

**Taxonomy and Palaeoecology of Ostracoda from the Middle to Late  
Pleistocene upper Karewa formation of Kashmir Valley, Northern India**

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**ABSTRACT** Ostracoda from a 25 m thick exposure in sediments of the upper Karewa formation indicate lacustrine conditions in Kashmir intermontane basin during the Middle to Late Pleistocene. The Middle to Late Pleistocene age is established on the basis of lithostratigraphy and confirmed by two thermoluminescence age determinations at the top of the section. The ostracod assemblages show that the lake water remained fresh, or at most was very slightly saline, throughout the period represented by the section. Nearly all ostracod taxa identified from the sediments are cold stenothermal forms and they include inhabitants of the littoral and profundal domain as well as running waters and springs. The Ostracoda present within the section indicate that during deposition of the upper Karewa sediments a large, but fairly shallow, well-oxygenated open-basin freshwater lake existed in that central part of the Kashmir Basin. Although the sequences suggest changes in water depth may have occurred, lacustrine conditions were otherwise largely unchanged over the period represented by the section, up until the demise of the lake during the early part of the Late Pleistocene.

**KEYWORDS:** *Pleistocene, Ostracoda, Kashmir, Palaeolimnology*

## INTRODUCTION

The sediments that accumulate in tectonic intermontane basins generally provide evidence for basin-margin tectonic activity. Although large-scale stratigraphical and sedimentological changes in basin sediments often relate to large-scale tectonic events, information about climate-related palaeoenvironments can sometimes be found within palaeontological and geochemical signatures. Here, we report work on the fossil ostracod faunas of the Kashmir intermontane basin, which lies in the northwest Himalaya. We discuss the occurrence, taxonomy and palaeoecology of ostracods from Kashmir, with particular emphasis on a single dated section in the Middle to Late Pleistocene basin-fill sediments.

Kashmir is an intermontane basin that developed on the back of imbricated thrust sheets during the Late Cenozoic (Fig. 1). The basin is around 140 km long and up to 60 km wide, oriented northwest to southeast (Burbank & Johnson, 1983). It is bounded by the Great Himalayan Range to the northeast and the Pir Panjal Range to the southwest. The accumulation of basin-fill sediments began around 4 MyrBP. The sediments, known informally as the Karewas (e.g. Bhatt, 1989), consist of fluvio-lacustrine sediments capped with aeolian loess. Low-energy lacustrine sedimentation was interrupted by several episodes of high-energy fluvial deposition, when thick conglomerates were deposited as a result of rapid basin-margin uplift. A combination of magnetic polarity stratigraphy and fission-track dating of volcanic ashes has allowed the development of an age model for the Karewa sediments, which indicates

that episodes of major basin-margin uplift occurred between 3 and 3.5, 2.7, 2.1 and 1.7 MyrBP (Burbank & Johnson, 1983). The focus of uplift switched from the Great Himalaya to the Pir Panjal Range around 2.1 to 1.7 MyrBP, as the location of thrusting changed from the Main Mantle Thrust to the Main Boundary Thrust (Fig. 2), as shown by palaeocurrent analysis of the Karewa sediments (Burbank & Johnson, 1983).

The Karewas, which consists of over 1300 m thickness of sediments, have been divided into an upper Karewa and lower Karewa formation by some workers (e.g. Bhatt, 1989), although opinions on the formal stratigraphic nomenclature of the sediments vary and in this paper we follow Burbank & Johnson (1983) in distinguishing *informally* between upper and lower Karewa sediments. The lower Karewa, which is the thicker of the two units (up to about 1300m: Burbank & Johnson, 1983), consists of lacustrine, deltaic and fluvial facies with four conglomerate units. During the lacustrine phases, the lake occupied much of the basin floor. The upper Karewa, which is the thinner of the two units ( $\leq 100$  m), is separated from the lower Karewa by an angular unconformity in the basin centre and a conglomerate bed along the Pir Panjal margin of the basin. The conglomerate bed marks rapid uplift of the Pir Panjal Range around 0.4 MyrBP (Burbank & Johnson, 1983). This uplift led to drainage of the large lower Karewa Lake and tilting of the lower Karewa sediments leading to downcutting and subsequent exposure, especially along the Pir Panjal margin of the basin. The upper Karewa sediments comprise, from the base of the unit upwards, the final conglomerate bed, lacustrine sediments of a restricted upper Karewa Lake and finally loess. Following the uplift of the Pir Panjal Range, the Karewa Lake became shallower and smaller in area as a result of drainage. Loess deposition took place on the exposed conglomerate

surfaces along the south-western basin margin and also into the lake itself: the upper Karewa Lake sediments are silt-rich and some of this silt was undoubtedly of aeolian origin. The lake finally drained in the Middle to Late Pleistocene (Holmes *et al.*, 1992), giving way to loess deposition across the entire basin floor (Rendell & Townsend, 1988). Subsequent downcutting has exposed the upper Karewa sediments in river valleys and gullies throughout the basin. Several residual lakes, notably Dal Lake, Manasbal Lake and Wular Lake, remain in the basin today, but they are tiny remnants of the larger lake that existed in the past. Bhatt (1989) proposed a simple model showing the evolution of the Karewa Lake from basin inception, through rapid uplift of the Pir Panjal around 0.4 MyrBP and up to present day (Fig. 3). Lake drainage is assumed to have been through the Baramulla Gorge (Fig. 4), the pathway taken by present-day drainage from the basin.

## **PREVIOUS WORK**

There are numerous publications on ostracods from the Karewa deposits and from the modern residual lakes in the basin. Bhatia (1968) provided a description of ostracod taxa found at a number of localities in the upper Karewa sediments. However, there is no stratigraphic information given about the samples and his palaeoenvironmental conclusions are highly generalized. Nonetheless, he was able to conclude that the upper Karewa Lake was large, permanent and slightly alkaline. Bhatia (1968) suggested that it was fed by a series of sluggish, vegetation-rich streams and was similar in character, if not in size, to the rather smaller present-day Wular Lake in Kashmir. Other, mainly taxonomic, descriptions of ostracods from the upper Karewa Lake include those of Singh (1972, 1977): some of the taxa reported in his papers suggest the existence of small marginal ponds around the edge of the



upper Karewa Lake. Singh (1973) argued that the deepest part of the lake extended through the centre of the basin and included the site at Pattan that forms the basis of the present paper. Ostracods are also described from the lower Karewa deposits (e.g. Singh, 1972, 1973, 1977) and indicate that this earlier, larger lake was deeper than the upper Karewa Lake and also organic rich, a conclusion that is supported by the relatively high organic content of much of the lower Karewa strata. Limited descriptions of modern ostracods from Kashmir can be found in Bhatia & Singh (1971) and Singh (1972).

