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ORIGINAL PAPER

Holocene paleoenvironmental evolution of the Acıgöl paleo maar lake (Nevşehir, Central Anatolia)

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Abstract

Acıgöl (Nevşehir, Central Anatolia) is a drained crater lake. Acıgöl maar was formed by the violent vapor explosions due to the interaction of hot rhyolitic magma with the (sub-)surface water during the latest Pleistocene. A 844 cm-deep borehole was drilled at the maar and 713 cm-thick Acıgöl Core Succession (ACS) was retrieved. The ACS is mainly composed of lower laminated and upper non-laminated mudstones (sandy, silty, and clayey) with rare organic and volcanic interlayers. Eleven ostracod taxa (*Cypris pubera*, *Plesiocypridopsis newtoni*, *Heterocypris salina*, *Eucypris* cf. *heinrichi*, *Candona candida*, *Candona meerfeldiana*, *Pseudocandona marchica*, *Cyclocypris* sp., *Ilyocypris bradyi*, *Limnocythere inopinata,* and *Darwinula stevensoni*) were determined in this study. Along with ostracods, gastropods (*Gyraulus piscinarum* and *Stagnicola* sp.), pelecypods (*Pisidium personatum*), charophytes, and fish remains were also observed, while diatoms are the most frequent and abundant assemblage of the ACS. The assemblage at the lower parts of ACS mainly indicates wetter, freshwater to oligohaline, and oligotrophic and relatively deep lacustrine conditions alternating with short lake shrinkage intervals. On the other hand, the fauna at the upper part of the ACS points out to saline, shallow, and warmer lacustrine conditions.

Keywords Acıgöl · Maar · Holocene · Ostracod · Gastropod · Paleoenvironment · Turkey

Introduction

Ostracods are microcrustaceans, having bivalved carapace (0.3–30 mm in length), live in almost all types of aquatic habitats ranging from small terrestrial wetlands (even rice fields) to deep marine/ocean facies (Meisch 2000). Their low Mg-calcite carapace consists of two valves hinging each other along the dorsal margin. Almost all Ostracoda taxa are adapted to particular aquatic conditions (e.g., salinity, depth, temperature, pH, dissolved oxygen content, and substrate); therefore, they could reflect ecological/environmental characteristics of the water (Holmes and Chivas 2002). The carapaces and valves of ostracods are usually well preserved and readily recognizable in rocks at any age ranging from Ordovician to Recent (Williams et al. 2008). Especially, in non-marine Quaternary sediments, ostracods are common along with the molluscs, diatoms, sporomorphs, charophytes, and fish teeths. Particularly ostracods are useful tools for paleoenvironmental, paleoecological, and even paleoclimatological studies by considering all these reasons (Ruiz et al. 2013).

Anatolia has a variety of actual aquatic bodies (e.g., lakes, ponds, streams, etc.) where different recent (live) non-marine ostracods were recovered (Külköylüoğlu et al. 2014; Akdemir et al. 2016; Yavuzatmaca et al. 2015, 2017). Besides the importance of these habitats for recent evaluations, their remnants may involve significant data on ancient conditions. Therefore, many studies have been realised on Neogene-Quaternary archive records of the fossil lakes and/or ponds of Anatolia to determine the ostracod fauna. Studies on Quaternary deposits (Şafak and Taner 1998; Beker et al. 2008; Meriç et al. 2009; Tunoğlu et al. 2012; Ocakoğlu et al. 2013, 2016; Tuncer and Tunoğlu 2015; Karayiğit et al. 2016; Tuncer et al. 2017; Berndt et al. 2019a, b; McCormack et al. 2019) are rare by comparison with European/Palearctic counterparts (Scharf 1983, 1993; Ricci Lucchi et al. 2000; Viehberg 2004; Scharf et al. 2005; Wilkinson

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et al. 2005; Pipík and Bubik 2006; Sohar and Meidla 2009, 2010; Anadón et al. 2012; Bellucci et al. 2012; Kalbe et al. 2015; Mazzini et al. 2015; Hajek-Tadesse et al. 2018).

In Central Anatolian Volcanic Province (CAVP), numerous volcanoes of Miocene to Late Pleistocene–Holocene age (Schmitt et al. 2011; Aydar et al. 2012) with different styles of eruption, vent type, and deposition are known. The Cappadocia region is part of CAVP and is famous with its ignimbritic landscape with their erosional patterns. There are at least nine ignimbrites described in the region, which are separated either by fluvio-lacustrine deposits or by lava flows emplaced between 10 and 2.5 Ma (Aydar et al. 2012). Central volcanoes also decorate the CAVP landscape, where Miocene aged Erdaş and Melendiz systems and voluminous Quaternary stratovolcanoes such as Erciyes and Hasandağ are observed. The monogenetic vents like cinder cones, fissural lavas, basaltic and rhyolitic maars, and domes complete whole volcanic history of the region (Çiner and Aydar 2019; Mouralis et al. 2019).

Acıgöl (Eski Acıgöl) is a desiccated crater lake located 2 km east of the Acıgöl district (Nevşehir, Central Anatolia) (Fig. 1). The brackish paleo lake was drained in 1972 (Kazancı et al. 1995; Kuzucuoğlu et al. 1998). The explosion crater is defined as Acıgöl maar formed (20,300 ± 600 year BP) by large vapor explosions due to the interaction of hot rhyolitic magma with the (sub-)surface water (Schmitt et al. 2011). The obsidians from Güneydağ dome were dated by fission track as 19,000 ± 7000 year BP and 20,000 ± 6000 year BP (Bigazzi et al. 1993). Moreover, oldest U-series age from Acıgöl is around 23,200 ± 2000 year BP (Roberts et al. 2001). These previous data indicate that the maar crater was formed in latest Pleistocene around 20,000–25,000 years ago. Two explosion craters are determined by Roberts et al. (2001) in the Acıgöl maar, and a core was obtained from 500 m-diameter northwestern crater (Fig. 1).

Kazancı et al. (1995) realized a detailed study in the Acıgöl maar and determined several facies from the maar fill. Kuzucuoğlu et al. (1998) drilled a-20 m-long core (ESK 95-3) in the Acıgöl maar and obtained a radiocarbon age (13,970 ± 220 year BP) at ca. 16.5 m depth that indicates a probable Late Glacial to Holocene age. Roberts et al. (2001) realized a multi-proxy analysis (isotopes, diatoms, pollens, etc.) along the sediment cores gathered from Acıgöl maar and acquired ca. 14,000 year BP radiocarbon age at ca. 14 m depth. The age data gathered from these studies show that most of the sediments were deposited during the Holocene. Their core sections are more or less correlated to the core evaluated in this study. Kuzucuoğlu et al. (1998) showed a radiocarbon age [8440 ± 160 year BP, calibrated by Roberts et al. (2001) as 9439 year BP] at the organic matter (OM) interlayers between 743 and 747 cm. Kuzucuoğlu et al. (1998) obtained another radiocarbon age [5800 ± 170 year BP, calibrated by Roberts et al. (2001) as 6635 year BP] at the upper part of the section (485–488 cm). Roberts et al. (2001) also applied U-series dating along the section that is conformable in depth (e.g., at a depth of ca. 700 cm, they obtained ca. 7000 year BP). They estimated the age of transition from laminated to non-laminated lithologies as ca. 6500 year BP. Roberts et al. (2016) made a multi-proxy investigation on another maar sequence at Nar Lake. Hydro-climate history and ontogeny of the Nar and Acıgöl were compared. The progressive infilling of the Acıgöl maar by sediment during the Holocene caused shallower conditions over time, whereas Nar Lake has remained deep.

