Freshwater Ostracoda from the Wetland Mid-Holocene Sediments, Dhamar Highlands, Yemen

Munef Mohammed and Dietmar Keyser

Abstract Sediments of early and mid-Holocene age of Qa'a Jahran-Dhamar highlands, Yemen, were analyzed for the occurrence of freshwater Ostracoda. Nowadays the study area is a semiarid region that receives limited moisture twice a year, usually in the form of a wet season in March–May and July–August. However, the high abundance of freshwater ostracods recorded from the subsurface marl deposits indicates a wetland (probably several ponds) in Jahran basin during the humid period of early and mid-Holocene**.** 15 species of ostracods have been identified; most of them are widely distributed across the Holarctic; however, some are previously recorded only from East Africa such as *Humphcypris* cf. *decipiens mawenzii* (Löffler, H., *Hochgebirgsforschung* 1:107-169, 1968).

Keywords Freshwater Ostracoda · Taxonomy · Paleoclimate · Holocene · Yemen

1 Introduction

Ostracoda are small crustaceans characterized by a bivalve shell hinged along the dorsal margin. Ostracod carapace vary extremely in shape and ornament (even within families); they may be spheroidal, elongated, inflated, or compressed (laterally or vertically) (Martens and Horne 2009). They have an ubiquitous distribution, a high taxonomical diversity, and an extensive fossil record. The rich ostracod fossil record is not only due to the easy preservation of their calcified shells but also due to their high adaptability to different environmental conditions. These characteristics make the group a useful study tool in multiple disciplines (Cohen and Morin 1990; Moore 1961). Ostracods are sensitive to fluctuations of ecological parameters mainly

M. Mohammed
Sana'a University, Sana'a, Yemen

D. Keyser (✉)
Biozentrum Grindel, Hamburg University, Hamburg, Germany
e-mail: keyser@uni-hamburg.de

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at the water-sediment interface, which can be temperature, salinity, pH, oxygen, turbulence or trophic level. The record of these variations can be observed at several levels: abundance, diversity, specific composition and carapace ornamentation (Carbonel et al. 1988).

Depending on a number of taxonomic studies of Crustacea, Karanovic (2012) demonstrates that ostracods are classified as a subclass of the class Maxillopoda or as a separate class within the subphylum Crustacea. In the current article Ostracods are accepted as a separate class within Crustacea. Martin and Davis (2001) and Horne et al. (2002) divide the class into subclass Myodocopa and Podocopa. Podocopida has representatives in both fresh and marine environments. The myodocopans (with orders Myodocopida and Halocyprida) are all marine. The podocopans are divided into three orders: the exclusively marine Platycopida, the ubiquitous Podocopida (the most diverse group of Ostracoda at the present day, found in marine, brackish, and nonmarine waters), and the Paleocopida which were diverse and widespread in the Paleozoic but are now represented only by the rare marine Puncioidea (Martens and Horne 2009).

Carapaces and valves of freshwater Ostracoda have been recorded for the first time from the Holocene sediments of Dhamar highlands. They were collected during several field trips carried out by the first author and some graduation students. The deposits that are exposed in the quarries and incomplete dry wells and their faunal content can be considered as an excellent evidence for the formation of wetland environments in tectonic depressions. Climatic change in the Holocene has been responsible for a number of lake formation and fluctuations documented from paleo records throughout different regions of the world (Lézine et al. 1998; de Menocal et al. 2000; Mischke 2001; Park and Cohen 2011; Engel et al. 2012). A number of archaeological and geological studies (Wilkinson 1997; Fleitmann et al. 2003; Mayewski et al. 2004; Davies 2006; Engel et al. 2012; Enzel et al. 2015) have recorded dramatic increase in regional summer rainfall on the Arabian Peninsula during the early and mid-Holocene. This rainfall increase is considered primarily the result of an intensified Indian summer monsoon as part of the insolation-driven, northward shift of the boreal summer position of the Intertropical Convergence Zone (ITCZ) over the deserts of North Africa, Arabia, and northwest India (Enzel et al. 2015).

Lake or marsh sediments in the intermountain basins of the highlands of Dhamar area indicate a period of higher moisture availability in the early and mid-Holocene (Wilkinson 1997; Davies 2006). The development of wetland environment in the intermountain basins of the western Yemeni highlands offered a habitat for a typical local freshwater fauna such as Ostracoda and mollusks. Little is known about the freshwater ostracods of Yemen. Malz (1976) discussed the changes of carapace morphology and the taxonomic problems of the Recent genera, *Heterocypris* Sars, 1903, and *Cyprinotus* Brady 1886, and their fossil relative *Cheikella* Sohn & Morris 1963, described 1963 from Tertiary freshwater deposits in Saudi Arabia. His study also includes some specimens from Yemen. The work by Dumont et al. (1986) focused on the taxonomy and distribution of Cladocera, Copepoda, and Ostracoda from freshwaters of South Yemen. Three valves of *Cyprinotus rostrata* Lowndes

1932, have been recorded by Mohammed (2004) from subrecent dry mud of Aden City. Mazzini and Sardella (2004) found some freshwater ostracods during their Quaternary study on Socotra Island. Mohammed et al. (2018) studied the taxonomy and distribution of Recent freshwater ostracods from the northern part of Socotra Island. The previous archaeological works (Wilkinson 1997; Wilkinson et al. 1997; Wilkinson and Edens 1999; Parker et al. 2006; Davies 2006) on the atmospheric processes and human activity of the Neolithic populations during the humid period of the Holocene in southern Arabia and on the Dhamar highland provided a significant information of some locations in the Jahran plain such as stratigraphic analysis including a detailed visual description of texture, color, structure, and a detailed physical analyses of sediment samples including laser particle size analysis and radiocarbon and accelerator mass spectrometry (AMS) age determinations based on bulk organic sediment and gastropods.

The present work aims to study the taxonomy and diversity of freshwater ostracods extracted from the early and mid-Holocene sediments of Qa'a Jahran-Dhamar highlands. Our study contributes to the biodiversity and distribution of Ostracoda and the history of the humid period during the early and mid-Holocene.

2 Study Area

Yemen is situated at the southwestern corner of the Arabian Peninsula. The geology of Yemen is composed of deposits, volcanic rocks, as well as Tertiary, Jurassic, and Cretaceous formations.

The territory could be divided into four main physiographic regions (Al-khirbash 2003; Al-Rawi 2008) as follows:

1-. The coastal plains, 30–60 km wide along the Red Sea and the Gulf of Aden. They contain numerous intermittent valleys enabling spate irrigation and important agricultural zones.
2-. The Yemen Mountains with very irregular and disunited topography and elevations ranging from a few hundred meters to 3760 m. It is a volcanic region running parallel to the Red Sea coast. Volcanic rocks are found in most of the central and southern highlands (NAPCD 2000).
3-. The Eastern Plateaus are divided in particular by Wadi Hadramaut and its tributaries.
4-. Desert regions, located between the Highlands and the Eastern Plateaus, are the Ramlat As Sabatayn to the south, where rainfall and vegetation are nearly absent, and the hyper-arid Rub'a Al Khali to the north, which is among the most desolate deserts in the world, with a rain fall of less than100 mm in a year.

The area under investigation in Dhamar City is an intermountain basin locally named (Qa'a Jahran) located in the western Yemen Mountains physiographic region. The volcanic plateau in Yemen is associated with the geological process of the opening of the Red Sea and Gulf of Aden. This province is characterized by the occurrence of Tertiary (Yemen Trap Series) and Quaternary (Yemen Volcanic Series) volcanoes. An extensive faulting and fracturing graben and half graben area, probably related to the Red Sea rifting, represent one of the main volcanic activities in the study area. The late Tertiary and the Quaternary volcanic activities (about 5 Ma ago) were confined to the area around Dhamar (Mattash et al. 2013). Yemen Trap Series (YTS) form a high plateau with an average elevation between 2000 and 2500 m, with peaks of more than 3500 m. Lesser volcanic activity continued in the Pliocene and the Quaternary in several areas inside the Yemen Trap Series, 10/20 km east of the city of Dhamar where the last basaltic lava eruption occurred in 1937 (Plakfer et al. 1987). Quaternary volcanoes consist mostly of tuffs (ashes) and vesicular basic lavas. Volcanism in Dhamar-Rada' is the most recent in Yemen and the field still contains sulfurous vents The region of Dhamar is also seismically very unstable, with several recorded historical earthquakes, the last strong destructive one occurring in 1982 (Langer and Merghelani, 1983; Langer et al. 1987; Arya et al. 1985). Dhamar region consists of a series of narrow intermountain tectonic basins surrounded by plateaus. Along the Red Sea, the highlands rise dramatically to the west. In less than 250 km, the topography climbs from sea level to greater than 3500 meters above sea level. The highest peak in the Dhamar region is Jebel al-Lisi, a Pleistocene age volcano (Davies 2006).

Qa'a Jahran (Figs. 1 and 2) is a semi-flat agricultural area about 100 km south of Sana'a surrounded by high plateaus rising approximately to 500 m. It is situated in a graben trough related to the tectonic regime of the opening of the Red Sea and rises to an average elevation of 2400 m above sea level (Figs. 2 and 3). Deep sediment accumulations of Quaternary alluvium and lake deposits varying in thickness were deposited on this plain. These deposits besides the anthropogenic terrace sequences on slope have provided a consistent environmental record of the basin (Wilkinson et al. 1997; Davies 2006). Depending on the detailed physical analyses carried out by Davies (2006) including laser particle size analysis, loss-on-ignition (LOI), and total carbon content, the stratigraphic section of Holocene in Qa'a Jahran is composed of thick gray marl lacustrine deposits accumulated during three humid periods and separated by periods of soil development followed by episodes of increased evaporation. In her study (Davies 2006) also cited that this Holocene section is about 2.50-m-thick and overlays the fine well-sorted alluvial sands which are probably of a Pleistocene age. A thicker section of Holocene sediments (about 2.8 m) has been encountered in our investigation in the current study. The variations in geomorphology are supposed to be the main reason of the differences in thickness of the Holocene sediments (Fig. 3). Throughout the Dhamar high plains, the paleosol, dominated by a generally thick humic buried horizon, provides a clear stratigraphic marker for the Holocene sediments. Wilkinson et al. (1997), Wilkinson et al. (1997), Parker et al. (2006), and Davies (2006) concluded that the properties of the Qa'a Jahran sediments suggest that the climate was wetter than today, presumably a result of enhanced monsoonal circulation, and that slopes were covered by more extensive and denser vegetation. The region lies within the area of the SW monsoon, which

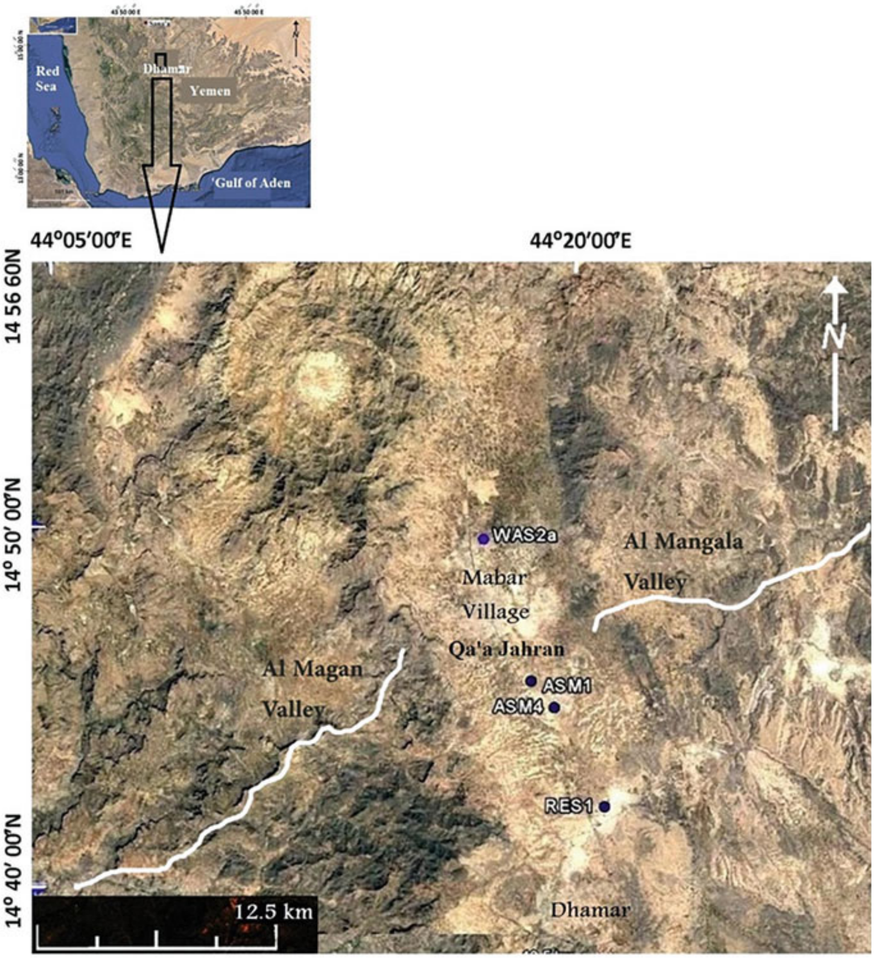

Fig. 1 Location of the study area

delivers to the highland 300 to 1000 mm rainfall per annum, usually in the form of wet seasons in March–May and July–August. Evaporation is high and may reach up to 1500–2500 mm/year in the western mountainous regions (NAPCD 2000). Valleys are the most important source of surface water in the area, but, currently, they are mostly dry, and floods occur only during the high rainy seasons. Only few springs are still perennial and many of them only appear in the summer (NAPCD 2000; Davies 2006; van Steenbergen et al. 2011). Groundwater systems are in a dynamic state, as a result of replenishment and discharge processes. Direct recharge of groundwater is generally very low in Yemen; it occurs mainly by infiltration of surface water from wadis. Consequently, the water table in Dhamar has strongly

