Mio–Pleistocene Ostracoda from the Zhada Basin (western Tibetan Plateau)

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Abstract
We present a list of Ostracoda (Crustacea) from stratigraphic sections of Mio–Pleistocene lacustrine deposits from Zhada Basin, western Tibetan Plateau. In this area, almost no taxonomical studies were carried out so far, and, aiming to a future use of ostracods as palaeoenvironmental proxy for this sector of the Tibetan Plateau, a documentation of several species was performed. The taxa Leucocytherella sinensis Huang, 1982, ?Leucocythere dorsotuberosa Huang, 1982, Leucocythere postilirata Pang, 1985, Ilyocypris spp., Eucypris cf. zandaensis Yang, 1982, ?Prionocypris sp., Paraecypris sp. and Leuco‑cytherella dangeloi sp. nov. were found and classified. The taxon Ilyocypris spp. probably represents three different species; other taxa in open nomenclature are Paraecypris sp., Eucypris cf. zandaensis and ?Prionocypris sp. The reported taxa from the Zhada Basin are mainly lacustrine species, and their diversity is comparable to those of other Neogene and Quaternary basins located on the Tibetan Plateau.

Keywords Neogene · Quaternary · Taxonomy · Biogeography · China · Lacustrine deposit

Introduction
There are many examples for the prominent role of Ostracoda (Crustacea) in different fields of geosciences and their use as palaeoenvironmental, palaeoclimatic and biostratigraphic indicators (Boomer et al. 2003; Horne 2003, 2007). Their sensitivity to environmental changes and their wide distribution in all types of water bodies call for their good documentation also in less studied areas. In contrast to the large number of geological and palaeontological studies on the Tibetan Plateau, research on ostracods in this area is rather rare and improved only in the last decade (Wrozyna et al. 2009; Frenzel et al. 2010; Mischke 2012). Investigations were mainly conducted in the more easily accessible northern and eastern part of the plateau (Zhang et al. 1989, 1994, 2006; Mischke et al. 2010), and only a few studies improved the available knowledge of the local ostracod fauna of its central and western part (Li et al. 1991; Zhu et al. 2010; Guo et al. 2016; Song et al. 2017; Alivernini et al. 2018a, b). Furthermore, ostracod studies in the central and southern parts of the Tibetan Plateau focussed on Holocene and Late Pleistocene faunas whereas the precursors of these mainly endemic species are not known. Investigations on Mio–Pleistocene ostracods from the Tibetan Plateau are restricted to its northeastern part so far (Sun 1988; Yang et al. 1997; Mischke et al. 2006, 2010; Wu et al. 2011; Lu et al. 2019) where they are a valuable tool for biostratigraphy in hydrocarbon exploration.

This work focuses on Mio–Pleistocene ostracods of the Zhada Basin located in the western Tibetan Plateau (Fig. 1). Previous works carried out in this area concern
its tectonic origins (Wang et al. 2004, 2008; Saylor et al. 2010a) and environmental history (Saylor et al. 2010b) using mostly sedimentological and pollen analyses. Kempf et al. (2009), who investigated petrographic and sedimentological properties, were the first to describe also elements of the ostracod fauna in this area. They found some typical endemic taxa like *Leucocytherella sinensis* and several not identified species. In this work, we present the Mio–Pleistocene ostracod assemblage recovered from 105 samples of Joel Saylor’s stratigraphic “South Zhada” (“SZ”) section (Fig. 2), located in the southern part of the Zhada Basin and already sedimentologically analysed and
Mio–Pleistocene Ostracoda from the western Tibetan Plateau

Study area

The Zhada Basin is the largest late Cenozoic sedimentary basin in the Tibet Autonomous Region. It is located north of the high Himalayan ridge crest in the western part of the orogen (≈32° N, 82° E; Fig. 1). The basin is at least 150 km long and 60 km wide, and the current outcrop extent of the basin fill covers at least 9000 km² (Saylor et al. 2010a). It is bounded by the South Tibetan detachment system to the southwest, the Indus suture to the northeast, and the Leo Pargil and Gurla Mandhata gneiss domes to the northwest and southeast, respectively (Saylor et al. 2010b). The Zhada Basin contains a thick sequence of late Neogene and early Quaternary fluvial and lacustrine deposits (Kempf et al. 2009) which allows the reconstruction of long-term climate history.

Materials and methods

Fieldwork

A total of 124 sediment samples from seven, relatively thick lake beds were collected from Saylor’s “South Zhada” section (Saylor 2008) in 2012 (Table 1). The selected lake beds are distributed more or less evenly over the 820-m-thick sediment sequence to enable the investigation and comparison of ostracods from stagnant-water deposits formed over the last ca. 8 million years as estimated by Saylor et al. (2010a). Sediment samples from individual lake beds were collected at ca. 0.5-m intervals (Table 1). The seven selected lake beds are located between 31.46538° N and 79.72865° E as the lowermost and northernmost position and 31.36556° N and 79.75152° E as the uppermost and southernmost position.