Despite the wealth of previous work on ostracods from Kashmir, many of the collections are not accompanied by detailed stratigraphical diagrams or information about sampling localities. As Bhatt (1989) has pointed out, the results of these investigations can only be used in a general way to inform on palaeoenvironment during upper Karewa times. Moreover, the taxonomy of some of the species described is open to question and requires reassessment in light of recent developments in the study of nonmarine ostracods (e.g. Meisch, 2000). In this paper, we describe the ostracod fauna from a logged and dated section through the upper Karewa sediments at a site near Pattan. This section is especially important, because it preserves the transition from lacustrine to aeolian sedimentation and thus records the demise of the upper Karewa lake in the central part of the basin. We describe the occurrence of ostracod species from the 25 m section and discuss their taxonomy and palaeoecological significance.

## **MATERIAL AND METHODS**

Ostracoda from the upper Karewa lacustrine sediments were studied from strata exposed in a gully near the village of Pattan (34.1456 °N: 74.5462 °E. 1676 metres

above sea level), ~25 km WNW of Srinagar (Fig. 4). Here, around 8 – 10 m thickness of loess overlies conformably the upper Karewa lake sediments. A total of 29 m of loess and lake sediments was exposed by digging vertical faces into the gully side. The gully extends a further 10 to 15 m below the base of the measured section, but the accumulation of slumped and washed material at the base made further excavation impossible. From the stratigraphy of the upper Karewa sediments elsewhere in Kashmir, the upper Karewa conglomerate is assumed to underlie the lake sediments at this site. However, despite extensive searches in this and neighbouring gullies, no trace of conglomerate beds was found and the unit was assumed not to be exposed in this locality. Samples for ostracod analyses were collected from the exposed faces in the gully using a trowel and dustpan. In all 82 samples were taken for the analysis of ostracod faunas. Individual samples covered about 5 cm stratigraphical thickness and were generally taken at 25 cm intervals throughout the section, although minor adjustments were made to sampling intervals or sample thickness to avoid sampling across observed boundaries in sediment units.

In the laboratory, 200 g of each sample was dispersed in deionised water and washed through a 63  $\mu\text{m}$  sieve. The residue was dried at 30°C and first checked under a binocular microscope for ostracod abundance within the sample. Because of wide variations in abundance, many of the samples were split to varying degrees using a mechanical splitter. Appropriate splitting factors were used to correct abundances after counting of species from the slides. In order to facilitate picking from the slides, the dry residue was again sieved through 355  $\mu\text{m}$ , 250  $\mu\text{m}$  and 180  $\mu\text{m}$  sieves, after which the material was amalgamated prior to taxonomic sorting.

Scanning electron micrographs were produced on a Cambridge Instruments Stereoscan 360 electron scanning microscope. For preparation ostracods were attached on a carrier with glue strips and then gold coated for 6 minutes at vacuum pressure.

## **Results**

### **Stratigraphy of the section**

The section at Pattan is composed predominantly of laminated to massive fine-grained sediments, mainly inorganic silty clays or silty-fine sands, with metre-scale medium to coarse sand units (Fig. 5). The finer sediments are typically calcareous ( $\text{CaCO}_3$  from 3 – 12 %) and poorly to very poorly sorted with mean grain size varying from about 2 to 10  $\mu\text{m}$ . The sand units are planar cross-bedded, slightly calcareous to non-calcareous ( $\text{CaCO}_3 < 1 \%$ ), and poorly to very poorly sorted with mean grain size from 250 to 600  $\mu\text{m}$ . The fine-grained silts become decalcified in the upper ~5 cm of the lake-sediment unit close to the boundary with the loess, probably as a result of pedogenic activity.

### **Ostracoda**

Ostracoda are an essential part of most of the sampled horizons from the section near Pattan. Only a few intervals lack ostracods; these are mainly the medium to coarse sands and the decalcified sediments close to the lake-sediment to loess transition (Fig. 5). Abundances of 200 to 1000 adult valves per 200 g sediment were commonly observed; some samples contained more than 4000 valves. The assemblages include several juvenile stages in most cases, exceptions occur only for rare taxa like *Prionocypris zenkerii* and *Potamocypris zschokkei*. In all 15 taxa out of

3 superfamilies have been identified from the Pattan section. Identification and taxonomy follow Hartmann (1964), Singh (1977), Meisch (2000) and Bates *et al.* (2002).

Class **Ostracoda** Latreille, 1806

Order **Podocopida** G.W. Müller, 1894

Suborder **Podocopina** Sars, 1866

Superfamily **Darwinuloidea** Brady & Norman, 1889

Family **Darwinulidae** Brady & Norman, 1889

Genus ***Darwinula*** Brady & Robertson, 1885

***Darwinula stevensoni*** Brady & Robertson, 1870

(Pl. 2, fig. 4)

Ecology: found in a variety of habitats, although occurs chiefly in permanent lakes (Singh, 1977). It is a non-swimmer and burrows in the upper surface of lake floors, particularly amongst vegetation detritus (Robinson, 1980). From laboratory experiments it is known that *D. stevensoni* can tolerate salinities ranging from distilled water to almost full sea water, but under natural conditions it reaches maximum densities in waters of up to 2 g/l TDS (total dissolved solids) (van Doninck *et al.*, 2003a).

The Darwinuloidea represent an almost exclusively asexual lineage over the last 200 million years, although rare living males have been found (Smith *et al.*, 2006). The life cycle of *D. stevensoni* depends on the seasonal temperatures and is prolonged (up to 4 years) in northerly latitudes close to the Arctic Circle (Ranta, 1979). In a study undertaken in Belgium, for example, the reproductive period started during March

when water temperatures exceeded 10°C, leading to maximum population densities during June/July (Van Doninck *et al.*, 2003b). Adults tolerate temperatures between 10°C and 30°C (Van Doninck *et al.*, 2003a).

Geographical distribution: cosmopolitan.

Stratigraphical range: Oligocene-Recent.

Superfamily **Cytheroidea** Baird, 1850

Family **Limnocytheridae** Klie, 1938

Subfamily **Limnocytherinae** Klie, 1938

Genus ***Limnocytherina*** Negadaev-Nikonov, 1967

***Limnocytherina sanctipatricii*** (Brady & Robertson, 1869)

(Pl. 1, fig. 21. Pl. 2, figs 9-12)

Remarks: probably described previously in Kashmir as *Limnocythere franki* Bathia, 1968 (Bhatia, 1970; Singh, 1977)

Ecology: typically inhabits the littoral and profundal zone of lakes and permanent small water bodies (Meisch, 2000). It is probably a cold-stenothermal species tolerating water temperature of not more than 15°C (Löffler, 1997). *L. sanctipatricii* may be attributed to well-oxygenated bottom waters (Scharf, 1983) and is possibly an indicator of holomictic conditions in oligotrophic lakes (Löffler, 1997). It is most probably a species of permanent waters, which produces one generation in the year and overwinters in an egg stage (Savolainen & Valtonen, 1983).

