathered from Kashmir's Pleistocene strata (Upper Karewa), and also shed insight on its ontogeny and provenance (Bhatia, 1968). A vigorous swimmer who favours muddy substrates is *Cypridopsis vidua.* Marginal shallow areas of permanent still freshwaters, like lakes, ponds, ditches, and flowing water with lots of vegetation, are preferred by this species (Staplin, 1963a; Singh,1977). A discussion was held regarding the ecological circumstances of various taxa of Quaternary ostracode from the Kashmir Valley. Lakes that are fresh and have a slight alkalinity and abundant aquatic vegetation are also known to harbor *Cypridopsis vidua* (Bhatia, 1971; Singh, 1977). Lakes with a lot of flora and shallow water up to 6.20 meters in depth are home to *Candona* sp. and represented by *Candona* sp. A and *Candona* sp. B. According to Mukerji (1972), the habitat depth range for *Candona* sp. is 5.23 meters, with pH values ranging from 7.10 to 9.00 and TDS levels between 100 and 180 ppm live in cold water stenothermic species. *Candona lactea* has been collected from lacustrine clays; terrace silts, and silts (Staplin, 1963b). It has also been taken from polyhaline waters (McKenzie, 1964) and is commonly found in rivers throughout England, Holland, and France (Swain, 1963). Furthermore, lacustrine deposits, fresh, clear alkaline lakes in the Kashmir valley, and Pleistocene freshwater are all known to contain *Candona lactea* (Bhatia, 1971; Singh, 1977). The new species discovered in the Upper Siwalik subgroup of Jammu is called *Zonocypris-Zonocypris barakhetarensis* sp. nov.

It is thought to represent freshwater lacustrine environments (Kundal, 2015). *Sclerocypris* sp. reported to transpire in ferruginous sands with varying particle sizes and minimal vegetation. *Sclerocypris dharwadensis* sp. was found in freshwater lakes in Dharward, Karnataka. Their brittle shells and tuberculate surface with marginal spines suggest that the ground is sandy. Additionally, Puri (1966) has made similar observations. Sharma *et al.* (2015) reported ostracods, specifically *Stenocypris sp*. and *Candona* sp. from the Polian Prohita (Dhok Pathan Formation) of Early Pliocene deposits of Himachal Pradesh and inferred a localized swampy to overbank pond environment within braided river system.

Molluscs

Molluscs encompass a diverse group of living species that are known to inhabit a wide range of environments, including aquatic (marine, freshwater, brackish water) and terrestrial habitats. They can often be found in dark gray to black mudstone and silty sandstones. Molluscs are characterized as vagrant and bottom-dwelling organisms, displaying adaptability to various ecological niches within their respective environments. The extant molluscans are known from marine, freshwater, brackish water and terrestrial environments. A few of them are burrowers in sand or mud. Generally, they are found in dark grey to black mudstone and silty sandstones. Most of the aquatic molluscans are preserved in situ. Contrary to this, the terrestrial fossils are commonly preserved far from their habitat. Therefore, aquatic molluscans should be better indicators of aquatic ecological conditions prevailing at any time. Similarly, if changes in the type and distribution of molluscans in time and space can be evaluated, ecological variation due to changes in climate as well as topography can also be understood. In the present collection, molluscans are represented by gastropods and bivalves, Gastropods of the present collection include *Gastrocopta* sp., *Gyraulus* sp., *Viviparus* sp., *Viviparus bengalinsis*, and *Bellamya celispirals*. Most of these taxa are commonly known to live in low energy environment ranging from ponds, lakes to margin of slow flowing river, but generally avoid fast flowing waters. The exclusive occurrence of gastropods opercula indicates predominance of current action, which was not only responsible for abundant vegetative matter but also in separating the opercula from the shell and depositing them in a different part of the basin. Bivalve includes *Lamellidens lewisi* and *Oxynaia* sp. indet. that have wide geographical and geological distribution. The living forms are exclusively aquatic (mostly marine and few freshwater) which have a range of adaptiability to depth, from shoreline to down to depth of about 6000 metres. In general, the molluscan fauna of the study area indicates freshwater, shallow lacustrine environment of deposition.