Micropalaeontological analysis

All 124 sediment samples were prepared for micropalaeontological analysis. The samples were treated with H₂O₂ (ca. 5–10% for about 1–2 h) to separate aggregates of mud, and they were subsequently sieved with water through a 200-µm-sieve to remove fine-grained particles. For quantitative ostracod analysis, the sieve residues were split into sub-samples using a microsplitter. Sixteen samples were barren of ostracods. The species proportions and the relative ostracod abundances were calculated considering all ontogenetic stages (juvenile and adult valves). To assess water turbulence (Boomer et al. 2003) and the possible removal of thinner and smaller juvenile valves by dissolution, the adult/juvenile ratio was determined. Identification was performed primarily with a low-power binocular microscope and was occasionally supported by a scanning electron microscope (SEM) as well as a Keyence Digital Microscope. The valves were classified and taxonomically attributed, where possible, by comparison with previous studies of ostracods from the Tibetan Plateau (Wrozya et al. 2009, 2010; Mischke et al. 2010; Akita et al. 2016) and using Chinese literature (Huang 1982; Hou et al. 2002; Hou and Gou 2007). In addition, an amended description of the valves was added.
Table 1  Samples number examined for ostracods (ZO) from seven locations (ZDS; Fig. 1b) and lake beds of the “South Zhada” section

| m above base | ZDS | Lake bed | ZO |
|--------------|-----|----------|----|
| 115.3        | 12  | 1        | 122|
| 114.95       | 12  | 1        | 121|
| 114.25       | 12  | 1        | 119|
| 113.9        | 12  | 1        | 118|
| 113.55       | 12  | 1        | 117|
| 112.85       | 12  | 1        | 115|
| 776          | 9   | 7        | 113|
| 775.5        | 9   | 7        | 112|
| 775          | 9   | 7        | 111|
| 774.5        | 9   | 7        | 110|
| 774          | 9   | 7        | 109|
| 773.5        | 9   | 7        | 108|
| 773          | 9   | 7        | 107|
| 772.5        | 9   | 7        | 106|
| 772          | 9   | 7        | 105|
| 771.5        | 9   | 7        | 104|
| 771          | 9   | 7        | 103|
| 770.5        | 9   | 7        | 102|
| 770          | 9   | 7        | 101|
| 769.5        | 9   | 7        | 100|
| 769          | 9   | 7        | 99 |
| 768.5        | 9   | 7        | 98 |
| 768          | 9   | 7        | 97 |
| 767.5        | 9   | 7        | 96 |
| 767          | 9   | 7        | 95 |
| 634.5        | 10  | 6        | 86 |
| 634          | 10  | 6        | 85 |
| 633.5        | 10  | 6        | 84 |
| 633          | 10  | 6        | 83 |
| 632.5        | 10  | 6        | 82 |
| 632          | 10  | 6        | 81 |
| 631.5        | 10  | 6        | 80 |
| 631          | 10  | 6        | 79 |
| 630.5        | 10  | 6        | 78 |
| 630          | 10  | 6        | 77 |
| 629.5        | 10  | 6        | 94 |
| 629          | 10  | 6        | 93 |
| 628.5        | 10  | 6        | 92 |
| 628          | 10  | 6        | 91 |
| 627.5        | 10  | 6        | 90 |
| 627          | 10  | 6        |     |
| 434.5        | 6   | 5        | 74 |
| 434          | 6   | 5        | 73 |
| 433.5        | 6   | 5        | 72 |
| 433          | 6   | 5        | 71 |
| 432.5        | 6   | 5        | 70 |
| 432          | 6   | 5        | 69 |
| 431.5        | 6   | 5        | 68 |
| 431          | 6   | 5        | 67 |

Table 1 (continued)

| m above base | ZDS | Lake bed | ZO |
|--------------|-----|----------|----|
| 430          | 6   | 5        | 65 |
| 429.5        | 6   | 5        | 64 |
| 429          | 6   | 5        | 63 |
| 428.5        | 6   | 5        | 62 |
| 428          | 6   | 5        | 61 |
| 415          | 6   | 5        | 60 |
| 412          | 6   | 5        | 59 |
| 405          | 6   | 5        | 58 |
| 398          | 6   | 5        | 57 |
| 379          | 5   | 4        | 42 |
| 378.5        | 5   | 4        | 43 |
| 378          | 5   | 4        | 44 (2 samples) |
| 377.5        | 5   | 4        | 45 |
| 377          | 5   | 4        | 46 |
| 376.5        | 5   | 4        | 47 |
| 376          | 5   | 4        | 48 |
| 375.5        | 5   | 4        | 49 |
| 375          | 5   | 4        | 50 |
| 374          | 5   | 4        | 52 |
| 373.5        | 5   | 4        | 53 |
| 373          | 5   | 4        | 54 |
| 372.5        | 5   | 4        | 55 |
| 329          | 5   | 3        | 29 |
| 328.25       | 5   | 3        | 28 |
| 327.5        | 5   | 3        | 27+27a |
| 326.75       | 5   | 3        | 26 |
| 326          | 5   | 3        | 25 |
| 325.25       | 5   | 3        | 24 |
| 324.5        | 5   | 3        | 23 |
| 323.75       | 5   | 3        | 22 |
| 323          | 5   | 3        | 21 |
| 322.25       | 5   | 3        | 20 |
| 291          | 4   | 3        | 39 |
| 289          | 4   | 3        | 36 |
| 280          | 4   | 3        | 37 |
| 261          | 3   | 2        | 19 |
| 260          | 3   | 2        | 18 |
| 241          | 3   | 2        | 17 |
| 239.5        | 3   | 2        | 1 |
| 239.3        | 3   | 2        | 2 |
| 239          | 3   | 2        | 16 |
| 237.5        | 3   | 2        | 15 |
| 236          | 3   | 2        | 14 |
| 234.5        | 3   | 2        | 13 |
| 233          | 3   | 2        | 12 |
| 231.5        | 3   | 2        | 11 |
| 230          | 3   | 2        | 10 (2 samples) |
| 229          | 3   | 2        | 9 |
| 228          | 3   | 2        | 8 |
| 227          | 3   | 2        | 7 |
Results

Presence of organism remains and preservation

In total, 105 sediment samples contained ostracod valves. From these samples, 6722 ostracod valves were recovered. Most valves are disarticulated, and adult valves are dominant. Juvenile valves, especially from silty to fine sandy sediments, are often deformed. Besides ostracod valves, gyrogonites of charophytes and mollusc shells, mostly fragments of Gastropoda, were found frequently in the samples.