Geographical distribution: alpine and prealpine lakes of Europe, North America, Russia, Asia.

Stratigraphical range: Pleistocene-Recent.

Family **Cytherideidae** Sars, 1925

Genus **Cytherissa** Sars, 1925

**Cytherissa lacustris** Sars, 1863

(Pl. 1, fig. 6)

Ecology: a cold stenothermal form (successful moulting under laboratory conditions only below 18°C) typically inhabiting deeper (> 3 m down to 220 m) waters, but also found occasionally in the littoral zone of lakes (Löffler, 1997; Meisch, 2000). It tolerates slightly saline (0.5-1.5 g/l) conditions (Meisch, 2000). Carbonel *et al.* (1988) point out that *C. lacustris* demands a minimum oxygen content of 3 mg l<sup>-1</sup> and is absent from substrates with high organic content. Consequently *C. lacustris* has been used as indicator for the onset of climatically-induced meromictic conditions in prealpine lakes (Löffler, 1997).

Geographical distribution: Europe, North America and Asia (Holarctic).

Stratigraphical range: Pliocene-Recent.

Superfamily **Cypridoidea** Baird, 1845

Family **Candonidae** Kaufmann, 1900

Subfamily **Candoninae** Kaufmann, 1900

Genus **Candona** Baird, 1845

**Candona candida** (O.F. Müller, 1776)

(Pl. 2, fig. 6)

Ecology: a typical cold-water species preferring freshwater, but can tolerate slightly saline water (maximum salinity: ~ 6 ‰) (Hiller, 1972; Meisch, 2000). It is reported

from nearly all types of aquatic habitat. The eggs of *Candona candida* are desiccation resistant, which allows the species to survive in temporary waterbodies.

Geographical distribution: Europe, North America, Asia (Holarctic).

Stratigraphical range: Upper Pliocene-Recent.

***Candona neglecta* Sars, 1887**

(Pl. 1, figs 16-17)

Ecology: currently found in springs, ponds and in the littoral and profundal zone of lakes. Belis *et al.* (1999) recorded *C. neglecta* as an indicator of the sublittoral zone. It prefers cold waters but tolerates a temporary increase in temperature above 20°C and a fairly wide range of salinities from 0.5 ‰ to 16 ‰ (Meisch, 2000). Like most other members of the genus, it is a burrowing form and is often found amongst lake-bottom detritus (Preece *et al.*, 1986). Juveniles of *C. neglecta* and other candonids have sometimes been mistaken for a separate species under the name *Candona lactea* (Preece *et al.*, 1986).

Geographical distribution: Holarctic: Europe, North Africa, Asia and North America (Meisch, 2000).

Stratigraphical range: Pleistocene-Recent.

Genus ***Pseudocandona* Kaufmann, 1900**

***Pseudocandona compressa* (Koch, 1838)**

(Pl. 1, fig. 12)

Ecology: lives in temporary and permanent water bodies with a clear preference for the littoral zone (Meisch, 2000). It tolerates salinities up to the mesohaline range.

Reproduction takes place from spring to summer with one generation per year (Meisch, 2000).

Geographical distribution: Europe, North America, Middle East, Siberia.

Stratigraphical range: Pliocene-Recent.

Subfamily **Cyclocypridinae** Kaufmann, 1900

Genus **Cypria** Zenker, 1854

**Cypria ophtalmica** (Jurine, 1820)

(Pl. 1, fig. 15)

Ecology: occurs in a wide range of aquatic habitats including lakes, streams, ponds, springs, cave waters and bogs (Meisch, 2000). In lakes it has been found in littoral environments as well as down to the great depths of the profundal zone (Meisch, 2000). It is also a good swimmer (Bathia & Singh, 1971). *Cypria ophtalmica* has a temperature optimum between 2.2 and 8.4°C and probably belongs to the cold stenothermal forms (Mallwitz, 1984). Reported salinity tolerance ranges from freshwater to lower oligohaline ( $\leq 5.8$  ‰), but it has also been collected from waters salinity of c. 25 ‰ (polyhaline) as inferred from chloride concentration (Meisch, 2000). It produces two generations annually and eggs that are desiccation resistant.

Geographical distribution: cosmopolitan.

Stratigraphical range: Miocene-Recent.

Genus **Cyclocypris** Brady & Norman, 1889

**Cyclocypris ovum** (Jurine, 1820)

(Pl. 1, figs 18-20)



Ecology: a common species that inhabits a wide range of aquatic habitats. It is especially common in the littoral zone of lakes but can be found in deeper waters, occasionally as deep as ~70 m (Meisch, 2000). In the Qilian Mountains of China it was abundant in the surface sediment of a freshwater (salinity of 0.5 ‰) lake at an altitude of 3200 m, but was rare in running waters (Mischke *et al.*, 2003). Maximum salinity in which the species has been reported is 6.4 ‰ (Meisch, 2000). It is generally associated with permanent waters, although has been reported from temporary habitats (Meisch, 2000).

Geographical distribution: Holarctic/cosmopolitan.

Stratigraphical range: Pleistocene-Recent.

Family **Ilyocyprididae** Kaufmann, 1900

Subfamily **Ilyocypridinae** Kaufmann, 1900

Genus ***Ilyocypris*** Brady & Norman, 1889

***Ilyocypris bradyi*** Sars, 1890

(Pl. 1, figs 1-2. Pl. 2, figs 1-3)

Remarks: this species may be identified conclusively by presence of a number of riplets on the inner margin of the left valve (Janz, 1994). However, these riplets are not always well preserved and indeed were not observed on the material from the Pattan section. We therefore refer to the material from Pattan as *Ilyocypris* cf. *bradyi*.

Ecology: characteristic of vegetation-rich, temporary and permanent running waters (Meisch, 2000), but is also found in shallow lakes, springs, marshes, rice-fields and interstitial habitats. It is a poor swimmer, tending instead to climb on aquatic

vegetation (Robinson, 1980). It can tolerate elevated salinity up to about 4.5 ‰ (De Deckker, 1981). It is a permanent form that produces two generations annually.

Geographical distribution: Holarctic.

Stratigraphical range: Miocene-Recent.

***Ilyocypris salebrosa*** Stepanaitys, 1960

(Pl. 2, figs 13-15)

Remarks: *I. salebrosa* is synonymous with *I. shawneetownensis* described by Staplin (1963), *Pelocypris alatabulbosa* (Delorme, 1970) and *I. steegeri* (Kempf, 1967).