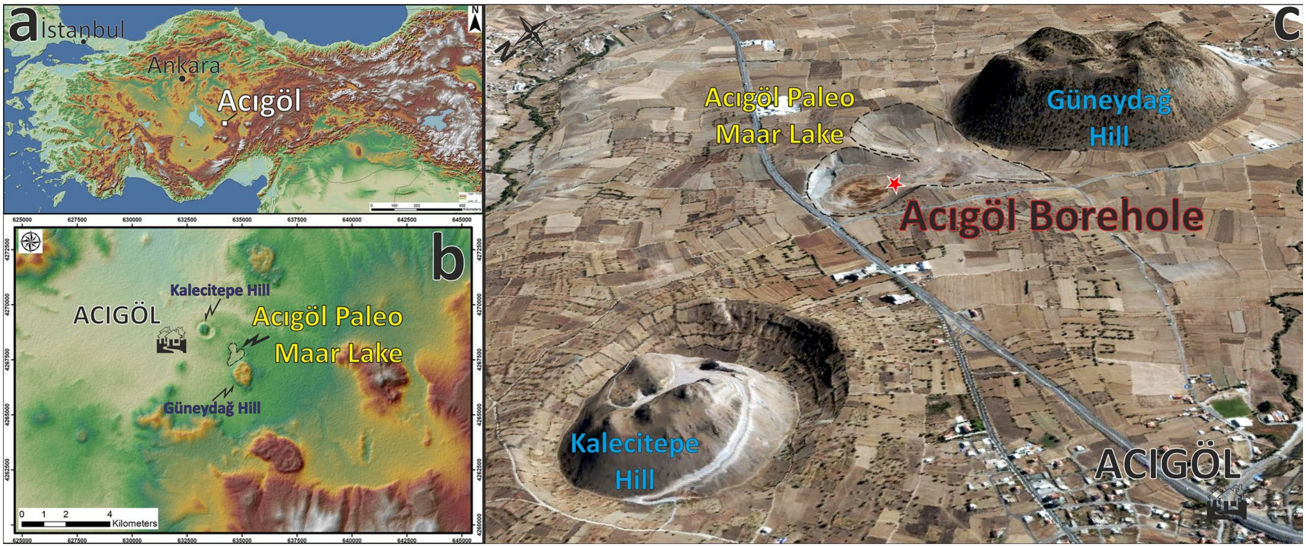

Fig. 1 DEM images showing **a** the location map of Turkey and **b** the location map of the Acıgöl maar and its surroundings. **c** Google Earth image of the Acıgöl maar and location of the borehole

The aim of this study is to evaluate Acıgöl Core Succession (ACS), to determine Holocene ostracod fauna, to exhibit vertical distribution and abundance of the ostracod taxa along the core sequence, and to make ostracod-based paleoenvironmental interpretations.

Methodology

Acıgöl borehole was drilled in July 2008 by Geoprobe® 5410 direct push tooling (Fig. 2). The drilling operation was terminated at 844 cm depth due to the mixing of soft underground sediments. The drilling operation was completed within nine different core sections (DR 1–9) and the cores (35 mm in diameter) were placed into plastic drainpipes from bottom to top and wrapped by stretched plastic film. A total of ca. 713 cm long core succession were retrieved from the Acıgöl paleo maar lake basin (Fig. 2).

The ACS was logged from bottom to top at Hacettepe University Paleontology Laboratory, and geological rock-colour chart produced by Munsell® was used for colour interpretations. The ACS was cut into roughly equal parts. One of the half cores was sampled at every ca. 7–8 cm interval (ca. 30 g) and 99 samples were collected along the ACS for micropaleontological analyses. According to the used sampling method, samples cut at every 7–8 cm represents whole interval, because we evaluated all of sediment material at every sampling interval (e.g., sampling depth 125 cm expresses the 122–129 cm interval). The rest half of the core was stored in a refrigerator (Hacettepe University Sedimentology Laboratory) for reference sampling.

In total, 99 inorganic samples (ca. 30 g) were aligned from bottom to top and put in beakers. They were reacted with dilute (5%) and hot (70 °C) hydrogen peroxide about 12 h and washed under the sieve mesh size of 250 µm and left for drying. The dried residuals were sieved using the sieve-set (mesh size of 1000, 500, and 250 µm respectively) and separated into plastic tubes. The residuals were picked up under Olympus SZ60. Well-preserved and readily recognizable forms (valves and/or carapaces) were aligned on an SEM sticky stamp.

SEM images were acquired by ZEISS EVO50 SEM at Hacettepe University SEM laboratory. SEM image processing was done by Corel® PHOTO-PAINT® X8. Distribution and abundance (number of valves) of each species at each sampling levels were plotted along the core by using Tilia. All obtained and selected ostracods are stored in Hacettepe University Paleontology Laboratory (collection name: Acıgöl).

Lithological characteristics of the Acigöl core succession (Acs)

The 713 cm-long ACS, completed at a depth of 844 cm, is mainly made up of mudstones (Fig. 3). The lower part of the ACS (ca. 640–834 cm) consists of silty mudstones, which bear lamination, calcareous nodes, and OM lumps and remains.

Fig. 2 Field photographs from the Acıgöl maar: **a** panoramic view towards SE, **b** NNE border, **c** Geoprobe® 5410 drilling machine and location the borehole

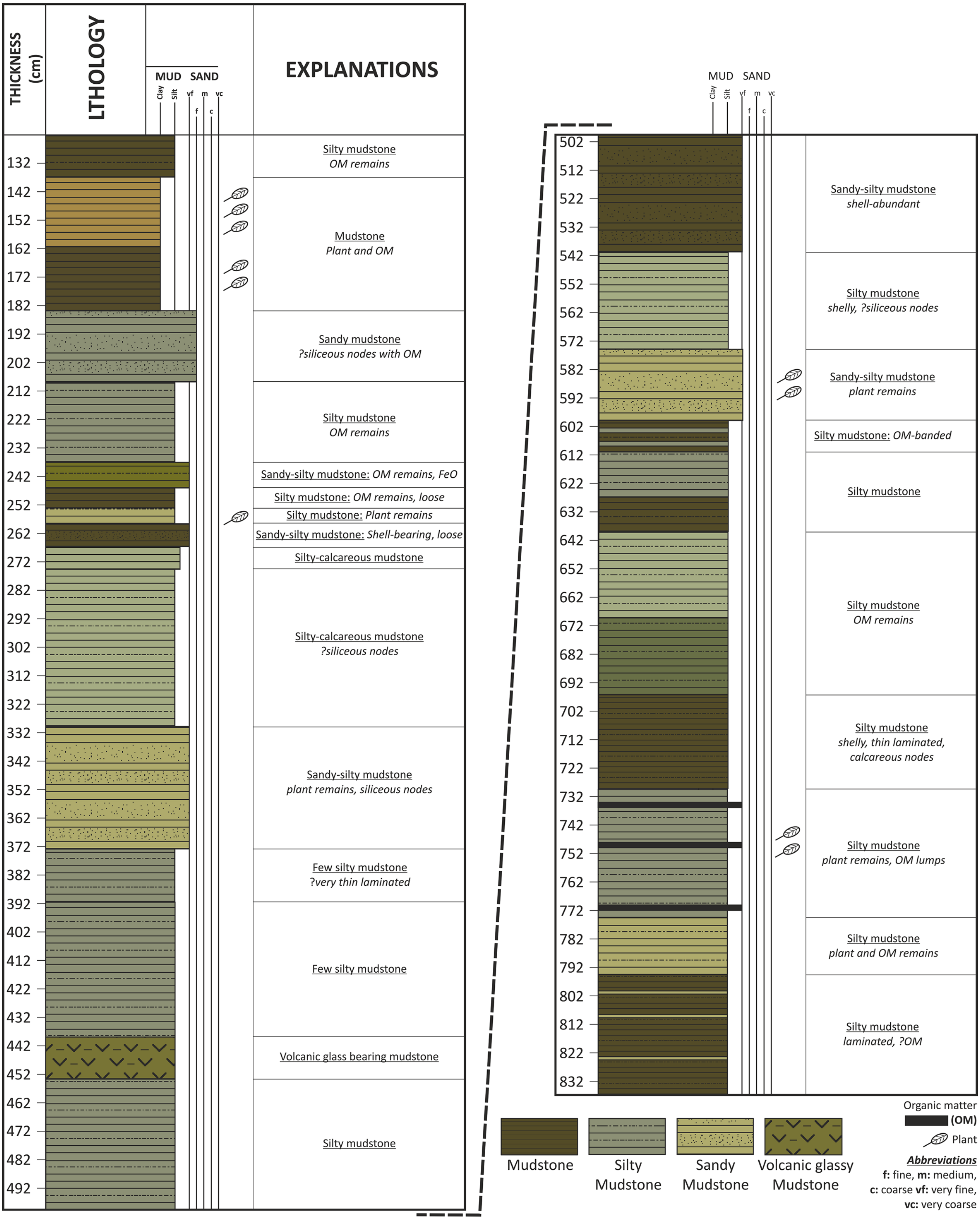

Fig. 3 Measured stratigraphic log and lithological characteristics of the ACS

These mudstones vary in colour from olive gray, light olive gray, and grayish olive to pale olive. Roberts et al. (2001) mention about the laminations in about similar depth to the basement of the core and observed the transition from laminated to non-laminated sediments at a depth of 650–700 cm and dated this boundary as ca. 6500 year BP.