Ostracod taxonomy

We recorded at least eight ostracod species in the 124 samples from the Zhada Basin (Table 2). The most abundant species is *L. sinensis* (Huang 1982) which often occurs in association with ?*Leucocythere dorsotuberosa* and *L. postilirata* (Table 2). Other abundant taxa are *Paraeucypris* sp. and *Leucocytherella dangeloi* sp. nov.

A systematic overview of the ostracod taxa of the Zhada Basin follows below. The synonymy lists contain selected papers as first description, emendations and other taxonomically important references. The systematic description is adopted from Martin and Davis (2001) and complemented from Fürstenberg et al. (2015).

| Class          | Ostracoda Latreille, 1802  |
|----------------|----------------------------|
| Order          | Podocopida Müller, 1894    |
| Suborder       | Cytherocopina Baird, 1850   |
| Superfamily    | Cytheroidea Baird, 1850     |
| Family         | Limnocytheridae Klie, 1938  |
| Subfamily      | Limnocytherinae Klie, 1938  |

Genus *Leucocytherella* Huang, 1982

*Leucocytherella sinensis* Huang, 1982

Figure 3a, b

1982 *Leucocytherella sinensis* Huang gen. et sp. nov.—Huang: 341–342; text-figs. 23–26; pl. 12: figs. 1–8; pl. 13: figs. 1–7 [type species of *Leucocytherella* Huang, 1982]

2015 *Leucocytherella sinensis* Huang—Fürstenberg et al.: 67–70; figs. 6, 10–12 [comprehensive synonymy list]

2016 *Leucocytherella sinensis* Huang—Akita et al.: 7; figs. 3/6–10

2016 *Leucocytherella sinensis* Huang—Guo et al.: fig. 2 [upper left valve]

2018a *Leucocytherella sinensis* Huang—Alivernini et al.: fig. 8/1

Studied material. 3202 valves (adults and juveniles, females and males, including specimens with complete carapaces).

Size. 0.64–0.75 mm (male); 0.64–0.72 mm (female).

Original description. (Huang 1982). Valve of female rectangular in lateral view, anterior end higher than posterior, two transverse sulci anterodorsally, radial pore canal zone moderately broad, with slender, straight and sparse radial pore canals. Hinge of left valve consists of an anterior small reniform tooth, a posterior small triangular one and middle shallow groove. Valve of male rather long, both ends nearly equivalently high. Valve of juveniles rather short, anterior end higher than posterior.

For a detailed description of the valves of recent specimens (adult and juveniles, males, females,) on the Tibetan Plateau see Fürstenberg et al. (2015).

Stratigraphic, ecological and geographic distribution. From Miocene to recent (Huang 1987). *Leucocytherella sinensis* is ubiquitous and endemic on the Tibetan Plateau above 4000 m above sea level (Akita et al. 2016). Valves of *L. sinensis* were found in lakes, ponds, rivers, and lagoon-like and estuary-like water bodies at lake shores in salinities of 0.08–12.81 psu. Specimens live on mud, sand, sandy gravel and in phytal habitats in permanent fresh to brackish lacustrine waters, preferentially in Ca²⁺ depleted waters. The nodes on the calcitic valves are more numerous and pronounced at low salinity and can be used as a proxy for palaeosalinity (Fürstenberg et al. 2015).

*Leucocytherella dangeloi* Alivernini sp. nov.

Figure 4a–g

Etymology. The name “dangeloi” was given to commemorate the death of Fabio D’Angelo, a young micropalaeontologist at the beginning of his academic career who died in 2012.

Holotype. A male right valve (0.70 mm). Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences. Collection number: 171681.
Table 2  Counted valves of ostracod species in sediment samples from the Zhada Basin (samples without ostracod valves not included)