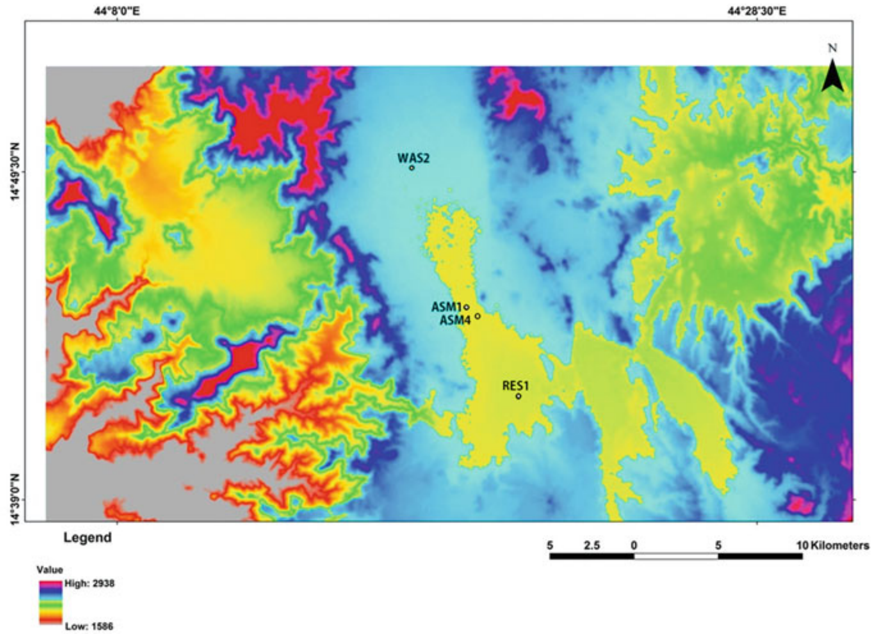

Fig. 2 Digital elevation model (DEM) of Qa'a Jahran

Fig. 3 Landscape of Qa'a Jahran. Photo taken from the northern hill

declined, and, at present, it is common to find wells producing from depths of more than 200–250 m (MWEY 2005; NWRAY 2006) (Fig. 4).

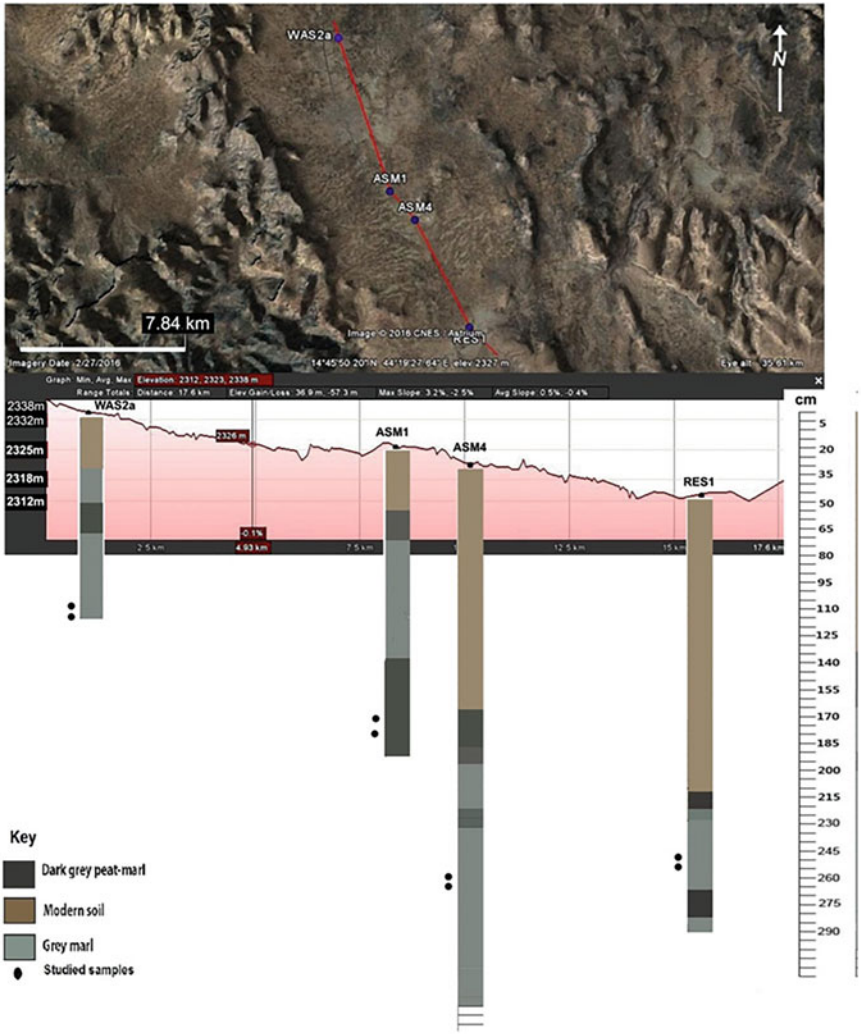

Fig. 4 A topographic profile showing the differences in the geomorphology of the present study sections (ASM4, RES1) and the sections (ASM1, WAS2a) of Mohammed et al. (2018)

3 Material and Methods of Study

A single field trip has been carried out to Qa'a Jahran-Dhamar area during November 2014 to collect the material used in the current study. The studied sections are located in two small villages: one section in Asam Village (ASM4), the other in Resabah Village (RES1). Sediment samples were collected vertically from the stratigraphic sections with an interval of 5 cm for carrying out various scientific investigations including the present study and graduation projects of students of the

Table 1 Geographical and sediment data

Studied sections	Sediments	Location	Latitude	Longitude
ASM 4	Marl, humus soils, mollusks, ostracods, shell debris, and small rock fragments	Asam Village	14°45′2.70”N	44°19′27.20″E
RES1	Travertine, humus soils, gastropods, debris of ostracod shells, and rock fragments	Resabah Village	14°42′20.00”N	44°20′52.40″E

Earth and Environmental Sciences, Sana’a University. Gray marl layers and organic soil horizons have been traced laterally through some sections exposed in wells drilled by local villagers in the Qa’a Jahran. Some field inspections of the sediment lithology, grain size, color, sedimentary structures, and distribution of mollusk shells have been carried out during the trip. Sediment samples were collected from the ASM4 (290 cm) and RES1 (240 cm) sections which were drilled using simple tools. The Holocene layers show similarity in lithology with the previous studied sections of Mohammed et al. (2018) and Davies (2006) but differ in thickness; however in Resabah Village (RES1), marl and sediments and structures mostly of evaporates and travertine have been encountered. The marl and travertine sequences in both sections are overlain by mid-Holocene very dark gray to black humus soils. These black organic soil horizons are capped by modern soil of fine sandy silt loam. In the thicker section (ASM4), the marl is underlain by gravel fine alluvial sands probably of Pleistocene age (Davies 2006; Parker et al. 2006). The sample locations along with geographical coordinates and the sediment characters are given in (Table 1). For the current study, marl sediment samples of a unit weight of 250 gram were analyzed. Samples were covered in a pan with 29% hydrogen peroxide to separate the very fine sediments from the shells. After allowing them to soak for about 12 hours, samples were washed with running tap water over a 200 mesh sieve (opening of 0.074 mm) to remove mud-size sediments. About 10 to 15 g of sandy sediment and shells (and rock fragments in some levels) were extracted from each sample. The ostracod fauna was collected by using a 00 brush, under a stereomicroscope. Ostracods are very well preserved; all the shells that are sufficient for identification were collected and placed into microslides. SEM micrographs of the recorded species were taken in the Zoological Institute and Museum at Hamburg University. A 21-megapixel digital camera was also used to photograph some species. Some SEM photos from (Mohammed et al. 2018) are used here for comparison purposes. Specimens of all ostracod species were deposited in the Department of Earth and Environmental Sciences, Faculty of Science, Sana’a University. All measurements are given in millimeters. Abbreviations used are ASM, Asam section; RES, Resabah section; WAS, Wasta section; RV, right valve; LV, left valve; C, carapace; V, valve; L, length; H, height.

4 Taxonomy and Ecology of Ostracoda

The systematic is based on Moore (1961), Hartmann and Puri (1974), Meisch (2000), and Karanovic (2012). The information on ecology of the species encountered in the current study has been gathered from several contributions (Ganning 1971; Hiller 1972; Hartmann and Hiller 1977; Meisch 2000; Frenzel et al. 2010; Fuhrmann 2012).

Because of the difficulties regarding identifying the juveniles of Ilyocypridids in ASM4 section, they have been counted separately and divided between the most abundant species. The large number of Pseudocandonids in RES1 section is referred to *Pseudocandona* spp.

Class Ostracoda Latreille, 1802
Subclass Podocopa Sars, 1866
Order Podocopida Sars, 1866
Suborder Cypridocopina Jones, 1901
Superfamily Cypridoidea Baird, 1845
Family Cyprididae Baird, 1845
Subfamily Cypridinae Baird, 1845
Genus *Cypris* O. F. Müller, 1776
Cypris bispinosa Lucas, 1849
(Pl. 1, figs. 1-3)

1849 *Cypris bispinosa* Lucas, p.82, pl.8: 7.
1961 *Cypris bispinosa* Lucas, Löffler 1961, p. 349.
2000 *Cypris bispinosa* Lucas, Meisch, pp. 274,275, Fig. 115A-D.
2001 *Cypris bispinosa* Lucas. Altinsaçli 2001, p. 346.

Material: Adult spines, 46; juvenile valves, 37.

Size: No adults have been encountered, probably due to their thin-shelled carapaces; nevertheless, valves of different stages and size of juveniles were found.

Occurrence: ASM4.

Distribution: Northwestern Europe, Azores and Canary Islands, Mediterranean area, the Middle East and Central Asia, France, England, and Germany (Meisch 2000; Vimpère and Colin 2003). **Remarks:** A small number of juvenile separated valves of the species were recorded; however, a considerable number of fragments and adult spines have been found, probably because of their thin calcareous shells.

Ecology: Prefer slightly temporary temperate ponds that are rich in aquatic vegetation, with a maximum salt content of 3.6‰, but it also lives in permanent freshwater.

Repository of the material: QJ. 1 (2).

Subfamily Herpetocypridinae Kaufmann, 1900.
Genus *Humphcypris* Martens 1997
Humphcypris cf. *anomala* (Lindroth 1953)
(Pl. 1, figs. 4, 5)

1953 *Stenocypris decipiens anomala* Lindroth, p. 78–80, Figs. 53–57.

1968 *Stenocypris decipiens mawenzii* Löffler 1968, p.157, Abb. 7, Tafel 6, Fig. a, b, c, d

?2015 *Humphcypris* cf. *brevisetosa* Kassa, p. 105, Fig. 5.14.H-K.

Material: Adult valves, 12; juvenile valves, 3.

Size: L: 1.14 mm, H: 0.52 mm.

Occurrence: ASM4.

Distribution:: It has been recorded from Swam River and Mawenzi, East Africa.

Remarks: The species is doubtfully identified as *H. anomala* because it differs from the specimens recorded by (Lindroth 1953) in the structure of the inner margin of the inner lamellae. It is also very close to *H. brevisetosa*, but our specimens possess a steeper antero-dorsal margin and are smaller in size. The relatively wider posteroventral margin and/or the general shape of our specimens differ from the other representatives of the genus.