The lower middle part (ca. 500–640 cm) of the ACS comprises of non-laminated, shell-bearing silty, and sandy mudstones (olive gray, dusky yellow, pale olive, and light olive gray in colour). Increasing number of the ostracod and mollusc shells is remarkable in even macro-observations (esp. 585–620 cm interval). Siliceous nodes and plant remains are also found in several levels.

The upper middle part (ca. 372–500 cm) of the ACS consists of light olive gray few silty mudstones with a particular ca. 15 cm-long horizon (439–454 cm interval), which is moderate olive brown in colour and composed of volcanic glass bearing mudstones (Fig. 3). This horizon is also the second remarkable zone where ostracod shells are superabundant in macro-observations.

The relatively coarser upper part of the ACS (ca. 122–372 cm) starts with the plant remains and siliceous nodes bearing dusky yellow sandy–silty mudstones (ca. 330–372 cm). It is overlain by finer pale olive silty calcareous mudstones (ca. 267–330 cm) that remarkably does not bear any shell remains. The ACS passes to olive gray sandy–silty shell and plant bearing mudstones with OM remains between ca. 237–267 cm and FeO particles are remarkable in moderate olive brown sandy–silty mudstones on the upper part (ca. 237–246 cm) (Fig. 3).

The uppermost part of the ACS (ca. 122–237 cm) starts with light olive gray silty mudstones and passes through the coarser sandy mudstones with siliceous nodes, respectively (ca. 184–237 cm). This interval also includes ostracod shells and OM remains. The overlying interval (ca. 122–184 cm) is composed of mudstones and silty mudstones. The finer olive gray-to-dark yellowish orange mudstones (ca. 137–184 cm) bear relatively abundant plant and OM remains, and it passes through the OM-bearing coarser walnut olive gray silty mudstones (ca. 122–137 cm) (Fig. 3).

Results

Faunal and floral findings

Eleven ostracod taxa (*Cypris pubera*, *Plesiocypridopsis newtoni*, *Heterocypris salina*, *Eucypris* cf. *heinrichi*, *Candona candida*, *Candona meerfeldiana*, *Pseudocandona marchica*, *Cyclocypris* sp., *Ilyocypris bradyi*, *Darwinula stevensoni,* and *Limnocythere inopinata*) belonging to ten genera of five families (Cyprididae, Candonidae, Ilyocyprididae, Darwinulidae, and Limnocytheridae) are determined along to ACS (Table 1). *Candona meerfeldiana* (ca. 52,000 valves corresponding to the 95% of the total number of ostracods) dominates the assemblage (total valve number: 54101). *Heterocypris salina* (580 valves, 1.07%), *L. inopinata* (304 valves, 0.57%), and *D. stevensoni* (171 valves, 0.32%) are other significant taxa of the assemblage. Other taxa consisting of *I. bradyi* (53 valves, 0.098%), *P. marchica* (31 valves, 0.057%), *Cyclocypris* sp. (27 valves, 0.050%), *Eucypris* cf. *heinrichi* (27 valves, 0.050%), *C. candida* (12 valves, 0.022%), *C. pubera* (6 valves, 0.011%), and *P. newtoni* (5 valves, 0.009%) are very rare in abundance.

Diatoms are the most frequent and abundant elements of the ACS. Other faunal and floral findings, which are relatively rare, are gastropods (*Gyraulus piscinarum* and *Stagnicola* sp.), pelecypods (*Pisidium personatum*), charophytes, and fish remains.

Ecological characteristic of the ACS ostracod and mollusc taxa

Cypris pubera mainly lives in permanent and shallow water bodies including littoral zones of lakes, ponds, and slow-flowing streams (Meisch 2000). It prefers very shallow–shallow zones of the lakes where plants and charophytes are sometimes dense so it is known as a phytophilic species (Anadón et al. 2012). The salinity range of the species ranges from freshwater to α-oligohaline (0–4.0‰) (Meisch 2000) (Table 2).

Plesiocypridopsis newtoni is a permanent species mainly preferring small and stagnant water bodies like ponds and subsequently littoral zones of lakes and slow-flowing streams (lotic) (Meisch 2000). The highest salinity value of the species exceeds up to 15.7‰ (De Deckker 1981) and range varies between freshwater and polyhaline (Meisch 2000). Recent representatives are mainly recorded in summer, and so, it is known as a warm-stenothermal species (Fuhrmann 2012) (Table 2).

Heterocypris salina (Plate 1, Figs. 1–3) can tolerate a wide range of salinity conditions and is recorded in freshwater-to-polyhaline (0.4–20‰) aquatic environments (Neale 1988; Griffiths and Holmes 2000). Because of its wide salinity range, it is not recommended to use the species as a salinity indicator alone (Meisch 2000). It prefers vegetation-rich aquatic environments (mainly lakes) dominated by shallow/littoral aquatic conditions (Anadón et al. 2012; Fuhrmann 2012; Tuncer et al. 2017) (Table 2).

Candona candida (Plate 1, Figs. 9–11) is widespread in many aquatic habitats: littoral zones of lakes, ponds, irrigation channels, peaty waters under acidic conditions, creeks, rivers, springs, wells, and groundwater environments (Meisch 2000). Hiller (1972) and De Deckker (1981) point

Table 1 Taxonomy of the Holocene Ostracoda fauna determined along the ACS (Meisch et al. 2019)

- Class Ostracoda Latreille, 1802
- Subclass Podocopa G.W. Müller, 1866
- Order Podocopida G.O. Sars, 1866
- Suborder Cypridocopina Baird, 1845
- Superfamily Cypridoidea Baird, 1845
  - Family Cyprididae Baird, 1845
    - Subfamily Cypridinae Baird, 1845
      - Genus *Cypris* O.F. Müller, 1776
        - ***Cypris pubera*** O.F. Müller, 1776
    - Subfamily Cypridopsinae Kaufmann, 1900
      - Genus *Plesiocypridopsis* Rome, 1965
        - ***Plesiocypridopsis newtoni*** (Brady & Robertson, 1870)
    - Subfamily Cyprinotinae Bronshtein, 1947
      - Genus *Heterocypris* Claus, 1892
        - ***Heterocypris salina*** (Brady, 1868)
    - Subfamily Eucypridinae Bronshtein, 1947
      - Genus *Eucypris* Vávra, 1891
        - ***Eucypris* cf. *heinrichi*** (Diebel & Pietrzeniuk, 1978)
  - Family Candonidae Kaufmann, 1900
    - Subfamily Candoninae Kaufmann, 1900
      - Genus *Candona* Baird, 1845
        - ***Candona candida*** (O.F. Müller, 1776)
        - ***Candona meerfeldiana*** Scharf, 1983
      - Genus *Pseudocandona* Kaufmann, 1900
        - ***Pseudocandona marchica*** (Hartwig, 1899)
    - Subfamily Cyclocypridinae Kaufmann, 1900
      - Genus *Cyclocypris* Brady & Norman, 1889
        - ***Cyclocypris* sp.**
  - Family Ilyocyprididae Kaufmann, 1900
    - Subfamily Ilyocypridinae Kaufmann, 1900
      - Genus *Ilyocypris* Brady & Norman, 1889
        - ***Ilyocypris bradyi*** Sars, 1890
  - Family Limnocytheridae Sars, 1925
    - Subfamily Limnocytherinae Sars, 1925
      - Genus *Limnocythere* Brady, 1868
        - ***Limnocythere inopinata*** (Baird, 1843)
- Superfamily Darwinuloidea Brady & Robertson, 1885
  - Family Darwinulidae Brady & Robertson, 1885
    - Genus *Darwinula* Brady & Robertson, 1885
      - ***Darwinula stevensoni*** (Brady & Robertson, 1870)