Bhatia (1968) recorded this species from the Karewa deposits of Kashmir under the synonym *I. shawneetownensis*.

Ecology: living specimens of this species are known from the shallow freshwater Dal Lake in Kashmir valley, where its presence is attributed to small sluggish tributary flowing into the lake from the north (Singh, 1977). Its wider presence within Pleistocene deposits of Europe, North-America and China is in contrast to the very restricted populations today (Mischke & Schudack, 2001; Bates *et al.*, 2002).

Geographical distribution: N. India, W. China (recent); W. Europe, N. America, C. Asia (Middle to Late Pleistocene).

Stratigraphical range: Pleistocene-Recent.

Family **Cyprididae** Baird, 1845

Subfamily **Cyprididae** Baird, 1845

Genus ***Eucypris*** Vávra, 1891

***Eucypris afghanistanensis*** (Hartmann, 1964)

(Pl. 1, figs 7-11)

Ecology: a cold stenothermal form living in slow flowing and standing waters, springs and shallow ponds (Hartmann, 1964). The presence of reduced natatory setae (antennule A2) in living specimens points on an epibenthic crawling or burrowing locomotion (Hartmann, 1964). *Eucypris afghanistanensis* is found in Quaternary lacustrine sediments of the Himalaya up to altitudes of 4500 m (Hartmann, 1975), where it is commonly associated with candonid ostracods as well as molluscs and *Chara*. In the Tso Kar Basin (Ladakh, N. India, 4500 m above sea level) recent valves of *E. afghanistanensis* were collected from the littoral zone of a lake and from shallow temporary ponds, with electrical conductivities ranging from 180 to 900  $\mu\text{Scm}^{-1}$  (corresponding to a salinity range of  $\sim 0.1\text{‰}$  to  $0.7\text{‰}$ ) and surface water temperatures of  $18^{\circ}\text{C}$  to  $25^{\circ}\text{C}$  (M. Kramer, unpublished). It has also been reported (as *Parastenocypris* sp.) from Quaternary deposits in the Lamayuru Basin at 3600 m a.s.l. in Western Ladakh (Kotlia *et al.*, 1997).

*Eucypris afghanistanensis* was first described by Hartmann (1964) from the Middle East. During ontogeny a variety of valve shapes is realized, whereby adult specimens range in length from 1.20 mm to 1.40 mm and have a height/length ratio of 0.44 to 0.49. On the basis of valve shape description it is synonymous with *Parastenocypris delormi* Singh, 1974, reported from Kashmir, and possibly *Eucypris gyirongensis* Huang, 1982 from the Tibetan Plateau.

Geographical distribution: Afghanistan, India, Tibetan Plateau?

Stratigraphical range: Pleistocene-Recent?

Genus ***Potamocypris*** Brady, 1870

***Potamocypris zschokkei*** (Kaufmann, 1900)

(Pl. 1, figs 13-14)

Ecology: a cold stenothermal species (temperature optimum of the parthenogenetic form c. 9°C), which shows a preference for shallow, slowly running waters (Meisch, 1984). It also occurs in springs and interstitial habitats. It produces two to three generations annually and is associated with permanent waters (Meisch, 1984, 2000).

Geographical distribution: Europe.

Stratigraphical range: Pleistocene-Recent.

Genus ***Prionocypris*** Brady & Norman, 1896

***Prionocypris zenkeri*** (Chyzer & Toth, 1858)

(Pl. 2, figs 7-8)

Ecology: prefers slow flowing streams and non-stagnant shallow waters with rich aquatic vegetation (Meisch, 2000). It was found in a number of artificial freshwater springs (water temperature: 13°-17°C, electrical conductivity 300-600  $\mu\text{Scm}^{-1}$ ) fed by deep groundwater in Northern Italy (Rossetti *et al.*, 2005). Sporadic occurrences of *P. zenkeri* in lake sediments may be related to transport from nearby springs or running waters. It seems to be a permanent form (Meisch, 2000).

Geographical distribution: Europe, Asia Minor (Turkey).

Stratigraphical range: Pleistocene-Recent.

Subfamily ***Cypridopsinae*** Kaufmann, 1900

Genus ***Cypridopsis*** Brady, 1867

***Cypridopsis vidua* (O. F. Müller, 1776)**

(Pl. 1, fig. 4)

Ecology: this common and prevalent ostracod species is found in a wide range of habitats including lakes, rivers, ponds, springs, wells, interstitial habitats and rice fields (Meisch, 2000; Rossi *et al.*, 2003). In lakes it prefers the vegetated littoral and sublittoral zones (Carbonel *et al.*, 1988). Generally the occurrence of *C. vidua* appears to be independent of current conditions (Curry, 1999). It is an active swimmer that can tolerate total dissolved solids up to 10.5 g/l (Curry, 1999), but is intolerant of low dissolved oxygen saturation (Meisch, 2000).

This summer form produces two generations annually, the first in early spring and the second in late summer, whereby only few adults overwinter (Meisch, 2000). The species is exclusively parthenogenetic.

Geographical distribution: cosmopolitan.

Stratigraphical range: Pliocene-Recent.

## **DISCUSSION**

The sediments at Pattan are predominantly lacustrine silts with minor units of fluviodeltaic sand. The existence of ripple laminae suggest a shallow waterbody: based on investigations at Pattan and elsewhere within the basin (Singh, 1982), the facies suggest that the water was often no more than about 2 m deep, only exceptionally deeper. The presence of large quantities of silt within the sediments suggests a high degree of aeolian input. The top of the Pattan section was dated to ~118 ka by means of thermoluminescence (Holmes *et al.*, 1992). Although the base of the measured section is undated, it must be younger than 0.4 MyrBP, which is the estimated age of the upper Karewa conglomerate unit that is assumed to underlie the

lake sediments. Luminescence dates from elsewhere in the basin indicate that the demise of the upper Karewa Lake probably took place sometime between about 80 and 110,000 yrBP (Rendell and Townsend, 1988, Gardner and Rendell, 1994).

In general, the ostracod species from the Pattan section show broad environmental tolerances and habitat preferences. Seven of the fifteen taxa found can tolerate freshwater conditions (salinity  $\leq 0.5$  ‰), but nearly all share a preference for oligohaline conditions (salinity 0.5 - 5 ‰). However, few of the taxa can tolerate waters with salinities greater than 15 ‰.