Ecology: Freshwater epigean lakes. Martens (1997) mentioned that most of the species occurring in the tropics are found in springs or streams at elevated altitudes or in high mountain lakes such as the present species (3580–4500 m).

Repository of the material: QJ. 2 (2).

Subfamily Cyprinotinae Bronstein, 1947
Genus *Heterocypris* Claus, 1892
Heterocypris salina (Brady 1868)
(Plate 1, figs. 6-10)

1868 *Cypris salinus* Brady, S. 368, pl. 28 Figs. 8–13.

1968 *Cyprinotus salinus* (Brady) Bhatia 1968, p. 471, pl.1, Fig. 1a-c, pl. 5, Fig. 9.

1980 *Hemicypris posterotruncata* (Brady) Bate et al. pl. 2, Fig. 6.

1996 *Heterocypris salina* (Brady) Schöning 1996, pp. 41–42, Figs.1–4, 7–9.

2001 *Heterocypris salina* (Brady), Griffiths et al. 2001, p. 763.

2004 *Heterocypris salina* (Brady) Rosenfeld et al., p. 173, pl. 1, Fig. 15.

2010 *Heterocypris* cf. *salina* (Brady) Mischke et al., Fig. 9.

2012 *Heterocypris salina* (Brady) Mischke et al., pl. 2, Fig. 7–10, 18.

2012 *Heterocypris salina* (Brady) Fuhrmann, p. 228, pl. 108, Fig. 1a-d, 2a-d.

2014 *Heterocypris salina* (Brady) Kalbe et al. 2014, Fig. 3 j.

2016 *Heterocypris salina* (Brady) Kalbe et al. 2016, Fig. 6 g-h.

Material: Adult valves, 517; Juvenile valves, 949. Carapaces, 14.

Size: RV, L, 1.13 mm; H, 0.70 mm. LV, L, 1.2 mm; H, 0.77 mm.

Occurrence: ASM4.

Distribution: Holarctic with introductions into the southern hemisphere (Meisch 2000).

Remarks: A large number of the species recorded in the present study are juvenile carapaces and valves.

Ecology: Very shallow, permanent, and temporary ponds with salinity range (0.4–8.6‰, oligohaline to low mesohaline). Animals may also occur in pure freshwater habitats. Temperature:16–22 °C., the species prefers habitats that are high in nutrients and low in temperature, low oxygen (< 1 ml/l.).

Repository of the material: QJ. 3 (2) (Plate 1).

Subfamily Cypridopsinae Kaufmann, 1900
Tribus CYPRIDOPSINI Bronstein, 1947
Genus *Cypridopsis* Brady, 1867
Cypridopsis vidua (O. F. Müller, 1776)
(Pl. 1, figs. 11 - 18)

1776 *Cypris vidua* O.F.Müller, p. 199.
1971 *Cypridopsis vidua* (O. F. Müller), Bhatia & Singh 1971, pl. 1, Fig. 9.
1977 *Cypridopsis vidua* (O. F. Müller), Bhatia & Singh 1977, p. 407, pl. 1, Fig. 1.
1984 *Cypridopsis vidua* (O. F. Müller),Martens 1984, p. 138.
1994 *Cypridopsis vidua* (O. F. Müller), Schöning 1994, p. 99.
2000 *Cypridopsis vidua* (O. F. Müller), Meisch, p. 372, Figs. 155, 156.
2012 *Cypridopsis vidua* (O. F. Müller), Mischke et al., pl. 1, Figs. 1–4.
2012 *Cypridopsis vidua* (O. F. Müller), Fuhrmann, p. 241, pl. 115, Figs. 1a-d, 2a-d.

Material: Valves, 452; Carapaces, 4.

Size: L, 0.75–0.73 mm; H, 0.48–0.47 mm; (the subovate form); L, 0.65–0. 61 mm; H, 0.41–0.43 mm, (the smaller triangular form).

Occurrence: ASM4, RES1.

Distribution: A cosmopolitan species, widely distributed throughout the faunal area. Pleistocene to Recent (Meisch 2000).

Remarks:: There are two different forms: the first one is a little bit larger in size and possesses asymmetrical valves; the second form is smaller in size with symmetrical valves. Several authors postulate these differences to intraspecific variability such as Fuhrmann (2012).

Ecology: *C. vidua* is a very active swimmer found in a wide range of habitat such as the shallow littoral zone of lakes and slow rivers, temporary ponds, springs wells, and interstitial habitat. Range of water salinity: freshwater to oligohaline (0–6‰) and temperature: 1.2–24 °C, high oxygen (> 0.8 ml/l). Muddy substrate.

Repository of the material: QJ. 4 (2).

Cypridopsis concolor Daday, 1900
(Pl. 2, fig. 19)

1900 *Cypridopsis vidua* var. *concolor* Daday, p. 190, Abb. 30a–c.
2000 *Cypridopsis vidua concolor* Daday, Meisch, p. 372
2012 *Cypridopsis concolor* Daday, Fuhrmann, p. 238, pl. 113, Figs. 2a-d.

Material: Adult valves, 6; carapaces, 4.

Size: RV, L, 0.48 mm; H, 0.31 mm. LV, 0.45 mm; H, 0.30 mm; W, 0.32 mm.

Occurrence: ASM1, WAS2.

Distribution: Budapest in Hungary, Negorci wetland in Macedonia, fossil from Pleistocene deposits in central Germany.

Remarks: The species was also found by Mohammed et al. (2018).

Ecology: According to Fuhrmann (2012), the species prefers small and temporary warm waters.

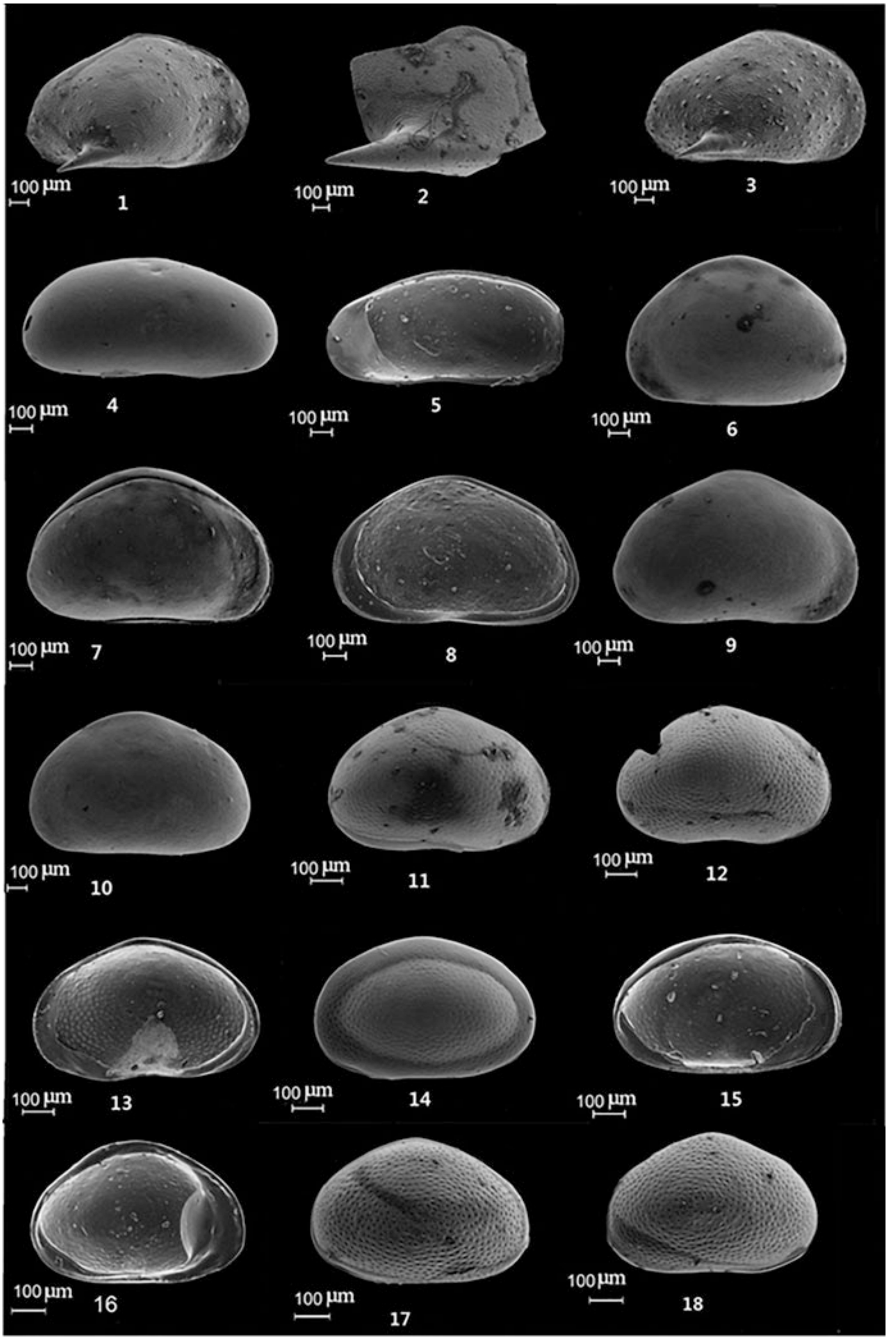

Plate 1 *1*. *Cypris bispinosa*, RV, lateral, external view, juvenile. (245 cm) ASM4. 2. *Cypris bispinosa*, (spine), RV, lateral, external view, adult. (245 cm) ASM4. 3. *Cypris bispinosa*, RV, lateral, external view, juvenile. (260 cm) ASM4. 4. *Humphcypris* cf. *anomala*, RV, lateral, external view, adult. (245 cm) ASM4. 5. *Humphcypris* cf. *anomala,* RV, lateral, internal view, adult. (245 cm) ASM4. 6. *Heterocypris salina*, LV, lateral, external view, adult. Level (250 cm) ASM4.

Repository of the material: QJ. 4 (3).

Genus *Sarscypridopsis* McKenzie 1977.
Sarscypridopsis aculeata (Costa, 1847)
(Pl. 2, Fig. 20)

1847 *Cypris aculeata* Costa, p. 11–12, pl. III, Fig. 5.
1977 *Sarscypridopsis aculeata* McKenzie, p. 49.
1996 *Sarscypridopsis aculeata* (Costa) Martens et al. 1996, p. 33, Figs. 4A-F.
1996 *Sarscypridopsis aculeata* (Costa) Schöning, p. 46, Figs. 24–26.
2001 *Sarscypridopsis aculeata* (Costa) Mischke, pl. II, Fig. 7.
2012 *Sarscypridopsis aculeata* (Costa), Fuhrmann, p. 248, pl. 118, Fig. 1a-d.
Material: Adults valves, 10; juveniles valves, 22.
Size: RV, L, 0.70 mm; H, 0.43 mm. LV, L, 0.66–0.69 mm; H, 0.44–0.45 mm.
Occurrence: ASM4, ASM1, WAS2.
Distribution: A cosmopolitan species (Meisch 2000).
Ecology: Very shallow temporary and permanent ponds, with salinity range (0.5–17‰; oligohaline to mesohaline the optimum salinity is 17‰) and low oxygen (< 1 ml/l). It prefers slightly brackish small water bodies of both inland and coastal type; the species is rare in freshwater. Water temperature: (3–25 °C).
Repository of the material: QJ. 5 (2).

Family Candonidae Kaufmann, 1900
Subfamily Candoninae Kaufmann, 1900
Tribus: Candonini Kaufmann, 1900
Group: Compressa
Pseudocandona Kaufmann, 1900
Pseudocandona albicans (Brady 1864)
Pseudocandona albicans
(Pl. 2, Figs. 21 - 30)

1864 *Candona albicans* Brady, p. 61, pl. IV. Figs. 6–10.(Brady 1864)
1968 *Candona albicans* Brady, Bhatia, p. 471, pl. 2, Figs. 4a-c.
1999 *Pseudocandona albicans* (Brady), Mazzini et al. 1999, pl. 2, Fig. 6
2001 *Pseudocandona albicans* (Brady), Meisch, p. 188, Fig. 79A-B.
?2001 *Pseudocandona albicans* (Brady), Griffiths et al., p. 762

Plate 1 (continued) 7. *Heterocypris salina*, full carapace, LV, lateral, external view, adult. (245 cm) ASM4. 8. *Heterocypris salina*, RV, lateral, internal view, adult. (245 cm) ASM4. 9. *Heterocypris salina*, RV, lateral, external view, adult. (260 cm) ASM4. 10. *Heterocypris salina*, RV, lateral, external view, adult. (260 cm) ASM4. 11. *Cypridopsis vidua*, RV, lateral, external view, adult. (245 cm) ASM4. 12. *Cypridopsis vidua*, RV, lateral, external view, adult. (260 cm) ASM4. 13. *Cypridopsis vidua*, RV, lateral, internal view, adult. (260 cm) ASM4. 14. *Cypridopsis vidua*, LV, lateral, external view, adult. (245 cm) ASM4. 15. *Cypridopsis vidua*, LV, lateral, internal view, adult. (245 cm) ASM4. 16. *Cypridopsis vidua*, LV, lateral, internal view, adult. (260 cm) ASM4. 17. *Cypridopsis vidua*, LV, lateral, external view, adult. (260 cm) ASM4. 18. *Cypridopsis vidua*, RV, lateral, external view, adult. (260 cm) ASM4.