Fishes

Cyprinid fishes inhabit small rivulets, streams, and ponds. Members of the family Cyprinidae flourish well in small ponds, pools and in bodies of stagnant or sluggish muddy waters. But a few of them prefer clean water bodies with sandy substrate. Extant members of this family are known from streams and rivulets of the Himalayan region (Kundal and Prasad, 2011).

Amphibians and Reptiles

Amphibians and reptiles are sensitive to climate change and useful for palaeoenvironmental studies. Amphibians are mostly water dependent and reptiles are mostly temperature dependent. Within a larger landscape, both Amphibians and reptiles play an important role to understanding of microhabitats and microclimates. Amphibians in the present collection are represented by fossil frogs' Anura and reptiles are represented by *Acrochordus dehmi* (snakes), *Crocodilus* sp. *Geoclemys hamiltoni, Gavialis* sp., *Trionyx* sp. *and Colossochelys atlas*. Due to small home ranges, frogs (*anurans)* reflect the local environmental conditions and provide information about the type of water bodies and terrestrial environment in which they live (Matthews and Measey, 2016). *Acrochordus* is a fully aquatic, fresh water snake lived in lakes, ponds, rivers and swamps generally found in shallow water bodies (Pratt *et al.*, 2010; Shine, 1986a,b) and distributed in Australia and Asia. Siwalik Group represented primarily aquatic environments and *Acrochordus dehmi* ecological similar to extant Genus *Acrochordus* (Hoffstetter, 1964). *Crocodilus* sp*. and Gavialis* sp., are inhabitants of lakes, swamps, and rivers (Verma *et al.,* 1998). *Geoclemys hamiltoni* Gray (1831) is a turtle found in Pakisstan, India, Nepal and Banglad*esh and* inhabits shallow ponds, ox-bow lakes, Ganges and reservoirs (Praschag *et al.,* 2020). *Trionyx* sp. found in lakes and also known as a soft shelled turtle (Geoffroy Saint-Hilaire, 1809). *Colossochelys atlas is a hervivores turtles and lives in terrestrial environment.*

Rodents

The small-scale vertebrate (rodents, micro-mammals) faunal assemblages are typically limited to narrow areas with limited lateral and vertical reach, signifying specific habitats. Stated differently, they portray autochthonous or partially autochthonous groups. On the other hand, most large vertebrate remains underwent extensive transportation before the burial. The tiny vertebrate remains have been revealed to be extremely helpful in reconstructing historical habitats. Micro mammal assemblages are a good source for palaeoecological reconstruction since they are limited to beds with limited lateral extent and are deposited quickly. As a result, they help recreate palaeoenvironmental conditions. Since they are small, sensitive, typically live in restricted spaces, and have a quick evolutionary history, rodents are employed as climate indicators. Since most rodent taxa are similar to extant forms, palaeoecological deductions follow the actualism principle.

Rodents in the present collection is represented by *Rattus, Golunda kelleri, Golunda* sp, *Mus* sp., *Mus jacobsi, Mus flynni, Parapelomys robertsi, Dilatomys pilgrim, Rhizomyides sivalensis, Dilatomys* sp., *(*Bushland/Forest community) and *Abudhabia* cf. *A. kabulense, ? Tatera pinjoricus, ? Cremnomys blanfordi, Millardia* sp. indet. (Wooded grassland/Savannas community).The living members of *Rattus* (*Rattus meltada*) and *Golunda (Golunda ellioti*) are known to live in crop fields, thickets and bushlands or densely vegetated plains. In fact, all terrestrial habitats, from houses and rice fields to marshy rain forest to edges of grasslands, are occupied by various species of *Rattus*. *Golunda-Golunda ellioti* (the extant species) also lives in field crops, heavily vegetative plains, bushlands, and grazing areas. The extant species of *Mus* - *Mus musculus*, *Mus booduga* - on the other hand, are adapted to ruderal habitats. *Mus musculus and Mus booduga* (extant species) are non-grazers that adapted to harsh conditions. Patnaik (2003) believes that *Dilatomys* may have preferred a grassy diet. *Cremnomys* also prefers wooded grasslands and thickets. *Millardia meltada* prefers cultivated fields, sometimes heavy shrubs and rocks. *Mus* and *Cremnomys* are not grazers, but *Golunda*, *Millardia* and *Nesokia* are prediminantly grazers. The living species of *Tatera,T. indica* is generally found in sandy plains and interdunal regions (Parkash, 1975). The African *Tatera* is known to live in dry steppe and sometimes in thickets along the edges of alluvial flats. *Parapelomys, Rhizomyides*, and *Golunda* are signs of sandy bushland conditions, while small mammals like *Cremnomys* and *Millardia* indicate the presence of woodland grassland (Patnaik 1995). *Dilatomys* liked grassy diets, and so on. It is also proposed by the evidence that variations in climate and environment throughout time affect the dietary patterns and body size of murid rodents (Patnaik 2003). Since they played an important ecological function during the Late Pliocene era, rodents were mostly connected with the Upper Siwalik deposits' terrestrial habitats (the wooded grassland/bushland community) (Kundal, 2015).