Ostracods such as *Limnocytherina sanctipatricii*, *Candona neglecta*, *Darwinula stevensoni* or *Cytherissa lacustris*, which are commonly found inhabiting the profundal zones of lakes, are abundant in the Pattan sediments. Similar findings are reported by Singh (1973), who underlines the profundal character of the ostracod fauna documented near Pattan. This support Bhatt's (1989) suggestion that the site falls within the deepest central part of the upper Karewa Lake. Furthermore *C. lacustris* and *L. sanctipatricii* are indicative of well-oxygenated bottom water conditions, which are typically present in cold and oligotrophic lakes (Danielopol *et al.*, 1985; Carbonel *et al.*, 1988; Scharf, 1991; Löffler, 1997). Oxygen saturated bottom waters may reflect low biological productivity within the lake, permanent circulation or inflow of cold and oxygen-saturated waters from glacial meltwater. However, low biological productivity is not consistent with the presence of taxa that show affinity for aquatic plants. Moreover, the contribution of glacial meltwater to the upper Karewa Lake is a matter for debate. Small glaciers are present in both the Pir Panjal and Great Himalayan Mountain ranges at present, although the total glaciated area is small. Glacial advances during the Pleistocene would undoubtedly have

increased the extent of glacial ice within the mountain ranges. However, the magnitude of those advances was limited and their timing uncertain (Holmes & Street-Perrott, 1989). Moreover, the timing of deposition of the sediments at Pattan is not well constrained, and it remains unclear whether, climatically, they represent a cold (glacial) or warm (interglacial) stage.

The ostracods *Ilyocypris salebrosa*, *Potamocypris zschokkei* and *Prionocypris zenkeri* are typically reported from running waters and may be linked to the influence of inflowing rivers and streams, despite the fact that the Pattan section lay towards the basin centre. Significantly however, these taxa show low abundances and lack complete ontogenies, which would tend to confirm that they are not *in situ* but have been transported by current action. Typical representatives of the littoral or the transitional zone towards running water are also common in the Pattan fossil assemblages. These are *E. afghanistanensis*, and *Pseudocandona* cf. *compressa* and *Ilyocypris* cf. *bradyi*.

The distribution of ostracod taxa within the Pattan section shows some stratigraphical variation (Fig. 5). The most notable changes are the reduction in the proportion of *E. afghanistanensis* and the rise in *D. stevensoni* and *C. ovum* in the upper half of the sequence. The association of *E. afghanistanensis* with running water is consistent with the occurrence of several prominent sand units in the lower 12 metres of the section. It is possible that the lake deepened during the latter part of the period represented by the section, such that the influence of inflowing streams was reduced as the distance between the Pattan site and the lakeshore increased. However, there is no other clear evidence within the ostracod assemblages of a significant increase in water depth and, for the most part, the ostracods suggest that the lake was cold

and well oxygenated at this site throughout the time represented by the section, with abundant aquatic plants.

In summary, the Ostracoda from Pattan show affinities to profundal, littoral and running water habitats. The lake water can be characterized as freshwater to slightly saline ranging from 0.5 ‰ to 5 ‰ on the basis of ostracod assemblages. The trace-element analyses undertaken on ostracods from this section (Holmes *et al.*, 1989) also point to a lake that was, at most, only slightly saline. Nearly all taxa are cold stenothermal forms, which may reflect the influence of surface water supply from nearby glaciers or generally cool air temperatures. The sediments of the upper Karewa formation mainly represent lacustrine conditions over large parts of the Kashmir Valley, with a deeper part stretching along tectonic strike of the basin (Singh, 1973). The ecological aspects of the ostracod assemblages from the section near Pattan are consistent with this suggestion. Although there is some ostracod evidence to suggest that the lake deepened during the latter part of the time represented by the Pattan section, limnological conditions remained broadly unchanged. The final drainage of the lake, in the early part of the Late Pleistocene, appears to have been quite abrupt, with no evidence for gradual shallowing. This is consistent with the previously-published ostracod trace-element data for this sequence. Once the lake had drained, lacustrine sedimentation was replaced by the accumulation of aeolian silt.

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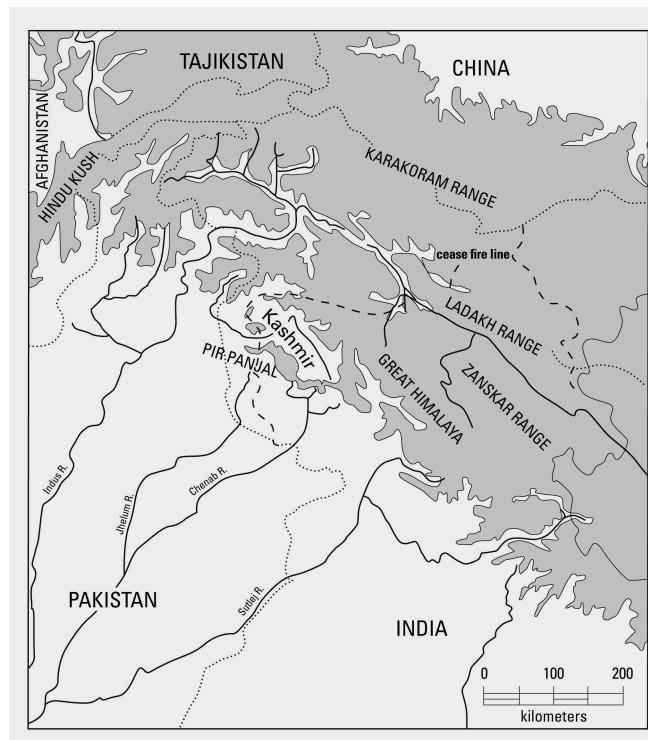