2011 *Pseudocandona albicans* (Brady), Özulug 2011, p. 95, Fig. 2.
2012 *Pseudocandona parallela* (G. W. Müller), Fuhrmann, p. 86, pl. 37, Fig. 1a-e, 2a-e.

Material: Adult valves, 50; juvenile valves, 697; carapaces, 40.

Size: LV, L, 0.71–0.79 mm; H, 0.4–0.44 mm; RV, L, 0.71–0.78 mm; H, 0.4 mm.

Occurrence: ASM4, RES1.

Distribution: Widely distributed. Britain; Tuscany, Central Italy; Germany; Istranca Streams, Turkey; Western Asia; and North America. Subrecent sediments from Sudan, mid- and late Holocene lakes of NW China.

Remarks: Two forms of *Pseudocandona albicans* have been found in Jahran basin, a pitted, thicker shell, and smaller form and a smooth and larger one. We think that the smaller ones are A-1 juveniles, although their inner lamella is fully developed and the shells are thicker and more calcified . One can also speculate, that these are two subspecies of *P. albicans*. All of them resemble *P. compressa* (Koch, 1838), but the latter is larger in size and has a beak-shaped anterior margin in dorsal view.

Fuhrmann (2012) is correct to assign the species to *P. parallela* (G.W.Müller), but the name *P. albicans* is used for this species by nearly all authors commonly for over 100 years. Therefore, we think it is acceptable to keep the name *P. albicans* for this species.

Ecology: Very shallow waters of lagoons and estuaries, swamps, ponds, and lakes and also in temporary waters with a muddy bottom. It prefers stagnant and slow-flowing waters. Salinity range: < 6.3‰, freshwater to low mesohaline, optimum salinity 5.5‰, and low oxygen (> 0 ml/l). Water temperature: 2–24 C°.

Repository of the material: QJ. 6 (2), QJ. 7 (2).

Pseudocandona marchica (Hartwig, 1899)
(Pl. 2, Figs. 31-34)

1899 *Candona marchica* Hartwig, p.183, Fig. 1.
1984 *Pseudocandona marchica* (Hartwig, 1899), Martens and Dumont, p. 100, pl. 2, Figs. F,H, pl.4 Figs. A-F.
2000 *Pseudocandona marchica* (Hartwig, 1899) Meisch, pp. 157–160, Fig. 66A-J.
2008 *Pseudocandona marchica* (Hartwig, 1899) Akdemir 2008, pl. 1, Fig. 1.
2009 *Pseudocandona marchica* (Hartwig, 1899) Pieri et al., pl. 4, A-D.
2012 *Pseudocandona marchica* (Hartwig, 1899) Fuhrmann, p. 76, pl. 32.

Material: Adult valves, 13; juvenile valves, 7.

Size: LV, L, 0.96 mm; H, 0. 54 mm; RV, L, 0.96–0.98 mm; H, 0.53–0.55 mm.

Occurrence: ASM4.

Distribution: Europe and Asia. Fossils in Pleistocene of Central Germany.

Remarks: Our specimens have been compared with that recorded in different works such as (Martens and Dumont 1984; Meisch 2000; Pieri et al. 2009; Fuhrmann 2012) and found that the species sometimes exhibits a minor difference in the shape of the caudal area of the carapace. . No adults regarding the current species found in the sediment samples of the section RES1; nevertheless the considerable number of Pseudocandonid juveniles that have been collected from that section may be related to *P. marchica.*

Ecology: Very shallow permanent and temporary small water bodies, the littoral zone of lakes, and both the epigean and hypogean habitats of streams, springs, brooks, swamps, and interstitial groundwater of rivers. Water salinity, (0–5‰, freshwater to oligohaline), probably high oxygen (> 3 ml/l); temperature, (2–22 C°); muddy bottom.

Repository of the material: QJ. 8 (2).

Fabaeformiscandona Krstic, 1972
Fabaeformiscandona breuili (Paris 1920)
(Pl. 2, Figs. 35-37)

1920 *Candona breuili* Paris, p. 477, pl. 18 Figs. 1–3.
2000 *Fabaeformiscandona breuili* (Paris), Meisch, p. 135, Figs. 56A-C,
2012 *Fabaeformiscandona breuili* (Paris), Fuhrmann, p. 46, pl. 17, Figs. 1a-f, 2a-b, 3a-b.

Material: Adult valves, 20; carapaces, 9; juvenile valves, 152; carapaces, 50.

Size: LV, L, 0.6 mm; H, 0.3 mm; W, 0.2 mm.

Occurrence: RES1.

Geographical distribution: Germany, France, and Czech Republic.

Remarks: The present species is abundant in the sediment samples of RES1.

Ecology: A hypogean species connected to underground waters. Reported from drainage pipes, springs, caves, and the interstitial groundwater. Mature females were found February, March, and May .

Repository of the material: QJ. 9 (2) (Plate 2).

Candonopsis Vavra 1891
Candonopsis kingsleii (Brady and Robertson, 1870)
(Pl. 3, figs. 38,39)
1870 *Candona kingsleii* Brady and Robertson, p.17, pl.9:11-12.

1974 *Candonopsis kingsleii* (Brady & Robertson), Bhatia and Singh, p. 407, pl. 3, Figs. 1,2.

1975 *Candonopsis kingsleii* (Brady & Robertson), Singh 1975, p. 373, pl. x, Figs. 7–10.

2000 *Candonopsis kingsleii* (Brady & Robertson), Meisch, pp. 209–211, Fig. 89A-L.

2012 *Candonopsis kingsleii* (Brady & Robertson), Fuhrmann, p. 102, pl. 45, Figs. 1a-e.

2014 *Candonopsis* cf. *kingsleii* (Brady & Robertson), Kalbe & Jagher 2014, Fig. 4u.

2015 *Candonopsis kingsleii* (Brady & Robertson), Kalbe et al. 2015, Fig. 6e-f, Fig. 7 h-k.

Material: Adult valves, 10.

Size: LV, L, 0.9 mm; H, 0.45 mm; RV, L, 0.85 mm; H, 0.42 mm.

Occurrence: ASM4, RES1.

Distribution: Widely distributed (Holarctic), Europe, Asia, Middle East, and North America (Meisch 2000).

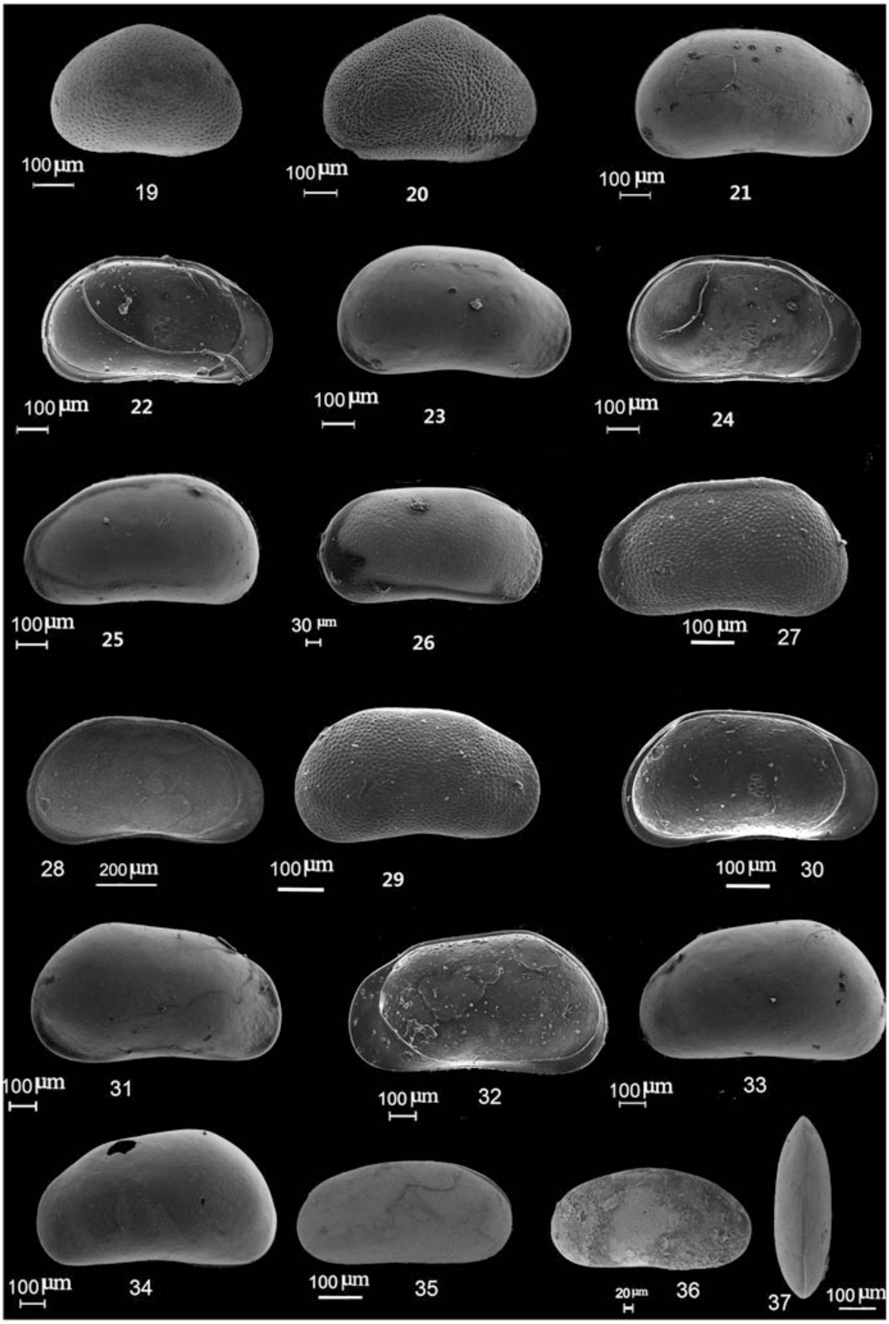

Plate 2 19. *Cypridopsis vidua,* LV, lateral, external view, adult. (260 cm) ASM4. 20. *Sarscypridopsis aculeate*, LV, lateral, external view, juvenile. (245 cm) ASM4. 21. *Pseudocandona albicans*, RV, lateral, external view, adult. (245 cm) ASM4. 22. *Pseudocandona albicans*, LV, lateral, internal view, adult. (260 cm) ASM4.23. *Pseudocandona albicans*, RV, lateral, external view, adult. (245 cm) ASM4. 24. *Pseudocandona albicans*, LV, lateral, internal view, adult.

Remarks: This elongate, laterally compressed species is rarely encountered in both sections, maybe because of its thin carapaces which easily fragmented.

Ecology: Very shallow lakes, swamps, and ponds, small permanent water bodies, and in temporary waters also, prefers the littoral zone of lakes, salinity, 0–5‰, freshwater to low oligohaline; temperature, 4–21 C°.

Repository of the material: QJ.10 (2).

Candonopsis boui Danielopol 1978.
(Pl. 3, Figs. 40-44)

1978 *Candonopsis boui* Danielopol, p. 15, abb. 49, C, D.

? 1980 *Candona* sp. McClure & Swain 1980, pl. 1, Fig. 12.

Material: Adult valves, 19.

Size: L, 0.75–0.77 mm; H, 0.3–0.38 mm.

Occurrence: ASM4, RES1.

Distribution: Pyrenees, France.

Remarks: The current species is distinctive by its laterally compressed, ovate, relatively medium sized carapace. It is close to *Candonopsis depressa* (Rome 1962) in general shape but smaller in size. It slightly resembles *C. africana* Klie 1944; *C. navicula* Daday, 1908; and C. *nama* Daday 1913, but differs in the outline and in size. It is also comparable to *C. tenuis* (Brady 1886), but our species is remarkably smaller in size, and the geographical distance between these species seems rather too great to accept them as conspecific

Ecology: A hypogean species occurs in interstitial habitat. It has a significantly longer duration of embryonic and postembryonic development (Danielopol 1978).