out that the highest recorded salinity value for the species is 5.7‰. It is mainly recorded in very shallow–shallow waters (Anadón et al. 2012; Bellucci et al. 2012). According to Delorme (1991), it can tolerate different water temperatures and pH values. The ranges of water temperature (11.40–30.0 °C) and pH (4.6–13.00) were compiled by Külköylüoğlu (2000, 2004). The species have been obtained from water bearing zero dissolved oxygen in December (Delorme 1991). On the other hand, Ruiz et al. (2013) suggested that *C. candida* might tolerate low concentrations for short terms. Meisch (2000) states that juveniles of this permanent species are dry-resistant and can be found in muddy substrate during the dry periods (Table 2).

Although *Candona meerfeldiana* (Plate 2, Figs. 1–7) dominates the fauna assemblage of the ACS, it has a rare and narrow distribution in faunal area (Table 3). Therefore, ecological knowledge on the species is insufficient. It is first obtained from Lake Meerfelder Maar (Germany; Scharf 1983) and recent representatives were mainly found at depths of 8–12 m in (Scharf 1983; Meisch 2000). Martín-Rubio et al. (2005) collected the species from relatively deeper waters (ca. 10 m). Meisch (2000) points out that the species is not frequent in shallow littoral zones of the lakes, while it is absent in the deepest parts. Ricci Lucchi et al. (2000) asserted that it mainly prefers oligotrophic conditions, while recent representatives meso-ipertrophic waters.

Table 2 Ecological characteristics (salinity, depth, temperature, and pH of the ambient water), habitat preferences, and geographic distribution of known ostracod species of the ACS

Ostracod Species	**Salinity**	**Depth**	**Temperature**	**pH**	**Habitat**	**Geographic Distribution *(3) (8)***
Cypris pubera	freshwater–α-oligohaline (0-4,0‰) ***3***	very shallow-shallow ***5***	mesothermophilic ***5***		phytophilic ***5***	AU, NA, NT, PA
Plesiocypridopsis newtoni	freshwater–polyhaline (0,3-25 ‰) ***3***	very shallow ***3***	warm-stenothermal ***3***			AT, OL, PA
Heterocypris salina	freshwater–polyhaline (0,4-20 ‰) ***0***	very shallow ***5***	termoeuryplastic ***3***	6,05-9,90 ***7***	phytophilic ***5***	NA, NT, OL, PA
Candona candida	freshwater–β-mesohaline (0-5,77 ‰) ***3***	very shallow ***5*** -deep ***3***	oligothermophilic ***3***	4,6-13,00 ***9***		NA, PA
Candona meerfeldiana	Inadequate data	?very shallow-shallow ***3***	?oligothermophilic ***3***			PA
Pseudocandona marchica	freshwater–α-oligohaline (0-4,0‰) ***0***	very shallow **5**	polythermophilic ***3, 4***		?phytophilic ***2***	PA
Darwinula stevensoni	freshwater–α-mesohaline (0-15 ‰) ***0***	very shallow-shallow ***5***	mesothermophilic ***3***	5,50-9,67 ***7***	phytophilic ***5***	AT, AU, NA, NT, OL, PA
Ilyocypris bradyi	freshwater–α-oligohaline (0,3-4,4 ‰) ***3***	?very shallow ***3***	oligothermophilic ***3*** - ?mesothermophilic ***7***	5,43-9,89 ***7***		NA, NT, OL, PA
Limnocythere inopinata	freshwater–polyhaline (0-25 ‰) ***6***	very shallow-shallow ***5***	polythermophilic ***5***	6,4-10,4 ***7***	phytophilic ***5***	AT, NA, PA
Venice Salinity Classification (Caspers, 1959) (‰ salinity) **Freshwater:** 0-0.5 **β-Oligohaline**: 0.5-3 **α-Oligohaline:** 3-5 **β-Mesohaline:** 5-10 **α-Mesohaline:** 10-18 **Polyhaline:** 18-30 **Euhaline:** 30-40 **Hyperhaline:** 40<	**Water Depth Classification (Wetzel 1983)** **Very shallow:** Littoral Zone where the light penetrates to the bottom **Shallow**: Middle Side/Photic Zone where photosynthesis could occur **Deep:** Aphotic Zone where the light cannot reach and the primary productivity does not occur		**Temperature Classicification (Meisch 2000; Frenzel 2010)** **Cold-stenothermal:** Species permanently live only in cold waters **Oligothermophilic:** Species preferring cold waters (winter forms) **Polythermophilic:** Species preferring hot/warm waters **Mesothermophilic:** Species between oligo and polythermophilic forms **Warm-stenothermal:** Species permanently live only in hot/warm waters **Thermoeuryplastic:** Species tolerating a wide range of temperatures			

The data are mainly compiled from 0: De Deckker (1981), 1: Neale (1988), 2: Griffiths and Holmes (2000), 3: Meisch (2000), 4: Fuhrmann (2012), 5: Anadón et al. (2012), 6: Ruiz et al. (2013), 7: Yavuzatmaca et al. (2017), 8: Meisch et al. (2019), 9: Külköylüoğlu (2004), and references therein

Abbreviations from Meisch et al. (2019): *ANT* = Antarctic, *AT* = Afrotropical, *AU* = Australasian, *NA* = Nearctic, *NT* = Neotropical, *OL* = Oriental, *PA* = Palearctic

Pipík and Bubik (2006) also obtained the species from both oligotrophic and eutrophic shallow lacustrine facies, relative abundance of the species dramatically increase in latter facies. *Candona meerfeldiana* is most probably an oligothermophilic species (Meisch 2000; Ricci Lucchi et al. 2000) (Table 2).

Pseudocandona marchica is mainly obtained from small wetlands (both permanent and temporary), lakes, and streams (epifaunal and/or infaunal) including littoral zones of the lakes, ponds, springs, and swamps (Meisch 2000). It is found with submerged plants in freshwater bodies (Griffiths and Holmes 2000) and is recorded from Eifelian Maar Lakes (Germany) at about 6 m depth (Scharf 1980; Meisch 2000). It mainly tolerates freshwater to α-oligohaline (even β-mesohaline; Anadón et al. 2012); salinity ranges up to 4‰ (De Deckker 1981). This polythermophilic species is accepted as a summer (spring) form (Fuhrmann 2012). Akdemir (2008) collected the species from Lake Meyil (Konya) with the salinity of 1‰ and the pH of 8.8 (Table 2).

Ilyocypris bradyi (Plate 3, Figs. 3–4) is mainly found in freshwater to α-oligohaline springs and ponds fed by springs. It is an oligothermophilic (even mesothermophilic, Yavuzatmaca et al. 2017) and rheophilic (living in lotic waters) and also live in rivers, lakes, and swampy environments (Meisch 2000). Akdemir (2008) obtained it from Lake Meyil (a sink hole lake, Konya) and Lake Acı (a maar lake, Konya) (Table 2).

Darwinula stevensoni (Plate 3, Figs. 5–6) prefers ponds and lakes along with the slow-flowing water bodies (Meisch 2000). It is recorded from freshwater to α-mesohaline salinities up to 15‰ and its pH interval is 7.0–10.3 (Hiller 1972). It is a mesothermophilic and phytophilic species, and frequently found in very shallow-to-shallow water bodies and optimum depth is about 6 m (Ricci Lucchi et al. 2000; Anadón et al. 2012). Akdemir (2008) collected the species from Lake Acı (Konya) at a depth about 12 m with a pH of 7.5 and from Lake Meyil (Konya) at a depth about 1 m and a pH of 8.8 (Table 2).