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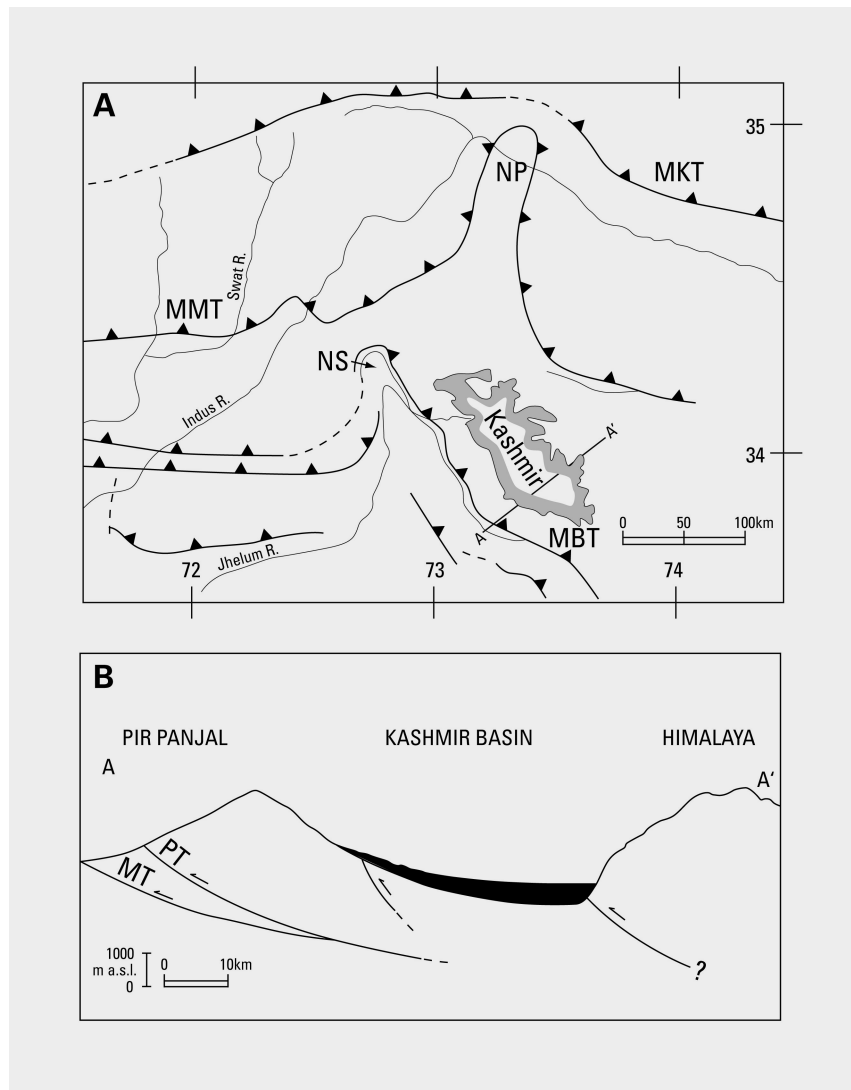
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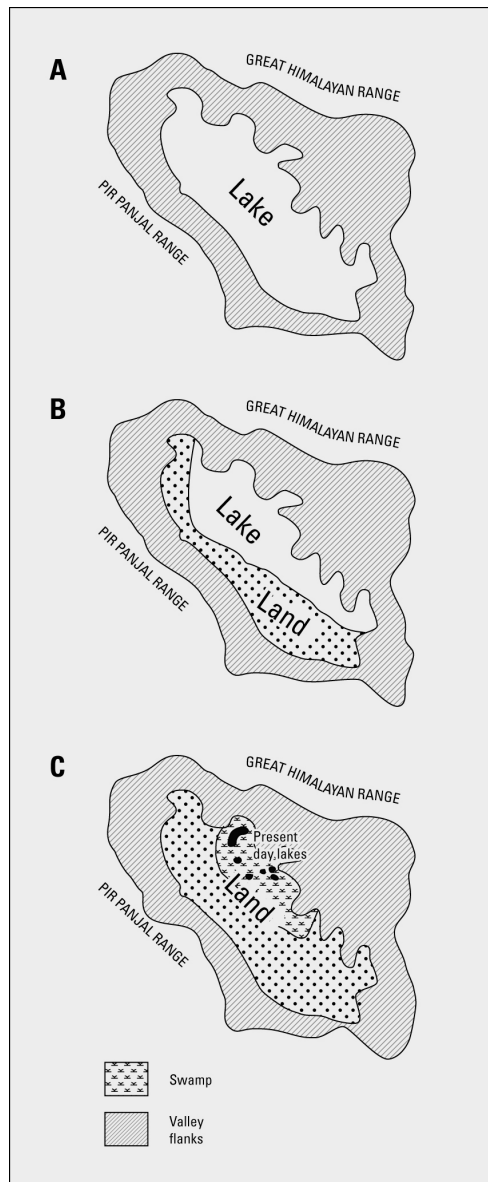
## FIGURES



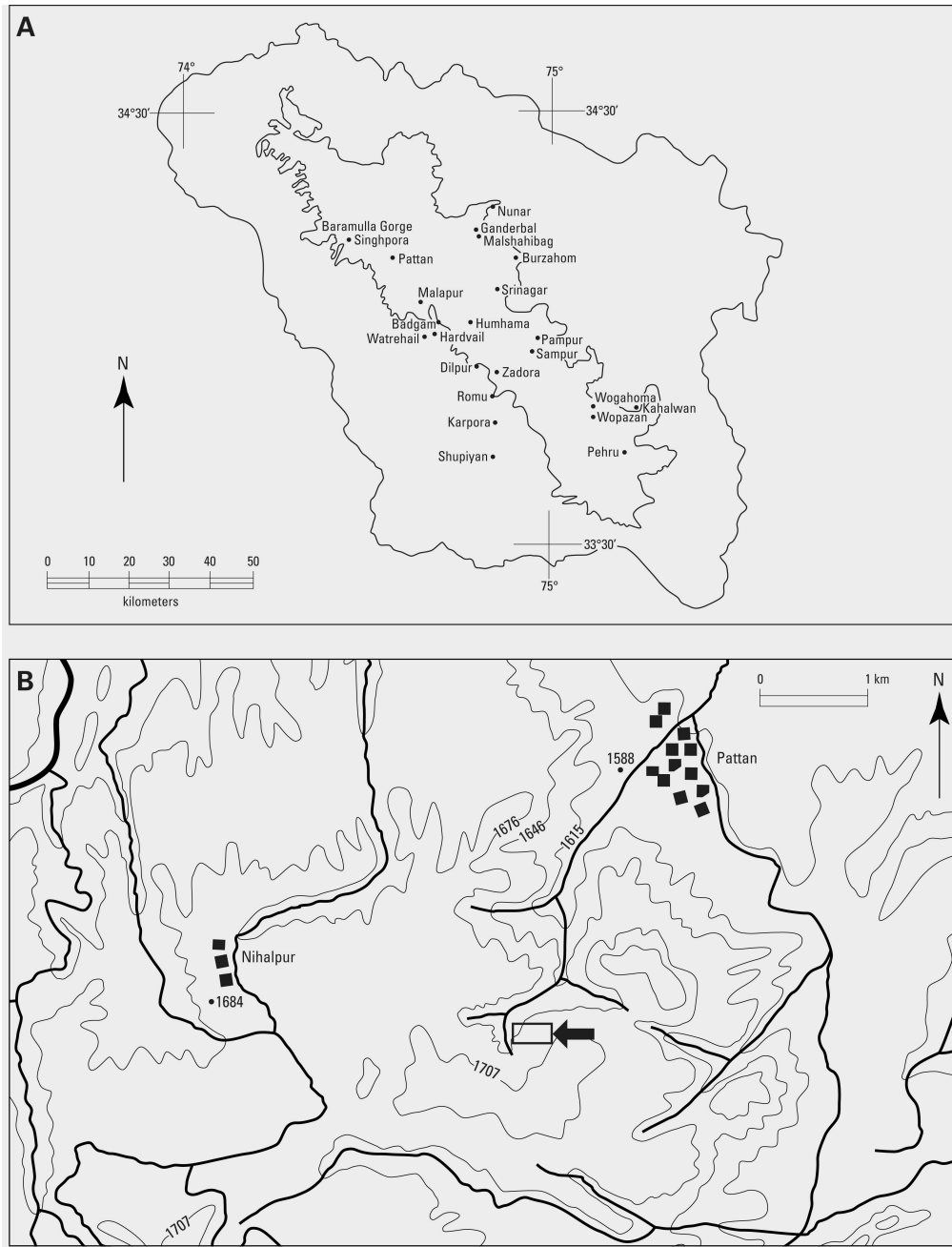
**Fig. 1.** Location of Kashmir intermontane basin. Shaded area is land over 2000 metres.