Repository of the material: QJ. 11 (2).

Family Ilyocyprididae Kaufmann, 1900
Ilyocypris decipiens Masi, 1905.
(Plate 3, Figs.45-48)

1905 *Ilyocypris decipiens* Masi, p. 127.

2000 *Ilyocypris decipiens* Masi, Meisch, p. 250, Fig. 106A-C.

Plate 2 (continued) (245 cm) ASM4.25. *Pseudocandona albicans*, LV, lateral, external view, adult. (260 cm) ASM4. 26. *Pseudocandona albicans*, RV, lateral, external view, juvenile. (260 cm) ASM4.27. *Pseudocandona albicans* LV, lateral, external view A-1 juvenile. (110 cm) WAS2.28. *Pseudocandona albicans*, LV, lateral, internal view, adult. (110 cm) WAS2. 29. *Pseudocandona albicans,* RV, lateral, external view, A-1 juvenile. (110 cm) WAS2. 30. *Pseudocandona albicans*, LV, lateral, internal view, A-1 juvenile. (120 cm) WAS2. 31. *Pseudocandona marchica,* RV, lateral, external view, adult. (245 cm) ASM4. 32- *Pseudocandona marchica,* RV, lateral, internal view, adult. (245 cm) ASM4. 33- *Pseudocandona marchica,* LV, lateral, external view, adult. (250 cm) ASM4. 34- *Pseudocandona marchica,* LV, lateral, external view, adult. (245 cm) ASM4. 35- *Fabaeformiscandona breuili* (Paris 1920), carapace, external lateral view,? adult. (160 cm) ASM1. 36. *Fabaeformiscandona breuili* (Paris 1920), LV, external lateral view, juvenile. (160 cm) ASM1.
37. *Fabaeformiscandona breuili* (Paris 1920), dorsal view, juvenile.(100 cm) WAS2.

2012 *Ilyocypris decipiens* Masi, Fuhrmann, p. 152, pl. 70, Figs. 1a-f, 2, 3a-c.
2013 *Ilyocypris* cf. *decipiens* Masi Mazzini et al., p. 762, pl. 2, figs. c-d.

Material: Adult valves, 130; juvenile valves, 528. **Size,** L, 0.83 mm; H, 0.45 mm.

Occurrence: ASM4.

Distribution: Europe, Turkey, the Middle East, and Siberia (Meisch 2000).

Remarks: The distribution and the shape of tubercles of the current species are different from those of the closely related ones, such as *I. gibba* (Ramdohr,1808), *I. monstrifica* (Norman,1862), and the tuberculated *I. bradyi* Sars,1890.

Ecology: Shallow ponds, estuaries, and lagoons, littoral zone of lakes, and temporary waters also. Water salinity, 0–2.2‰, freshwater to oligohaline; temperature, 14–20 C°.

Repository of the material: QJ. 12 (2).

Ilyocypris bradyi Sars, 1890
(Pl. 3, figs. 49-54)

1890 *Ilyocypris bradyi* Sars, p. 59
1999 *Ilyocypris bradyi* Sars, Mohammed, p. 23, pl. V, Fig. 1. 2
2001 *Ilyocypris bradyi* Sars, Griffiths et al., p. 762.
2004 *Ilyocypris bradyi* Sars, Rosenfeld et al. 2004, pl. 1, Fig. 8.
2012 *Ilyocypris bradyi* Sars, Mischke et al. 2012, pl. 2, Fig. 23–25.
2012 *Ilyocypris bradyi* Sars, Fuhrmann, p.150, pl. 69, Figs. 1a-f, 2a-d.
2014 *Ilyocypris bradyi* Sars, Kalbe et al. figs. e-f.
2015 *Ilyocypris bradyi* Sars, Kalbe et al. Fig. 7 m-n.

Material: Adult valves, 588; carapaces, 3; juvenile valves, 1877.

Size:: L, 0.96 mm; H, 0.52 mm.

Occurrence: ASM4.

Distribution: Worldwide.

Ecology: Very shallow water bodies, springs, ponds, swamps, and estuaries, temporary waters also. Salinity range: 0–4.5‰, freshwater to oligohaline, probably high oxygen (> 2.5 ml/l). Temperature: 1–25 C°.

Repository of the material: QJ. 13 (2) (Plate 3).

Ilyocypris cf. *grabschuetzi* Fuhrmann and Pietrzeniuk 1990.
(Pl. 4, Figs. 55-61)

1990 *Ilyocypris grabschuetzi* Fuhrmann and Pietrzeniuk p. 206, Abb. 2, pl. 2, Figs. 3–4, pl. 2, Figs. 41–44.
2012 *Ilyocypris grabschuetzi* Fuhrmann and Pietrzeniuk, Fuhrmann, p.160, pl. 74, Figs. 1a-e, 2a-e.

Material: Adult valves, 364; juvenile valves, 1351.

Size: L, 0.95–1,00 mm; H, 0.52–0.53 mm.

Occurrence: ASM4.

Distribution: Quaternary sediments from mid Germany.

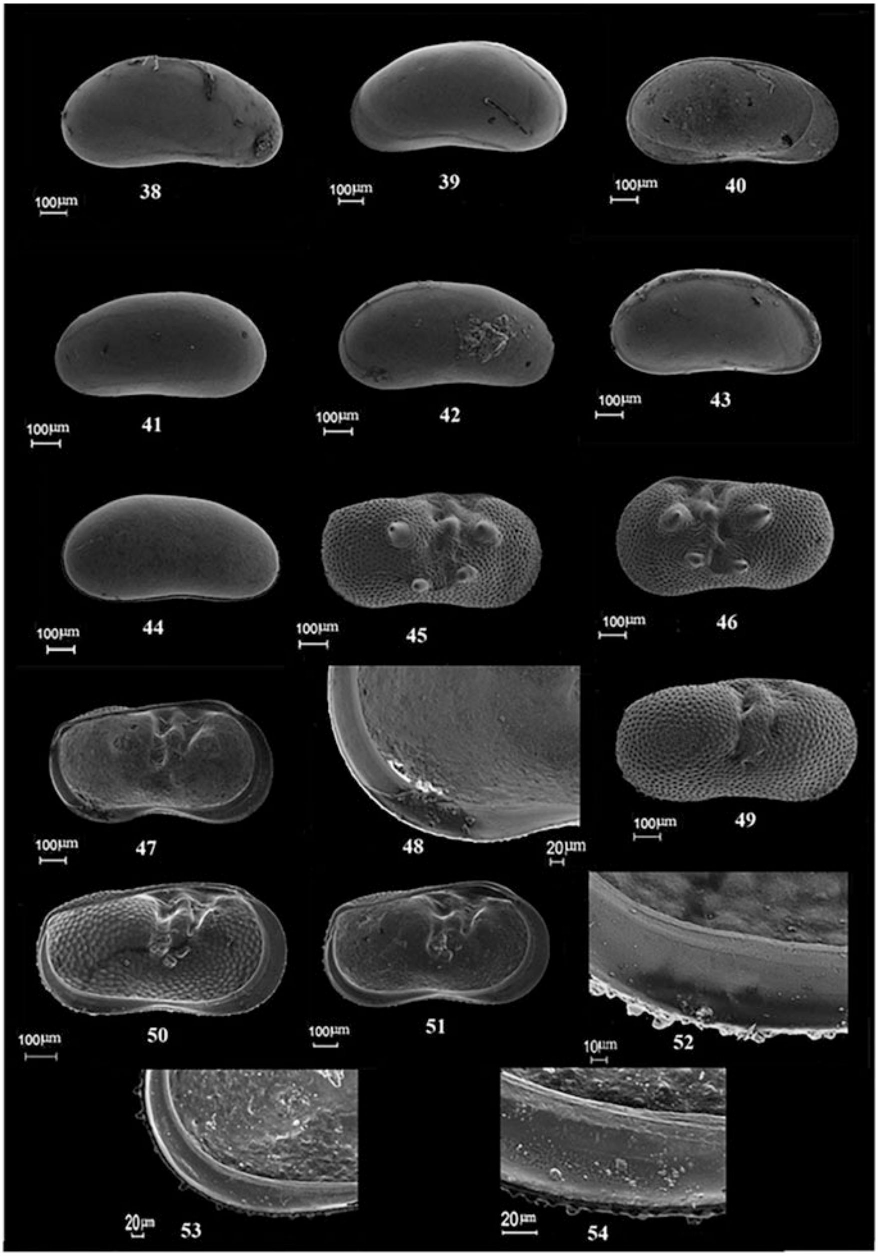

Plate 3 38. *Candonopsis kingsleii*, RV, lateral external view, adult. (225 cm) RES1. 39. *Candonopsis kingsleii*, LV, lateral external view, adult. (245 cm) ASM4. 40. *Candonopsis boui,* LV, lateral internal view, adult. (245 cm) ASM4. 41. *Candonopsis boui,* LV, lateral external view, adult. (245 cm) ASM4. 42. *Candonopsis boui,* RV, lateral external view, adult. (245 cm) ASM4. 43. *Candonopsis boui,* RV, lateral external view, adult. (220 cm) RES1. 44. *Candonopsis boui,* RV, lateral external view, adult. (245 cm) ASM4. 45. *Ilyocypris decipiens*, RV, lateral external view, adult. (160 cm) ASM4. 46. *Ilyocypris decipiens*, LV, lateral external view, adult. (160 cm) ASM4. 47. *Ilyocypris decipiens*, LV, lateral internal view, adult. (160 cm) ASM4. 48. *Ilyocypris decipiens*,

Remarks: It has been distinguished by its relatively larger size and the remarkable distribution of spines. It resembles *I. absetiva* Fuhrmann, 2008, but differs in the distribution of the spines in the posterior half.

Ecology: Small permanent water bodies.

Repository of the material: QJ. 14 (2).

Ilyocypris gibba (Ramdohr, 1808)
(Pl. 4, Figs. 62-64)

1808 *Cypris gibba* Ramdohr, p.91,pl.3:13,14,17

1992 *Ilyocypris* cf. *I gibba* (Ramdohr), Martens et al.1992, p. 106, Figs. 5, J-M.

1994 *Ilyocypris* cf. *I gibba* (Ramdohr), Schöning, p. 94, pl. 1, Fig. 13.

1999 *Ilyocypris gibba* (Ramdohr), Mohammed, pp. 22, 23, pl. 4, Figs. 5–8.

2000 *Ilyocypris gibba* (Ramdohr), Meisch, p. 245, Fig. 104.

2004 *Ilyocypris gibba* (Ramdohr), Rosenfeld et al., pl. 1, Fig. 7.

2012 *Ilyocypris gibba* (Ramdohr), Mischke, et al., pl. Figs. 20–22.

2013 *Ilyocypris biplicata* (Koch, 1838) Furhmann, p. 148, pl. 68, Fig. 1a-f, 2a-d.

2015 *Ilyocypris gibba* (Ramdohr), Kassa 2015, Fig. 5.15. (A-D).

2016 *Ilyocypris* cf. *gibba* (Ramdohr) Kalbe et al., Fig. 7, d-f.

Material: Adult valves, 355; juvenile valves, 1062.

Size: L, 0.84–0.85 mm; H, 0.5.

Occurrence: ASM4.

Distribution: Worldwide. General distribution: Europe, Africa, the Middle East, Central Asia, China, and America.

Remarks: The characters of the marginal ripplets on the inner lamella, density of pits, and spines are used here to differentiate between our non-tuberculated *I. gibba* and its closely related *I. bradyi*. The work of Meisch (2000) is followed in the current work in considering *Ilyocypris biplicata* (Koch, 1838) a synonym of *I. gibba* (Ramdohr, 1808).

Ecology: Prefers small and shallow permanent water bodies with clayey or sandy substrate. Also recorded from temporary pools, springs, brooks, slightly salty waters, and rice fields. Water salinity: <5, freshwater to oligohaline and high oxygen (>5.0 ml/l). Temperature: 5–19 C°.

Repository of the material: QJ. 15 (2).

Superfamily Darwinuloidea Brady & Robertson, 1885.
Family Darwinulidae Brady & Robertson, 1885

Plate 3 (continued) LV, postero-ventral inner lamellae view, adult. (160 cm) ASM4. 49. *Ilyocypris bradyi*, RV, lateral external view, adult. (160 cm) ASM4. 50. *Ilyocypris bradyi*, LV, lateral internal view, adult. (160 cm) ASM4. 51. *Ilyocypris bradyi*, LV, lateral internal view, adult. (245 cm) ASM4. 52. *Ilyocypris bradyi*, LV, ripplets, inner lamellae view, adult. (160 cm) ASM4. 53. *Ilyocypris bradyi*, LV, postero-ventral inner lamellae view, adult. (245 cm) ASM4. 54. *Ilyocypris bradyi*, LV, ripplets, inner lamellae view, adult. (245 cm) ASM4.

