OSTRACODS FROM THE END-PERMIAN MASS EXTINCTION IN THE ARAS VALLEY SECTION (NORTH-WEST IRAN)

by JANA GLIWA1, MARIE-BÉATRICE FOREL2, SYLVIE CRASQUIN2, ABBAS GHADERI3 and DIETER KORN1

1Museum für Naturkunde, Leibniz Institute for Evolution & Biodiversity Science, Invalidenstraße 43, 10115, Berlin, Germany; jana.gliwa@mfn.berlin
2CR2P, MNHN-SU-CNRS, 8 rue Buffon, 75005, Paris, France
3Department of Geology, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran

Typescript received 13 December 2019; accepted in revised form 19 May 2020

Abstract: The Aras Valley section (north-west Iran) exposes a sedimentary succession that allows the study of ostracod diversity patterns during/across the end-Permian mass extinction. For the present study, 59 samples were investigated for their ostracod abundances, which ranged from 4 to 31500 specimens per 500 g. In 45 sample horizons, the ostracods were identified to the species level. In total, 3425 specimens were determined and 62 species were identified, of which one genus and ten species are described for the first time: Fabalicypris veronicae Gliwa, sp. nov., Orthobairdia capuliformis Gliwa, sp. nov., Araxobairdia formosa Gliwa, gen. et sp. nov., Bairdiacypris kathleenae Gliwa, sp. nov., Eumiraculum mettei Gliwa, sp. nov., Liuzhinia julfensis Gliwa, sp. nov., Carinaknightina hofmanni Gliwa, sp. nov., Cavellina fosteri Gliwa, sp. nov., Cavellina hairapetiani Gliwa, sp. nov. and Hungaroleberis striatus Forel, sp. nov.

The assemblages show, at the end-Permian mass extinction event, a complete turnover from a low-diversity Fabalicypris-dominated pre-extinction community to a more diverse Bairdiacypris-dominated post-extinction community. The turnover coincides with the significant temperature increase that was previously recorded from north-west Iranian sections. The low diversity in the horizon immediately below the extinction horizon indicates that environmental changes, such as thermal stress, may have had an impact on the ostracod assemblages prior to the extinction event. In comparison with other diverse ostracod assemblages from the Palaeotethyan realm, the ostracods of the Aras Valley section are not associated with microbialites.

Key words: Ostracods, Iran, end-Permian, extinction, diversity, thermal stress.

The environmental conditions during the end-Permian mass extinction event (EPME), and the environmental parameters that could have triggered the most severe biodiversity crisis in the Phanerozoic, are still a matter of debate. A valuable fossil group in the study of the nature of the extinction event is the Ostracoda, which has been studied in various sections around the world. Diversity patterns of ostracods in successions including the EPME are important for our understanding of the changing palaeoenvironmental conditions during this event, given that they may indicate fluctuations in salinity and oxygen content of the seawater. The most common scenarios for explaining the extinction include the combination of several effects (on temperature, oxygen content, seawater pH), all induced by the eruption of the Siberian Traps (Erwin 1994; Kidder & Worsley 2004; Svensen et al. 2009; Burgess & Bowring 2015; Bond & Grasby 2017). In the marine realm, the effects of the volcanism are summarized as the ‘deadly trio’ (Bijma et al. 2013): (1) the recurring expansion of oceanic anoxic zones (Wignall & Twitchett 1996; Isozaki 1997; Brennecka et al. 2011; Song et al. 2012; Grasby et al. 2013; Clarkson et al. 2016; Lau et al. 2016; Zhang et al. 2018); (2) high-magnitude global warming (Joachimski et al. 2012; Sun et al. 2012; Schobben et al. 2014; Song et al. 2014); and (3) acidification of the ocean water (Payne et al. 2007; Hinojosa et al. 2012).

The study of Recent and fossil ostracods and their habitats has contributed significantly to ecological studies of historical and geological time scales. The taxonomic distribution of ostracods provides insights into the ecological state and the stability of an environment (Boomer et al. 2003; Yasuhara et al. 2003; Crasquin et al. 2010; Forel et al. 2013). Furthermore, occurrences of certain taxa can serve as a proxy for environmental parameters, such as trophic conditions or salinity (Forel et al. 2011;
For this reason, sedimentary successions covering the EPME in the Palaeotethys have already been studied intensively for their ostracod content (Wang 1978; Chen & Shi 1982; Shi & Chen 1987, 2002; Hao 1996; Crasquin-Soleau et al. 2004a, b, 2006a, b; Crasquin-Soleau & Kershaw 2005; Crasquin et al. 2008, 2010; Mette 2008, 2010; Liu et al. 2010; Forel & Crasquin 2011; Forel 2012, 2014; Forel et al. 2013, 2015; Wan et al. 2019). Griesbachian ostracods were found almost exclusively associated with microbialites (Forel et al. 2009, 2013, 2015; Forel 2012, 2014), which led to the hypothesis that a microbial refuge allowed the ostracods to survive the possibly adverse environmental conditions, such as anoxic or dysoxic phases (Forel et al. 2013). In the absence of microbialites, adverse conditions in the aftermath of the EPME generally led to low abundances and low diversity of ostracod assemblages (Crasquin & Forel 2014), and hence taxonomy and diversity patterns of this time interval are difficult to study at the species level. The preservation of the material is often poor and hampers identification at the species level. With the investigation of the Aras Valley section (north-west Iran), we are able to record ostracod occurrences before, during and after the extinction in a complete succession without sedimentary gaps (Ghaderi et al. 2014a; Leda et al. 2014; Gliwa et al. 2020a). The rock interval immediately above the extinction horizon is a shale succession with very high and relatively diverse ostracod content. Furthermore, the ostracod succession can be correlated with the evolutionary history of other fossil groups such as conodonts (Ghaderi 2014; Ghaderi et al. 2014a), ammonoids (Ghaderi et al. 2014a; Korn et al. 2016; Kiesling et al. 2018; Gliwa et al. 2020a) and brachiopods (Ghaderi et al. 2014b). In this study we describe, for the first time, the taxonomic characteristics of ostracods at the EPME interval in the Aras Valley section; this will allow the investigation of palaeoenvironmental changes that can be linked to the extinction event.

GEOLOGICAL SETTING

The Aras Valley section (39.015°N, 45.434°E), which was described in detail by Gliwa et al. (2020a), is located c. 19 km north-west of the towns of Julfa (or Jolfa, East Azerbaijan Province, Iran) and Dzhulfa (or Culfa, Nakhichevan province, Azerbaijan). The outcrop has a position 2 km to the north-west of the Dorasham 1 section of Ruzhencev et al. (1965) (Fig. 1).

During the Lopingian, north-west Iran was positioned at the north-western margin of the Sanandaj–Sirjan Terrane of the Cimmerian microcontinent, located between Neotethys and Palaeotethys. The investigated section was located at a latitude close to the equator (Fig. 1; e.g. Stampfl & Borel 2002; Muttoni et al. 2009). At the EPME, the Sanandaj–Sirjan Terrane with the north-west Iranian sections was largely covered by a shallow to moderately deep sea. The north-west Iranian sediments are mostly composed of open sea deposits from an outer shelf setting (Kozur 2007; Leda et al. 2014; Gliwa et al. 2020a).

The sedimentary succession of the Aras Valley section, which belongs to a north-inclined monocline, is mainly composed of Wuchiapingian–Griesbachian sedimentary rocks, exposed across a lateral extension of 200 m. The exposed succession has a total thickness of 37 m including the extinction horizon and the Permian–Triassic boundary (PTB; Fig. 2). A comprehensive biostratigraphic investigation of the section, including detailed documentation of ammonoid and conodont occurrences, was carried out by Ghaderi et al. 2014a and Gliwa et al. 2020a. The position of the extinction horizon (set as 0.00 m) is, as in other Iranian PTB sections, defined at the top of the Paratirolites Limestone at the transition to the argillaceous Aras Member (‘Boundary Clay’), which corresponds to the transition from the Clarkina hauschkei zone to the Hindeodus praeparvus–H. changxingensis zone (Fig 2; Kozur 2005, 2007; Ghaderi et al. 2014a; Leda et al. 2014; Gliwa et al. 2020a). Detailed facies investigation of the Aras Valley section (Gliwa et al. 2020a) and of the neighbouring Ali Bashi section (Leda et al. 2014), furthermore, indicates a sudden decrease of skeletal carbonate producers as well as the complete disappearance of cephalopods and other macrofossils above the Paratirolites Limestone, which confirms the position of the extinction horizon. In contrast to the other north-west Iranian sections, the shale-dominated post-extinction horizon (Aras Member) has a relatively larger thickness of 2.50 m, which enables detailed investigation of the extinction interval. The PTB, marked by the first occurrence of the conodont species Hindeodus parvus, is located at the base of the Claraia Beds at +2.55 m (Fig. 2; Ghaderi et al. 2014a).

Several north-west Iranian PTB sections (Ali Bashi, Zal) have been investigated in detail for their conodont biostratigraphy (Kozur 2005, 2007; Shen & Mei 2010; Ghaderi et al. 2014a). These studies demonstrated that the succession of conodont zones does not lack any of the zones recognized in other regions such as South China. As shown by Gliwa et al. (2020a), the Aras Valley section very closely resembles the Ali Bashi and Zal sections, both in lithology and stratigraphic succession of conodont zones, reflecting the completeness of the stratigraphic succession. Furthermore, the δ13C_carb curve of the Aras Valley section parallels that of other sections and does not show any evidence for a stratigraphic gap (Gliwa et al. 2020a).

In the present study, we focus on the interval from −3.80 m to +7.00 m with respect to the extinction
horizon. This includes the pre-extinction interval of the Ali Bashi Formation (Changhsingian) and the post-extinction interval of the Elikah Formation (latest Changhsingian – Griesbachian). The lithostratigraphic scheme for the Transcaucasus region was developed by Stepanov et al. (1969) and Ghaderi et al. (2014b) and is described in detail for the Aras Valley section in Gliwa et al. (2020a). The interval studied here for ostracods has a thickness of 10.80 m and includes the following three lithological units.

1. Paratirolites Limestone (late Changhsingian): together with the underlying Zal Member, this forms the Ali Bashi Formation. It is composed of red to purple nodular limestone and has a total thickness of 4.60 m. Its upper limit is marked by the abrupt change from carbonates to shales at the base of the overlying Aras Member. The top 4 cm of the member is marked by conspicuous bioturbation; a dense accumulation of keratose sponge remains occurs in the upper 2 cm (Gliwa et al. 2020a). The extinction event was interpreted to have taken place between the first occurrence of the keratose sponges and the initial deposition of the ‘Boundary Clay’ (Aras Member; Gliwa et al. 2020a).

2. Aras Member (‘Boundary Clay’; latest Changhsingian): it is the lowest member of the Elikah Formation and consists of 2.50 m-thick purple and light grey shales with a few marly intercalations. The deposition of this shale horizon is interpreted as the result of a drastic decrease of carbonate production (Richoz et al. 2010; Leda et al. 2014).

3. Claraia Beds (earliest Griesbachian): only the basal 4.50 m of the Claraia Beds was logged in the present study; the entire member reaches a total thickness of...
approximately 280 m in the Ali Bashi Mountains (Stepanov et al. 1969). The Claraia Beds are composed of mostly grey to beige platy limestone beds with shale intercalations.

**OSTRACOD STUDIES IN THE TRANSCAUCAUSIAN REGION**

In the present study, we investigated the ostracod succession of the Aras Valley section. The studied interval covers almost the entire Lopingian Paratirolites Limestone, the extinction horizon, the Aras Member and the lower part of the Induan Claraia Beds (Fig. 2). The Dorasham 2 section, which is very similar in the lithological succession (e.g. Zakharov 1992), is located c. 10 km towards the East on the northern side of the Araxes River in the Nakhichevan province of Azerbaijan (Fig. 1). This section was investigated for its ostracod content by Belousova (1965); she studied 500 specimens that were assigned to 26 species. The stratigraphic resolution in that study was, however, very coarse; Belousova (1965) separated only two units (‘Dzhulfian’ and ‘Induan’), of which the latter includes most of the Zal Member plus the Paratirolites Limestone. The ostracod assemblages of both units show the same diversity. Most of the identified species in that study belong to smooth forms of the family Bairdiidae.

A more detailed stratigraphic assignment was provided by Kotlyar et al. (1983). They separated the ‘Induan’ unit by Belousova (1965) into five subunits, of which the lower four belong in the Zal Member. The topmost of the five is the Paratirolites Limestone, which was regarded as one single unit. According to Kotlyar et al. (1983), the diversity decreases from c. 20 species to only four species. 
during the ‘Dorashamian’ (= Changhsingian) interval. Both Belousova (1965) and Kotlyar et al. (1983) described only the succession below the extinction horizon (as shown by Zakharov 1992), precluding any statement on the influence of the extinction event itself.

The Zal section, which is located c. 35 km south-east of the Aras Valley section and 24 km south of Julfa (Fig. 1), was studied by Mette (2008, 2010) with a focus on the ostracod assemblages on both sides of the extinction horizon. He described a complete faunal turnover at the extinction horizon and a post-extinction assemblage of the ‘Boundary Clay’, which is of low diversity and dominated by a single species of the genus Indivisia.

**MATERIAL AND METHOD**

For ostracod abundance data and taxonomy, we prepared a total of 59 samples, ranging from 0.4 to 1 kg. Samples from limestone and marly limestone beds (c. 0.4 kg each) were processed using hot acetylation following Crasquin-Soleau & Kershaw (2005). For the wet sieving process, we used two sieves with 1.5 mm and 0.063 mm mesh sizes to remove the coarse fractions from the residue. Very soft shale samples (1 kg each) from the Aras Member were processed only with water before the wet sieving process. Ostracod specimens of 45 of the 59 sample horizons were identified. The remaining 14 sample horizons yielded ostracods but were not analysed to the species level. In order to obtain a representative sample of the ostracod assemblages, only samples with more than 40 identified specimens were used for calculating the species richness.

An investigation of internal taxonomic features was not possible because of the preservation of the specimens with sparry calcite infill; hence we assumed that the largest specimens of a species represent the adult stage.

Most of the ostracods recovered from the studied samples have smooth external surfaces lacking informative elements such as ornamentation. As a consequence, our taxonomic investigation relies on traditional morphological measurements of the length and height of the carapaces and valves. Other morphological characters such as the position of maximum length and height have also been determined and compared for species delimitation. All taxonomic analysis and discussions performed have been quantified as much as possible with, for example, measurements of angles and relative length proportions of individual features such as dorsal or ventral border.