| ZHADA BASIN | Ilyocypris spp. | Leucocytherella sinensis | Leucocythere dorsotuberosa | Leucocythere postilirata | Paraeucypris sp. | ?Prionocypris sp. | Leucocytherella dangeloi sp. nov. | Eucypris cf. zandaensis |
|-------------|-----------------|--------------------------|---------------------------|--------------------------|-----------------|------------------|--------------------------------|------------------------|
| Z01         | 6               | 4                        | 0                         | 1                        | 0               | 0                | 0                              | 0                      |
| Z02         | 32              | 68                       | 1                         | 4                        | 0               | 0                | 0                              | 0                      |
| Z03         | 16              | 43                       | 15                        | 4                        | 0               | 0                | 0                              | 0                      |
| Z04         | 48              | 6                        | 16                        | 18                       | 0               | 0                | 0                              | 0                      |
| Z05         | 10              | 0                        | 0                         | 4                        | 0               | 0                | 0                              | 0                      |
| Z06         | 2               | 0                        | 2                         | 0                        | 0               | 0                | 0                              | 0                      |
| Z07         | 4               | 2                        | 1                         | 8                        | 0               | 0                | 0                              | 0                      |
| Z08         | 27              | 0                        | 0                         | 12                       | 0               | 0                | 0                              | 0                      |
| Z09         | 14              | 0                        | 2                         | 2                        | 0               | 0                | 2                              | 0                      |
| Z010        | 36              | 33                       | 5                         | 1                        | 0               | 0                | 0                              | 0                      |
| Z010d       | 40              | 0                        | 3                         | 0                        | 0               | 0                | 8                              | 0                      |
| Z011        | 25              | 7                        | 3                         | 14                       | 0               | 0                | 0                              | 1                      |
| Z012        | 13              | 1                        | 0                         | 5                        | 1               | 0                | 0                              | 0                      |
| Z013        | 20              | 0                        | 8                         | 12                       | 0               | 0                | 0                              | 0                      |
| Z014        | 11              | 0                        | 3                         | 4                        | 0               | 0                | 0                              | 0                      |
| Z015        | 37              | 0                        | 0                         | 5                        | 0               | 0                | 0                              | 0                      |
| Z016        | 7               | 10                       | 26                        | 4                        | 0               | 0                | 0                              | 0                      |
| Z017        | 12              | 1                        | 9                         | 3                        | 0               | 0                | 0                              | 0                      |
| Z018        | 2               | 57                       | 44                        | 1                        | 1               | 0                | 12                             | 0                      |
| Z018a       | 37              | 29                       | 18                        | 11                       | 2               | 0                | 0                              | 0                      |
| Z019        | 3               | 12                       | 16                        | 43                       | 3               | 0                | 0                              | 0                      |
| Z020        | 5               | 8                        | 45                        | 11                       | 0               | 0                | 1                              | 0                      |
| Z021        | 4               | 0                        | 4                         | 0                        | 12              | 0                | 0                              | 0                      |
| Z022        | 0               | 3                        | 26                        | 1                        | 0               | 0                | 0                              | 0                      |
| Z023        | 0               | 0                        | 10                        | 0                        | 0               | 0                | 0                              | 0                      |
| Z024        | 0               | 33                       | 64                        | 6                        | 0               | 0                | 0                              | 0                      |
| Z025        | 1               | 1                        | 0                         | 0                        | 1               | 0                | 3                              | 0                      |
| Z026        | 0               | 0                        | 0                         | 3                        | 0               | 0                | 0                              | 0                      |
| Z027        | 0               | 8                        | 8                         | 0                        | 0               | 0                | 4                              | 0                      |
| Z027a       | 0               | 35                       | 49                        | 5                        | 1               | 0                | 0                              | 0                      |
| Z028d       | 1               | 33                       | 24                        | 0                        | 5               | 0                | 34                             | 0                      |
| Z029        | 1               | 3                        | 11                        | 0                        | 5               | 0                | 0                              | 0                      |
| Z036        | 22              | 8                        | 2                         | 2                        | 2               | 0                | 0                              | 0                      |
| Z037        | 10              | 18                       | 37                        | 8                        | 0               | 0                | 0                              | 0                      |
| Z039        | 27              | 19                       | 46                        | 2                        | 0               | 0                | 7                              | 0                      |
| Z042        | 0               | 0                        | 6                         | 0                        | 0               | 0                | 0                              | 0                      |
| Z043        | 0               | 5                        | 10                        | 5                        | 7               | 0                | 10                             | 0                      |
| Z044        | 0               | 7                        | 7                         | 12                       | 15              | 0                | 13                             | 0                      |
| Z045        | 5               | 11                       | 2                         | 1                        | 86              | 0                | 0                              | 0                      |
| Z046        | 7               | 10                       | 5                         | 7                        | 64              | 0                | 46                             | 0                      |
| Z047        | 0               | 15                       | 3                         | 0                        | 0               | 0                | 9                              | 0                      |
| Z048        | 3               | 6                        | 0                         | 1                        | 29              | 0                | 0                              | 0                      |
| Z049        | 3               | 27                       | 0                         | 2                        | 70              | 0                | 0                              | 0                      |
| Z050        | 1               | 42                       | 1                         | 3                        | 46              | 0                | 5                              | 0                      |
| Z052        | 10              | 3                        | 0                         | 2                        | 68              | 0                | 6                              | 0                      |
| Z053        | 1               | 93                       | 6                         | 2                        | 52              | 1                | 1                              | 2                      |
| Z054        | 1               | 44                       | 9                         | 4                        | 15              | 0                | 22                             | 1                      |
| Z055        | 6               | 23                       | 7                         | 1                        | 25              | 0                | 30                             | 0                      |
| ZHADA BASIN | Ilyocypris spp. | Leucocythere | Leucocythere | Paraecycypris sp. | Leucocytherella | Dangeloi sp. nov. | Eucypris cf. zandaensis |
|-------------|-----------------|--------------|--------------|------------------|----------------|-----------------|------------------------|
| Z055d       | 1               | 0            | 0            | 0                | 0              | 0               | 0                      |
| Z057        | 0               | 4            | 4            | 0                | 0              | 0               | 0                      |
| Z058        | 22              | 1            | 0            | 1                | 0              | 0               | 0                      |
| Z059        | 3               | 4            | 0            | 3                | 0              | 1               | 0                      |
| Z060        | 0               | 78           | 9            | 0                | 0              | 0               | 0                      |
| Z061        | 0               | 5            | 1            | 0                | 0              | 0               | 0                      |
| Z062        | 7               | 7            | 1            | 0                | 2              | 27              | 0                      |
| Z063        | 71              | 7            | 1            | 3                | 8              | 0               | 1                      |
| Z064        | 11              | 50           | 0            | 0                | 16             | 2               | 9                      |
| Z065        | 6               | 53           | 4            | 1                | 1              | 0               | 12                     |
| Z067        | 0               | 108          | 0            | 0                | 0              | 0               | 18                     |
| Z068        | 0               | 172          | 0            | 0                | 0              | 0               | 25                     |
| Z069        | 6               | 116          | 0            | 0                | 0              | 0               | 18                     |
| Z070        | 2               | 35           | 0            | 1                | 0              | 0               | 45                     |
| Z071        | 2               | 53           | 1            | 0                | 0              | 0               | 35                     |
| Z072        | 0               | 61           | 0            | 0                | 0              | 0               | 21                     |
| Z073        | 0               | 81           | 0            | 0                | 0              | 0               | 18                     |
| Z074        | 0               | 64           | 6            | 0                | 0              | 0               | 28                     |
| Z077        | 6               | 0            | 6            | 11               | 0              | 0               | 4                      |
| Z078        | 0               | 1            | 0            | 0                | 0              | 0               | 0                      |
| Z079        | 0               | 0            | 4            | 1                | 0              | 0               | 0                      |
| Z080        | 0               | 8            | 5            | 1                | 0              | 0               | 0                      |
| Z081        | 0               | 12           | 0            | 0                | 0              | 0               | 0                      |
| Z082        | 0               | 6            | 0            | 0                | 0              | 0               | 0                      |
| Z083        | 0               | 2            | 4            | 0                | 0              | 0               | 0                      |
| Z084        | 0               | 9            | 30           | 0                | 0              | 0               | 0                      |
| Z085        | 0               | 5            | 16           | 3                | 0              | 0               | 0                      |
| Z086        | 0               | 0            | 12           | 4                | 0              | 0               | 0                      |
| Z089        | 0               | 17           | 9            | 0                | 0              | 0               | 0                      |
| Z090        | 0               | 82           | 61           | 0                | 0              | 0               | 0                      |
| Z091        | 2               | 4            | 23           | 30               | 0              | 0               | 0                      |
| Z092        | 29              | 144          | 62           | 19               | 0              | 0               | 0                      |
| Z093        | 16              | 25           | 26           | 9                | 0              | 0               | 0                      |
| Z094        | 0               | 0            | 22           | 0                | 0              | 0               | 0                      |
| Z095        | 0               | 53           | 20           | 5                | 14             | 0               | 0                      |
| Z096        | 0               | 64           | 9            | 4                | 20             | 0               | 1                      |
| Z097        | 0               | 62           | 1            | 18               | 14             | 0               | 1                      |
| Z098        | 0               | 121          | 4            | 4                | 0              | 0               | 0                      |
| Z099        | 0               | 98           | 1            | 6                | 0              | 0               | 0                      |
| Z0100       | 0               | 120          | 10           | 2                | 4              | 0               | 0                      |
| Z0101       | 0               | 63           | 12           | 0                | 0              | 0               | 1                      |
| Z0102       | 0               | 51           | 26           | 0                | 0              | 0               | 6                      |
| Z0103       | 0               | 119          | 12           | 4                | 0              | 0               | 6                      |
| Z0104       | 0               | 103          | 10           | 33               | 0              | 0               | 0                      |
| Z0105       | 0               | 11           | 1            | 1                | 0              | 0               | 0                      |
| Z0106       | 0               | 1            | 9            | 0                | 0              | 0               | 0                      |
| Z0107       | 0               | 21           | 12           | 1                | 0              | 0               | 0                      |
| Z0108       | 0               | 67           | 12           | 6                | 3              | 0               | 0                      |
Studied material. 506 valves (adults and juveniles, females and males, including specimens with complete carapaces).