Darwinula stevensoni (Brady & Robertson, 1870)
(Pl. 4, figs. 65-69)

1870 *Polycheles stevensoni* Brady & Robertson, p.25, pl.7: 1–7,pl.10: 4–14.
1980 *Darwinula stevensoni* (Brady & Robertson), McClure and Swain, p2. 1, Figs. 16–18.
2000 *Darwinula stevensoni* (Brady & Robertson), Meisch, p. 49, Fig. 16a-e.
2004 *Darwinula stevensoni* (Brady & Robertson), Rosenfeld et al., pl.1, Fig. 6.
2010 *Darwinula stevensoni* (Brady & Robertson), Mischke & Almogi-Labin 2010, Fig. 9. 12.
2012 *Darwinula stevensoni* (Brady & Robertson), Fuhrmann, p. 14, pl. 1, Fig. 1a-f.
2012 *Darwinula stevensoni* (Brady & Robertson), Mischke et al., pl. 1, Figs. 10,11.
2014 *Darwinula stevensoni* (Brady & Robertson), Kalbe, et al., Fig. 3i.
2015 *Darwinula stevensoni* (Brady & Robertson), Kassa, Fig. 5.14A,B.
2016 *Darwinula stevensoni* (Brady & Robertson), Kalbe, et al., Fig. 6 r,s.

Material: Adult valves, 315; carapaces, 5; juvenile valves, 453; carapaces, 10.
Size: L, 0.63 mm; H, 0.26–0.28 mm.
Occurrence: ASM4.
Distribution: Cosmopolitan.
Ecology: Very shallow to shallow lakes, ponds, lagoons, and estuaries, slow streams and temporary waters also; salinity, 0–12‰, freshwater to oligohaline; temperature, 1–27 C°. The species is characterized by its relatively long life cycle.
Repository of the material: QJ. 16 (2).

Superfamily Cytheroidea Baird, 1850
Family Limnocytheridae Klie, 1938
Limnocythere inopinata (Baird, 1843).
(Pl. 4, Figs. 70-72)

1843 *Cythere inopinata* Baird, p.195.
1994 *Limnocythere inopinata* (Baird), Schöning, p. 93, pl. 1, Fig. 1.
2000 *Limnocythere inopinata* (Baird), Meisch, p. 179, Fig. 76.A-B
2012 *Limnocythere inopinata* (Baird), Mischke, et al., pl. 1, Fig. 21.
2012 *Limnocythere inopinata* (Baird), Fuhrmann, p. 278, pl.133, Figs. 1a-b, 2a-d, 3a-d.
2014 *Limnocythere inopinata* (Baird), Kalbe et al., Fig. 3.k.

Material: Adult valves, 23.
Size: L, 0.58 mm; H, 0.31 mm.
Occurrence: ASM4.
Distribution: Widely distributed, Holarctic (Meisch 2000).
Ecology: Tolerates a wide range of habitats. Very shallow to shallow water bodies, lagoons, lakes, estuaries, slow brooks, and rivers; salinity, 0–6.7‰, freshwater to low mesohaline; temperature, 0.5–24 C°, low oxygen, > 0.5 ml/l. *L. inopinata* occurs in waters that are enriched in Na-HCO3 but depleted in Ca (Holmes et al. 1999, Mischke 2001).
Repository of the material: QJ. 16 (2) (Plate 4).

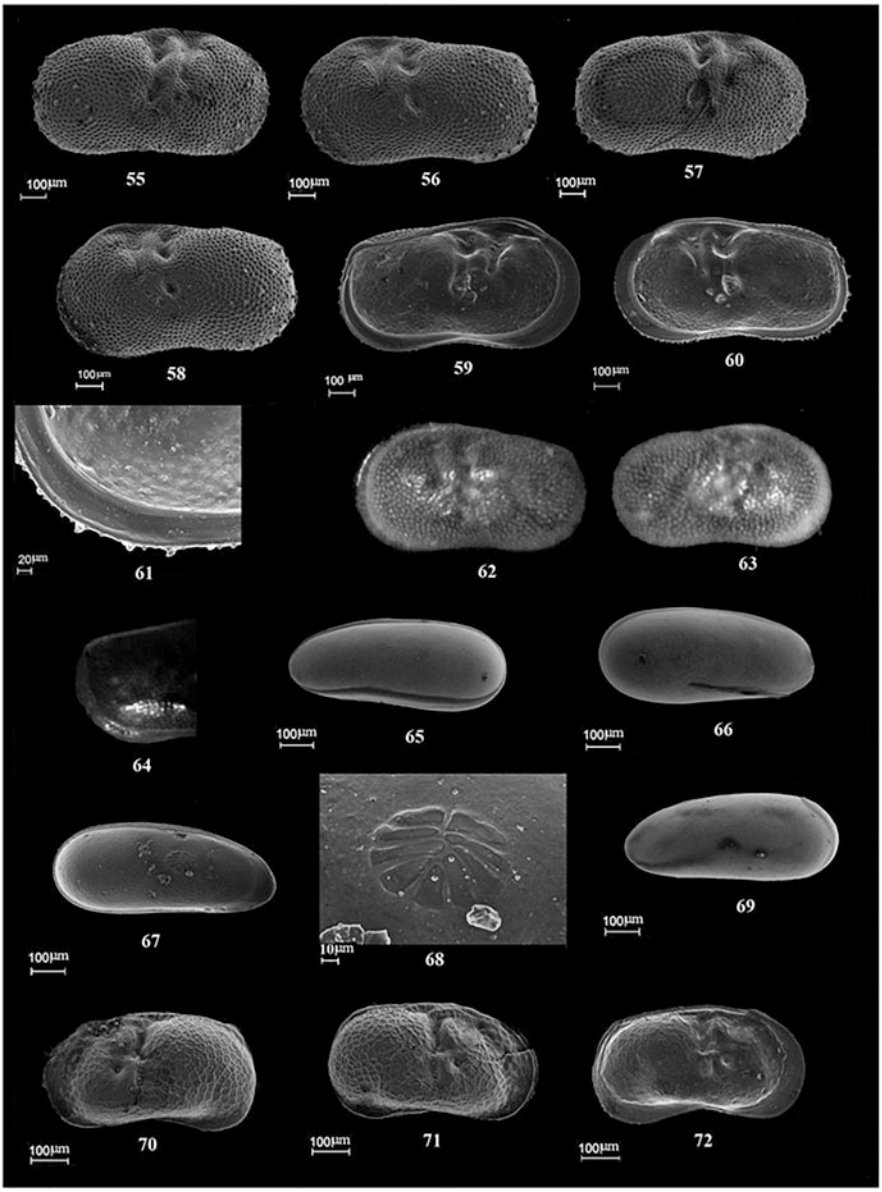

Plate 4 55. *Ilyocypris* cf. *grabschuetzi*, RV, lateral external view, adult. (245 cm) ASM4. 56. *Ilyocypris* cf. *grabschuetzi*, LV, lateral external view, adult. (245 cm) ASM4. 57. *Ilyocypris* cf. *grabschuetzi*, RV, lateral external view, adult. (160 cm) ASM4. 58. *Ilyocypris* cf. *grabschuetzi*, RV, lateral external view, adult. (160 cm) ASM4. 59. *Ilyocypris* cf. *grabschuetzi*, LV, lateral internal view, adult. (245 cm) ASM4. 60. *Ilyocypris* cf. *grabschuetzi*, RV, lateral internal view, adult. (245 cm) ASM4. 61. *Ilyocypris* cf. *grabschuetzi*, LV, postero-ventral inner lamellae view, adult. (245 cm) ASM4. 62. *Ilyocypris gibba*, LV, lateral external view, adult. (245 cm), ASM4. Size: L: 0.85 mm, H: 0.5 mm. 63. *Ilyocypris gibba*, RV, lateral external view, adult. (245 cm), ASM4. Size: L: 0.85 mm, H: 0.5 mm. 64. *Ilyocypris gibba*, LV, ripplets, internal view, adult. (245 cm), ASM4. 65. *Darwinula stevensoni*, carapace, LV lateral external view, adult. (260 cm)

5 Distribution and Paleoecology of Ostracods

High and intermediate abundance and diversity of ostracods have been determined from the present studied sections, ASM4 and RES1, respectively (Figs. 5 and 6). The large number of juveniles encountered in the studied sections indicates autochthonous ostracod assemblages in low-energy water environments. In general the recorded freshwater ostracods indicate an extensive wetland in the area under investigation. In their study, Parker et al. (2006) carried out thoroughly comparisons of the climate proxy and radiocarbon dates from different cites of the Arabian Peninsula. That included the Neolithic occupations of Arabia, lacustrine sediments in the Yemen Highlands around Dhamar, the Awafi sequence from United Arab Emirates, and the Qunf Cave in Dhofar from Southern Oman. They concluded that the moist periods of the Yemeni highlands could fall in the range 12,100 Cal. yr. BC and 3890–3900 Cal. yr. BC. Sediment depths and ostracod distribution will be described here from the surface.

6 Distribution of Ostracods in Asam Section (ASM4)

In the larger stratigraphic section ASM4 (300 cm), sediments underneath the modern soil are composed mainly of unbedded marl between the levels 285 cm and about 145 cm. However, two dark gray horizons of organic soils are distinguished at the levels between 205–185 cm and 145–135 cm. A stratigraphic unconformity separates these Holocene marls from the underlying (300–290 cm) gravel fine sands which are supposed to belong to the late Pleistocene (Davies 2006 and Parker et al. 2006 regarded the occurrence of gravels to be deposited during the late glacial periods before 10,000 cal. yr. BP. Ostracods were encountered between the levels 275 cm and 145 cm with variable richness and diversity (Fig. 5). A high diversity (15 species) and richness (9980 shells) of ostracods were determined from the current section.

The Ostracod assemblage in ASM4 is composed of *Candonopsis kingsleii*, *Candonopsis boui*, *Cypridopsis vidua*, *Cypris bispinosa*, *Darwinula stevensoni*, *Heterocypris salina*, *Humphcypris* cf. *anomala*, *Ilyocypris bradyi*, *I. decipiens*, *I. gibba*, *I.* cf. *grabschuetzi*, *Limnocythere inopinata, Pseudocandona albicans*, *P. marchica*, and *Sarscypridopsis aculeata*. The highest value is recorded for *Ilyocypris bradyi*; however, *I.* cf. *grabschuetzi*, *I. gibba*, and *Heterocypris salina* are found in

Plate 4 (continued) ASM4. 66. *Darwinula stevensoni*, RV, lateral external view, adult. (245 cm) ASM4. 67. *Darwinula stevensoni*, LV, lateral internal view, adult (245 cm) ASM4. 68. *Darwinula stevensoni*, details of muscle scars, LV. 69. *Darwinula stevensoni*, LV, lateral external view, adult. (245 cm) ASM4. 70. *Limnocythere inopinata*, LV, lateral external view, adult (260 cm) ASM4. 71. *Limnocythere inopinata*, RV, lateral external view, adult (260 cm) ASM4. 72. *Limnocythere inopinata*, LV, lateral internal view, adult (245 cm) ASM4.