For the validation of the species identification and for illustration of different ontogenetic stages within a species, all specimens assigned to a new species and some selected examples of already described species were plotted in a length/height (L/H) diagram. The ontogenetic stages below the adult stage are abbreviated to ‘A’ with a running number in the direction of the smallest instars. The stratigraphic position of individual specimens and the range of species are given in metres from the base of the extinction horizon (top surface of the Paratiroilites Limestone).

**SYSTEMATIC PALAEONTOLOGY**

Only the ten newly introduced species are fully described in detail here. Remarks are given for some taxa, defined from other sections; all other species are figured. We use the systematic classification proposed by Moore (1961) and modified by Horne et al. (2002). All specimens are permanently stored in the micropalaeontology collection of the Museum für Naturkunde, Berlin, Germany. The material is stored in cardboard slides or glued on scanning electron microscopy pads. All type specimens are stored in cardboard slides and have a unique catalogue number with the prefix ECO. All other displayed specimens are stored under a sample identifier consisting of the sample name and a successive number (AV prefix referring to the Aras Valley section), followed by the sample depth in centimetres (‘n’ for negative values) and the preparation batch (if present).

**Abbreviations.** AB, anterior border; ADB, anterodorsal border; AVB, anteroventral border; DB, dorsal border; H, height; Hmax, maximum height; L, length; Lmax, maximum length; LV, left valve; PB, posterior border; PDB, posterodorsal border; PVB, posteroventral border; RV, right valve; VB, ventral border; W, width; Wmax, maximum width. The dimensions used in the species description refer to the specimen with the smallest and largest dimensions in each species.

- Class OSTRACODA Latreille, 1806
- Subclass PODOCOPA Müller, 1894
- Order PODOCOPIDA Sars, 1866
- Suborder BAIRDIOCOPINA Gründel, 1967
- Superfamily BAIRDIOIDEA Sars, 1887
- Family BAIRDIIDAE Sars, 1887

**Genus FABALICYPRIS Cooper, 1946**

*Type species.* Fabalicypris wileyensis Cooper, 1946, by original designation.

*Fabalicypris obunca* Belousova, 1965

**Figure 3A-C**

1965 *Fabalicypris obuncus* Belousova, p. 264, pl. 50, fig. 5a, b.

1965 *Fabalicypris hoxabarensis* (Harlton); Belousova, pl. 50, fig. 6a, b.

**Material.** 732 complete carapaces (L = 221–883 μm).
Remarks. The late Permian specimens identified as ‘Fabalicypris hoxabarenensis Harlton’ by Belousova (1965) from the neighbouring Dorasham section (Azerbaijan) were erroneously attributed to that species. The drawing of the holotype of Fabalicypris hoxabarenensis by Harlton (1927) shows a very pronounced pointed posterior end and large overlap at DB and VB, which is not the case in the illustrated specimen in Belousova (1965). Furthermore, the DB by Harlton (1927) is nearly straight in comparison to the uniformly convex DB displayed in Belousova (1965). Given that the carapace outline in lateral and dorsal view is very similar, we assign these specimens to F. obuca, which is described to have a strong intraspecific variability (Belousova 1965).

Fabalicypris obuca is very similar in its overall appearance to Fabalicypris parva Wang, 1978, which was found in various late Permian successions from the Palaeotethys (Wang 1978; Shi & Chen 1987; Crasquin-Soleau et al. 1999, 2004b; Mette 2008; Crasquin et al. 2010; Forel 2012; Forel et al. 2013, 2015). A synonymy of F. parva and F. obuca may be considered, but this is a topic beyond this study.

Occurrence. Dorasham, Azerbaijan, Wuchiapingian–Changhsingian (Belousova 1965); Aras Valley, Paratirolites Limestone (Changhsingian), from −3.80 to −0.01 m (Fig. 4).

Fabalicypris cf. minuta Cooper, 1946
Figures 3H–L, 5
cf. 1946 Fabalicypris minuta Cooper, p. 60, pl. 5, figs 31–32.

Material. 85 complete carapaces (L = 452–1214 μm).

Remarks. The L/H diagram of the specimens from our material enables a distinction of five ontogenetic stages (A–4 juvenile stage to adult stage, Fig. 5). The Aras Valley material is, with respect to the lateral and dorsal outlines of the carapaces, similar to the Pennsylvanian Fabalicypris minuta Cooper, 1946 from Illinois (Cooper 1946). The specimen described by Cooper (1946) is c. 200 μm shorter than our material of the adult stage; it would fit in the range of the A–1 instars of our material (Fig. 5). Our material shows strong intraspecific variation, noticeable in the carapace H/L ratio and the posterior and ventral overlapping areas. The preservation of our material does not allow an unequivocal attribution to F. minuta, given that the overlapping area in our specimens appears indistinct. Changhsingian specimens attributed to F. minuta were recorded at Meishan, South China (Shi & Chen 1987; Crasquin et al. 2010).

Occurrence. Aras Valley; Aras Member (Changhsingian), from +0.05 to +0.60 m (Fig. 4).

Fabalicypris veronicae Gliwa sp. nov.
Figures 3M–Q, 6
LSID. urn:lsid:zoobank.org:act:B0C4661D-6AB1-43E2-BBD0-F7063C6EEFB7

Derivation of name. Named after Veronica Piazza, honouring her encouragement during the progress of this work.

Type specimens. Holotype: complete carapace ECO104 (Fig. 3M, N), sample AV028. Paratype: complete carapace ECO105 (Fig. 3O, P), sample AV015.

Type locality and horizon. Aras Valley; Aras Member (Changhsingian), +0.28 m.

Material. 69 complete carapaces (L = 461–1285 μm; Fig. 6).

Diagnosis. Species of Fabalicypris with straight and horizontal DB at RV, elongate symmetrical carapace in lateral view and slender in dorsal view.

Description. Carapace elongate, subuniform in lateral view with Hmax located at mid-L; slender (W/L c. 0.30–0.33) in dorsal view with acuminate anterior end and largest width in the posterior third. Overlap of larger left valve all around the right valve; overlap thinner along AVB and more pronounced at ventral and posterior margin. Dorsal margin uniformly convexly rounded at LV; DB straight, horizontal and long (c. 50% of Lmax) at RV. Distinct angulations between DB and ADB as well as between DB and PDB (both c. 150°). ADB straight to slightly concave;
FIG. 4. Distribution of analysed samples in the lithological column of the Aras Valley section. Occurrences of ostracod specimens per species are displayed by their symbol width.

Abbreviation: EH, extinction horizon.
anterior and posterior maximum of convexity at lower third of $H_{max}$. Posterior end slightly more broadly rounded than anterior end. Surface smooth.

Remarks. The species is very similar to the early Permian Bairdiacypris ventralis Chen, 1958 from South China, particularly in the general outline of the carapace and the angulations of the dorsal margin. The specimens of Chen & Shi (1982) would plot, in the L/H diagram, in the range of the stages A-2, A-1 and adults of *F. veronicae* (Fig. 6). However, the present specimens are slenderer in dorsal view ($W/L = 0.30–0.33$, compared with $W/L c. 0.40$ in the illustrated specimens of Chen 1958). The ventral view of the new species indicates a clear offset of the ventral overlap in the anterior half of the carapace, which is typical for *Fabalicypris* (Fig. 3N, P). A ventral view was not illustrated for *Bairdiacypris ventralis* in Chen & Shi (1982); such a ventral structure is also neither mentioned in the original description nor clearly visible in the original illustrations of this species in Chen (1958).

Occurrence. Aras Valley; Aras Member (Changhsingian), from +0.05 to +0.28 m (Fig. 4).

Genus ORTHOBAIRDIA Sohn, 1960

Type species. *Bairdia cestriensis* Ulrich, 1891; subsequently designated by Sohn (1960).
**Orthobairdia capuliformis** Gliwa sp. nov.

**Figures 3Y–AF, 7**

*LSID.* urn:lsid:zoobank.org:act:911A476B-9A4C-4E59-8C83-C51EF1885374

**Derivation of name.** From Latin *capulus* = coffin; after outline shape of the carapace in dorsal view.

**Type specimens.** Holotype: complete carapace ECO106 (Fig. 3Y, Z), sample AVn023. Paratype: complete carapace ECO107 (Fig. 3AA), sample AVn062.

**Type locality and horizon.** Aras Valley; Paratirolites Limestone (Changhsingian), at −0.23 m.

**Material.** 188 complete carapaces (L = 281–870 μm; Fig. 7).

**Diagnosis.** A species of *Orthobairdia* with distinct dorsal angulations and large H/L ratio; slight concavity at the base of AVB; posterior end slightly tapered in lateral and dorsal view.

**Description.** Medium-sized specimens with sub-ovate outline in lateral view; fusiform with acuminate ends and almost parallel sides in dorsal view; H<sub>max</sub> at the angulation between DB and ADB and L<sub>max</sub> in the lower third of H; W<sub>max</sub> distributed around the middle third of the carapace; W/L c. 0.40 in adult carapaces. Left valve overlaps right valve all around the carapace except for the anterior and posterior ends, widest overlap along DB and at oral concavity. Dorsal margin of right valve distinctively separated in three parts by uniform angulations; angulations in dorsal margin of left valve appear more rounded. Straight to slightly concave DB bent towards the straight ADB with an angle of 135–140°. AB uniformly rounded with large radius of curvature, maximum around mid-H. Anterior end slightly tapered. Slight concavity in AVB; not present in A-4 instars (Fig. 7). Ventral margin of left valve uniformly convex with median oral concavity in the right valve. PVB slightly tapered with narrow lateral compression. PB narrowly rounded with maximum of convexity in the lower fourth of H. Posterior end bairdiid, slightly elongate, with concave PDB in adult specimens. Posterior end shorter, narrower with straight and steep PDB in juvenile specimens. PDB bent towards DB in an angle of 130–135°. Surface smooth.

**Remarks.** The juvenile specimens of *Orthobairdia capuliformis* have a stronger angulation in the right valve between DB and PDB than adult ones (Fig. 7). In juveniles (A-4 to A-1) the DB is bent towards the ADB at an angle of 123–135° while it ranges from 140 to 145° in adult specimens. Compared with adult specimens, some juvenile specimens have a very thin overlap of the LV also at the posterior end (Fig. 3AC). The H/L ratio decreases throughout ontogeny; the mean H/L ratio in stage A-4 juveniles is 0.67 and decreases in A-3 to A-1 instars, which show very similar mean H/L ratios between 0.62 and 0.63; the mean H/L in adults decreases further to 0.58. The juvenile specimens are very similar to the late Permian *Silenites sasakwaformis* Shi in Shi & Chen, 1987, which is known from South China and the Central Alborz Mountains in Iran (Shi & Chen 1987; Crasquin et al. 2010; Forel et al. 2015). However, the AB in *S. sasakwaformis* is more broadly rounded and the posterior end is less bairdiid, as it is in the adult specimens of the new species. The adult specimens resemble the Lopingian *Orthobairdia zaliensis* Mette, 2010 from north-west Iran and Azerbaijan by their similar outline in dorsal view. However, the dorsal margin of *O. zaliensis* is not distinctively angulated and its H/L ratio is lower than that of *O. capuliformis*. The new species resembles, in its
Genus **ARAXOBAIRDIA** Gliwa nov.

**LSID.** urn:lsid:zoobank.org:act:DD77A055-09DB-487B-AA70-93A505731F73

**Type species.** *Araxobairdia formosa* sp. nov.

**Derivation of name.** Referring to the type locality at the Araxes (Aras) River.

**Diagnosis.** Genus of the family Bairdiidae with subfusiform carapace in lateral view. Hexagonal outline with subparallel sides and generally large width in dorsal view. Straight DB with shoulder-like depression at the PDB in lateral view. Fine horizontal striation on the carapace surface.

**Assigned species.** *Araxobairdia formosa* sp. nov.

**Remarks.** The new genus is attributed to the superfamily Bairdiodae because of the carapace features. Any other features that are indicative for this superfamily cannot be analysed in this material; the inner lamella with vestibulum is not visible, because the carapace is filled with sparry calcite or sediment and isolated valves are not well preserved; muscle scars and hinge are not preserved. The new genus shows typical carapace features of the family Bairdiidae: in lateral view, the carapace outline is rounded trapezoidal and has a uniformly angulated dorsal margin with slightly concave ADB and PDB leading to bairdiid anterior and posterior borders. Only *A. formosa* (this study) from the Changhsingian is hitherto attributed to this genus.

*Araxobairdia formosa* Gliwa sp. nov.

**Figures 8A–H, 9**

**LSID.** urn:lsid:zoobank.org:act:78EA6E7D-9CE7-48F4-8929-EAC6EF6D987C

**Derivation of name.** From the Latin *formosa* (beautiful).

**Type specimens.** Holotype: complete carapace ECO108 (Fig. 8A, G), sample AVn062. Paratype: complete carapace, ECO109 (Fig. 8E), sample AVn062.

**Type locality and horizon.** Aras Valley; *Paratirolites* Limestone (Changhsingian), −0.62 m.

**Material.** 68 complete carapaces (L = 374–742 µm; Fig. 9), 25 single valves and 14 fragments.

**Diagnosis.** Species of *Araxobairdia* with striated carapace surface, longitudinal shallow ribs merging into the posterior and anterior ends. Carapace subfusiform in lateral view with uniformly angulated dorsal margin and hexagonal outline with subparallel sides in dorsal view.

**Description.** Subfusiform carapace with symmetric trapezoidal outline in lateral view; Hmax and Wmax distributed along the middle third of Lmax. Hexagonal outline with subparallel sides and generally large width (W/L = 0.56–0.58) in dorsal view. Plump carapace shape with laterally inflated valves and large flat ventral surface. Shallow shoulder-like depression at the antero- and posterodorsal lateral surface, more distinct at the PDB. Lmax in the lower half of the Hmax. Left valve overlaps right valve all around the carapace, with dorsal offset at the angulations between PDB and DB as well as between DB and ADB (visible in dorsal view; Fig. 8G). The tripartite dorsal margin is distinct at both valves. DB long (one-third of Lmax), slightly convex in right valve and straight to slightly concave in left valve. DB gently bent towards ADB (c. 150°). Straight PDB bent against the DB at c. 145°. AB uniformly rounded with maximum of convexity below mid-H. Ventral margin uniformly convex in left valve and slightly concave in the median portion of right valve. PB has a narrower radius of curvature than AB, with maximum of convexity located at the lower third of Hmax. Carapace surface striated on the lateral and dorsal surface with 13–14 longitudinal ribs that merge in the posterior and anterior ends. Ventral ribs run uniformly convex and parallel to the ventral margin, dorsal ribs are tripartite and run parallel to the dorsal margin. The ribs in the median area are almost straight. Striation on the ventral side less pronounced with almost smooth surface in the central ventral area.