Proboscideans

Proboscideans are fully herbivores and existed in a diverse environment during the Miocene period, including dense forests and wide grasslands (Franze and Pickford, 2013). The Siwalik proboscideans thrived in various habitats, demonstrating the region's changing climate over millions of years. The Upper Siwalik Subgroup of Jammu preserved a good assemblage of elephant fossils, which includes *Stegolophodon* sp., *Stegolophodon latidens, Stegodonts, Elephas planifrons, Elephas hysudricus, and Elephas maximus indicus* (Kundal and Kundal, 2011). *Stegolophodon* sp.exhibits brachyodont cheek teeth with thick enamel and relatively few cementers. The molar brachyodonty in *Stegodonts* indicates an adaptation to browsing or mixed feeding in forested environments (Janis, 1986). Moreover, the fauna has brachyodont teeth, and are adapted to a diet of soft plants, such as buds, young leaves, and fruits, suggesting that their habitats were not open lands but a forested/ woodland environment (Tsubamoto *et al.,* 2005). The hypsodont elephantine *Elephas planifrons* and *Elephas hysudricus* were dominantly grazers (Patnaik *et al*., 2019). *Elephas planifrons* fossils discovered from Rathian (Pinjor Formation), Pakistan shows a substantial temperature change from the Miocene to Pleistocene, with large grasslands and a savannah-like habitat (Raza *et al.,* 2023). The Siwaliks of Pakistan (Sardhok, Panjan Sher Shahana, Kurla Sharif) contain fossils of *Elephas planifrons*, *Elephas hysudricus*, ranging in age from the Late Pliocene (Piacenzian) to Late Early Pleistocene (Calabrian), suggesting a savannah-like environment for these areas, according to comparisons with the well-dated mammalian fauna from various Siwalik sites across the Indian subcontinent (Abbas *et al.,* 2019). *Elephas maximus,* an Asian elephant is a major contributor of organic carbon from browse (C_3 plants) as reflected in the carbon isotope compositions of bone collagen (Sukumar, 1989; 2003; Sukumar and Ramesh, 1992; Pushkina *et al.,* 2010; Rivals *et al.,* 2012) and basically a mixed feeder.