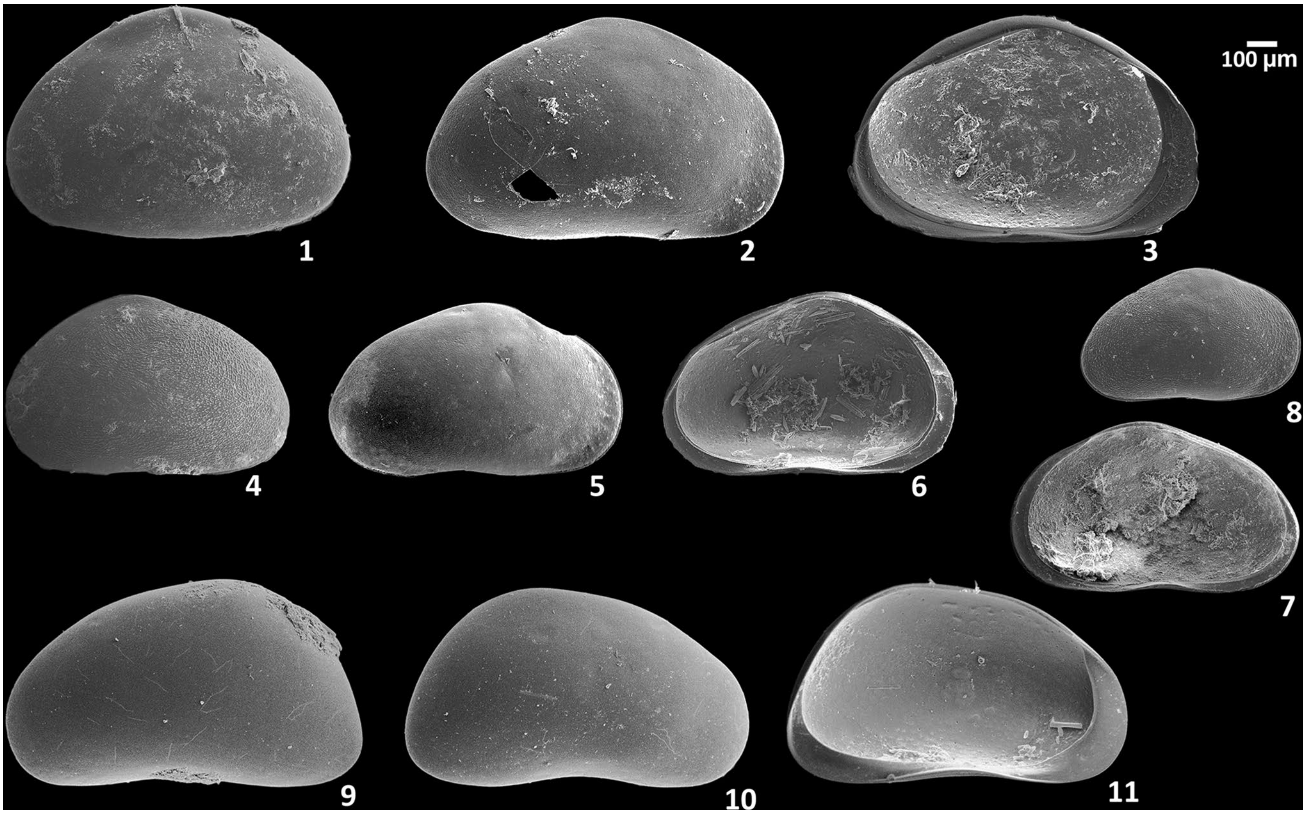

Plate 1 1–3 *Heterocypris salina* (Brady, 1868); 1 LVe (l: 1164.78 µm, h: 793.83 µm); 2 RVe (l: 1205.2 µm, h: 742.66 µm); 3 LVi (l: 1183.73 µm, h: 776.47 µm). 4–8 *Eucypris* cf. *heinrichi* (Diebel and Pietrzeniuk, 1978); 4 LVe (l: 958.132 µm, h: 604.625 µm); 5 RVe (l: 993.133 µm, h: 574.49 µm); 6 LVi (l: 998.195 µm, h: 626.598 µm); 7 RVi (l: 978.83 µm, h: 581.6 µm); 8 RVe (juvenile) (l: 739.84 µm, h: 441.85 µm). 9–11 *Candona candida* (O.F. Müller, 1776); 9 LVe (l: 1205.8 µm, h: 718.08 µm); 10 RVe (l: 1161.28 µm, h: 674.27 µm); 11 LVi (l: 1147.93 µm, h: 654.66 µm)

Limnocythere inopinata (Plate 3, Figs. 7–13), like many of the obtained taxa, is a tolerant species to environmental conditions. It is mainly found in ponds, swamps, lakes, slow-flowing creeks, and streams having muddy and/or sandy substrate. It is a polythermophilic and phytophilic species recorded from highly alkaline waters (Meisch, 2000). It also known as "Summer Form" (Fuhrmann 2012) (Table 2).

Gyraulus piscinarum (pulmonate gastropod; Plate 4, Figs. 2–3) is mainly found in steady, slow-flowing fresh waters, on the edge of the lakes, shallow depths on muddy grounds, or on aquatic plants (maximum salinity: 5.2; pH: 5.2–9.7). Its geographical distribution is Palearctic (Yıldırım and Karaşahin 2000; Şereflişan et al. 2009).

The genus *Stagnicola* (pulmonate gastropod; Plate 4, Fig. 1) prefers steady, slow-flowing and vegetated freshwater bodies. The muddy shallows of small water resources are common in temporary aquatic areas periodically drying. It is also observed in marshes and shallow channels. It can adapt to a wide range of temperature and dissolved oxygen conditions (maximum salinity: 9.5; pH: 7) (Akbulut et al. 2009).

Pisidium personatum (sphaeriid pelecypod; Plate 4, Figs. 4–5) is mainly observed in small stagnant and slow-flowing freshwaters, springs, lakes, ponds, channels, and temporary waters. It can rapidly form colonies in artificial aquatic areas. It prefers nutrient-rich water (pH: > 5). Its geographical distribution is Palearctic (Akbulut et al. 2009). This species was also recorded from the Late Miocene deposits of Central Anatolia (Sandıklı, Koçgazi-Afyon) (Schütt 1991; Schütt and Kavuşan 1994), and from the Pleistocene strata of Lake Beyşehir (Konya) (Girod 2013). As being an element of the Sarmatian age of the Central Paratethys, this bivalve species indicates the possibility of the faunistic relations between the habitats of Central Anatolia with Southern and Central Europe (Schütt and Kavuşan 1994).

The known ostracod species of the ACS is mainly recorded along the Palearctic ecozone, and *C. meerfeldiana* significantly has the narrowest distribution and rarest occurrence among the other determined species.