**Remarks.** It is not possible to define boundaries between different ontogenetic stages in the L/H diagram; most of the specimens plot in a continuous scatter line (Fig. 9). However, there are clear morphological differences between adults and juveniles: juveniles generally show a more uniformly rounded dorsal margin, a larger radius of curvature at the AB and Hmax located slightly behind mid-L (Fig. 9).

Strongly ornamented representatives of the Bairdiidae, such as *Abrobairdia*, *Ceratobairdia*, *Petasobairdia*, *Psychobairdia* from the Permian–Triassic transitional time interval display typical Mesozoic–Cenozoic affinities (Crasquin & Forel 2014). Elongated ornamentation, such as lateral horizontal ridges are for example present in *Abrobairdia* Chen in Chen & Shi, 1982 (e.g. the Changhsingian *A. brevicosta* Chen & Shi, 1982 from South China) and in *Psychobairdia* Kollmann, 1960 (e.g. *P. ruttneri*...
Kristan-Tollmann, 1991 from north-east Iran). However, with the fine horizontal striation of the carapace surface and its large width, together with the shoulder-like depression at the PDB, *A. formosa* has a unique appearance among the Bairdiidae.

Occurrence. Aras Valley; *Paratirolites* Limestone (Changhsingian), from +0.30 to −0.23 m (Fig. 4).

Genus BAIRDIA McCoy, 1844

Type species. *Bairdia curta* McCoy, 1844; subsequently designated by Ulrich & Bassler (1923).

*Bairdia? kemerensis* Crasquin-Soleau in Crasquin-Soleau et al., 2004b

Figures 8Z–A, 10A–C, 11

2004b *Bairdia? kemerensis* Crasquin-Soleau in Crasquin-Soleau et al., p. 285, pl. 2, figs 1–5.

2014 *Bairdia? kemerensis* Crasquin-Soleau; Forel, p. 7, text-fig. 4B–I.

Remarks. The ontogenetic stages of *B. kemerensis* differ mainly in the position and shape of the PB, which was already investigated by Forel (2014): with progressing ontogeny, the posterior maximum of convexity migrates dorsally and the PB generally becomes wider (Fig. 11). The studied specimens show, furthermore, a decrease in the H/L ratio from c. 0.56 in A-4 juveniles to c. 0.49 in the adult stage, which has a more elongated carapace shape. Small pustule-like elevations are visible on the surface of one specimen from the Early Triassic *Claraia* Beds (Fig. 8AB). These so-called 'shell pustules' were also observed on *Bairdiacypris ottomanensis* specimens from our study material and on material from the Zal section (Mette 2008, 2010; see remarks in the description of *B. ottomanensis* below).

Occurrence. Çüürük dağ, Western Taurus, Turkey, Griesbachian (*Crasquin-Soleau et al. 2004b, Forel 2014*); Aras Valley, north-west Iran, Claraia Beds (Griesbachian), from +2.88 to +6.05 m (Fig. 4).
Genus BAIRDIACYPRIS Bradfield, 1935

Type species. Bairdiacypris deloi Bradfield, 1935 by original designation.

Bairdiacypris ottomanensis Crasquin-Soleau in Crasquin-Soleau et al., 2004b

Figures 10F–P, 12

2004b Bairdiacypris ottomanensis Crasquin-Soleau in Crasquin-Soleau et al., p. 285, pl. 2, figs 13–24. 2014 Praezabythocypris? ottomanensis (Crasquin-Soleau); Forel, p. 11, text-fig. 8F–H. (for more synonymy)

2015 Praezabythocypris cf. ottomanensis (Crasquin-Soleau); Forel et al., p. 11, text-figs 5AG–AJ, p. 13, text-figs 7A–B.

2019 Bairdiacypris ottomanensis Crasquin-Soleau; Wan et al., p. 8, text-fig. 4.2.

Material. 964 complete carapaces (L = 216–1014 μm; Fig. 12).

Remarks. The species was originally attributed to Bairdiacypris but included in Praezabythocypris by Mette (2010). In the genus description by Kozur (1985), the differentiation between Bairdia-

cypris and Praezabythocypris is based on a larger overlap of the left valve in Praezabythocypris and different muscle scar patterns, which are neither visible nor mentioned in the material described by Mette (2010) and also not illustrated by Kozur (1985). The lateral outline of the carapace and the angulate dor-
sal margin are characteristic for Bairdiacypris. Therefore, we fol-

low the original attribution of the species to the genus Bairdiacypris. The specimen identified as B. ottomanensis by Liu et al. (2010) is excluded from this species because it shows no species-specific angulations in the dorsal margin.

As mentioned by Crasquin-Soleau et al. (2004b), there is a conspicuous intraspecific variation within Bairdiacypris, noticeable in a varying slope of the DB. In our material, smaller specimens have a more steeply sloping DB and a more narrowly rounded posterior margin with a maximum of convexity located in the lower third of H_max (Figs 10F–L, 12). In contrast, larger specimens (identified as adults and A-1 instars) have a straight to slightly anteriorly/posteriorly tilted DB and a more rounded and higher posterior maximum of convexity (Fig. 10F–I, M–O). This may indicate ontogenetic development towards a slightly posteriorly tilted or slightly anteriorly tilted DB and a widely rounded posterior margin with a higher maximum of convexity in the adult specimens. This morphological transition was partially recognized by Forel (2014) and is also recognized in some modern Bairdioidea, such as Neonesidea oligodentata (Kajiyama, 1913) (Smith & Kamiya 2002).

The specimens of our material can be divided in two mor-

photypes (Fig. 12): morphotype A, specimens with maximum of convexity in the lower third of H_max (in A-5 to A-3) or slightly below mid-H_max (in A-3 to adults) and DB distinctly or slightly posteriorly tilted (Fig. 10F–M); and morphotype B, specimens with a posterior widening and a slightly anteriorly tilted DB, with the maximum of height located more posteri-

orly (Fig. 10N–P). Morphotype A is present in all ontogenetic stages (A-5 to adults), whereas morphotype B starts in A-1 and is also present in the adult stage, where it represents the largest specimens (Fig. 12). These two morphotypes are inter-

preted here to represent sexual dimorphism. The division into the different morphotypes becomes visible in the A-1 stage of our material, where morphotype B starts to develop. Sexual dimorphism features on the carapace of some recent taxa are also known to become visible during A-1, for example, in Uncinocythere occidentalis (Smith & Kamiya 2005). In general, sexual dimorphism in B. ottomanensis is indicated by an inflated posterior part of the carapace in female specimens (Crasquin-Soleau et al. 2004b). Sexual dimorphism in the Podocopida is known from several modern and fossil exam-

ples, which show that male specimens are generally smaller; the posterior part of the female carapace, which contains the brood pouch, is usually inflated (Jannusson 1985; Tanaka & Ikeya 2002; Smith & Hiruta 2004; Sato & Kamiya 2007; Tanaka & Seto 2010; Ozawa 2013; Forel et al. 2019). In our material, the specimens of morphotype B show a posterior widening and a slightly anteriorly tilted DB, with the maximum of height located more posteriorly (Fig. 10N–P). This posterior widening may be caused by the development of a brood pouch. Furthermore, morphotype B specimens are generally larger. We, therefore, interpret morphotype B as represent-

ing female specimens.

FIG. 10. SEM micrographs of ostracods from the Aras Valley section, north-west Iran. A–C, Bairdia? kemenensis Crasquin-Soleau, 2004: A, AV450X-72, right lateral view; B, AV450X-110, right lateral view; C, AV450X-05, right lateral view. D–E, Bairdia sp. 5: D, AV700-29, right lateral view; E, AV700-37, right lateral view. F–P, Bairdiacypris ottomanensis Crasquin-Soleau, 2004: F, AV450X-99, morphotype B, right lateral view; G, AV310-86, morphotype B, right lateral view; H, AV255SH-03, morphotype B, dorsal view; I, AV310-99, morphotype B, right lateral view; J, AV227-60, right lateral view; K, AV171SH-30, right lateral view; L, AV605-110, right lateral view; M, AV171SH-02, right lateral view; N, AV310-87, morphotype A, right lateral view; O–P, AV125SH-09, morphotype A: O, right lateral view; P, dorsal view. Q–S, Bairdiacypris sp. 1: Q, AV260-14, right lateral view; R, AV088X-39, right lateral view; S, AV075SH-14, right lateral view. T–V, Bairdiacypris sp. 2: T, AV116XSH-07, right lateral view; U, AV116XSH-42, right lateral view; V, AV265SH-92, right lateral view. W–X, Bairdiacypris sp. 3: W, AV116SH-66, right lateral view; X, AV116SH-74, right lateral view. Y–Z, Bairdiacypris sp. 4: Y, AV195TE-53, right lateral view; Z, AV152PO-23, right lateral view. AA–AB, Bairdiacypris cf. longirobusta Chen, 1958: AA, AV265SH-56, right lateral view; AB, AV288SH-158, left lateral view. AC–AF, Bairdiacypris zaliensis Mette, 2010: AC, AV227-31, right lateral view; AD, AV227-34, right lateral view; AE, AV227-18, right lateral view; AF, AV227-19, right lateral view. Scale bars represent 100 μm.
Some specimens show a pustular shell surface (Fig. 10J), which was already mentioned by Mette (2008, 2010) in material from Zal. In these studies, the pustules were interpreted to be caused by environmental deterioration and changes in water chemistry. However, in our material, the specimens with pustules are clearly preserved as steinkerns and the pustules may correspond to filled pore channels. This interpretation is further supported by the occurrence of pustules in other specimens from various species (Liuzhinia antalyaensis and Bairdia? kemerensis) in our material, which are also preserved as steinkerns.

**Occurrence.** Çürük dağ, Western Taurus, Turkey, Griesbachian (Crasquin-Soleau et al. 2004b; Forel 2014); Laolongdong section, Sichuan, South China, Griesbachian (Crasquin-Soleau & Kershaw 2005); Dajiang, Guizhou, South China, Griesbachian (Forel et al. 2009; Forel 2012); Elikah River, Central Alborz Mountains.

**FIG. 11.** Length/height scatter plot comparing Bairdia? kemerensis Crasquin-Soleau, 2004 from the Aras Valley section with the specimens described by Crasquin-Soleau et al. (2004b) and (Forel 2014) from Çürük dağ, Western Taurus, Turkey. Displayed specimens from left to right: AV450-08, AV450-67, AV310-36. Scale bar represents 100 μm.

**FIG. 12.** Length/height scatter plot of Bairdiacypris ottomanensis Crasquin-Soleau, 2004 from the Aras Valley section. Displayed specimens from left to right: upper row, AV605-110, AV310-115, AV088TE-02; lower row, AV171SH-02, AV255SH-03, AV125SH-09. Scale bar represents 200 μm.
northern Iran, Changhsingian–Griesbachian (Forel et al. 2015); Zal, north-west Iran, Changhsingian–Griesbachian (Mette 2008, 2010); Aras Valley, north-west Iran, Aras Member and Claraia Beds (Changhsingian–Griesbachian), from +0.75 to +7.00 m (Fig. 4).

*Bairdiacypris kathleenae* Gliwa sp. nov.

Figures 13A–F, 14

**LSID.** urn:lsid:zoobank.org:act:68BFFDA7-3DA8-41F0-B1B3-2ED3DCF6F30A

**Derivation of name.** Named after Kathleen Schindler, who supported this work with her diligence and patience during the preparation of the material.

**Type specimens.** Holotype: complete carapace ECO110 (Fig. 13A, B), sample AV265. Paratype: complete carapace ECO111 (Fig. 13D), sample AV288.

**Type locality and horizon.** Aras Valley; Claraia Beds (Griesbachian), +2.65 m.

**Material.** 26 complete carapaces (L = 811–1049 µm; Fig. 14).

**Diagnosis.** Species of *Bairdiacypris* with *H*<sub>max</sub> located posterior to mid-*L*, large overlap of left valve all around the right valve and high posterior maximum of convexity.

**Description.** Carapace elongate, subreniform in lateral view with *H*<sub>max</sub> in posterior half and *L*<sub>max</sub> in the upper third of the carapace; oblong in dorsal view with slightly acuminate ends and largest width in the posterior third. Wide overlap of the larger left valve all around right valve, thinner along AVB. Dorsal margin nearly uniformly rounded at left valve and with very tenuous angulations in the right valve at the DB–PDB transition (c. 150°) located at the posterior third of *L*<sub>max</sub> and DB–PDB transition (c. 160°) slightly anterior to mid-*L*. Anterior end long, broadly rounded, truncate dorsally, with maximum of convexity approximately at mid-*H*. VB concave in right valve and straight to slightly concave in left valve. Posterior end broadly rounded with maximum of convexity slightly above mid-*H*. Surface smooth.

**Remarks.** The general outline and the wide overlap of the left valve in *B. kathleenae* are similar to the Lopingian *Fabalicypris visnoensis* Kozur, 1985 from the Bük Mountains in Hungary. However, the *H*/*L* ratio of *B. kathleenae* is generally higher and the posterior maximum of convexity is located above the medium height. Furthermore, there is no ventral offset of the overlapping left valve, which would indicate an affiliation to *Fabalicypris*.

In lateral view, the new species resembles the morphotype B specimens of *B. ottomanensis*, but the new species has a broader overlap. The difference between the two species is most prominent in dorsal view; compared with *B. ottomanensis*, *B. kathleenae* possesses a more elongated carapace with nearly parallel valve outlines.

**Occurrence.** Aras Valley; Aras Member and Claraia Beds (Changhsingian–Griesbachian), from +1.52 to +3.75 m (Fig. 4).

**Family INDET.**

**Genus EUMIRACULUM** Chen in Shi & Chen, 1987

**Type species.** *Eumiraculum changxingensis* Chen in Shi & Chen, 1987 by original designation.

*Eumiraculum mettei* Gliwa sp. nov.

Figures 15Q–U, 16, 17

**LSID.** urn:lsid:zoobank.org:act:26DC9D83-051B-4647-9F86-739111334D87

**Derivation of name.** Named after Wolfgang Mette, who first documented specimens of the new species from north-west Iran.