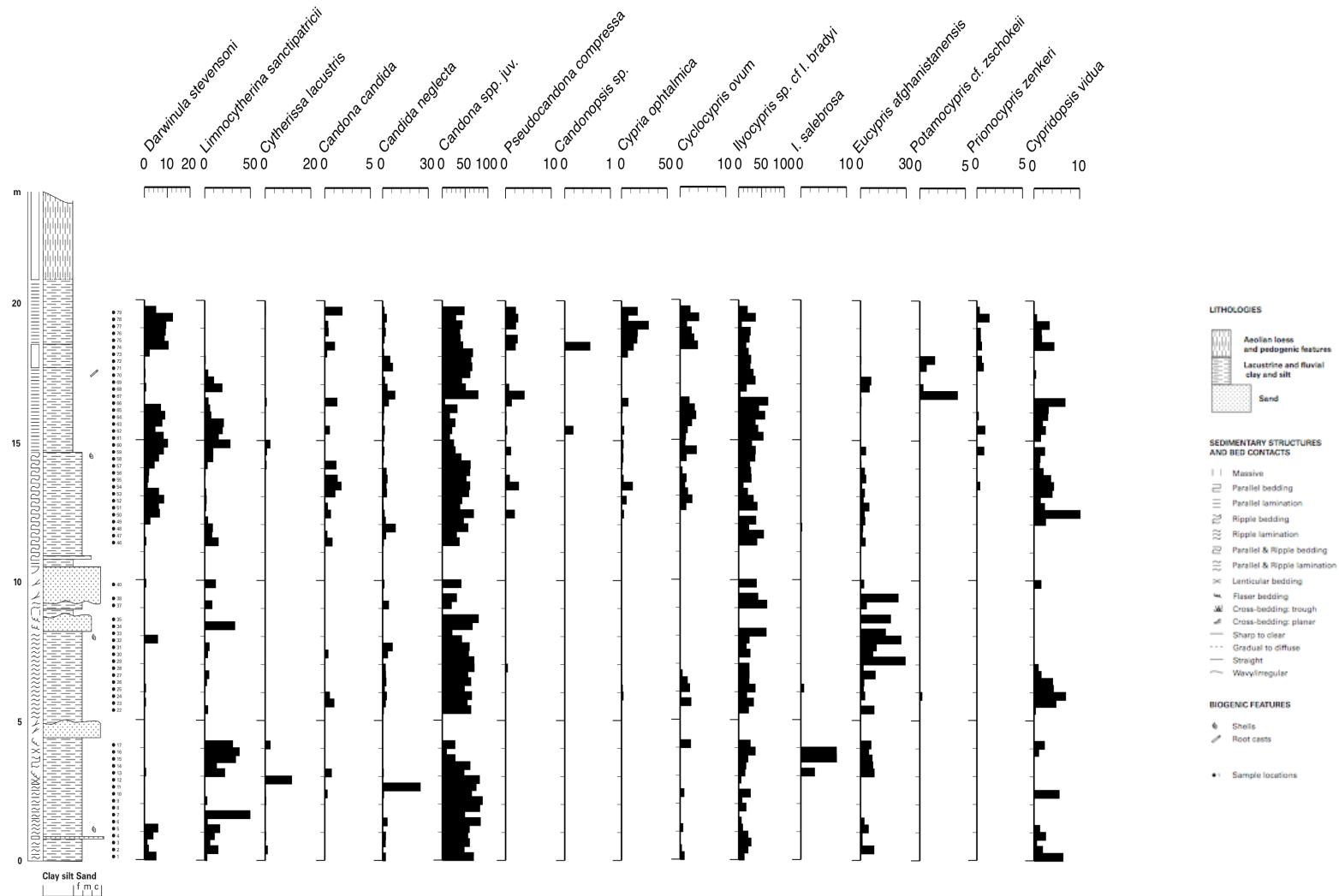
**Fig. 2.** Tectonic setting of Kashmir intermontane basin. (A) major fault systems. (B) cross-section of the basin showing the major structural features. MBT = Main Boundary Thrust, MMT = Main Mantle Thrust, MKT = Main Karakoram Thrust, NPS = Nanga Parbat syntax, NS = Northwest syntax, PT = Panjal Thrust, MT = Muree Thrust. Black shading represents Karewa sediments. From information in Middlemiss (1910), Wadia (1934) and Burbank & Johnson (1983).



**Fig. 3.** Evolution of lakes in Kashmir intermontane basin. A. Karewa Lake in lower Karewa times, B. restricted lake during upper Karewa times after large-scale drainage, C. Present-day configuration, following final drainage of the Karewa Lake. (Redrawn from Bhatt, 1989).



**Fig. 4.** Location of the study site near Pattan. (A) Outline showing maximum extent of upper Karewa Lake sediments and inferred approximate shoreline of the upper Karewa Lake. Pattan is marked, along with other important upper Karewa sites. (B) Detailed location map of the measured section (marked by unfilled rectangle and arrow). Contours and spot heights are in metres.