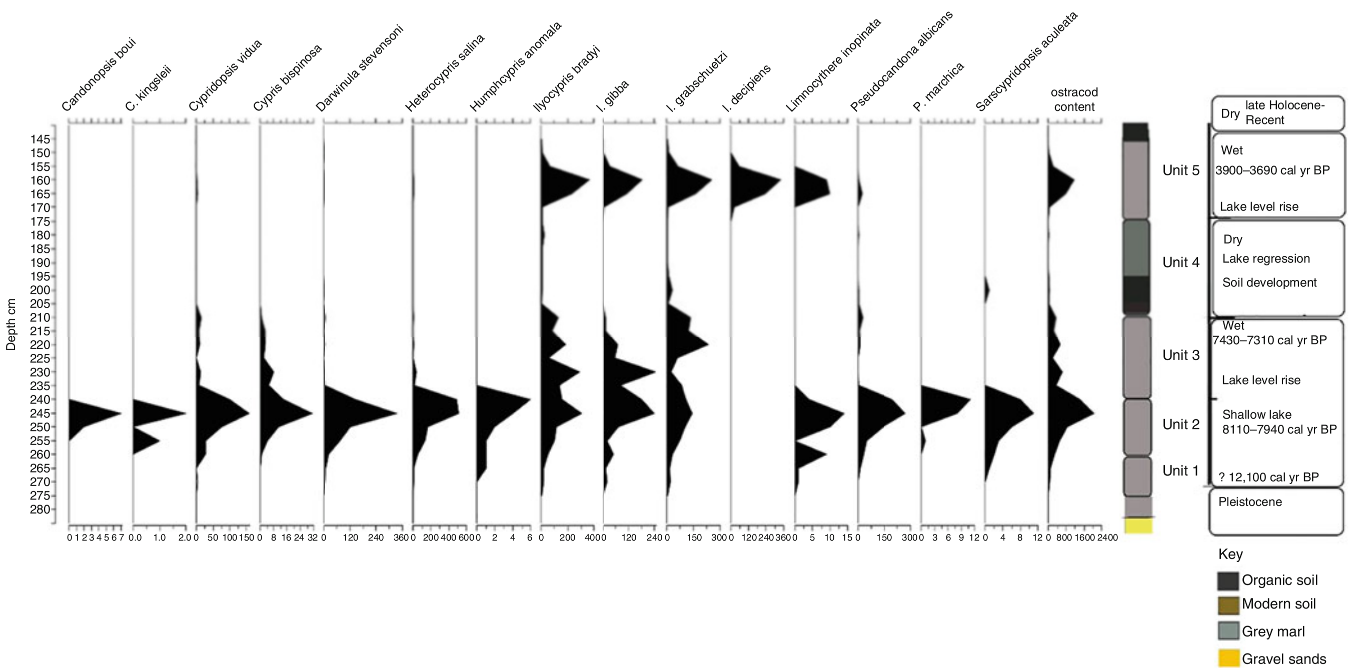

Fig. 5 Distribution and environmental interpretation of ostracods in ASM4 section

large numbers. *I. bradyi* and *I.* cf. *grabschuetzi* are frequent in all the samples which contain ostracods. A relatively moderate abundance was recorded for *Pseudocandona albicans*, *Darwinula stevensoni*, *Ilyocypris decipiens*, and *Cypridopsis vidua* and lesser abundance regarding *Cypris bispinosa*, *Limnocythere inopinata*, *Sarscypridopsis aculeata*, *Pseudocandona marchica*, and *Humphcypris* cf. *anomala.* The species *Candonopsis kingsleii* and *Candonopsis boui* are rarely encountered.

Based on the distribution of ostracods, five units could be distinguished for the stratigraphic section ASM4:

1. Unit1 (275 cm–265 cm) > 8000 cal yr. BP: This unit is represented by 10 cm of light gray marl and greenish clay. Fe staining is also observed in some levels. It witnesses the onset of the humid period of the early Holocene and contains the oldest evidences regarding the development of a wetland in the section. A very few shells of *I. bradyi*, *I. gibba* and a single valve of *P. albicans* are reported from the lowermost sediments of the current unit (275 cm). A relatively higher abundance and species diversity occurred in the upper part (270 cm, 265 cm). Ostracod assemblage are here represented by *C. vidua*, *D. stevensoni*, *H. salina*, *H.* cf. *decipiens*, *I. bradyi*, *I. gibba*, *I. grabschuetzi*, *L. inopinata*, *P. albicans*, and *S. aculeata*. Species belonging to *Ilyocypris* dominate in the ostracod association which reflects the high influence of flowing streams. The other species point to shallow warm water conditions. Species preferring different habitats such as the permanent water bodies (*D. stevensoni*) and ephemeral waters (*H. salina*), fresh to oligohaline conditions (Ilyocypris spp.), or higher salinities (*H. salina*, *S. aculeata*) co-occur and probably indicate the deposition of shells under different environmental conditions and post mortem transportation. Fresh oligohaline waters of a shallow lake rich in vegetation fed by streams could be suggested for this unit.
2. Unit 2 (260 cm–240 cm) 8110–7940 cal yr. BP: It is composed of homogeneous light gray marls with a distinctive occurrence of mollusks occurring in levels 250–240 cm. The highest species values and abundance of ostracods are reported in this unit, particularly for the sediment sample at a depth of 245 cm. Species diversity and abundance markedly increased from the lower sediments (260–250 cm) and reached their maximum occurrence in 245 cm. Then it decreased again in the uppermost part in 240 cm. The ostracod association is composed of *C. boui*, *C. kingsleii*, *C. vidua*, *C. bispinosa*, *D. stevensoni*, *H. salina*, *H.* cf. *decipiens*, *I. bradyi*, *I. gibba*, *I. grabschuetzi*, *L. inopinata*, *P. albicans*, *P. marchica*, and *S. aculeata*. The distinctive high diversity and abundance of ostracods for this unit points to fluvial shallower waters and more stable environmental conditions (Mischke 2001). A mixing of waters of variable origin (e.g., perennial or seasonal, running, or stagnant) is evidenced here by the simultaneous occurrence of ostracods belonging to different habitats. *C. boui* which occurs in interstitial waters (Danielopol 1978) suggests a groundwater flow in or through the lake. The running waters dwelling *Ilyocypris* species occurred in a large proportion which indicates a high input of inflowing streams. Although

the bulk of ostracods of the current unit occur in a wide range of habitats such as permanent waters or seasonal desiccations, the presence of some ostracod species (*D. stevensoni* and *Pseudocandona* spp.) is significant because of their relatively long life cycle which indicates a permanence of water body. The large number of juveniles of *Ilyocypris* spp., *H. salina*, *P. albicans*, and *D. stevensoni* in addition to the occurrence of thin-shelled species (*C. boui*, *C. kingsleii*, *H.* cf. *decipiens* and *P. marchica*) suggests an autochthonous biocoenosis in a low-energy environment. A fresh to slightly brackish (low mesohaline) very shallow lake with a dense vegetation is proposed for this unit.

3. Unit 3 (235 cm–210 cm) 7430–7310 cal yr. BP: This unit displays a conspicuous decrease in species diversity and abundance of the shallow water species, *C. vidua*, *D. stevensoni*, *H. salina*, and *p. albicans*, whereas the species *C. boui*, *C. kingsleii*, *H. decipiens*, *L. inopinata*, *P. marchica*, and *S. aculeata* totally disappeared. In contrast, high values of *Ilyocypris* species are encountered here particularly in the level 230 cm. The ostracod association for this unit suggests a wetter climate period and high influx from the nearby streams into the lake with probably a remarkable rising of the lake level. The occurrence of few shells of the shallow water species could be due to a post mortem transportation from the littoral environments to the deeper waters. A relatively slight increasing in valves of *C. vidua*, *D. stevensoni*, *H. salina*, and *p. albicans* could be noticed in the uppermost sediment of this unit (210 cm) which may indicate a subsequent regression of the lake level. Very low salinities (fresh to lower oligohaline) are inferred for this unit by the dominance of *Ilyocypris* spp.
4. Unit 4 (205 cm–175 cm): A regressive trend followed by a distinctive desiccation of the lake is indicted by the sudden and noticeable decreasing of *I. bradyi* and *I.* cf. *grabschuetzi* and the absence of *I. gibba*. Nevertheless, *I. bradyi* and *I.* cf. *grabschuetzi* are present in all the sediment samples of this unit which could be attributed to transportation by slowly flowing streams and/or reworking of sediments. Very minor individuals of *C. vidua*, *D. stevensoni*, *H. salina*, and *P. albicans* are sporadically found in some levels. The arid conditions interpreted here are confirmed by the occurrence of about 20-cm-thick dark gray organic soil almost at the base of this unit. This soil horizon is regarded to indicate terrain stability and a development of vegetated landscapes with sufficient moisture to support soil formation.
5. Unit 5 (170 cm–145 cm) 3900–3690 cal yr. BP: The light marl sediment of this unit displays highly weathered mollusks. Ostracod associations are distinguished by a remarkable high abundance of *Ilyocypris* spp. (*I. bradyi*, *I. gibba*, *I. grabschuetzi*, *I. decipiens*) with very low numbers of the species *C. vidua*, *D. stevensoni*, *H. salina*, *P. albicans*, and *L. inopinata*. At the base of this unit (170 cm), *Ilyocypris* species show relatively low values; however, a sudden increase of their valves is reported from the overlying sediments (165–160 cm). Assemblages of ostracod encountered indicate a significant discharge of streams into the lake in a wetter climate period. Mischke (2001) regarded the simultaneous occurrence of *L. inopinata* with high abundance of *Ilyocypris salebrosa* and low ostracod diversity as indication for a high lake level. Such deeper

conditions of a lake could be determined here from the co-occurrence of *L. inopinata* and the huge number *Ilyocypris* species besides the absence of complete mollusk shells. The presence of very few shallow water condition species is attributed to transportation from their shallow environments to deeper waters by bottom currents. Ostracod abundance and diversity decreased in the upper levels (155 cm, 145 cm) of this unit and totally disappeared from the entire overlying sediments. The present unit testifies probably reappearance of lake during the last humid mid-Holocene period. The overlying (10 cm) thick humus soil indicates persistence of moisture for a long time. This soil horizon is overlain by thick calcrete sediments. A fresh to slightly oligohaline waters could be inferred from the ostracod assemblages for this unit.

7 Distribution of Ostracods in Resabah Section (RES1)

The depth of the current section is about (240 cm) from the surface. It is located in a morphologic low depression, south-easterly of the basin. Sediment sequences are mainly composed of whitish creamy, massive travertine of about 50 cm thickness, overlain by a 55 cm thick dark gray humus soil horizon which in turn is covered by 125 cm of modern historic soils. The ostracod taxa encountered are belonging to Candoninae and show stratigraphic variables in abundance and diversity in the studied samples (Fig. 6). Ostracod association is composed of: *Candonopsis boui*, *Candonopsis kingsleii*, *Cypridopsis vidua*, *Pseudocandona* spp., and *Fabaeformiscandona breuili.* Although the dominated taxon is *Pseudocandona*, almost all the valves and carapaces are of juveniles. Only two adult valves belonging to *P. albicans* were found. The shells of this taxon are referred to *Pseudocandona* spp. because of difficulties in distinguishing between the juveniles. Valves and carapaces of *Fabaeformiscandona breuili* are less abundant, whereas *Candonopsis boui*, *Candonopsis kingsleii*, and *Cypridopsis vidua* are sporadically occurred in minor values. According to Danielopol (1978), Candoninae represent the largest number of hypogean species worldwide. The Ostracod association in RES1 displays mostly a domination of subterranean species such as *F. breuili* and *C. boui*. The occurrence of valves and full carapaces of *F. breuili* and the shorter and laterally compressed valves of *C. boui* is of great interest for they reflect their interstitial habitat of groundwater (Danielopol 1978; Meisch 2000). *P. albicans* lives in a wide range of environments including springs and subterranean habitats. The almost absence of adults of *P. albicans* could be regarded to indicate temporary waters and seasonal desiccations (Meisch 2000). Ostracod species together with the sediment characters indicate fresh to slightly mesohaline ephemeral waters of a pond fed by groundwater and precipitation. In general, the minor stream discharge into the depression could be due to the widely distributed catchment area in low morphology occurring to the east of the site. Three units could be recognized from distribution of ostracods:

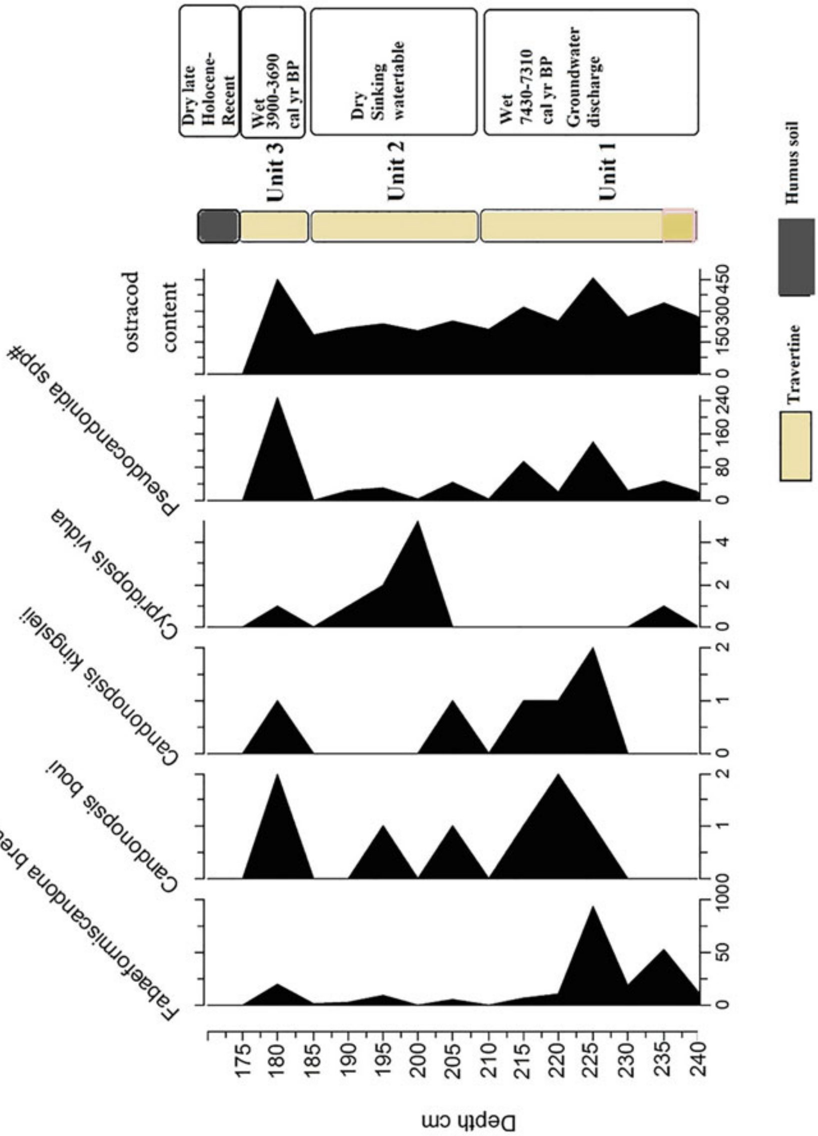

Fig. 6 Distribution and environmental interpretation of ostracods in RES1 section