Size. 0.58–0.72 mm (males); 0.58–0.70 mm (females).

Diagnosis. Typical Leucocytherella species but with smooth surface and posterior part relatively higher compared to anterior part than in L. sinensis, more evident in the left valve. Lophodont hinge.

Locality and age. Zhada Basin, sample Z068 (ca. 4 million years).

Description and comparison. Carapace nearly rectangular. The posterior part of valves of L. dangeloi sp. nov., as well as of L. sinensis, is more rounded and higher than the anterior one, but this difference is more pronounced in L. dangeloi sp. nov. with an even higher rounding (Fig. 5; Table 3). Valves smooth and less pitted than those of L. sinensis. Weak dorsomedial sulcus at half-length of carapace. Protuberance in the anterodorsal part of the carapace. Protuberance in the anterodorsal part of the carapace. Protuberance in the anterodorsal part of the carapace.

ZHADA BASIN | Ilyocypris spp. | Leuco- | Leucocythere dorsotuberosa | Leucocythere postilirata | Paraecyc- | ?Prionocy- | Leucocytherella dangeloi sp. nov. | Eucypris cf. zandaensis
---|---|---|---|---|---|---|---|---
Z0109 | 0 | 32 | 4 | 18 | 62 | 0 | 0 | 0
Z0110 | 0 | 11 | 12 | 4 | 24 | 0 | 10 | 1
Z0111 | 0 | 82 | 3 | 23 | 21 | 0 | 9 | 2
Z0112 | 0 | 109 | 14 | 13 | 4 | 0 | 0 | 0
Z0113 | 0 | 63 | 8 | 1 | 4 | 0 | 0 | 0
Z0115 | 0 | 2 | 0 | 0 | 1 | 0 | 1 | 0
Z0117 | 0 | 0 | 0 | 0 | 75 | 0 | 0 | 0
Z0118 | 3 | 4 | 0 | 0 | 6 | 0 | 0 | 0
Z0119 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0
Z0121 | 0 | 0 | 1 | 0 | 4 | 0 | 0 | 0
Z0122 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0
Total | 676 | 3202 | 1061 | 457 | 802 | 5 | 506 | 13

ZooBank LSID. The nomenclatural act established herein is registered under urn:lsid:zoobank.org:act:463C6374–8ACB–4AD0–B365–6092BA87EADC.

Stratigraphic distribution. Miocene (Messinian) and Pliocene.