**Type specimens.** Holotype: complete carapace ECO112 (Fig. 15Q), sample AVn003. Paratype: complete carapace ECO113 (Fig. 15R), sample AVn140.

**Type locality and horizon.** Aras Valley; Paratirolites Limestone (Changhsingian), –0.03 m.

**Material.** 6 complete carapaces, 9 single valves (L = 359–534 µm; Fig. 16) and 6 fragments.

**Diagnosis.** A species of *Eumiraculum* with subtriangular to drop-shaped carapace outline, two spines on the right valve and one spine on the left valve.

**Description.** Subtriangular to drop-shaped carapace outline in lateral view with *L*<sub>max</sub> and *H*<sub>max</sub> located close to the middle of the carapace; straight invaginated DB with lateral dorsomedical and mid-dorsal areas on both valves domed upwards, giving the DB a convexly rounded appearance in lateral view. Larger left valve overlaps right valve all around the carapace with maximum overlap at DB and VB, minimum at the posteroventral margin. Shallow lateral depression at the PB on both valves. Two small spines on right valve in posterodorsal and mid-posterior position (Fig. 17); one spine on dorsal margin of left valve, located in the posterior third and oriented slightly upward; this spine divides the outline of the dorsal margin in a concavely rounded posterior part and a convexly rounded anterior part, which merges uniformly to the AB. Uniformly and broadly rounded
AB. Transition between PB and VB gently angled at both valves (c. 125°). VB and PB uniformly curved. Posterior end with maximum of convexity located very high, in posterodorsal position. Carapace surface smooth.

Remarks. The new species resembles the Changhsingian material described as ‘Eumiraculum desmaresae’ by Forel et al. (2015) from the Central Alborz Mountains in Iran in its general outline of both valves in lateral view. However, the illustrated specimens of ‘E. desmaresae’ do not show any spines on the shell surface. The outline of E. mettei is also similar to the Lopingian E. desmaresae Forel in Forel et al., 2013 from the Bük Mountains in Hungary. In this species, the right valve overlaps the left valve at the AB and the anterior cardinal angle is underlain by a spine, which is not the case in the newly described species. E. mettei differs from the Lopingian E. changxingensis Chen in Shi & Chen (1987) from South China in its cardinal angles, which are located not higher than the dorsal margin but on the same height; and by its lateral surface, which is not marked by a longitudinal groove. In lateral view, the carapace shape of the new species is very close to the early Wuchiapingian Microcheilinella wujiapingensis Zazalli in Zazzali et al. (2015) from Sichuan (China), but this is characterized by a smooth shell surface without spines.

Occurrence. Zal, north-west Iran, Wuchiapingian–Changhsingian (Mette 2008, 2010); Aras Valley, Paratirolites Limestone (Changhsingian), from −3.30 to −0.03 m (Fig. 4).

Genus LIUZHINIA Zheng, 1976

Type species. Liuzhinia subovata Zheng, 1976, by original designation.

Liuzhinia julfensis Gliwa sp. nov.

Figures 15AA–AF, 18

2008 Liuzhinia sp.1; Mette, p. 215, pl. 2, figs 15–17.
2010 Liuzhinia sp. 1; Mette, p. 31, pl. 4, figs 7–9.
Liuzhinia antalyaensis

**Type specimens.** Holotype: complete carapace ECO114 (Fig. 15AF), sample AV467. Paratype: complete carapace ECO115 (Fig. 15AE), sample AV310.

**Type locality and horizon.** Aras Valley; Claraia Beds (Griesbachian), +3.10 m.

**Material.** 29 complete carapaces (L = 527–659 μm; Fig. 18).

**Diagnosis.** Species of Liuzhinia with subtrapezoidal carapace with H_max located anteriorly to mid-L and very low position of maximum of convexity at the anterior and posterior ends.

**Description.** Subtrapezoidal, elongated outline in lateral view; H_max located in the anterior third of L_max. Very thin overlap of the larger left valve, particularly visible along the VB. Dorsal margin straight to slightly rounded with a gentle angulation between PDB and DB, located in the posterior fourth of L_max. DB slightly convex, uniformly and broadly rounded to the AB. Anterior end rounded with large radius of curvature and maximum of convexity located in the lower fourth of H_max. VB straight to very slightly concave. Posterior end more narrowly rounded with maximum of convexity located in lower fourth of H_max. Short, convex PDB bent towards the DB with an angle of 125–135°. Carapace surface smooth.

**Remarks.** The new species resembles the Griesbachian Liuzhinia antalyaensis Crasquin-Soleau in Crasquin-Soleau et al., 2004b in its general lateral outline, but L. julfensis is more elongate (lower H/L) with a lower H/L in the holotype of 0.48 compared with H/L = 0.57 in L. antalyaensis. Furthermore, the anterior maximum of convexity is located lower than in L. antalyaensis. The latest Permian L. praantalyaensis Forel in Crasquin et al., 2010 from Meishan (Crasquin et al. 2010) has a similar lateral outline but differs by its narrower posterior end and by its anterior maximum of convexity located at mid-H. In contrast to the specimens figured by Mette (2008, 2010), the shell surface of our material is smooth without any pustules. These ‘pustulae’, described in Mette (2008, 2010) as an ‘ecophenotypic feature’ derive from its preservation as steinkern and are not specific features for the species.

**Occurrence.** Zal, north-west Iran, Griesbachian (Mette 2008, 2010); Aras Valley, Aras Member and Claraia Beds (Changhsingian–Griesbachian), from +1.71 to +4.67 m (Fig. 4).

**Order PALAEOCOPIDA Henningsmoen, 1953**

**Suborder KIRKBYOCOPINA Gründel, 1969**

**Superfamily KIRKBYOIDEA Ulrich & Bassler, 1906**

**Family KIRKBYIDAE Ulrich & Bassler, 1906**

**Genus CARINAKNIGHTINA Sohn, 1970**

**Type species.** Carinaknightina carinata Sohn, 1970, by original designation.

**Carinaknightina hofmanni** Gliwa sp. nov.  

**Figures 19O–V, 20**

**LSID.** urn:lsid:zoobank.org:act:4334AE3B-8DD2-4900-86E6-8945CB176132

**Derivation of name.** Named after Richard Hofmann, for his scientific and good-humoured support.

**Type specimens.** Holotype: complete carapace ECO116 (Fig. 19O, P), sample AV028. Paratypes: complete carapace ECO117 (Fig. 19Q), sample AV028; complete carapace ECO118 (Fig. 19U, V), sample AV028.

**Type locality and horizon.** Aras Valley; Aras Member (Changhsingian), +0.28 m.

**FIG. 15.** SEM micrographs of ostracods from the Aras Valley section, north-west Iran. A–D, Microcheilinella cf. perexilis Shi in Shi & Chen, 1987: A, AV005TE-45, right lateral view; B, AV005XTE-18, right lateral view; C, AV005XTE-19, right lateral view; D, AV005TE-46, dorsal view. E–I, Microcheilinella sp. 1: E, AV005TE-24, right lateral view; F, AV015Z-24, right lateral view; G–H, AV005XTE-02: G, right lateral view; H, ventral view; I, AV015Z-02, right lateral view; J, AV015Z-42, right lateral view; K–L, AV005TE-27: K, right lateral view; L, dorsal view. M–P, Microcheilinella sp. 2: M, AV015TE-10, right lateral view; N, AV015TE-09, right lateral view; O, AV015TE-08, right lateral view; P, AV015TE-10, dorsal view. Q–U, Eumiraculum mettei Gliwa, sp. nov.: Q, holotype ECO112, right lateral view; R, paratype ECO113, right lateral view; S, AVn330-88, right lateral view; T, left valve, AVn40-84, left lateral view; U, right valve, AVn040-12, right lateral view. V–W, Liuzhinia? sp. 1: V, AV005X-17, right lateral view; W, AV005XTE-11, right lateral view. X–Z, Liuzhinia antalyaensis Crasquin-Soleau, 2004: X, AV227-25, right lateral view; Y, AV227-64, right lateral view; Z, AV260-66, right lateral view. AA–AF, Liuzhinia julfensis Gliwa, sp. nov.: AA, AV310-65, right lateral view; AB, AV310-34, right lateral view; AC, AV227-20, right lateral view; AD, AV227-16, right lateral view; AE, paratype ECO115, right lateral view; AF, holotype ECO114, right lateral view. Scale bars represent 100 μm.
Material. 23 complete carapaces (L = 367–601 μm; Fig. 20).

Diagnosis. Species of Carinaknightina with subrectangular to subtriangular carapace, velate ridge running parallel to the marginal ridge. Two distinct lateral ridges extending from posterodorsal to mid-anterior area.

Description. Subrectangular to subtriangular carapace in lateral view; H max located in the anterior third and L max close to the middle of the carapace. Both valves approximately equal in size, no overlap visible. Long (70–75% of L max), straight DB with dorsal ridge. Velate ridge, parallel to the marginal ridge, extending from below the anterior cardinal angle to below the posterior cardinal angle. AB rounded with maximum of convexity at the lower third of H max. Straight to slightly concave VB. PB uniformly rounded. Anterior cardinal angle = 125–140°, posterior cardinal angle c. 120°. One major lateral ridge, extending from the posterodorsal to mid-anterior area, along the dorsomedian area and above a slightly oval pit at the median area, which is located slightly behind mid-length. Another, shallower and shorter lateral ridge extends along the mid-dorsal area subparallel to the major lateral ridge. Intra-ridge areas are reticulate with relatively large reticules that have thick muri.

Remarks. The new species is similar, in its reticulate surface and lateral outline, to the Wuchiapingian C. tricarinata Kozur, 1985 from the Bükk Mountains in Hungary. However, C. tricarinata has a significantly shallower kirkbyan pit and a larger H/L ratio. Furthermore, the new species has only two distinct lateral ridges. The most ventral ridge in C. tricarinata is not present in C. hofmanni.

Occurrence. Aras Valley; Aras Member (Changhsingian), +0.28 m (Fig. 4).

Order PLATYCOPIDA Sars, 1866
Suborder PLATYCOPINA Sars, 1866
Superfamily CAVELLINOIDEA Egorov, 1950
Family CAVELLINIDAE Egorov, 1950
Genus CAVELLINA Coryell, 1928
Type species. Cavellina pulchella Coryell, 1928, by original designation.

Cavellina fosteri Gliwa sp. nov.
Figures 21J–W, 22

LSID. urn:lsid:zoobank.org:act:5408B079-A444-4DDF-87EE-B8E526F87FCB

FIG. 16. Length/height scatter plot of Eumiraculum mettei Gliwa, sp. nov. from the Aras Valley section.

FIG. 17. Specimen of Eumiraculum mettei Gliwa, sp. nov. (holotype, ECO112) with magnified spines on the right valve. Scale bars represent 100 μm.
*Derivation of name.* Named after William J. Foster, who provided the authors with new ideas.

*Type specimens.* Holotype: complete carapace ECO119, morphotype A (Fig. 21T, U), sample AV028. Paratypes: complete carapace ECO120, morphotype B (Fig. 21L, M), sample AV075; complete carapace ECO121, morphotype A (Fig. 21R, S), sample AV028.

*Type locality and horizon.* Aras Valley; Aras Member (Changhsingian), +0.28 m.

*Material.* 109 complete carapaces (L = 277–635 μm; Fig. 22).

*Diagnosis.* Species of *Cavellina* with subrectangular (morphotype A) to subovate (morphotype B) carapace, broadly rounded anterior half and inflated posterior part (morphotype B); posteroverentral area and anterior margin laterally compressed.

*Description.* The species shows two morphologies, marked as morphotype A and B: morphotype A (Fig. 21J–Q) is subrectangular in lateral view with \( H_{\text{max}} \) located in the anterior third of \( L_{\text{max}} \). Right valve overlaps left valve all around the carapace with smallest overlap at AB and PB. Fusiform shape in dorsal view with tapered anterior and posterior ends and \( W_{\text{max}} \) (W/L c. 0.30) slightly posterior to mid-L. DB long (c. 65% of \( L_{\text{max}} \)), straight to slightly convex. PB broadly rounded, with angle between PB and DB c. 90°. VB slightly concave to straight. DB long, uniformly rounded, maximum of convexity slightly below mid-H. Posteroverentral area and anterior margin laterally compressed. Shallow sulcus located in mid-dorsal area extending down to mid-H of the carapace. Carapace surface smooth.

Morphotype B (Fig. 21R–V) is subovate in lateral view with \( H_{\text{max}} \) in the middle third \( L_{\text{max}} \). Wedge-shaped in dorsal view with bulbous posterior and tapered anterior part (W/L c. 0.40). Right valve larger than left valve, overlapping all around the carapace with maximum at DB. Posteroverentral area and anterior margin laterally compressed. Sulcus visible at mid-dorsal area. DB bent towards PB with an angle of 100–110°; PB uniformly and more narrowly rounded than AB. AB broadly rounded with maximum of convexity slightly below mid-H. VB straight to slightly concave, sometimes slightly convex. Dorsal margin in left valve slightly concave, bent with an angle c. 150° between ADB and the nearly straight DB; dorsal margin in right valve convex and uniformly rounded, PB rounded with maximum of convexity located slightly above mid-H. Carapace surface smooth.

*Remarks.* The two morphotypes are interpreted to represent sexual dimorphs. Sexual shell dimorphism in platycopids and specifically in cavellinids is already well-known; it is induced by an enlargement of the domiciliary cavity in the most posterior part of the female specimens (heteromorphs) due to egg care (Jaanusson 1985). Morphotype B shows a bulbous, inflated posterior part, which is wedge-shaped in dorsal view (Fig. 21S, U), a character that is known in female carapaces of cavellinids. The carapace of morphotype A, which is interpreted to represent the male morphology of larger specimens (from A-1 stage), is more rectangular in overall shape as well as fusiform and slim in dorsal view (Fig. 21K, M). This dimorphism is expressed only in the adult and A-1 instar specimens.

*Occurrence.* Aras Valley; Aras Member (Changhsingian), from +0.28 to +1.52 m (Fig. 4).

**Cavellina hairapetiani** Gliwa sp. nov.

Figures 21X–AA, 23

*LSID.* urn:lsid:zoobank.org:act:DDEED02C-5616-4857-9114-8FA05C4D2492

*Derivation of name.* Named after Vachik Hairapetian, who supported the authors during field work in north-west Iran.
Type specimens. Holotype: complete carapace ECO122 (Fig. 21X, Y), sample AV125. Paratype: complete carapace ECO123 (Fig. 21Z, AA), sample AV116.