1. Unit 1 (240 cm–210 cm) 7438–7310 cal yr. BP: A massive travertine is the main component of this unit. Ostracod association is characterized by the domination of juveniles of *Pseudocandona* spp.; however, *F. breuili*. Was recorded in a considerable number. Few individuals belonging to *C. boui* and *C. kingsleii* were found. Autochthonous biocoenosis could be evidenced from the presence of juveniles of *F. breuili* and *Pseudocandona*. The absence of *Ilyocypris* could be referred to the very low discharge of streams into the pond. Evaporative conditions of spring waters enriched in calcium dominated. This interpretation derived from the occurrence of travertine and the subterranean species. This small pond was essentially fed by groundwater and precipitation. Fresh to low mesohaline was probably the water during the time at the current unit.
2. Unit 2 (210–185): Although there are no differences in sediment quality with unit 1, this unit displays a conspicuous decreasing in ostracod abundance especially for *F. breuili.* This may be referred to sinking of groundwater table in a drier climate. A relatively moderate abundance was reported for the juveniles of *Pseudocandona* which could indicate that the inflow streams had some connections to groundwater discharge. The occurrence of minor valves of *C. vidua* is probably drifted by streams into the depression.
3. Unit 3 (185–180) 3900–3690 cal yr. BP: A short period of wetter condition is inferred for this unit. This interpretation is evidenced by the increased abundance of *Pseudocandona* and *F. breuili*. A rising groundwater condition is indicated by the comparatively considerable number of *F. breuili* and connected to more precipitation during the mid-Holocene. Seasonal desiccation again is evidenced here by the total absence of the adults of *Pseudocandona.* Fresh to slightly mesohaline waters (5.5‰) are inferred. The current unit is overlain by thick dark gray humus soils of mid-Holocene.

8 Results and Discussion

Noticeable differences in diversity and abundance could be deduced from the distribution of freshwater ostracods of the studied sections ASM4 and RES1, which reflects variable environmental conditions of their habitats. These variations have occurred probably because of the remarkable differences of geomorphological features in the Jahran basin. In the thicker section ASM4, species composition, abundance, and distribution of ostracods in the studied sediments reflect the development of a lake fed mainly by flowing streams. The inferred lake is characterized by dense vegetated fresh to slightly saline waters and high dissolved oxygen. Variation of wet period and lake level fluctuations also could be determined for the current section. Two humid periods and two dry conditions represented by two sequences of light gray lake marls, and two layers of humus dark gray soils (paleosol) were recognized. Each marl layer is capped by a single paleosol horizon. The first and older humid period occurred in units 1, 2, and 3. Shallow lake environments were induced for marls of unit 1 and 2 near the base of the section. In addition, a regressive trend of lake could be noticed upwardly from unit 1 to unit 2. Shallower conditions of unit 2 were followed by deeper lake conditions interpreted for unit 3 in a wetter climate. This interpretation is indicated by the conspicuous changing of ostracod shells collected from the lower marls. Based on location, lithology, and stratigraphic position, sediments of the current thicker section have been correlated to radiocarbon dated ones of Bayt Nahmi section of Davies (2006) (Fig. 7). Marls of unit 1, 2, and 3 which were deposited during the older (first) humid period are found to be corresponding to M1, BK1, M2, and M3 lacustrine marls recorded by (Davies 2006). Radiocarbon age of Davies (2006) for M2 and M3 marls which return an age of 8110–7940 cal yr. BP and 7430–7310 cal yr. BP are given for unit 2 and unit 3 subsequently. Desiccation periods which are represented by the occurrence of humus dark soil horizons (ab1 and ab2 paleosols) encountered by Davies (2006) within the older marls of Bayt Nahmi are absent at their counterpart marls of the present studied units 1, 2, and 3. It is suggested here to indicate different environmental conditions of marsh in Bayt Nahmi section and lake in ASM4 section. However, lake level fluctuations deduced from the lower marls of ASM4 due to climatic variations probably meet the development of paleosols ab1 and ab2 in Bayt Nahmi. The light gray marls of the first humid period are overlain by dark soil horizon and dark gray marls of unit 4 and evidence phases of land surface stability and point to period of drier conditions. The sediments accumulated during this dry phase are proposed to be eroded in Bayt Nahmi section and a distinct erosional unconformity occurred between M3 lacustrine marls and the overlying marsh deposits. A second humid period is inferred for unit 5 in ASM4 section. Ostracod association indicates strong flowing streams into the lake during wetter climate. These upper marls were found to be deposited under deep lake conditions and are correlated to the dated (3900–3690 ca yr. BP) marsh marl deposits of Davies (2006).

In contrast to ASM4, a relatively lower species diversity and abundance were recorded from the travertine sediments of RES1 section. A pond fed by groundwater and precipitation rather than flowing streams is recognized. Ostracod associations evidenced the occurrence of two humid (units 1 and 3) periods separated by a single dry phase (unit 2). However, no changes in sediment characters have been noticed within the travertine sequences of the three units. No ostracods have been found in the dark soil horizon overlying the uppermost travertine of unit 3. The relatively larger number of *F. breuili* found in the lower travertine of unit 1 indicates a high discharge of groundwater. In contrast, the unit 3 exhibits lesser influence related to the groundwater discharge. Because of its less thickness and different sediment component, no precise correlation could be established with marls of Asam sections, nevertheless, at least the uppermost travertine (unit 3) could be regarded to meet that interpreted for ASM4 at unit 5. The interpreted early and mid-Holocene humid periods for this study have been documented in several studies in different regions, such as Wilkinson et al. (1997), Davies (2006), Parker et al. (2006), Pietsch and Kůhn (2010), Fleitmann et al. (2011) from Yemen, Engel et al. (2012) from Saudi Arabia, Fleitmann and Matter (2009) from Yemen and Oman, and Mischke (2001) from NW China. De Menocal et al. (2000) attributed the intensified monsoon precipitation over southern Arabia during the early to mid-Holocene to be caused

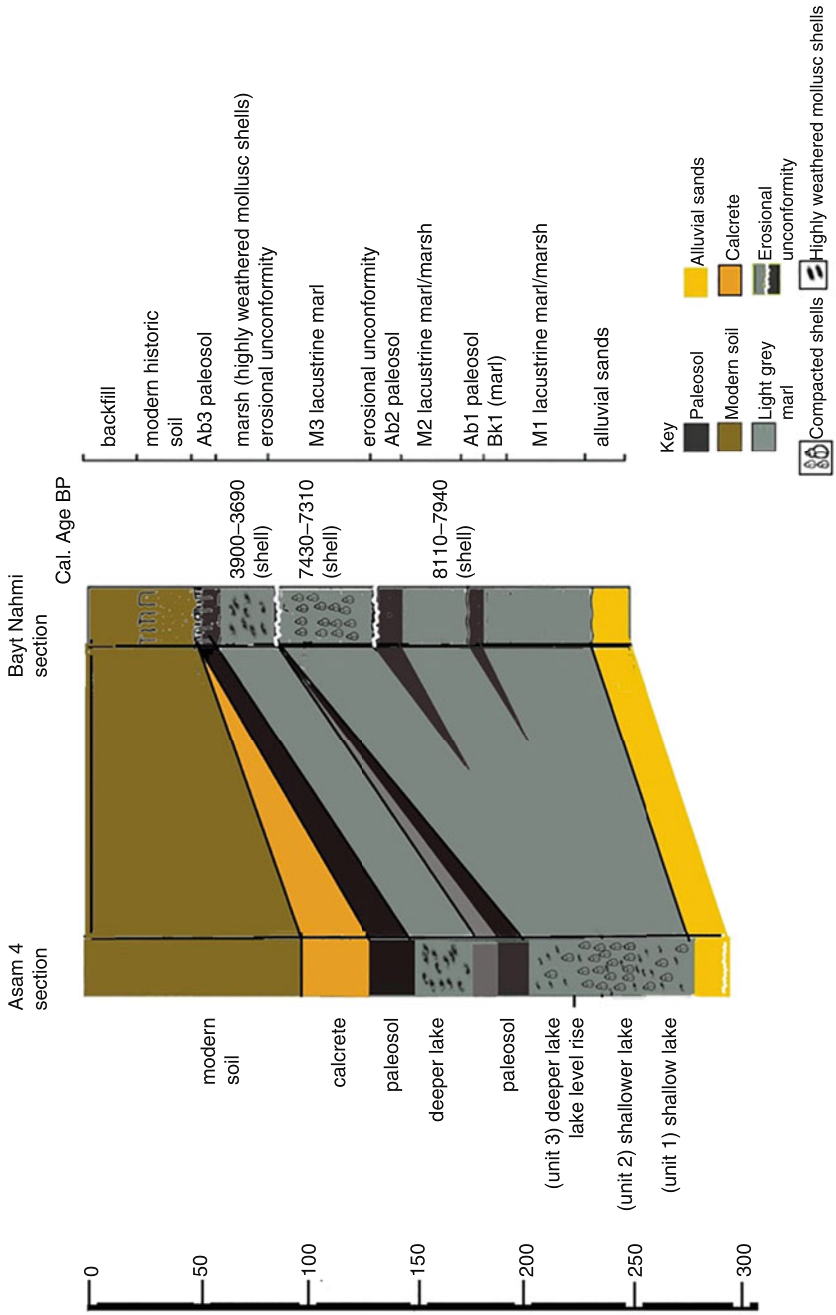

Fig. 7 Stratigraphic and facies correlation between the present study ASM4 section and Bayt Nahmi section of Davies (2006)

by the northward incursion of the Indian Ocean monsoon due to increased solar radiation.

9 Conclusion

A large number (13660) of valves and carapaces of ostracods were recorded from the sediments of two sections, ASM4 and RES1. Material used in the study has been collected vertically with an interval of 5 cm from two holes dug in Jahran basin sediments – Dhamar highlands. Most of the recorded species are cosmopolitan, but some are known only from the Holarctic realm. A single African species *Humphcypris* cf. *anomala* Lindroth 1953 was found. In both sections, climatic and environmental fluctuations occurred in different stages. Based on ostracod distribution and paleoecological evidences, 5 and 3 units have been distinguished for ASM4 and RES1, respectively. The larger ostracod diversity and abundance from particular levels of ASM4 indicated the development of fresh to slightly oligohaline waters of lake rich in aquatic vegetation occurred during two wetter climatic events. However, two dry periods represented by dark gray humus soils were reported. The older humus separated between the two marl units of the humid conditions; the second one is overlying the uppermost marl unit (unit 5). Lake level variations were determined on the basis of ostracod species composition. Fresh to slightly mesohaline waters of a pond with groundwater discharged was determined for the second section RES1. Changes regarding water table linked to climatic variations were recognized depending on differences of ostracod association. Sediments of the thicker ASM4 section almost documented the entire climatic variations dominated during the early to mid-Holocene. Marls of ASM4 section are corresponding to their radiocarbon dated counterpart of Bayt Nahmi section of Davies (2006). Results of Parker et al. (2006) regarding comparisons for the records of the climate proxy and radiocarbon dates from different cites of the Arabian Peninsula are also considered. These age correlations show that the older humid period probably commenced during the late Pleistocene and continued to about 7430–7310 cal yr. BP. The second humid period occurred in 3900–3690 cal yr. BP, possibly during the early Bronze age.

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