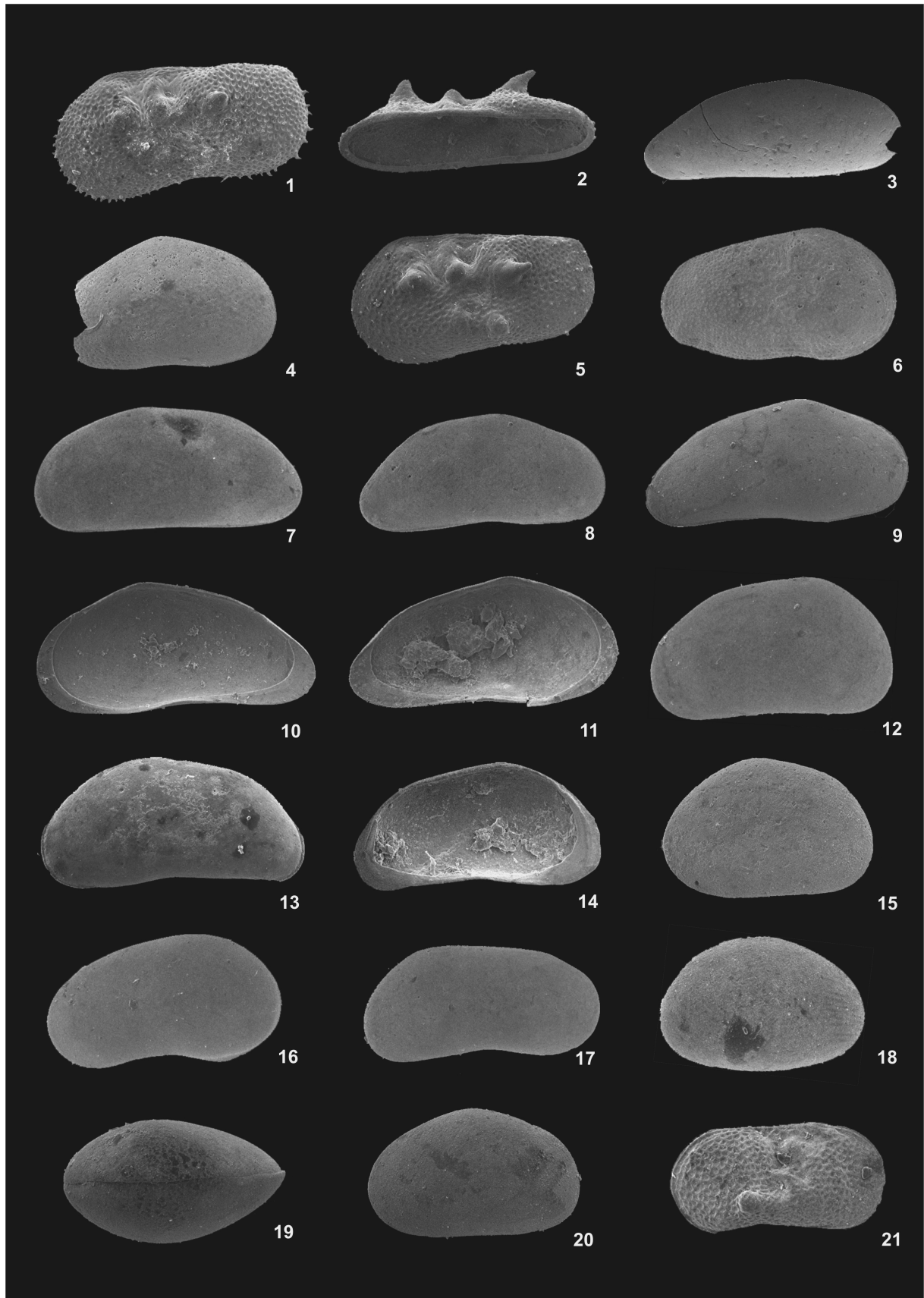


**Fig. 5.** Ostracods from the Pattan sequence (as percentages of total valves recovered) alongside the lithostratigraphic log

## Explanation of plate 1.

LV: left valve, RV: right valve, ex: external view, in: internal view, DV: dorsal view, L: length, H: height, W: width, (L, H, W given in mm).

1: *Ilyocypris* cf. *bradyi* LV ex L: 0.788 H: 0.412 (16563); 2: *Ilyocypris* cf. *bradyi* RV L: 0.619 (16564); 3: *Eucypris afghanistanensis* (juvenile) RV ex L: 0.853 H: 0.332; 4: *Cypridopsis vidua* ex L: 0.544 H: 0.362; 5: *Ilyocypris* sp. (juvenile) LV ex L: 0.582 H: 0.398 (16565); 6: *Cytherissa lacustris* RV ex L: 0.801 H: 0.468 (16566); 7: *Eucypris afghanistanensis* LV ex L: 1.120 H: 0.532 (16567); 8: *Eucypris afghanistanensis* RV ex L: 1.090 H: 0.517 (16568); 9: *Eucypris afghanistanensis* (juvenile) RV ex L: 0.661 H: 0.320 (16569); 10: *Eucypris afghanistanensis* (juvenile) RV in L: 0.698 H: 0.335 (16570); 11: *Eucypris afghanistanensis* (juvenile) LV in L: 0.713 H: 0.352 (16571); 12: *Pseudocandona compressa* LV ex L: 0.786 H: 0.467 (16572); 13: *Potamocypris zschokkei* LV ex L: 0.662 H: 0.326 (16573); 14: *Potamocypris zschokkei* LV in L: 0.677 H: 0.353 (16574); 15: *Cypria ophtalmica* LV ex L: 0.498 H: 0.338 (16575); 16: *Candona neglecta* (male) LV ex L: 1.310 H: 0.744 (16576); 17: *Candona neglecta* (female) RV ex L: 1.090 H: 0.546 (16577); 18: *Cyclocypris ovum* ex L: 0.454 H: 0.308 (16578); 19: *Cyclocypris ovum* (carapace) DV L: 0.456 W: 0.261 (16579); 20: *Cypridopsis vidua* ex L: 0.468 H: 0.288 (16580); 21: *Limnocytherina sanctipatricii* (female) RV ex L: 0.603 H: 0.307 (16581). Selected specimens are deposited in the Department of Palaeontology, Natural History Museum, London; accession numbers are in parentheses.





## Explanation of plate 2.

(abbreviations as for plate 1). 1: *Ilyocypris* cf. *bradyi* RV ex L: 0.719 H: 0.387 (16582); 2: *Ilyocypris* cf. *bradyi* LV in L: 0.765 H: 0.415 (16583); 3: inner lamella of postero-ventral area from 2; 4: *Darwinula stevensoni* LV in L: 0.610 H: 0.247; 5: *Darwinula stevensoni* DV L: 0.635 W: 0.212; 6: *Candona candida* RV ex L: 0.798 H: 0.445; 7: *Prionocypris zenkeri* LV ex L: 1.320 H: 0.756 (16587); 8: outer margin of antero-ventral area of 033; 9: *Limnocytherina sanctipatricii* (female) RV ex L: 0.531 H: 0.276 (16589); 10: *Limnocytherina sanctipatricii* (male) LV ex L: 0.651 H: 0.311 (16590); 11: *Limnocytherina sanctipatricii* (male) RV ex L: 0.683 H: 0.324 (16591); 12: *Limnocytherina sanctipatricii* RV ex L: 0.588 H: 0.317 (16592); 13: *Ilyocypris salebrosa* DV L: 0.693 (16593); 14: *Ilyocypris salebrosa* RV ex L: 0.695 H: 0.402 (16594); 15: *Ilyocypris salebrosa* LV ex L: 0.826 H: 0.468 (16595). Selected specimens are deposited in the Department of Palaeontology, Natural History Museum, London; accession numbers are in parentheses.