Type locality and horizon. Aras Valley; Aras Member (Changhsingian), +1.25 m.

Material. 9 complete carapaces (L = 484–529 µm; Fig. 23).

Diagnosis. Species of Cavellina with a high H/L ratio and a short subcircular to oval carapace in lateral view; in dorsal view wedge-shaped with a strongly inflated posterior part.

Description. Short, subcircular to oval carapace in lateral view. H\textsubscript{max} located in the middle or slightly posterior to it, I\textsubscript{max} located around mid-H. In dorsal view wedge-shaped with large width (W/L c. 0.5) and asymmetrical posterior part with wider right valve. W\textsubscript{max} distributed around the posterior half of the carapace. Right valve overlaps smaller left valve at dorsal and ventral margin in lateral view. At PB, left valve slightly longer than right valve, no overlap visible. Dorsal margin uniformly rounded. Posterior part of left valve strongly inflated; PB rounded with smaller radius of curvature than in AB; maximum of convexity located at the upper third of H\textsubscript{max}. Straight to convex VB. AB rounded with maximum of convexity in the lower half of H. ADB straight to slightly convex, gently bent towards the straight-to-convex PDB (c. 15°). AB tapered. Very shallow sulcus visible in the anterodorsal area. Surface smooth.

Remarks. The largest specimens of *C. hairapetiani* have usually a more elongate carapace compared with the smaller ones. It is unclear which growth stage the large specimens belong to, given that the L/H diagram shows one uniform scatter without distinct stage boundaries (Fig. 23). All 14 specimens possess a strongly inflated posterior part, which may indicate an attribution to female representatives (Jaanusson 1985) of all recovered specimens. It is not clear from the material whether the new species is generally characterized by this posterior enlargement of the carapace or if male representatives have not been discovered yet. The new species slightly resembles, in its general short and wedge-shaped appearance, *C. alpina* (2008) +484–529°. AB tapered. Very shallow sulcus visible in the anterodorsal area. Surface smooth.

Type species. *Hungaroleberis retiferus* Tóth & Cséfán, 2018 by original designation.

*Hungaroleberis striatus* Forel sp. nov.

Figures 24V–AB, 25, 26

**LSID.** urn:lsid:zoobank.org:act:FB8A5EFB-677E-455D-B4B6-EB3B0F621F5

**Derivation of name.** From the Latin *striatus*, striate, referring to the ornamentation.

Type specimens. Holotype: complete carapace ECO124 (Fig. 24V), sample AVn330. Paratype: complete carapace ECO125 (Fig. 24W), sample AVn330.

Type locality and horizon. Aras Valley; *Paratirolites* Limestone (Changhsingian), −3.30 m.

Material. 73 complete carapaces (L = 309–740 µm; Fig. 25).

Diagnosis. Species of *Hungaroleberis* with striate surface.

Description. Carapace of medium size, ovoid to subquadrate in lateral view, with H\textsubscript{max} at AD angulation and I\textsubscript{max} at tip of...
rostrum at or slightly above mid-L; lenticular in dorsal view
with W_{max} at mid-L; right valve overlapping left valve all around
the carapace except at rostral incisure, with maximum along
ADB; dorsal margin angulate with long, straight-to-slightly con-
vex PDB and shorter (c. 1/3 of L_{max}) convex ADB; AD angula-
tion more or less salient, located in anterior third of L_{max};
ventral margin uniformly arched; PB large without caudal pro-
cess, rounded in small specimens to vertical in larger ones; ros-
tral incisure weakly developed; AVB not extending past the tip
of the rostrum; rostrum triangular, laterally compressed at both
valves; surface with numerous shallow concentric striations
(Fig. 26) that appear deeper along the rostrum.

Remarks. Hungaroleberis striatus is close to the Guadalupian–
Lopingian H. gussevaae (Crasquin-Soleau in Crasquin-Soleau &
Baud, 1998) from Hydra Island, Greece (Crasquin-Soleau &
Baud 1998). However, H. gussevaae has a narrower and more
tapered PB and a smooth surface. Furthermore, H. gussevaae is
smaller and shorter than H. striatus (size range in Crasquin-
Soleau & Baud 1998: L = 0.41–0.60 mm; H = 0.31–0.43 mm). It
is worth noting that the diagnosis of H. gussevaae states that
‘right valve slightly overlaps the left one’ and that the only illus-
tration of left lateral view of a carapace (Crasquin-Soleau &
Baud 1998, pl. 7, fig. 4) shows obvious overlap along dorsal
margin with maximum along posterior half. This pattern clearly
differs from H. striatus where the maximum occurs along ADB.
The dispersal of the L/H scatter plot for H. striatus (Fig. 25)
indicates that several ontogenetic stages are present for this spe-
cies, with immature specimens (e.g. Fig. 24Y, Z) having a nar-
rrower PB and more asymmetrical carapace in lateral view
compared with larger specimens (e.g. Fig. 24V).

The genus Hungaroleberis was introduced to accommodate
‘Cylindroleberididae with valves ovoid in lateral view; rostrum
and rostral incisure weakly developed; posterior margin arched
without caudal process; valve surface reticulate or smooth’ (Tóth
& Cséfán 2018, p. 362). Hungaroleberis striatus displays all diag-
nostic features of the genus but its striate surface shows that the
surface ornamentation of Hungaroleberis is more variable than
previously thought. Hungaroleberis striatus is the sixth reported
species of this genus that is documented from Wordian

FIG. 20. Length/height scatter plot
of Carinaknightina hofmanni Gliwa, sp. nov. from the Aras Valley sec-
tion.

FIG. 21. SEM micrographs of ostracods from the Aras Valley section, north-west Iran. A–C, Buregia? sp. 1: A, AV171SH-69, left lat-
eral view; B, AV185SH-42, ventral view; C, AV260-23, ventral view. D–E, Indivisia sp. 1: D, AV260-18, left lateral view; E, AV260-47,
left lateral view. F–G, Indivisia sp. 2: F, AV260-24, right lateral view; G, AV260-29, right lateral view. H–I, Langdaia sp. 1: H, AV260-
38, left lateral view; I, AV260-37, left lateral view. J–W, Cavellina fosteri Gliwa, sp. nov.: J–K, AV028YTE-82, morphotype B: J, left lat-
eral view; K, dorsal view; L–M, paratype ECO120, morphotype B: L, left lateral view; M, dorsal view; N, AV075SH-27, morphotype B,
left lateral view; O, AV075XSH-45, morphotype B, left lateral view; P, AV116Y-17, left lateral view; Q, AV116XSH-38, left lateral view;
R–S, paratype ECO121, morphotype A: R, left lateral view; S, dorsal view; T–U, holotype ECO119, morphotype A: T, left lateral view;
U, dorsal view; V, AV028YTE-83, left lateral view; W, AV075SH-07, left lateral view. X–AA, Cavellina hairapetiani Gliwa, sp. nov.: X–
Y, holotype ECO122: X, dorsal view; Y, left lateral view; Z–AA, paratype ECO123: Z, left lateral view; AA, dorsal view. AB, Cavellina
sp. 1, AV116XSH-73, left lateral view. Scale bars represents 100 μm.
(Crasquin-Soleau & Baud 1998) to Bajocian (Tóth & Cséfán 2018) strata. In terms of palaeogeographical distribution, Guadalupian occurrences of Hungaroleberis are known only from Greece (Crasquin-Soleau & Baud 1998); the genus is more widely distributed in Lopingian rocks, e.g. Greece (Crasquin-Soleau & Baud 1998), South China (Crasquin et al. 2010) and Iran (this work). According to current knowledge, Middle and Late Jurassic occurrences of Hungaroleberis are restricted to Hungary (Tóth & Cséfán 2018).

Occurrence. Aras Valley; Paratirolites Limestone (Changhsingian), −3.30 to −1.40 m (Fig. 4).

RESULTS

For the present study with a focus on the EPME, 59 samples from the Aras Valley section (north-west Iran) were investigated for their ostracod content. The ostracod abundances of the samples ranged from 4 to 31 500 specimens per 500 g. In total, 3425 specimens were identified to the species level with 62 species belonging to 23 genera and 12 families (Fig. 4; see Tables 1–3 for a list of all identified species and Gliwa et al. 2020, table S1 for specimen occurrences per species and sample horizon).

FIG. 22. Length/height scatter plot of Cavellina fosteri Gliwa, sp. nov. from the Aras Valley section.

FIG. 23. Length/height scatter plot of Cavellina hairapetiani Gliwa, sp. nov. from the Aras Valley section.
Ten species and one genus are described here for the first time. 36 species are kept in open nomenclature because of poor preservation of the specimens.

Length/height diagrams show that for most of the studied species, the values of ontogenetic stages plot in distinct clusters. As Boomer et al. (2003) showed for other occurrences, such a distribution in which several juvenile stages as well as the adult stage are represented in the samples, indicates the absence of a strong energetic sorting process due to transportation over long distances. Furthermore, the usually complete preservation of carapaces lets us assume that the specimens represent autochthonous material (Brouwers 1988). The abundance, diversity and taxonomic patterns within the three lithological units of the studied interval show the following characteristics.

1. Paratirolites Limestone: the abundance of ostracods in this pre-extinction interval ranges usually between 200 and 300 specimens but reaches 600–700 in the horizons at −3.30 m, −0.40 m and −0.03 m (Fig. 27). The species diversity is generally low with 3–8 species per sample (Fig. 27). A monospecific assemblage occurs at −0.01 m in the topmost horizon of the Paratirolites Limestone; this exclusively contains the species Fabalicypris obunca.

The ostracod assemblages within the Paratirolites Limestone are mainly composed of species of the order Podocopida, of which the species Fabalicypris obunca is predominant. The only exception occurs in the interval from −3.30 to −1.40 m, which is marked by abundant occurrences of Hungaroleberis striatus, the only myodocopid species in the studied section. Up to 43% of the total specimens consists of this possibly nektonic/planktonic ostracod species (Fig. 27).

2. Aras Member: the abundance of ostracods in the samples is very heterogeneous and ranges from 6 to 31 500 per 500 g material. The samples between +0.45 and +0.75 m and at +1.25 m are marked by very low numbers (6–46 specimens), while sample +1.71 m contains ostracod mass occurrences c. 31 500 specimens per 500 g material. The diversity increases within the Aras Member; it reaches a maximum of 16 species at +1.16 m but subsequently drops to four species at +1.71 m. This first diversity increase in the lower part of the Aras Member is paralleled by a complete faunal turnover (Fig. 4). The poorly diverse Fabalicypris-dominated ostracod assemblage from the Paratirolites Limestone was replaced by a relatively diverse Bairdiacypris-dominated assemblage. The assemblage in the Aras Member is dominated by podocopid species but the occurrences of platycopid and palaeocopid species show that diversity increases also on a higher taxonomic level (Fig. 27).

3. Claraia Beds: the abundance of ostracods in the lower 0.70 m of the Claraia Beds is relatively high, ranging from 1000 to 2500 specimens per 500 g sample material, with occasional very low numbers (down to four specimens) in the upper part of the sampled interval (+3.20 m to +7.00 m). A peak of diversity (15 species) occurs at +2.65 m and is immediately followed by low species numbers (between two and five in samples +3.10 to +6.05 m). Up to the sample at +6.05 m, the assemblages are dominated by Bairdiacypris ottomanensis. In the uppermost sample (+7.00 m), the taxonomic composition changes to a Bairdia-dominated assemblage together with occurrences of Liuzhinia sp. 2 and only one specimen of B. ottomanensis. All assemblages in the Claraia Beds are dominated by podocopid species. The only occurrences of Palaeocopida and Platycopida in the lower part are paralleled by the short diversity peak at +2.65 m (Fig. 27).

DISCUSSION

Palaeoenvironmental setting

With the occurrence of the Bairdiidae, Palaeocopida and Cavellinidae, the ostracod assemblages of the Aras Valley section show a characteristic genus composition, typically found in tropical marine environments (Crasquin-Soleau et al. 2004a). Following the interpretations of Peterson & Kaesler (1980), Melnyk & Maddocks (1988) and Costanzo & Kaesler (1987), some genera, families and superfamilies have distinct characteristics with regard to their environment: (1) Bairdiidae are present in deep to shallow environments with normal marine salinity; (2) Microcheilinella, Basslerella and Kirkbyidae are instead distributed in environments with normal salinity and oxygenation on the distal platform; (3) Cavellinidae occur in shallow (large, robust forms) but also in relatively deeper settings on the intermediate zone of the platform (small forms); the diversity of cavellinids increases in shallower settings and they occur in euryhaline environments; and (4) Orthobairdia are predominantly distributed in distal platform environments.

The species composition with the presence of Orthobairdia in the Paratirolites Limestone and Microcheilinella, small Cavellinidae, Kirkbyidae and Basslerella in the Aras Member confirms the already published environmental interpretation, which suggested a deep shelf setting throughout the investigated part of the section with no large-scale bathymetric changes (Leda et al. 2014; Gliwa et al. 2020a). Relatively high occurrences of cavellinids in the lower half of the Aras Member may indicate a more proximal setting, which is not supported by the
microfacies analysis of this section interval (Gliwa et al. 2020a). Furthermore, the high number of bairdiid species (Fig. 27) indicates that the investigated part of the section was formed under normal marine conditions with normal salinity.

Low-diversity Paratirolites Limestone and EPME/extinction horizon. The very low diversity in the upper Paratirolites Limestone terminates in a monospecific assemblage with Fabalicypris obunca in the uppermost sample horizon (∼0.01 m). In the marine, littoral habitat, the diversity of ostracod assemblages is mostly constrained by water energy, sediment substrate type, salinity, nutrient availability, concentration of dissolved oxygen, temperature and their fluctuations (Benson et al. 1983; Dingle & Giraudieu 1993; Hinz-Schallreuter & Schallreuter 1999; Frenzel & Boomer 2005). The samples from the Aras Valley section were deposited in an outer shelf environment below the storm wave base, in a low-energy environment (Leda et al. 2014; Gliwa et al. 2020a). The sediment substrate throughout the section consisted of fine-grained carbonate mud with a varying clay content (Gliwa et al. 2020a). A significant change of diversity and composition between the assemblages, caused by variable substrate type or water energy, is, therefore, not expected in the studied section interval.