Artiodactyls

The palaeoenvironment of Artiodactyla, or even-toed ungulates, has changed dramatically over millions of years. These mammals initially ascended in the early Eocene, approximately 53 million years ago, in forested areas. As climates cooled down and habitats changed, they adapted to diverse environments, from woods and open plains in the Oligocene to vast grasslands in the Miocene (Retallack, 2004). By the Pleistocene, several artiodactyls had adapted to colder climates and more diversified habitats, such as tundra and steppes. This versatility has enabled them to thrive in different modern habitats, including deserts, woods, and grasslands. Artiodactyla in the present collection represented is by *Doracatherium minus, Listriodon* sp., *Potamochoerus* sp., *Sus falconeri, Sus giganteus, Sus* sp*., Sus scrofa, Giraffa* sp., *Gazella* sp., *Gazella gen.indet, Gazella superb, ?Cervus sivalensis, Cervus triplidens, Cervus punjabiensis, Dicoryphochoerus* sp., *Cervus* sp., *Hemibos* sp., *Hemibos acuticornis, Hemibos triqutricornis, Antilope* sp., *Boselaphus tragocamelus, Bos* sp., *Bos namadicus, Boselaphus* sp., *Camelus sivalensis, and Sivacapra sivalensis. Dorcatherium*(Tragulidae) was a woodland dweller, small ruminant preferred humid and forested conditions (Agusti and Anton, 2002). It lived along riverbanks and foraged in surrounding woodlands (Grizmek, 1972). The collection of the artiodactyla fossil *Doracatherium* from Hasnot offers the best record of this genus in the Siwalik area.Suids typically signify marshy areas close to a fluvial regime's banks. In this study, Suids are represented by *(?)Listriodon* sp., *?Potamochoerus*sp., *Sus falconeri*, *Sus giganteus*, *Sus* sp., and *Sus scrofa*. Widely held modern suids live in forests and need aquatic environments such as lakes, ponds, and rivers (Grzimek, 1972). Giraffid from the Upper Siwalik of the Jammu region is represented by *Giraffa* sp. *Giraffa camelopardalis* currently lives in the sub-Saharan bush land. The *Giraffa* in the wild is acclimated to an open habitat in which it can flee from any potential predator without the assistance of broken ground or trees. Even when food is scarce, the animal's long neck and legs allow it to feed on foliage that most other large herbivores cannot reach (Churcher, 1978). Aslam *et al.* (2021) gave a brief account the origins and patterns of distribution of late Miocene to Pliocene suids in the Siwalik region. Two different species of *Tragoportax* and three species of *Gazella* (*Gazella* sp., *G.lydekkeri*, and *G. superba*) are among the recently found bovid remains from the Late Miocene–Early Pliocene at Padhri in the Potwar Plateau, Pakistan. A mixed woodland and shrub land biome designated by the coexistence of *boselaphines, antilopines*, and *bovines.* Because these genera had previously inhabited forests and shrub lands that were replaced by grasslands with the arrival of the Pliocene, habitat alterations may have contributed to the extinction of *Tragoporta*x and *Gazella* species from the Siwalik during the Early Pliocene (Khan *et al.,* 2022). *Tragulids* are suggestive of a humid climate with a lot of vegetation cover that was dominated by forest landscapes during the upper middle Siwalik Dhok Pathan Formation (Khan *et al.,* 2012). *Hippohyus sivalensis* is an Artiodactyls species of Middle and Upper Siwalik subgroups that lived in the late Miocene to Pliocene age. This suid species is classified as a grazing species since it was predominantly adapted to grassland settings.