Genus Leucocythere Kaufmann, 1892

L. dangeloi sp. nov., as well as of L. sinensis, is more rounded and higher than the anterior one, but this difference is more pronounced in L. dangeloi sp. nov. with an even higher rounding (Fig. 5; Table 3). Valves smooth and less pitted than those of L. sinensis. Weak dorsomedial sulcus at half-length of carapace. Protuberance in the anterodorsal part of the carapace. Protuberance in the anterodorsal part of the carapace. Protuberance in the anterodorsal part of the carapace.

Table 2 (continued)

| ZHADA BASIN | Ilyocypris spp. | Leuco-cytherella sinensis | Leucocythere dorsotuberosa | Leucocythere postilirata | Paraecyc- | ?Prionocy- | Leucocytherella dangeloi sp. nov. | Eucypris cf. zandaensis |
|---|---|---|---|---|---|---|---|---|
| Z0109 | 0 | 32 | 4 | 18 | 62 | 0 | 0 | 0 |
| Z0110 | 0 | 11 | 12 | 4 | 24 | 0 | 10 | 1 |
| Z0111 | 0 | 82 | 3 | 23 | 21 | 0 | 9 | 2 |
| Z0112 | 0 | 109 | 14 | 13 | 4 | 0 | 0 | 0 |
| Z0113 | 0 | 63 | 8 | 1 | 4 | 0 | 0 | 0 |
| Z0115 | 0 | 2 | 0 | 0 | 1 | 0 | 1 | 0 |
| Z0117 | 0 | 0 | 0 | 0 | 75 | 0 | 0 | 0 |
| Z0118 | 3 | 4 | 0 | 0 | 6 | 0 | 0 | 0 |
| Z0119 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| Z0121 | 0 | 0 | 1 | 0 | 4 | 0 | 0 | 0 |
| Z0122 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Total | 676 | 3202 | 1061 | 457 | 802 | 5 | 506 | 13 |

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Fig. 3 Leucocytherella sinensis a left valve external view, sample Z063; b right valve internal view, sample Z063. ?Leucocythere postilirata c LV ext., sample Z0104; d RV int., sample Z037; e RV int., sample Z037. ?Leucocythere dorsotuberosa f RV ext., sample Z0110; g RV ext., sample Z0112; h RV int. juv., sample Z0112
Fig. 4  Leucocytherella dangeloi Alivernini sp. nov.  a RV int., sample Z068;  b RV ext., sample Z069 (holotype);  c LV int., sample Z068;  d LV ext., sample Z069;  e LV ext. in transmitted light, sample Z068 (scale on the right square);  f central muscle scars;  g marginal pore canals
Fig. 5 Comparison between *L. sinensis* (a LV ext.; b RV ext.) from Fürstenberg et al. (2015; modified) and *L. dangeloi* Alivernini sp. nov. (c LV ext; d RV ext). In *L. dangeloi* the posterior part shows more pronounced rounding than in *L. sinensis* as well as valves more smooth and less pitted.

Table 3 Comparison of valve attributes for *L. sinensis* Huang. 1982 and *Leucocytherella dangeloi* Alivernini. sp. nov.

| Attributes                | *Leucocytherella sinensis* Huang. 1982 | *Leucocytherella dangeloi* Alivernini. sp. nov. |
|---------------------------|----------------------------------------|-----------------------------------------------|
| Carapace form             | Nearly rectangular                      | Nearly rectangular                            |
| Posterior part/anterior part | The beginning of the postero–ventral marginal rounding is significantly closer to the anterior margin than to the posterior one | The beginning of the postero–ventral marginal rounding is significantly closer to the posterior margin than to the anterior one. Posterior part higher rounded than in *L. sinensis* |
| Curvature carapace        | In adult males, posterior part supracurvate anterior part equicurvate (following Lüttig 1962) | Posterior and anterior parts infracurvate (following Lüttig 1962) |
| Ornamentation             | Reticulation patterns. pronounced nodes in the anterior part | No reticulation patterns are recognisable. un-noded or weakly noded valves |
| Range size (adult)        | Males: 0.6–0.85 mm                      | Males: 0.6–0.72 mm                            |
|                           | Females: 0.57–0.79 mm                   | Females: 0.68–0.70 mm                         |
| Stratigraphy              | From Miocene to recent (Huang 1985)     | Miocene (Messinian) and Pliocene               |

2018a  *Leucocythere? dorsotuberosa* Huang—Alivernini et al.: fig. 8e–g + 8i

2018b  *Leucocythere? dorsotuberosa* Huang—Alivernini et al.: fig. 3 [3rd from left]

**Studied material.** 1061 valves (females, males, juveniles, including specimens with complete carapaces).

**Size.** 0.65–0.77 mm (males); 0.65–0.74 (females).
Original description (Huang 1982: 335). Male valve rectangular, anterior end higher than posterior, dorsal margin nearly straight, ventral margin distinctly concave in the middle. Valves with reticulation. Two transverse sulci anterodorsally, and an alar protuberance extending posteroventrally to medioventrally, and a tubercle in posterodorsal position. Marginal pore-canals zone broad, comprising 10–11% of the length of carapace, marginal pore-canals slender, not numerous, several are furcated, anteriorly with 19 marginal pore-canals. Hinge of the left valve consists of sockets in numerous, several are furcated, anteriorly with 19 marginal pore-canals. Hinge of male, female and juvenile bulgy. Juvenile valve short, anterior broadly rounded, dorsal in between.

Valve of male is longer than that of female, posterior bulgy. Juvenile valve short, anterior broadly rounded, dorsal margin slightly rounded. Hinge of male, female and juvenile are similar. Valves are transparent. Carapaces sub-rectangular in lateral view.