Given that most of the marine ostracod species are stenohaline, salinity changes have a major influence on
TABLE 1. Ostracod assemblages of the Paratirolites Limestone of the Aras Valley (north-west Iran) with all identified species.

| Class   | Subclass | Superfamily | Family | Genus and Species                                                                 |
|---------|----------|-------------|--------|----------------------------------------------------------------------------------|
| Ostracoda Latreille, 1806 | Podocopa Müller, 1894 | Cypridoidea Baird, 1845 | Paracypris | sp. 1                                                                            |
|         |          |             |        | Fabalicypris obunca Beloussova, 1965                                              |
|         |          |             |        | Fabalicypris blumenstengeli Crasquin, 2008                                        |
|         |          |             |        | Orthobairdia capuliformis Gliwa, sp. nov.                                         |
|         |          |             |        | Araxobairdia formosa Gliwa, gen. et sp. nov.                                      |
|         |          |             |        | Bairdia sp. 1                                                                     |
|         |          |             |        | Family indet.                                                                     |
|         |          |             |        | Eumiraculum mettei Gliwa, sp. nov.                                                 |

TABLE 2. Ostracod assemblages of the Aras Member of the Aras Valley (north-west Iran) with all identified species.

| Subclass | Podocopa Müller, 1894 | Order Podocopida Sars, 1866 | Suborder Podocopina Gründel, 1967 | Superfamily Bairdioidea Sars, 1887 | Family Bairdiidae Sars, 1887 | Bairdia hassi Sohn, 1960 |
|----------|-----------------------|-----------------------------|-----------------------------------|-----------------------------------|-----------------------------|-------------------------|
|          |                       |                             |                                    |                                   |                             | Bairdia cf. piscariformis Chen, 1958 |
|          |                       |                             |                                    |                                   |                             | Bairdia sp. 2             |
|          |                       |                             |                                    |                                   |                             | Bairdia sp. 3             |
|          |                       |                             |                                    |                                   |                             | Bairdia sp. 4             |
|          |                       |                             |                                    |                                   |                             | Bairdiacypris Kathleenae Gliwa, sp. nov. |
|          |                       |                             |                                    |                                   |                             | Bairdiacypris ottomanensis Crasquin-Soleau, 2004 |
|          |                       |                             |                                    |                                   |                             | Bairdiacypris zaliensis Mette, 2010 |
|          |                       |                             |                                    |                                   |                             | Bairdiacypris sp. 1       |
|          |                       |                             |                                    |                                   |                             | Bairdiacypris sp. 2       |
|          |                       |                             |                                    |                                   |                             | Bairdiacypris sp. 3       |
|          |                       |                             |                                    |                                   |                             | Fabalicypris sp. 4        |
|          |                       |                             |                                    |                                   |                             | Fabalicypris veronicae Gliwa, sp. nov. |
|          |                       |                             |                                    |                                   |                             | Fabalicypris cf. minuta Cooper, 1946 |
|          |                       |                             |                                    |                                   |                             | Fabalicypris sp. 1        |
|          |                       |                             |                                    |                                   |                             | Fabalicypris sp. 2        |
|          |                       |                             |                                    |                                   |                             | Fabalicypris sp. 3        |
|          |                       |                             |                                    |                                   |                             | Kempfina sp. 1            |
|          |                       |                             |                                    |                                   |                             | Kempfina sp. 2            |
|          |                       |                             |                                    |                                   |                             | Kempfina qinglai (Crasquin), 2008 |
|          |                       |                             |                                    |                                   |                             | Praezabythocypris pulchra Kozur, 1985 |
|          |                       |                             |                                    |                                   |                             | Praezabythocypris cf. pulchra sensu Forel, 2014 |
|          |                       |                             |                                    |                                   |                             | Family indet.             |
|          |                       |                             |                                    |                                   |                             | Liuzhinia? sp. 1          |
|          |                       |                             |                                    |                                   |                             | Liuzhinia julensis Gliwa, sp. nov. |
|          |                       |                             |                                    |                                   |                             | Liuzhinia antalyaensis Crasquin-Soleau, 2004 |
|          |                       |                             |                                    |                                   |                             | Superfamily Cytheroidea Baird, 1850 |
|          |                       |                             |                                    |                                   |                             | Family Bythocytheridae Sars, 1928 |
|          |                       |                             |                                    |                                   |                             | Callicythere sp. 1        |
|          |                       |                             |                                    |                                   |                             | Callicythere sp. 2        |
|          |                       |                             |                                    |                                   |                             | Family Cytherideidae Sars, 1925 |
|          |                       |                             |                                    |                                   |                             | Basslerella sp. 1         |

1034 PAPERS IN PALAEONTOLOGY, VOLUME 7
their distribution (Mesquita-Joanes et al. 2012). Faunal changes linked to salinity changes are mainly recognized in marginal marine, coastal environments, where terrestrial freshwater input lowers salinity and constrains the distribution of marine ostracod species (Frenzel & Boomer 2005). A major change in salinity, caused by freshwater input, is not suspected for the Aras Valley section because of the lack of indications of prominent terrigenous input, implying a large distance to the coastline. Furthermore, high numbers of specimens of the Bairdiidae, which are usually found within a normal marine setting of freshwater input, is not suspected for the Aras Valley section. A major change in salinity, caused by freshwater input lowers salinity and constrains the distribution of marine ostracod species (Frenzel & Boomer 2005). A major change in salinity, caused by freshwater input, is not suspected for the Aras Valley section because of the lack of indications of prominent terrigenous input, implying a large distance to the coastline. Furthermore, high numbers of specimens of the Bairdiidae, which are usually found within a normal marine setting of freshwater input, is not suspected for the Aras Valley section.

Although some Recent ostracod species are known to tolerate low oxygen levels, or even prefer it; they are able to survive within hypoxic conditions for a short time (Jahn et al. 1996; Modig & Ólaffson 1998; Rossi et al. 2002; Corbari et al. 2004). However, ostracods in general are very sensitive to oxygen level changes and depletion (Buhl-Mortensen et al. 2009). Low oxygen conditions in the marine habitat usually lead to a decreased diversity of ostracods (Modig & Ólaffson 1998; Buhl-Mortensen et al. 2009). The low-diversity ostracod assemblage of the Paratiroлитes limestone in the Aras Valley section may, therefore, be caused by a decrease in dissolved oxygen, leading to the local disappearance of the species. Uranium isotopes from the nearby Zal section indicate an onset of anoxic conditions at the EPME (Zhang et al. 2018). However, in the present study as well as in other north-west Iranian sections, the low diversity of the Paratiroлитes Limestone is also paralleled by the occurrence of other oxygen-dependent organisms such as ammonoids, sponges, gastropods, bivalves and echinoderms (Leda et al. 2014; Gliwa et al. 2020a). Evidence for a bioturbated sea floor up to the uppermost bed of the Paratiroлитes Limestone (Gliwa et al. 2020a) indicates normal marine oxygen concentrations of the bottom waters.

Temperature was identified as a major influence on the diversity and population size of marine assemblages (Heip 1976; Cronin 1991; Cronin et al. 1995), although studies of fossil and extant ostracods indicate that few species appear to have an extreme thermal tolerance window (e.g. Kükköylüoğlu et al. 2003). Unstable environmental conditions, such as sealevel fluctuation, as well as high sealevels, which are accompanied by temperature change in the habitat, lead to lower ostracod diversity (Slipper 2005; Crasquin et al. 2010). Regarding for example the fossil record of the Early Toarcian warming, it was suggested that a decrease in ostracod diversity and the extinction of many species, can be connected to a rapid temperature increase (Gómez & Arias 2010). The dramatic temperature increase of c. 7–10°C at the EPME in north-west Iran is assumed to have started directly at the extinction horizon (Schobben et al. 2014). This coincides with the disappearance of Fabalicypris obunca and the
complete faunal turnover at the transition to the Aras Member. Consequently, a linkage between the rapid temperature change and the impoverishment of the ostracod fauna is possible. Rapid warming may have exceeded the temperature tolerance limit of *F. obunca* and led to the extinction of the species and to the replacement of the community in the Aras Valley section.

**High post-extinction diversity.** Compared with the *Paratirolites* Limestone, the post-extinction assemblages from the Aras Member represent a more diverse benthic ostracod community even at a higher taxonomic level (Fig. 27). Relatively diverse ostracod assemblages in the aftermath of the EPME have also been recorded from very proximal siliciclastic environments (Crasquin *et al.* 2017) or in association with microbial build-ups (Forel *et al.* 2009, 2013, 2015; Forel 2012, 2014). This led to the hypothesis of a microbial refuge, which protected ostracods from an assumed oxygen-poor environment. The high abundance and diversity of ostracods in the Aras Valley section is not associated with microbialites, which indicates that these assemblages were probably not stressed by large-scale environmental changes, such as changes in dissolved oxygen concentrations. This is also suggested by the occurrence of Bairdiidae, which were found throughout the investigated interval. Bairdiidae are usually found in marine environments that are well-oxygenated (Kornicker 1961; Maddocks 1969; Melnyk &
and indicate normal marine salinity (Kornicker 1961; Crasquin-Soleau et al. 1999). Their presence in the entire investigated section interval and their predominance in the assemblages, except from the lower third of the Aras Member (Fig. 27) indicate that the post-extinction assemblages were also not suffering low oxygen concentrations or strong salinity changes.

The temperature reconstruction for the Permian–Triassic transition in South China and north-west Iran (Joachimski et al. 2012; Sun et al. 2012; Schobben et al. 2014) shows that the post-extinction interval is characterized by high-temperature seawater (c. 38°C). In general, the thermal tolerance of marine ostracods is still poorly characterized. However, a summary of marine Eocene taxa (e.g. Hazel & Holden 1971) shows that many of them are eurythermal. Ostracods have, in contrast to many other marine organisms, such as cephalopods, foraminifers or echinoderms, a very broad temperature tolerance (Ganning 1971) and some species have a comparatively high thermal limit, which was demonstrated for freshwater species (Wickstrom & Castenholz 1973, 1985; Küüköylüoğlu et al. 2003; Küüköylüoğlu 2004; Vandekerkhove et al. 2013). For example, specimens of Thermopsis thermophila were even found in hot springs at water temperatures above 50°C (Küüköylüoğlu et al. 2003). This could indicate that some species were able to tolerate the presumably hot post-extinction climate.

CONCLUSIONS

In the Aras Valley section (north-west Iran), which spans the EPME and the PTB, 59 sampled horizons yielded ostracods: we report here on the occurrence of 62 species, of which ten species and one genus are new: Fabalicypris veronicae Gliwa, sp. nov., Orthobairdia capuliformis Gliwa, sp. nov., Araxobairdia formosa Gliwa, gen. et sp. nov., Bairdiacypris kathleenae Gliwa, sp. nov., Eumiraculis mettei Gliwa, sp. nov., Liuzhinia julifensis Gliwa, sp. nov., Carinaknightina hofmanni Gliwa, sp. nov., Cavellina fosteri Gliwa, sp. nov., Cavellina hairapetiani Gliwa, sp. nov. and Hungaroleberis striatus Forel, sp. nov.

The species compositions of all samples represent a typical tropical marine environment. The occurrences of taxa, which are usually found in distal platform environments (Microcheilinella, Orthobairdia, Basslerella and Kirkbyidae) confirm a deep shelf setting without large-scale bathymetric changes, as already suggested from the microfacies analysis. Furthermore, a high number of occurrences of the Bairdiidae, which are present throughout the entire succession, indicate open marine conditions with normal marine salinity and oxygen concentrations.

The pre-extinction ostracod assemblage of the Paratiriolites Limestone is dominated by Fabalicypris obunca, which forms a monospecific assemblage in the uppermost sample. The low diversity of this assemblage may be caused by depleted oxygenation of the habitat, although sedimentological and palaeontological investigations of the studied section, as well as neighbouring sections, suggest an oxygenated environment. The subsequent total faunal turnover at the EPME and the transition from the Paratiriolites Limestone to the Aras Member (‘Boundary Clay’) coincides with the massive temperature increase, which was determined for north-west Iran. The post-extinction assemblages are dominated by Bairdiacypris ottomanensis and show a relatively high diversity in the immediate aftermath of the EPME. Compared with other diverse ostracod assemblages from the Palaeotethyan realm, the ostracods of the Aras Valley section are not associated with microbialites.

Acknowledgements. We are indebted to the Aras Free Zone Office (Juija) for logistical support for the field sessions. We thank Kathleen Schindler (Berlin) for processing the ostracod samples. Many thanks to William J. Foster (Dublin) for discussions and his helpful comments on the manuscript. Furthermore we are indebted to Avraham Honigstein (Jerusalem), Frank Scholze (Darmstadt), Gengo Tanaka (Kanazawa) and an anonymous reviewer for reviews of an earlier version of the manuscript. For financial support of the project, we acknowledge the Deutsche Forschungsgemeinschaft (DFG project Ko1829/18-1) and the TERSANE research group (FOR 2332).

DATA ARCHIVING STATEMENT

This published work and the nomenclatural acts it contains, have been registered in ZooBank: http://zoobank.org/References/E6A6F765-45C0-43A9-B3BD-1E3446BAD2B0

Data for this study are available in the Dryad Digital Repository: https://doi.org/10.5061/dryad.dncjsxkwc

Editor. Yue Wang

REFERENCES

ARAKEYAN, R. A., GRUNT, T. A. and SHEVYREV, A. A. 1965. Kratkiy stratigraficheskiy ocherk. 20–25. In RZUHENCEV, V.E. and SARYTCEVA, T.G. (eds). Rasvitie i smena morskikh organizmov na rubezhe Paleozoya i Mezozoya. Trudy Paleontologicheskogo Instituta Akademiya Nauk SSSR, 108. [in Russian]

BAIRD, W. 1845. Arrangement of the British Entomostraca, with a list of species, particularly noticing those which have as yet been discovered within the bounds of the Club. History of the Berwickshire Naturalists’ Club, 2, 145–158.

BELOUSOVA, Z. 1965. Evolution and succession of organisms at Paleozoic-Mesozoic boundary. Trudy Paleontologicheskogo Instituta Akademii Nauk SSSR, 108, 245–265.

Maddocks 1988) and indicate normal marine salinity (Kornicker 1961; Crasquin-Soleau et al. 1999). Their presence in the entire investigated section interval and their predominance in the assemblages, except from the lower third of the Aras Member (Fig. 27) indicate that the post-extinction assemblages were also not suffering low oxygen concentrations or strong salinity changes.