The Bovidae family is widely dispersed in Tertiary deposits and even now because of their ability to adapt to a variety of environmental variables, including wide spaces and even desert areas. Here the Bovidae family is represented by *Gazella* sp., *Gazella gen. indet.*, and *Gazella superba* in the Upper Siwalik of Jammu region. *G. bennetti* is Gazella's living representative. Based on its habitat, it is likely that the family lived in forests and subsisted on green grass, twigs, and lives close to riverbanks. The presence of fossilized ungulates at Nagri suggests that the area was formerly covered in shrub land to woodland. *Hipparion,* giraffids, rhinocerotids, and bovid abundance indicate woodland to savannah environment at or close to the type location during the early Late Miocene. Limited data suggests that nearby open forest regions and a humid closed canopy forest with sporadic, intermittent, and permanent bodies of water existed throughout the deposition period (Khan *et al*., 2012). *Camelus sivalensis* Falconer and Cautley,1836 are actively mobile having terrestrial environment, brower-grazer diet and taphonomic phosphatic based on vertebra. The first appearance at first recorded appearance at 5.33-2.59Ma and last recorded appearance at 3.60-0.78Ma. *Boselaphus* sp. is a bovide prefers undulating topography, open grassland, savannas, thin bush and scattered low trees, rarely in thick forests (Blanford 1888; Prater 1980). During the Pleistocene Epoch, *Bos namadicus* Falconer and Cautley 1836 and *Bos* sp., might have experience a drier climate, a climate suitable for the growth of C4 type grasses based on oxygen isotope data from fossil remains (Osborne and Sack 2012). *Boselaphus tragocamelus* is a mixed feeder and the dominate diet of *Boselaphus tragocamelusis* is woody vegetation in dry tropical forests of India (Solounias and Moelleken 1993; Khan, 1994). Rütimeyer (1865) first time describe the genus *Hemibos* based on fossils specimens found in Plio-Pleistocene deposits of India. During the early Pleistocene times, *Hemibos* was a grazer (ground) as well as browser. The genus *Hemibos* represented by five species, out of five species *H. antelopinus, H. triquetricornis*, and *H. acuticornis*, recovered from the Pinjor formation (Pliocene-Pleistocene deposit) of the Siwalik and other from China (*H. gracilis)* and Rome, Italy (*H. galerianus). Hemibos* was ground-dwelling grazer and browser that lived during the lower and early Pleistocene period.On the basis of carbon isotope data, *Cervidae* preferred C3 vegetation in forests parts during early Pliocene and shift to C4 vegetation in diet and more open over time. *Cervidae* of the Siwalik fed entirely on C_4 vegetation in open grassland settings in early Pleistocene (Waseem *et al.,* 2023). *Cervus sivalensis, Cervus triplidens, Cervus punjabiensis, Dicoryphochoerus* sp., *Cervus* sp., were prefer tropical in distribution and certainly inhabited woodland or open country, not closed country. After 7.4Ma, grassy woodland or open woodland environments existed on the basis of carbon isotope data (Khan *et al.,* 2014).

Perissodactyls

Perissodactyla Owen, 1848 are odd-toe ungulates, herbivores and a group of three families *viz*. Equidae (horses), Tapiridae (the tapirs) and Rhinocerotidae (rhinos). These three families well flourished during Palaeogene and Neogene times. Their feeding habits classify them as either grazers, which primarily consume grasses, or browsers, which feed on shoots and leaves from trees and bushes. In the study area, Perissodactyla is represented in the present collection by four species of Equidae -*Equus sivalensis, Hipparion antilopinum, Hipparion* sp*., Hipparion theobaldi; two species of* Tapiridae -*Coelodonta sivalensis, Coelodonta* sp., and one species of Rhinocerotidae - *Aceratherium* sp., *Rhinoceros* sp.

Family Equidae has shifted from browsing (C_3) to grazing C_4 grasses in Late Pliocene (Uno *et al.,* 2011). Increase in complexity, sharp buccal apices cusps and high Hypsodonty Index HI index also indicated a C_4 diet for Equidae (Wolf *et al.,* 2013; Fortelius and Solunieus, 2000; Khan *et al.,* 2020). *Equus sivalensis,* an extinct species of stenonine horse of Indian subcontinent has been reported from the Siwalik Group, dating from from 2.6 to 0.6Ma (Rook *et al.*, 2019). Additionally, some specimens have been reported below the Gauss–Matuyama boundary (>2.6 Ma) (Patel *et al.,* 2018). *Equus sivalensis* is a grazer (Bernor *et al.*, 2019). *Hipparion,* a genus of three-toed horses, mostly occurred in Middle Siwalik Subgroup. Specifically, *H. antelopinum i*s known for its very hypsodont teeth, small size, complex enamel plications and oval protocone, where as *H. theobaldi* exhibits a narrow crown and hypsodonty. The degree of hypsodonty and brachydonty in these species is directly related to environmental conditions. The coarse grasses consumed by hyposodont species indicate they lived in open habitat environmental conditions (Lacombat, 2005; Prasad *et al.,* 2007; Verma *et al.,* 2012). Tapirs are herbivores and preferto live in tropical forests, woodlands, grasslands and marshes areas. *Coelodonta sivalensis and Coelodonta* sp. are mixed feeders of middle Pleistocene age and considered East Asia as evolutionary and cradle of genus *Coelodonta.*