Further description. Wrozyna et al. (2009) observed on recent valves that female carapaces are more triangular, the posterior to anteriormedian region bears protuberances interrupted by a mediadorsal sulcus partly divided by a central node. In dorsal view, anterior and posterior ends are pointed. Right valve overlaps left valve anteroventrally and posteriorly in a lobe-like protrusion (modified from Wrozyna et al. 2009).

Remarks. The found valves of ?L. dorsotuberosa have a lophodont hinge. Wrozyna et al. (2009) and Danielopol et al. (1989) doubted that ?L. dorsotuberosa belongs to the genus Leucocythere because of the different hinge, lophodont in ?L. dorsotuberosa instead of the typically anterior significantly smaller tooth than the posterior one and a crenulated hinge bar of the genus Leucocythere.

Stratigraphic, ecological and geographic distribution. Pliocene to recent (Huang 1982). Living ?L. dorsotuberosa occur mainly in brackish lakes (ptial and muddy substrate) and its marginal lagoon-like water bodies on the Tibetan Plateau. Living individuals have also been found in freshwater, but in low numbers only. Empty valves of ?L. dorsotuberosa were found in higher proportions at larger water depth of modern Tibetan lakes (Akita et al. 2016).

?Leucocythere postilirata Pang, 1985

1985 Leucocythere postilirata sp. nov.—Pang: 257; pl. 2: figs. 13–16
2009 ?Leucocythere dorsotuberosa f. postilirata Pang—Wrozyna et al.: 670–671; pl. 2: figs. 1, 3, 10, 12–13
2010 ?Leucocythere dorsotuberosa f. postilirata Pang—Wrozyna et al.: fig. 3/4
2016 ?Leucocythere dorsotuberosa f. postilirata Pang—Akita et al.: fig. 2
2018 ?Leucocythere dorsotuberosa f. postilirata, Pang—Alivernini et al.: fig. 8/e–f

Studied material. 457 valves (adults and juveniles, females and males, including specimens with complete carapaces).

Size. 0.78–0.92 mm (males); 0.75–0.88 (females).

Original description (Pang 1985: 257). Elongated carapace. Valve of male of elongated kidney shape. Anterior slightly higher and/or has the same height as posterior. Both ends curved. Dorsal margin is elongated and almost straight, mediadorsal slightly curved. The anteromediadorsal area is compressed. Two transverse sulci anterdorsally, the more anterior sulcus shorter than the more posterior one. A rounded node is located between the sulci, another more pronounced bulge behind the posterior sulcus and a third at the end of both sulci. A distinctive anterodoradorsal carina occurs where the dorsal margin meets the anterior one, another carina runs along the central ventral side below the sulci. A third carina lays posteriorly and protrudes the valve outline. The ventral and posterior carinae are not connected to each other. The maximum width lies at ¼ length of the valve. Valve not curved so much, ornamented with a net of large alveoli. Valves of female shorter than male, kidney shaped. Anterior higher than posterior. Posterior carina and ventral carina weak (modified from Wrozyna et al. 2009).

Further description. As already observed by Wrozyna et al. (2009), the valves present a typical sharp carina running parallel to the ventral margin, more distinct on the right valve. Another more or less developed carina runs parallel to the anteroventral margin. Additionally, a marginal parallel posterior carina following the curvature of the margin can be more or less developed, separated from or fused with the ventral carina. The valves are strongly reticulated.

Remarks. Wrozyna et al. (2009) and Frenzel et al. (2010) regard ?L. postilirata as morphotype of ?L. dorsotuberosa with most pronounced medio-ventral and anterior and often posterior carinae as protruding foldings of the valve. On the basis of the remarkable differences in morphology of both forms, they are discriminated as two species in this paper, as it was done in the original description.

Stratigraphic, ecological and geographic distribution. Living specimens reported from Nam Co and Pumoyong Co;
Early Holocene of Peiku Co (Peng 1997), Pleistocene of Kunlun Mountains (Pang 1985), Late Pleistocene of Bangong Lake (Li et al. 1991), Cenozoic of Siling and Bangkok lakes (Pang 1985), Cenozoic of the Qaidam Basin (Sun 1988). Living ?L. postilirata occur where ?L. dorsotuberosa is present. According to Wrozyna et al. (2009), ?L. postilirata shows a higher salinity tolerance (max. 8–10 psu) than ?L. dorsotuberosa in Nam Co, and occurs below the thermocline (20–30 m). Relative abundances increase with water depth.

Suborder Cypridocopina Jones, 1901
Superfamily Cypridoidea Baird, 1845
Family Ilyocyprididae Kaufmann, 1900

Genus Ilyocypris Brady and Norman, 1889

Ilyocypris spp.

Figure 6a–h

Studied material. 676 valves (adults and juveniles, including specimens with complete carapaces).

Remarks. The species of the genus Ilyocypris are often hard to discriminate relying on hard parts only, even in well-studied regions as Central Europe (Meisch 2000). Hou et al. (2002) list eleven Ilyocypris species for the Tibetan Plateau but many of them are of dubious taxonomic state. The partly poor preservation of our material and impossible attribution of most juvenile valves to adult stages makes it difficult to discriminate and identify Ilyocypris species from the Zhada Basin.

All documented valves bear the typical characters of the genus—a rectangular carapace in lateral view, about 1 mm long, with pitted to smooth surface and two conspicuous transverse dorsolateral sulci; the left valve overlaps the right one.