The temperature reconstruction for the Permian–Triassic transition in South China and north-west Iran (Joachimski et al. 2012; Sun et al. 2012; Schobben et al. 2014) shows that the post-extinction interval is characterized by high-temperature seawater (c. 38°C). In general, the thermal tolerance of marine ostracods is still poorly characterized. However, a summary of marine Eocene taxa (e.g. Hazel & Holden 1971) shows that many of them are eurythermal. Ostracods have, in contrast to many other marine organisms, such as cephalopods, foraminifers or echinoderms, a very broad temperature tolerance (Ganning 1971) and some species have a comparatively high thermal limit, which was demonstrated for freshwater species (Wickstrom & Castenholz 1973, 1985; Küüköylüoğlu et al. 2003; Küüköylüoğlu 2004; Vandekerkhove et al. 2013). For example, specimens of Thermopsis thermophila were even found in hot springs at water temperatures above 50°C (Küüköylüoğlu et al. 2003). This could indicate that some species were able to tolerate the presumably hot post-extinction climate.

CONCLUSIONS

In the Aras Valley section (north-west Iran), which spans the EPME and the PTB, 59 sampled horizons yielded ostracods: we report here on the occurrence of 62 species, of which ten species and one genus are new: Fabalicypris veronicae Gliwa, sp. nov., Orthobairdia capuliformis Gliwa, sp. nov., Araxobairdia formosa Gliwa, gen. et sp. nov., Bairdiacypris kathleenae Gliwa, sp. nov., Eumiraculam mettei Gliwa, sp. nov., Liuzhinia julifensis Gliwa, sp. nov., Carinaknightina hofmanni Gliwa, sp. nov., Cavellina fosteri Gliwa, sp. nov., Cavellina hairapetiani Gliwa, sp. nov. and Hungaroleberis striatus Forel, sp. nov.

The species compositions of all samples represent a typical tropical marine environment. The occurrences of taxa, which are usually found in distal platform environments (Microcheilinella, Orthobairdia, Basslerella and Kirkbyidae) confirm a deep shelf setting without large-scale bathymetric changes, as already suggested from the microfacies analysis. Furthermore, a high number of occurrences of the Bairdiidae, which are present throughout the entire succession, indicate open marine conditions with normal marine salinity and oxygen concentrations.

The pre-extinction ostracod assemblage of the Paratiriolites Limestone is dominated by Fabalicypris obunca, which forms a monospecific assemblage in the uppermost sample. The low diversity of this assemblage may be caused by depleted oxygenation of the habitat, although sedimentological and palaeontological investigations of the studied section, as well as neighbouring sections, suggest an oxygenated environment. The subsequent total faunal turnover at the EPME and the transition from the Paratiriolites Limestone to the Aras Member (‘Boundary Clay’) coincides with the massive temperature increase, which was determined for north-west Iran. The post-extinction assemblages are dominated by Bairdiacypris ottomanensis and show a relatively high diversity in the immediate aftermath of the EPME. Compared with other diverse ostracod assemblages from the Palaeotethyan realm, the ostracods of the Aras Valley section are not associated with microbialites.

Acknowledgements. We are indebted to the Aras Free Zone Office (Juija) for logistical support for the field sessions. We thank Kathleen Schindler (Berlin) for processing the ostracod samples. Many thanks to William J. Foster (Dublin) for discussions and his helpful comments on the manuscript. Furthermore we are indebted to Avraham Honigstein (Jerusalem), Frank Scholze (Darmstadt), Gengo Tanaka (Kanazawa) and an anonymous reviewer for reviews of an earlier version of the manuscript. For financial support of the project, we acknowledge the Deutsche Forschungsgemeinschaft (DFG project Ko1829/18-1) and the TERSANE research group (FOR 2332).

DATA ARCHIVING STATEMENT

This published work and the nomenclatural acts it contains, have been registered in ZooBank: http://zoobank.org/References/E6A6F765-45C0-43A9-B3BD-1E3446BAD2B0

Data for this study are available in the Dryad Digital Repository: https://doi.org/10.5061/dryad.dncjsxkwc

Editor. Yue Wang

REFERENCES

ARAKEYAN, R. A., GRUNT, T. A. and SHEVYREV, A. A. 1965. Kratkiy stratigraficheskiy ocherk. 20–25. In RZUHENCEV, V.E. and SARYTCEVA, T.G. (eds). Rasvitie i smena morskikh organizmov na rubezhe Paleozoya i Mezozoya. Trudy Paleontologicheskogo Instituta Akademiya Nauk SSSR, 108. [in Russian]

BAIRD, W. 1845. Arrangement of the British Entomostraca, with a list of species, particularly noticing those which have as yet been discovered within the bounds of the Club. History of the Berwickshire Naturalists’ Club, 2, 145–158.

BELOUSOVA, Z. 1965. Evolution and succession of organisms at Paleozoic-Mesozoic boundary. Trudy Paleontologicheskogo Instituta Akademii Nauk SSSR, 108, 245–265.
paleoceanography of the Eurasian Basin, Arctic Ocean. *Paleoceanography, 10*, 259–281.

DINGLE, R. and GIRA UDEAU, J. 1993. Benthic Ostracoda in the Benguela System (SE Atlantic): a multivariate analysis. *Marine Micropaleontology, 22*, 71–92.

EGOROV, V. 1950. *Frasnian ostracods from Russian platform*. *I. Kloedenellidae*. VNIGRI (All Russia Petroleum Research Exploration Institute), 175 pp. [in Russian]

— 1954. *Indivisiniae. A new family of Kloedenellidae from the Frasnian strata of Russian platform*. VNIGRI (All Russia Petroleum Research Exploration Institute), 1, 5–21. [in Russian]

ERWIN, D. H. 1994. The Permo-Triassic extinction. *Nature*, 367, 231–236.

FOREL, M.-B. 2012. Ostracods (Crustacea) associated with microbialites across the Permian-Triassic boundary in Dajiang (Guizhou Province, south China). *European Journal of Taxonomy*, 19, 1–34.

— 2014. Heterochronous growth of ostracods (Crustacea) from microbial deposits in the aftermath of the end-Permian extinction. *Journal of Systematic Palaeontology*, 13, 315–349.

and CRASQUIN, S. 2011. Lower Triassic ostracods (Crustacea) from the Meishan section, Permian-Triassic boundary GSSP (Zhejiang Province, South China). *Journal of Systematic Palaeontology*, 9, 455–466.

— KERSHAW, S., FENG, Q. and COLLIN, P.-Y. 2009. Ostracods (Crustacea) and water oxygenation in the earliest Triassic of South China: implications for oceanic events at the end-Permian mass extinction. *Australian Journal of Earth Sciences*, 56, 815–823.

— BRUHWILER, T., GOUDEMANN, N., BUCHER, H., BAUD, A. and RANDON, C. 2011. Ostracod recovery after Permian-Triassic boundary mass-extinction: the south Tibet record. *Palaeogeography, Palaeoclimatology, Palaeoecology, 308*, 160–170.

— HIPS, K., KERSHAW, S., COLLIN, P.-Y. and HAAS, J. 2013. Biodiversity evolution through the Permian-Triassic boundary event: ostracods from the Bükkl Mountains, Hungary. *Acta Palaeontologica Polonica, 58*, 195–219.

— CHITNARIN, A., ANGIOLINI, L. and GAE-TANI, M. 2015. Precocious sexual dimorphism and the Liliput effect in Neo-Tethyan Ostracoda (Crustacea) through the Permian-Triassic boundary. *Palaeoecology, 58*, 409–454.

— THUY, B. and WISSHAK, M. 2019. Digging into the ancestral stocks of Jurassic lineages: ostracods (Crustacea) from Carnian (Late Triassic) sponge mounds from the Maantang Formation (South China). *BSGF Earth Sciences Bulletin, 190* (9), 1–29.

FRENZEL, P. and BOOMER, I. 2005. The use of ostracods from marginal marine, brackish waters as bioindicators of modern and Quaternary environmental change. *Palaeogeography, Palaeoclimatology, Palaeoecology, 225*, 68–92.

GANNING, B. 1971. On the ecology of *Heterocypri s salinus, H. incongruens* and *Cypridopsis aculeata* (Crustacea: Ostracoda) from Baltic brackish-water rockpools. *Marine Biology, 8*, 271–279.

GHADERI, A. 2014. Stratigraphy and paleoecology of the Upper Permian to Permian-Triassic boundary in the northwest of Iran based on biostratigraphic data of conodonts and brachiopods. PhD thesis, Ferdowsi University of Mashhad, 488 pp.

— LEDA, L., SCHOBEN, M., KORN, D. and ASHOURI, A. R. 2014a. High-resolution stratigraphy of the Changhsingian (Late Permian) successions of NW Iran and the Transcaucus based on lithological features, conodonts and ammonoids. *Fossil Record, 17*, 41–57.

— GARBELLI, C., ANGIOLINI, L., ASHOURI, A. R., KORN, D., RETTORI, R. and GHARAEI, M. H. M. 2014b. Faunal change near the end-Permian extinction: the brachiopods of the Ali Bash Mountains, NW Iran. *Rivista Italiana di Paleontologia e Stratigrafia, 120*, 27–59.

GLIWA, J., GHADERI, A., LEDA, L., SCHOBEN, M., TOMÁS, S., FOSTER, W. J., FOREL, M.-B., GHANIZADEH TABRIZI, N., GRASBY, S. E., STRUCK, U., ASHOURI, A. R. and KORN, D. 2020a. Aras Valley (Northwest Iran); high-resolution stratigraphy of a continuous central Tethyan Permian–Triassic boundary section. *Fossil Record, 23*, 33–69.

— FOREL, M.-B., CRASQUIN, S., GHADERI, A. and KORN, D. 2020b. Data from: Ostracods from the end-Permian mass extinction in the Aras Valley section (north-west Iran). *Dryad Digital Repository*. https://doi.org/10.5061/dryad.dnjsxkw

GÓMEZ, J. and ARIAS, C. 2010. Rapid warming and ostracods mass extinction at the Lower Toarcian (Jurassic) of central Spain. *Marine Micropaleontology, 74*, 119–135.

GRAMM, M. N. 1975. Ostracods of the genus Microcheilinella in the Middle Triassic of the southern Primorye. *Palaeontologisch-Zhurnal, 3*, 83–88.

GRASBY, S., BEAUCHAMP, B., EMBRY, A. and SANEI, H. 2013. Recurrent Early Triassic ocean anoxia. *Geology, 41*, 175–178.

GRÜNDDEL, J. 1967. Zur Grossgliederung der Ordnung Podocypidea G. W. Müller, 1894. *Neues Jahrbuch für Geologie & Paläontologie, Monatshefte, 6*, 321–332.

— 1969. Neue taxonomische Einheiten der Unterklasse Ostracoda (Crustacea). *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte, 6*, 353–361.

HAO, W. 1996. Ostracods from the Upper Permian and Lower Triassic of the Zhenfeng Section, South China. *Journal of Geosciences, Osaka City University, 39*, 19–27.

HARLTON, B. H. 1927. Some Pennsylvanian Ostracoda of the Glenn and Hoxbar Formations of southern Oklahoma and of the upper part of the Cisco Formation of northern Texas. *Journal of Paleontology, 1*, 203–212.

— 1933. Micropaleontology of the Pennsylvanian Johns Valley Shale of Ouachita Mountains, Oklahoma and its relationships to the Mississippian Caney Shale. *Journal of Paleontology, 7*, 3–29.

HAYEZ, J. E. and HOLDEN, J. C. 1971. Ostracoda of Late Eocene age from Eua, Tonga. *Geological Survey Professional Paper, 640-D, D1–D11*.

HEIP, C. 1976. The life-cycle of *Cyprideis torosa* (Crustacea, Ostracoda). *Oecologia, 24*, 229–245.

HENNINGSMOEN, G. 1953. Classification of Paleozoic straight-hinged ostracods. *Norsk Geologisk Tidsskrift, 31*, 185–290.

HINOJOSA, J. L., BROWN, S. T., CHEN, J., DEPAOLO, D. J., PAYTAN, A., SHEN, S.-Z. and PAYNE, J. L. 2012.
Evidence for end-Permian ocean acidification from calcium isotopes in biogenic apatite. Geology, 40, 743–746.

HINZ-SCHALLREUTER, I. and SCHALLREUTER, R. 1999. Ostrakoden: 255 Einzeldarstellungen. Ferdinand Enke Verlag, Stuttgart.

HORNE, D. J., COHEN, A. and MARTENS, K. 2002. Taxonomy, morphology and biology of Quaternary and living Ostracoda. 5–36. In HOLMES, J. A. and CHIVAS, A. (eds). The Ostracoda: Applications in Quaternary research. Geophysical Monograph Series, 131. American Geophysical Union.

— BRANDÃO, S. N. and SLIPPER, I. I. 2011. The Platy-copid signal deciphered: responses of ostracod taxa to environmental change during the Cenomanian-Turonian Boundary Event (Late Cretaceous) in SE England. Palaeogeography, Palaeoclimatology, Palaeoecology, 308, 304–312.

ISOZAKI, Y. 1997. Permo-Triassic boundary superanoxia and stratified superocean: records from lost deep sea. Science, 276, 235–238.

JAANUSSON, V. 1985. Functional morphology of the shell in platycope ostracodes: a study of arrested evolution. Lethaia, 18, 73–84.

JAHN, A., GAMENICK, I. and THEEDE, H. 1996. Physiological adaptations of Cyprideis torosa (Crustacea, Ostracoda) to hydrogen sulphide. Marine Ecology Progress Series, 142, 215–223.

JOACHIMSKI, M. M., LAI, X., SHEN, S., JIANG, H., LEO, G., CHEN, B., CHEN, J. and SUN, Y. 2012. Climate warming in the latest Permian and the Permian–Triassic mass extinction. Geology, 40, 195–198.

JONES, T. R. 1901. On some Carboniferous shale from Siberia. Geological Magazine, 8, 433–436.

KAJIYAMA, E. 1913. On the Ostracoda from Misaki. Part 3. Doubutsugaku Zasshi, 25, 1–16.

KIDDER, D. L. and WORSLEY, T. R. 2004. Causes and consequences of extreme Permo-Triassic warming to globally equable climate and relation to the Permo-Triassic extinction and recovery. Palaeogeography, Palaeoclimatology, Palaeoecology, 203, 207–237.