Rhinocerotidae is *represented in the present collection by Aceratherium* sp. and *Rhinoceros* sp. *Aceratherium* sp. has been reported from Middle Siwalik Subgroup (Perim Island), India and from Chinji Formation, Pakistan (Matthew, 1929). This species also has also been reported from Hasnot, Pakistan (Lydekker, 1884) and Dhokpathan Formation, India (Khan *et al.,* 2009). *Aceratherium* first appeared in the early Late Miocene and became abundant during this period. During Late of Middle Miocene, the climate was dry and cold and became wetter. *Aceratherium* declined towards the end of the Late Miocene as the environment became drier, with increase in temperature and decrease in humidity (Cerdeno and Nieto, 1995). *Rhinoceros* sp. are large herbivores mammals found in various parts of the world. In Africa, there are two primary types, the black rhinoceros, which are browsers and the white rhinoceros, which are grazers. The Indian rhinoceros is considered an intermediate feeders and is more grazer.

Carnivores

Carnivores are meat-eating animals that are relatively rare in Siwalik region. They are represented by five species *viz. Ictitherium sivalense. Crocuta mordax, Crocuta feline, Panthera cristata, and Ursus* sp., *Ictitherium sivalense* Lydekker, 1877 *is a* ground dwelling carnivore ranging in age from Middle Miocene to Early Pliocene. *Crocuta mordax and Crocuta feline range in age from Early Pleistocene to Recent and their diet primarily consisted of herbivores for survivals. Panthera cristata and Ursus* sp., are carnivores. At 1.4, the taxa such *as Canis cautleyi (carnivores)*, *Sivatherium (herbivores)*, and *Lycyaena (carnivores)* were regionally disappeared and the carnivore taxa such as *Panthera*, *Ursid*, *Crocuta* and Herpestids were appeared at 1.4 Ma ago.

From the palaeoecological analysis of recovered fauna and flora, it is apparent that there were two important palaeocommunities existed in Late Pliocene-Early Pleistocene times - 1) aquatic community 2) terrestrial community (Table 3). It is thus concluded that permanent, shallow water lacustrine/paludal basins existed in pockets in the Outer northwest Siwalik of Jammu and Kashmir, India during the Late Pliocene - Early Pleistocene times.

Conclusions

The Upper Siwalik Subgroup (5.33-1.6Ma) of the Outer northwest Himalaya of Jammu province, Jammu and Kashmir,

Table 3: Palaeocommunity structure of the Pliocene-Pleistocene deposits in the Siwalik of Jammu and Kashmir, India