Vertical distribution of ostracods and paleoenvironmental interpretations

Ostracods and the accompanying assemblages with varied distribution along the ACS suggest significant

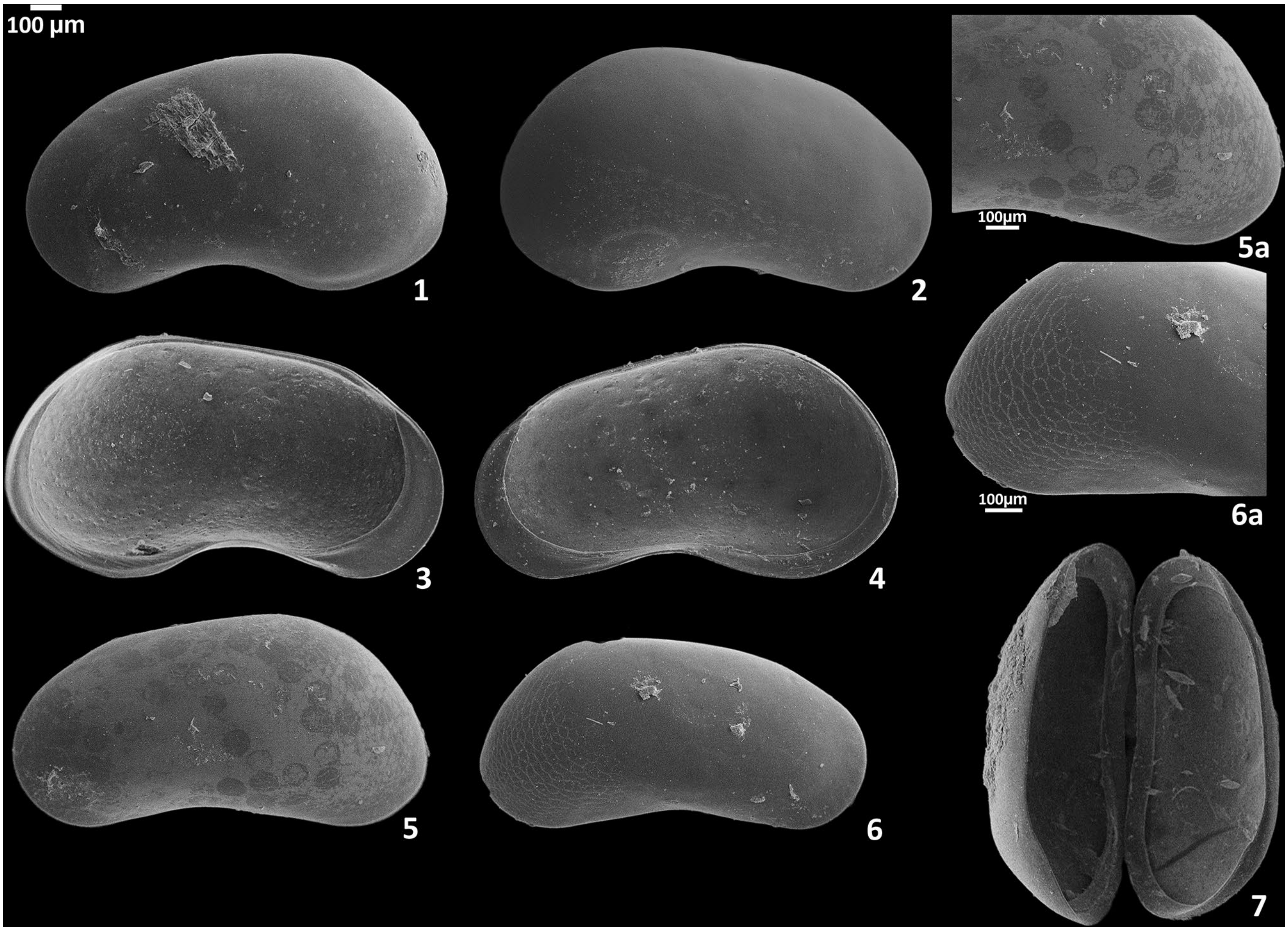

Plate 2 1–7 *Candona meerfeldiana* Scharf, 1983; 1 Male-LVe (l: 1382.91 μm, h: 778.18 μm); 2 Male-RVe (l: 1413.9 μm, h: 793.25 μm); 3 Male-LVi (l: 1439.05 μm, h: 789.93 μm); 4 Male-RVi (l: 1389.65 μm, h: 780.92 μm); 5 Female-LVe (l: 1362.27 μm, h: 690.1 μm); 6 Female-RVe (l: 1270.86 μm, h: 609.38 μm); 7 Carapace-Dorsal (l: 1264.88 μm, w: *967.84 μm)

Table 3 Occurrence and distribution of the species *C. meerfeldiana*

Taxa	Locality	Age	Study
Candona meerfeldiana	Rieti Basin (Central Italy)	Late Pleistocene–Holocene	Ricci Lucchi et al. (2000)
Candona meerfeldiana	Lake Meerfelder Maar (Germany)	Late Glacial (Weichselian) and Recent	Scharf (1983, 1984, 1993)
Candona meerfeldiana	Krumvíř (Czech Republic)	Quaternary	Pipík and Bubik (2006)
Candona meerfeldiana	A ditch in Luxembourg	Recent	Unpublished data from Meisch (2000)
Candona cf. *meerfeldiana*	Hula Basin (Israel)	Pleistocene	Kalbe et al. (2015)
Candona cf. *meerfeldiana*	Lake Caicedo de Yuso-Arreo (Western Ebro Basin, Spain)	Recent	Martín-Rubio et al. (2005)

paleoenvironmental conditions (Fig. 4). As the lowermost part of the ACS, the ostracods are almost absent; no interpretation could be made. The first significant appearance of ostracods is observed at a depth of ca. 809 cm (Fig. 4). They become abundant to the ca. 780 cm where number of valves reach up to 1700. *Candona meerfeldiana,* dominant species of the ACS, co-occurs with *H. salina*, *L. inopinata,* and *I. bradyi* along that interval and they show relatively deepening freshwater to oligohaline lacustrine conditions. Upwards (731–773 cm), the abundance of *C. meerfeldiana* gradually and remarkably decreases, while *H. salina*, *L. inopinata,* and charophytes slightly increase (Fig. 4). This variation may