KIESSLING, W., SCHOBKEN, M., GHADERI, A., LAU, K. V., MAHER, K., ALTINER, D., KELLEY, B. M., LATREILLE, P. A. 1806. Thermopsis ther-

KUMP, L. R., LEHRMANN, D. J., SILVA-TAMAYO, J., WEAVER, K. L., YU, M. and PAYNE, J. L. 2016. Marine Ecology Progress Series, 301 pp. Amand Koenig, Paris,

KORNY, D., KRÁH, M., SCHOBKEN, M. and ASHOURI, A. R. 2016. The ammonoids from the Late Permian Paratirilites Limestone of Julfa (East Azerbaijan, Iran). Journal of Systematic Palaeontology, 14, 841–890.

KORNICKER, L. S. 1961. Ecology and taxonomy of recent Bairdiinae (Ostracoda). Micropaleontology, 7, 55–70.

KOTLYAR, G. V., ZAKHAROV, Y. D., KOCHYRKE-VICZ, B. V., KROPATCHEVA, G. S., ROSTOVCEV, L. O., CHEDJIA, I. O., VUKS, G. P. and GUSEVA, E. A. 1983. Proekt No 106 (“Permo-Triasovaya stadiya geologicheskoy evolyutsii”) Mezhduunarodnoy programmy geologicheskoy korrelyatsii. Posdnepernskiy etap evolyutsii organicheskogo mira. Dzhulficheskiy i dorashamskiy yarusy SSSR (Evolution of the latest Permian biota, Dzhulfian and Dorashamian stages of the USSR). Akademiya Nauk SSSR, Biologo-Pochvennyi Institut, Leningrad. [in Russian]

KOZUR, H. W. 1985. Neue Ostracoden-Arten aus dem Oberen Mittelkarbon (Höheres Moskovian), Mittel- und Oberperm des Bükk-Gebirges (N-Ungarn). Geologisch-Paläontologische Mitteilungen Innsbruck, Sonderband, 2, 1–145.

— 2005. Kozur, H. W. (2004). Pelagic uppermost Permian and the Permian–Triassic boundary conodonts of Iran. Part II: investigated sections and evaluation of the conodont faunas. Hallesches Jahrbuch für Geowissenschaften, Reihe B, Heft, 19, 49–86.

— 2007. Biostratigraphy and event stratigraphy in Iran around the Permian–Triassic Boundary (PTB): implications for the causes of the PTB biotic crisis. Global & Planetary Change, 55, 155–176.

— and METTE, W. 2006. Iranokirkbya brandneri n. gen. n. sp., a new kirkbyid ostracod from the Late Permian (Dorashamian) of Zal, NW Iran. Geo. A, 3, 85–91.

KRISTAN-TOLLMANN, E. 1991. Ostracods from the Middle Triassic Sina Formation (Aghdarband Group) in NE-Iran. Abhandlungen der Geologischen Bundesanstalt, 38, 195–200.

KÜLKÖYLUOĞLU, O. 2004. On the usage of ostracods (Crustacea) as bioindicator species in different aquatic habitats in the Bolu region, Turkey. Ecological Indicators, 4, 139–147.

— MEISCH, C. and RUST, R. W. 2003. Thermopsis thermophila n. gen. n. sp. from hot springs in Nevada, USA (Crustacea, Ostracoda). Hydrobiologia, 499, 113–123.

LATREILLE, P. A. 1806. Genera crustaceorum et insectorum: Secondum ordinem naturalen in familias disposita, iconibus exemplisque plurimis explicate. Tomus I. Amand Koenig, Paris, 301 pp.

LAU, K. V., MAHER, K., ALTINER, D., KELLEY, B. M., KUMP, L. R., LEHRMANN, D. J., SILVA-TAMAYO, J. C., WEAVER, K. L., YU, M. and PAYNE, J. L. 2016. Marine anoxia and delayed Earth system recovery after the end-Permian extinction. Proceedings of the National Academy of Sciences, 113, 2360–2365.

LEDA, L., KORN, D., GHADERI, A., HAIRAPETIAN, V., STRUCK, U. and REIMOLD, W. U. 2014. Lithostratigraphy and carbonate microfacies across the Permian–Triassic boundary near Julfa (NW Iran) and in the Baghuk Mountains (Central Iran). Facies, 60, 295–325.

LIU, H., WANG, Y., YUAN, A., YANG, H., SONG, H. and ZHANG, S. 2010. Ostracod fauna across the Permian–Triassic boundary at Chongyang, Hubei Province, and its implication for the process of the mass extinction. Science China Earth Sciences, 53, 810–817.

MADDocks, R. F. 1969. Revision of Recent Bairdiidae (Ostracoda). United States National Museum Bulletin, 295, 1–126.

MANDELSTAM, M. I. 1960. [Subfamily Sigilliuminae]. 398. In CHERNYSHEVA, N. E. (ed.) Osnovy paleontologii: Arthropoda, Trilobitomorpha et Crustaceomorpha. State Scientific Technological Publishing House, Moscow.
McCOY, F. 1844. A synopsis of the characters of the Carboniferous limestone fossils of Ireland. Dublin University Press, 207 pp.

MELNYK, D. H. and MADDOWKS, R. F. 1988. Ostracode biostratigraphy of the Permo-Carboniferous of central and north-central Texas, Part I: paleoenvironmental framework. Micropaleontology, 34, 1–20.

MESQUITA-JOANES, F., SMITH, A. J. and VIEHBERG, F. A. 2012. The ecology of Ostracoda across levels of biological organisation from individual to ecosystem: a review of recent developments and future potential. 15–35. In HORNÉ, D. J., HOLMES, J., RODRIGUEZ-LAZARO, J. and VIEHBERG, F. A. (eds). Ostracoda as proxies for Quaternary climate change. Elsevier.

METTE, W. 2008. Upper Permian and lowermost Triassic stratigraphy, facies and ostracods in NW Iran: implications for the P/T extinction event. Stratigraphy, 5, 205–219.

MODIG, H. and ÖLAFSSON, E. 1998. Responses of Baltic benthic invertebrates to hypoxic events. Journal of Experimental Marine Biology & Ecology, 229, 133–148.

MOORE, R. C. 1961. Treatise on invertebrate paleontology. Part Q. Arthropoda 3. Crustacea, Ostracoda. Geological Society of America & University of Kansas Press.

MÜLLER, G. W. 1894. Die Ostracoden des Golfs von Neapel und der angrenzenden Meeresabschnitte. Flora & Fauna Neapel, 21, 1–413.

MÜLLER, G. W. 1906. Ostracoda. Wissenschaftliche Ergebnisse der Deutsche Tiefsee-Expedition 1898–1899, 8, 154 pp.

MUTTONI, G., GAETANI, M., KENT, D. V., SCIUNNACH, D., ANGIOLINI, L., BERRA, F., GARZANTI, E., MATTEI, M. and ZANCHI, A. 2009. Opening of the Neo-Tethys Ocean and the Pangea B to Pangea A transformation during the Permian. GeoArabia, 14, 17–48.

OZAWA, H. 2013. The history of sexual dimorphism in Ostracoda (Arthropoda, Crustacea) since the Palaeozoic. 51–80. In MORIYAMA, H. (ed.) Sexual dimorphism. IntechOpen, Rijeka, 149 pp.

PAYNE, J. L., LEHRMANN, D. J., FOLLETT, D., SEIBEL, M., KUMP, L. R., RICCARDI, A., ALTNER, D., SANO, H. and WEI, J. 2007. Erosional truncation of uppermost Permian shallow-marine carbonates and implications for Permian–Triassic boundary events. Geological Society of America Bulletin, 119, 771–784.

PETERSON, R. M. and KAESLER, R. L. 1980. Distribution and diversity of ostracode assemblages from the Hamlin shale and the Americas Limestone (Permian, Wolfcampian) in Northeastern Kansas. The University of Kansas Paleontological Contributions, 100, 1–26.

RICHOW, S., KRYSTYN, L., BAUD, A., BRANDNER, R., HORACEK, M. and MOHTAT-AGHAI, P. 2010. Permian–Triassic boundary interval in the Middle East (Iran and N. Oman): progressive environmental change from detailed carbonate carbon isotope marine curve and sedimentary evolution. Journal of Asian Earth Sciences, 39 (4), 236–253.

ROSSI, V., TODESCHI, E., GANDOLFI, A., INVIDIA, M. and MENOZZI, P. 2002. Hypoxia and starvation tolerance in individuals from a riverine and a lacustrine population of Darwinula stevensoni (Crustacea: Ostracoda). Archiv für Hydrobiologie, 154, 151–171.

RUZHENCEV, V., SARYTCHEVA, T. and SHEVYREV, A. 1965. Biotratigraphischen vyyvody. Trudy Paleontologicheskogo Instituta Akademiya Nauk SSSR, 108, 93–116. [in Russian]

SARS, G. O. 1866. Oversigt af marine Ostracoeder. Norske Videnskaps-Akademis, Förhandlingar, 1865, 1–130. [in Norwegian]

— 1887. Nye bidrag til kundskaben om Middelhavets invertebratfauna. IV, Ostracoda mediterranea (sydeuropæiske Ostracoder). Archiv für Mathematik og Naturvidenskab, 12, 173–324.

— 1922–1928. An account of the Crustacea of Norway. Vol. 9, Crustacea. Bergen Museum, 9, 1–277.

SATO, T. and KAMIYA, T. 2007. Taxonomy and geographical distribution of recent Xestoleberis species (Cytheroidea, Ostracoda, Crustacea) from Japan. Paleontological Research, 11, 183–228.

SCHOBLEN, M., JOACHIMSKI, M. M., KORN, D., LEDA, L. and KORTE, C. 2014. Palaeotethys seawater temperature rise and an intensified hydrological cycle following the end-Permian mass extinction. Gondwana Research, 26, 675–683.

SCOTT, H. W. 1959. The type species of Paraparappites Ulrich & Bassler. Journal of Paleontology, 33, 670–674.

— 1961. Suborder Beyrichicopina Scott n. suborder. Suborder Kloedenellucopina Scott n. suborder. Q111–Q180. In MOORE, R. C. (ed.) Treatise on invertebrate paleontology. Part Q. Arthropoda 3. Geological Society of America & University of Kansas Press.

SHEN, S.-Z. and MEI, S.-L. 2010. Lopingian (Late Permian) high resolution conodont biostratigraphy in Iran with comparison to South China zonation. Geological Journal, 45, 135–161.

SHI, C.-G. and CHEN, D.-Q. 1987. The Changhsingian ostracodes from Meishan, Changxing, Zhejiang. Comparison to South China zonation. Geological Journal, 39, 135–161.

SLIPPER, I. J. 2005. Ostracod diversity and sea-level changes in the Late Cretaceous of southern England. Palaeogeography, Palaeoclimatology, Palaeoecology, 225, 266–282.

SMITH, R. J. and HIRUTA, S. 2004. A new species of Metycypsis (Limnoictheridae, Cytheroidea, Ostracoda, Crustacea) from Hokkaido, Japan. Species Diversity, 9, 37–46.

— and KAMIYA, T. 2002. The ontogeny of Neonesidea oligodontata (Bairdioidae, Ostracoda, Crustacea). Hydrobiologia, 489, 245–275.

— —— 2005. The ontogeny of Uncincocythere occidentalis (Kozloff and Whitman, 1954) Hart, 1962 (Crustacea). Hydrobiologia, 538, 217–229.

SOHN, I. G. 1960. Paleozoic species of Bairdia and related genera. United States Geological Survey Professional Paper, 330-A, 1–105.
— 1908. New American Paleozoic Ostracoda. Preliminary revision of the Beyrichiidae, with descriptions of new genera. Proceedings of the United States National Museum, 35, 277–340.

— 1923. Paleozoic Ostracoda: their morphology, classification, and occurrence. Maryland Geological Survey, Silurian, 9, 271–391.

VANDEKERKHOVE, J., MARTENS, K., ROSSETTI, G., MESQUITA-JOANES, F. and NAMITOKO, T. 2013. Extreme tolerance to environmental stress of sexual and parthenogenetic resting eggs of *Eucypris virens* (Crustacea, Ostracoda). *Freshwater Biology*, 58, 237–247.

WAN, J., YUAN, A., CRASQUIN, S., JIANG, H., YANG, H. and HU, X. 2019. High-resolution variation in ostracod assemblages from microbialites near the Permian–Triassic boundary at Zuodeng, Guangxi region, South China. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 335, 109349.

WANG, S.-Q. 1978. Late Permian and Early Triassic ostracods of western Guizhou and northeastern Yunnan. *Acta Palaeontologica Sinica*, 17, 277–312.

WICKSTROM, C. E. and CASTENHOLZ, R. W. 1973. Thermophilic ostracod: aquatic metazoan with the highest known temperature tolerance. *Science*, 181, 1063–1064.

— 1985. Dynamics of cyanobacterial and ostracod interactions in an Oregon hot spring. *Ecology*, 66, 1024–1041.

WIGNALL, P. B. and TWITCHETT, R. J. 1996. Oceanic anoxia and the end Permian mass extinction. *Science*, 272, 1155–1158.

YASUHARA, M., YAMAZAKI, H., IRIZUKI, T. and YOSHIIWA, S. 2003. Temporal changes of ostracode assemblages and anthropogenic pollution during the last 100 years, in sediment cores from Hiroshima Bay, Japan. *The Holocene*, 13, 527–536.

ZAKHAROV, Y. D. 1992. The Permo-Triassic boundary in the southern and eastern USSR and its intercontinental correlation. 46–55. In SWEET, W. C., ZUNYI, Y., DICKINS, J. M. and HONGFU, Y. (eds). Stratigraphy, classification and relations with the western Tethys. World & Regional Geology, 2. Cambridge University Press.

ZAZZALI, S., CRASQUIN, S., DECONINCK, J.-F. and FENG, Q. 2015. Biodiversity across the Guadalupian-Lopingian Boundary: first results on the ostracod (*Crustacea*) fauna, Chaotian section (Sichuan Province, South China). *Geodiversitas*, 37, 283–314.

ZHANG, F., ROMANIELLO, S. J., ALGEO, T. J., LAU, K. V., CLAPHAM, M. E., RICHOZ, S., HERRMANN, A. D., SMITH, H., HORACEK, M. and ANBAR, A. D. 2018. Multiple episodes of extensive marine anoxia linked to global warming and continental weathering following the latest Permian mass extinction. *Science Advances*, 4, e1609221.

ZHENG, S. 1976. Early Mesozoic ostracods from some localities in South West China. *Acta Palaeontologica Sinica*, 15, 77–93.