Aquatic Community		Terrestrial Community	
Lake/pond/Lacustrine/Riverine community		Wooded grassland/Savannas community	Bushland/Forest community
Flora: Charophytes: *Hornichara maslovi* *Chara contraria* *Chara rantzieni* *Chara rantzieni sivalensis* *Chara globularis globularis* *Lychnothamnous breviovatus* *Lamprothamnium papulosum* cf. *Lamprothamnium* *Lychnothamnus barbatus* Angiosperm seeds: *Boraginocarpus lakhanpalii*	Fauna: Ostracods: *Hemicypris* *Hemicypris megalops* sars *Hemicypris pyxidata* *Candona lactea* Baird *Sclerocypris?* sp.indet. *Cypridopsis* sp. Indet *Cypris subglobosa* Sowerby *Cypris* cf. *C. decaryi Cypridopsis* sp.A *? Cypridopsis* sp. *Candona* sp.A *Candona* sp.B *Eucypris* sp.A *Eucypris* sp.B *Stenocypris major* (Baird) *Stenocypris* sp. *Zonocypris barakhetarensis* sp. nov. *Ilyocypris bradyi* Sars *Ilyocypris* sp. *Darwinula* sp. *Darwinula jammuensis* sp. nov. *Potamocypris* sp Gastropods: *Gastrocopta* sp. *Gyraulus* sp. *Viviparus* sp. *Viviparus bengalinsis* *Bellamya celispirals* Bivalves: *Lamellidens lewisi* *Oxynaia* sp. indet Fishes: Cyprnide fishes-Gen. sp. Indet. Artiodactyla: *Hexaprotodon* sp. *Hexaprotodon sivalensis* *Hippopotamus* sp. Reptiles: *Acrochordus dehmi* (snakes) Crocodilia *Crocodilus* sp. *Geoclemys hamiltoni* *Gavialis* sp. *Trionyx* sp.	Fauna: Proboscideans: *Anancus falconeri* *Gomphotherium* sp. *Stegodon ganesa* *Stegodon insignis* Artiodactyls: *Antilope* sp. *Boselaphus tragocamelus* *Bos* sp. *Bos namadicus* *Boselaphus* sp. *Camelus sivalensis* *Gazella* sp. *Gazella gen. indet* *Gazella superba* *Giraffa* sp. *Sivacapra sivalensis* Perissodactyla: *Coelodonta sivalensis* *Coelodonta* sp. *Equus sivalensis* *Hipparion* *antilopinum* *Hipparion* sp. *Hipparion theobaldi* Carnivores: *Crocuta.mordax* *Crocuta feline* *Ictitherium sivalense* Rodents: *Abudhabia* cf. *A. kabulense* *? Tatera pinjoricus* *? Cremnomys blanfordi* *Millardia* sp. indet.	Proboscideans: *Stegolophodon* sp. *Stegolophodon latidens* *Elephas planifrons* *Elephas hysudricus* *Elephas maximus indicus* Artiodactyls: *Cervus sivalensis* *Cervus triplidens* *Cervus punjabiensis* *Doracatherium minus* *Dicoryphochoerus* sp. *Cervus* sp. *Hemibos* sp. *Hemibos acuticornis* *Hemibos triqutricornis* *(?)Listriodon* sp. *? Potamochoerus* sp. *Sus falconeri* *Sus giganteus* *Sus* sp. *Sus. scrofa* Perissodactyla: *Aceratherium* sp. *Rhinoceros* sp. Carnivores: *Panthera cristata* *Ursus* sp. Reptiles *Varanus* sp. (varanide)- Lizards Lacertilia indet. *Colossochelys atlas* Rodents: *Parapelomys robertsi* *Golunda kelleri* *Golunda* sp *Dilatomys pilgrim* *Rhizomyides sivalensis* *cf. Rattus* *Mus* sp. *Mus jacobsi* *Dilatomys* sp. *Mus flynni*

India contains a rich diverse groups of organisms *viz*. charophytes (8%), angiosperm seeds (2%), ostracodes (19%), gastropods (19%), bivalves (2%), fishes (1%), amphibians (1%), reptiles (8%), rodents (12%), proboscideans (8%), artiodactyls (25%), perissodactyls (7%), and carnivores (4%). Among these diverse groups, artiodactyls had the highest biotic diversity followed by ostracods, gastropods, rodents, charophytes, reptiles, proboscideans, perissodactyls, carnivores, bivalves, angiosperm seeds, fishes and amphibians. From the palaeoecological analysis of recovered fauna and flora from the Upper Siwalik Subgroup of Jammu province of Jammu and Kashmir, it is apparent that there were two important palaeo-communities - 1) aquatic community and 2) terrestrial community. The aquatic community is mainly represented by lacustrine/paludal fauna and flora, whereas the land community is known by wooded grassland and bushland taxa. Charophytes, angiosperm seeds, ostracods, gastropods, bivalves, fishes, and amphibians indicate freshwater lacustrine environment, and reptiles, rodents, proboscideans, artiodactyls, perissodactyls and carnivores indicate terrestrial environment. The fauna and flora favour both a terrestrial and a shallow freshwater lacustrine palaeoenvironment for the sedimentary beds of the Upper Siwalik Subgroup of Jammu province. The recovered fauna also suggested a mixed type feeder (C_3 browser and C_4 grazers) were existed during Late Pliocene – Early Pleistocene times.

Authors' Contributions

SNK: Formal Analysis, Writing, Original Draft, Methodology, Reviewing and Editing, Analyzed. **NUN:** data Conceptualization, Investigation & Data Curation. **BA**: Data Curation. **MI:** Visualization. **AB:** Methodology.

Conflict of Interest

Authors has no any competing Interests and Funding

Data Availability Statements

The data (maps, citations, webpage, published specimen data, etc.) used in the manuscript is linked with DOI / website as in the reference list. The repository of the specimen data is lying along with the concern author who published the data and cited in the text. Some of the specimen's data is along with the corresponding author.

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