Based on outline and ornamentation, three morphotypes, probably different species, are recognisable: (a) well-rounded anterior and posterior end in lateral view, surface weakly or not pitted, no tubercles; (b) well-rounded anterior and posterior end in lateral view, surface weakly pitted, five distinct tubercles similar to Qinghaicypris subpentanoda Yang, 1982; (c) lateral view with truncated posterior end similar to Ilyocypris inermis Kaufmann, 1900, surface pitted, no tubercles. Left valves of the two well-rounded morphotypes a and b show distinct marginal ripples on the inner lamella of both ends. This character resembles Ilyocypris bradyi Sars, 1890 and Ilyocypris decipiens Masi, 1905 (Mazzini et al. 2014) but the ripples are more numerous and can be found at the anterior end as well.

Family Cyprididae Baird, 1845

Subfamily Eucypridinae Baird, 1845

Genus Eucypris Vávra, 1891

Eucypris cf. zandaensis Yang, 1982

Figure 7a, b

1982 Eucypris zandaensis Yang sp. nov.—Yang in Huang et al.: 330; pl. 2: figs. 1–9
2002 Eucypris zandaensis Yang, 1982—Hou et al.: 169; pl. 19: figs. 5–10

Studied material. 13 valves (adults and juveniles).

Size. 0.78–1.1 mm.

Original description. (Hou et al. 2002) Valves big, female elliptical in lateral view, dorsal margin straight and short inclining to the posterior part in lateral view, ventrally slightly concave, highest point at 2/5 of length, network of lines on the valve, marginal pore channels thick and numerous, central muscle scars with four in front of two others, oviduct traces, male valve longer, traces of four loops of testes recognisable.

Remarks. Our material differs from the male adult description in having a slightly more trapezoidal outline of the right valve and being slightly smaller. Unfortunately, only three adult valves were available.

Distribution. Plio–Pleistocene of Zanda, Zhada Basin (Hou et al. 2002).

Genus Prionocypris Brady and Norman, 1896

?Prionocypris sp.

Figure 7g, h

Studied material. 5 valves (only juveniles).

Size. 0.78–1.00 mm.

Description. Valves rounded triangular with highest point at about a third of length, anterior margin broadly rounded, posterior end more pointed, dorsal margin only very weakly curved over the hinge, ventral side slightly concave. Surface of valves smooth. No lists recognisable on inner lamella of the juvenile valves. Central muscle scars paw-like, marginal pore channels straight and numerous.
Fig. 6 *Ilyocypris* spp. (a–c morphotype) a LV ext., sample Z010; b RV ext., sample Z010; c LV ext., sample Z010; (d, e morphotype c) d RV ext., sample Z010; e RV ext., sample Z010; (F juven.; morph. a?)

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Fig. 7 *Eucypris* cf. *zandaensis* a RV ext., sample Z095; b RV int., sample Z096. *Paraeucypris* sp. c LV ext., sample Z053; d RV int., sample Z053; e LV int., sample Z053; f RV ext., sample Z053; g *Prionocypris* sp. h LV int., sample Z018; i LV ext., sample Z018
Remarks. No adult valves were available for description. Adult valves are needed for a comprehensive description of this species.

Genus *Paraecypris* Schneider in Mandelstam et al., 1957

*Paraecypris* sp.

Figure 7c–f

Studied material. 802 (adults and juvenile).

Size. 0.86–1.5 mm.

Description. Valves elongated elliptical in lateral view, both ends well rounded, highest point well in front of mid-length, posterior part of right valves more slender than anterior one, dorsal margin along the hinge straight and distinctively inclined towards posterior, ventral margin slightly concave. Surface of valves smooth or fine pitted. Hinge with a simple groove in the left valve and a smooth bar in the right valve. Central muscle scars of the typical cypridid paw-like pattern.

Discussion and conclusion

Our list of ostracod taxa from the Zhada Basin contains at least eight species, several of them are already described for the Tibetan Plateau. Among them, the opportunistic and ubiquitous *L. sinensis* is the most abundant species. *Leucoocytherella sinensis* is often observed together with the deeper lacustrine species ?*L. dorosotuberosa* and ?*L. postilirata* as it is known for recent faunas (Wrozyna et al. 2009; Akita et al. 2016). Kempf et al. (2009) list only five species from the Zhada Basin. One of them, *Candona xizangensis* Huang, 1982, was not found in our study. Adding *C. xizangensis* to our list results in a minimum of nine species, representing a low diversity for the studied area and time. Akita et al. (2016) found eleven species in the recent Tangra Yumco lake system, a number comparable to our count from the Zhada Basin. Considering that other investigated Cenozoic to modern lake basins of the Tibetan Plateau (Wrozyna et al. 2010; Mischke 2012; Alivernini et al. 2018a) with different salinities and depths have a similar low-diversity fauna, we assume the high altitude and the relative isolation of the Tibetan Plateau as the cause for the low diversity observed in the Zhada Basin.

The newly described species *L. dangeloi* sp. nov. is very interesting for the evolution of the genus *Leucoocytherella* Huang, 1982, endemic to the Tibetan Plateau. All specimens of the genus described so far and studied by Fürstenberg et al. (2015) belong to *L. sinensis* Huang, 1982. The accompanying taxa of the species *L. dangeloi* sp. nov. from the Zhada Basin are, similar to the recent ostracod fauna of the Tibetan Plateau, mainly lacustrine species. Thus, the association of *L. dangeloi* sp. nov. with the lacustrine species points to a lacustrine habitat of the new species as well.

The species assemblage changes recorded in the sampled lake beds of the “South Zhada” section (Table 2) probably reflect changes in the depositional setting including more shallow and deltaic conditions or also deeper environments. However, combined sedimentological and geochemical analyses together with quantitative palaeoecological analysis of ostracod species assemblage data from the sediments of the Zhada Basin based on the presented taxonomical research are required to better understand the Miocene to Pleistocene environmental and climatic history of the western Tibetan Plateau.

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