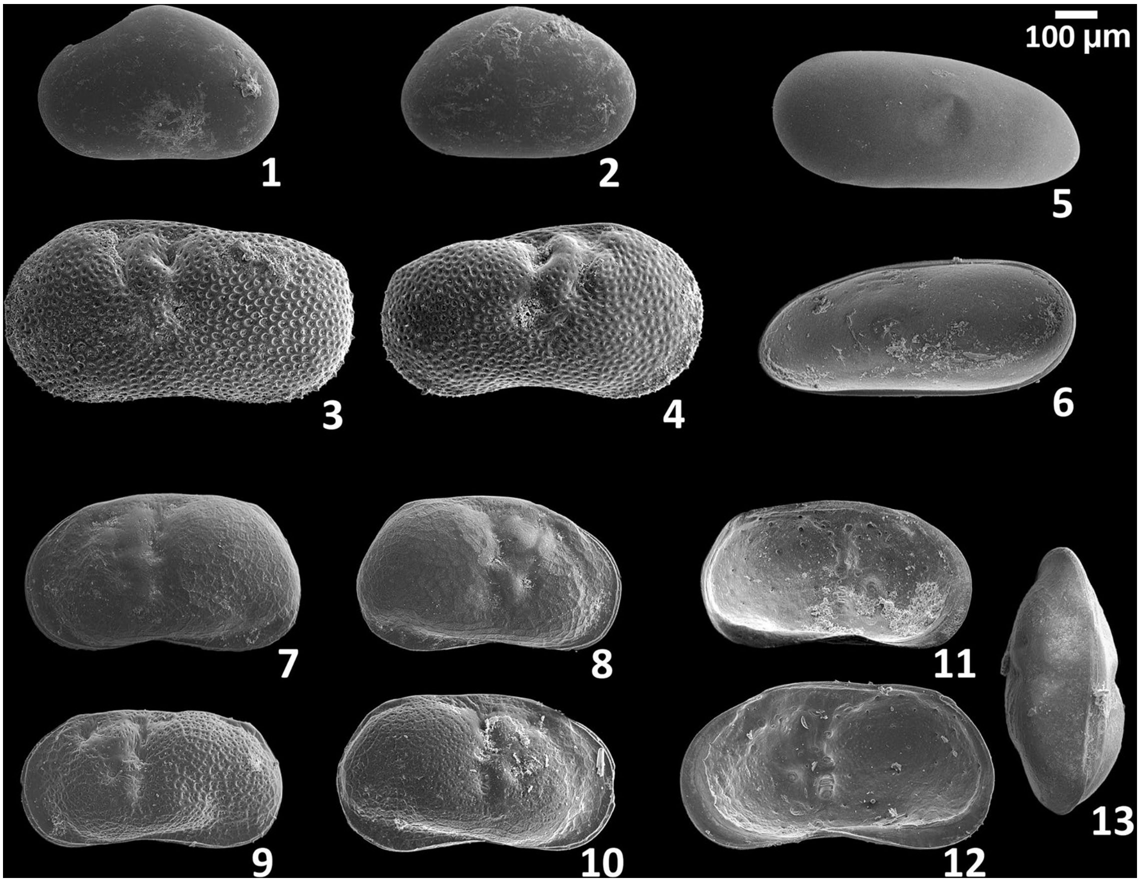

Plate 3 1–2 *Cyclocypris* sp.; 1 LVe (l: 545.14 µm, h: 347.43 µm); 2 RVe (l: 567.82 µm, h: 369.74 µm). 3–4 *Ilyocypris bradyi* Sars, 1890; 3 LVe (l: 845.47 µm, h: 436.49 µm); 4 RVe (l: 776.11 µm, h: 420.96 µm). 5–6 *Darwinula stevensoni* (Brady & Robertson, 1870); 5 RVe (l: 739.84 µm, h: 322.53 µm); 6 RVi (l: 769.62 µm, h: 333.18 µm). 7–13 *Limnocythere inopinata* (Baird, 1843); 7 LVe (l: 666.67 µm, h: 375.51 µm); 8 RVe (l: 640.22 µm, h: 366.97 µm); 9 LVe (l: 631.61 µm, h: 320.35 µm); 10 RVe (l: 667.88 µm, h: 362.66 µm); 11 LVi (l: 653.74 µm, h: 334.16 µm); 12 RVi (l: 756.88 µm, h: 403.58 µm); 13 Carapace-Dorsal (l: 650.7 µm, w: 268.37 µm)

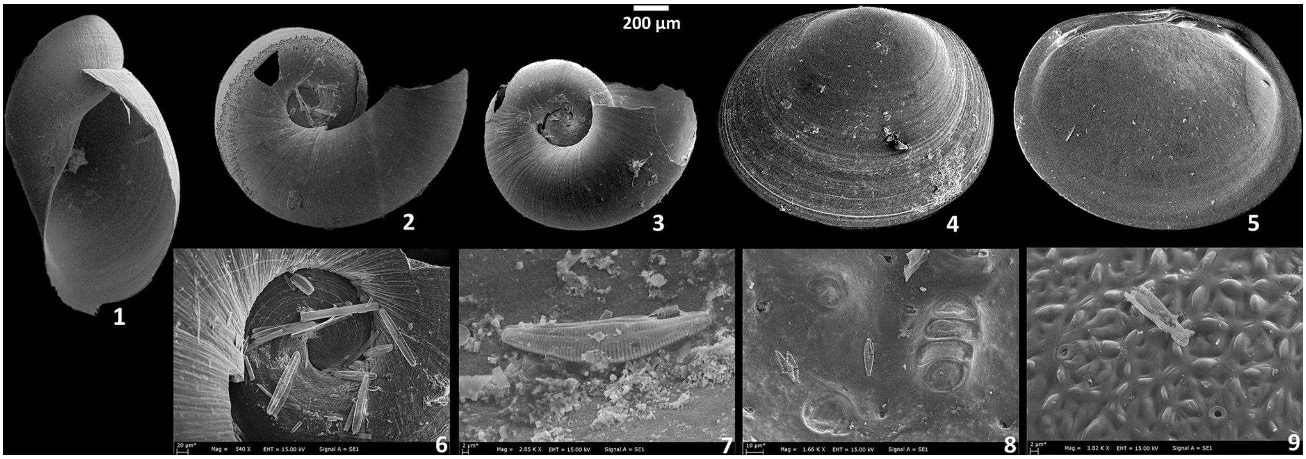

Plate 4 1 *Stagnicola* sp.; 2–3 *Gyraulus piscinarum;* 4–5 *Pisidium personatum;* 6–9 diatoms on ostracod valves. *LVe* External view of the left valve, *RVe* External view of the right valve, *LVi* Internal view of the left valve, *RVi* Internal view of the right valve, *l* length, *h* height, *w* width

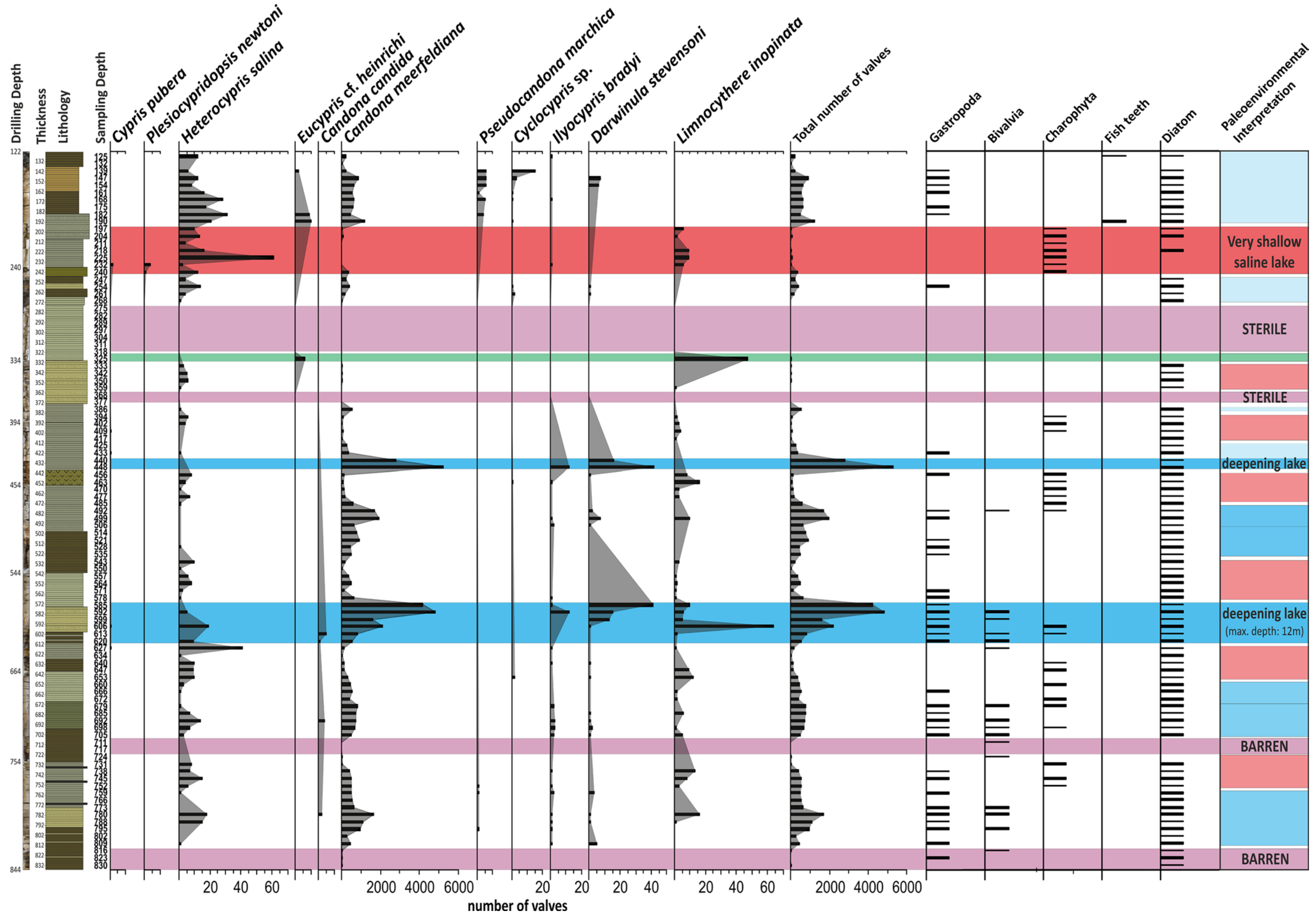

Fig. 4 Distribution and abundance of the ostracods and other elements along the core (dark shades of blue express relatively dilute and deeper terms, while dark shades of red sign relatively saline and shallow terms)

be the indicator of the shallowing lake level as 711–724 cm interval is very rare in terms of ostracods. Abundance of ostracod commences to increase at 705 cm. Especially, relative increase of *I. bradyi* points out the spring charging to the lake basin indicating the slightly rising lake level along with the *C. meerfeldiana*. Upwards increasing of charophytes and decreasing of *C. meerfeldiana* and *I. bradyi* may indicate the shallowing conditions. Moreover, relative abundance of shallow-depended and salinity-tolerant species *H. salina* and *L. inopinata* (polythermophilic) at 627–653 cm interval supports the shallowing lacustrine conditions.

One of the most striking variations along the ACS was observed at 585–620 cm interval (Fig. 4). Shallow lacustrine conditions with increasing number of ostracods at the lower parts gradually pass through the deeper (ca. 6–12 m) lacustrine (lake level rise) conditions. 592 cm (4800 valves of *C. meerfeldiana*) and 585 cm (4187 valves of *C. meerfeldiana*) depths are extremely abundant levels in terms of ostracods. As well as the superabundance of *C. meerfeldiana,* paucity of very shallow to shallow species (*H. salina* and *L. inopinata*) and the absence of charophytes may show the freshwater to oligohaline relatively deepening conditions with the occurrence of spring-depended *I. bradyi*.

The fauna of overlying interval (543–578 cm) is also dominated by *C. meerfeldiana*. However, a sharp decrease in abundance may be the indicator of slight lake level drops by comparing the underlying level. The lake level again relatively increases (not deeper than ca. 10 m) from 535 to 492 cm where abundance of *C. meerfeldiana* (ca. 1950 valves) remarkable increases, while *H. salina* is almost absent (Fig. 4).

At 448 cm, abundance of ostracods reaches the highest number along the ACS. *Candona meerfeldiana* (5240 valves), *D. stevensoni* (42 valves), and *I. bradyi* (12 valves) are obtained, respectively (Fig. 4). The fauna assemblage is the indicator of freshwater to oligohaline, spring-fed, and deepening lacustrine environment, not deeper than 12 m. Although the abundance tends to decrease (total number of valves ca. 2800) at the upper level (440 cm), it is possible to mention about almost similar depositional environment.

From the 440 cm to the floor of ACS, the abundance is no longer very high and the assemblages mainly indicate shallower and relatively saline conditions. The interval between 333 and 433 cm is represented by a sparse ostracod fauna compared to the older levels. Shallowing and very shallow lacustrine conditions were common. A striking peak observed in *L. inopinata* (47 valves) at 325 cm may signal the higher alkalinity (even salinity). Moreover, the overlying interval 275–318 cm is sterile (Fig. 4), which may be related to possible very high alkaline conditions.

The ostracods appear again as of the 268 cm level and the fauna indicates shallow and slightly saline conditions to the 240 cm. The lake most probably retreated at the 197–232 cm interval. As an indicator of these conditions, the fauna becomes abundant in terms of salinity-tolerant *H. salina*, *L. inopinata,* and *P. newtoni* which also prefer very shallow and relatively warm waters. Existence of phytophilic *C. pubera* is another indicator of very shallow lake conditions.

The uppermost interval 125–190 cm mainly consists of *C. meerfeldiana*, *H. salina*, *P. marchica, Cyclocypris* sp., and *D. stevensoni* (Fig. 4). The fauna points out a small lake-level rise with shallow and warm lacustrine conditions. Salinity-tolerant *H. salina* is still common but not abundant by comparing the underlying level and *L. inopinata* is absent, so that the lake may not have been very saline and alkaline. Furthermore, summer species *P. marchica* mainly found in freshwater to α-oligohaline (up to 4‰) small water bodies.

The total abundance of species under deepening lake conditions has increasing trends, in contrast to shallow lake conditions (Fig. 4). It shows that how the different species can populate together as long as habitat conditions are suitable. On the other hand, many juveniles and adults of *C. meerfeldiana* are gathered together at many levels. Besides, the number of valves is higher than carapaces at these levels.

Discussion

Ostracod-based interpretations along the ACS are comparable to the data generated in the previous studies. Not only the vertical abundance of the ostracod assemblages, but also change in species diversity throughout the sediment profile also shows alternating paleoenvironmental/paleoecological conditions.

During the deposition of the laminated lower part of ACS, the freshwater to oligohaline, oligotrophic, and relatively deep lacustrine conditions prevailed and short-term lake-level drop fluctuations were common. Our findings are comparable to data by Roberts et al. (2001) who mention about the deep and dilute lake with wetter climatic conditions up to ca. 650 cm deep (ca. 6500 year BP). However, as from this shift point, they asserted that main lake regression started where planktonic diatoms and mesic deciduous trees declined. Our data do not indicate a distinct lake regression at this threshold, and on the contrary, *C. meerfeldiana* is superabundant at several overlying intervals (585–620 cm and 440–448 cm). In the latter interval (440–448 cm), where a 15-cm-thick volcanic glass-bearing mudstone level is observed, the overmultiplying abundance of the *C. meerfeldiana* may be related to a volcanic activity in maar and deepening lake conditions. Increasing abundance of *I. bradyi* at several levels may be the indicator of springs charging to the basin instead of surface streams. Similarly, Jones et al. (2007) suggested that the groundwater recharge was active instead of surface flows at the paleo lake basin.

The ostracod fauna varies significantly as from 440 cm the abundance of the whole assemblage and the dominant species *C. meerfeldiana* strikingly commences to decrease. Moreover, ostracods and other elements are absent at several overlying levels. The interval most probably corresponds to Late Holocene by comparing the data from Kuzucuoğlu et al. (1998) and Roberts et al. (2001). Late Holocene dryer climatic conditions at Eastern Mediterranean were determined along the Acıgöl cores revealed by Roberts et al. (2001) and the term of the oak decline triggered by the human impact was estimated as 4000–4500 year BP. The signals of the dryer Late Holocene are provided by ostracod data. The wider sterile/barren intervals are overlain by the very shallow–shallow, warmer, and saline lacustrine conditions. Roberts et al. (2001) determined a sedimentary unit, which is equivalent of silty calcareous mudstone level (265–330 cm) of the ACS. This sedimentary unit is partly comprised of dolomite and talc, indicating hyper-saline/alkaline conditions between 4200 and 2500 year BP. Relative abundance of alkaline tolerant *L. inopinata* at 325 cm and absence of ostracods at overlying 275–318 cm also corroborate these conditions. Our results on shallowing lake conditions at 197–232 cm interval are comparable with data from Roberts et al. (2016). However, the authors indicate that some of the changes recorded in Acıgöl during the last 2000 years reflect the ontogeny rather than climate change.

The U-series age data (ca. 7000 year BP at 7 m depth) by Roberts et al. (2001) indicate that deepest part of the ACS (844 cm) most probably corresponds to 8000–8500 year BP. The interval involves the Early–Middle Holocene (Greenlandian-Northgrippian) transition (8200 year BP). The Greenlandian (Early Holocene) in ACS is ambiguous. It can be suggested that large part of the ACS was deposited during Northgrippian (Middle Holocene)—Meghalayan (Late Holocene).

Within the ostracod population structure observations, it is observed that *C. meerfeldiana* is well distributed in ontogenic series (many juveniles and adults) at almost all sampling levels indicating stagnant conditions. Moreover, valve/carapace ratio is very high, probably indicating the low sedimentation rate allowing the disarticulation of carapaces to single valves (Keatings et al. 2007).

Frequently found diatoms can be abundant in some levels indicating the change in pH and hydrothermal silica input to the Acıgöl paleo maar lake where intense volcanic activities were prevailed. On the other hand, diatoms are almost absent at the upper part (275–330 cm) corresponding to the Late Holocene. Roberts et al. (2001) suggest that the ion concentration increase of lake water due to evaporation causes diatom dissolution during the deposition of that part.

Our paleoenvironmental interpretations substantially based on vertical distribution and abundance of ostracods provide to determine changing conditions along the ACS. Although the results are compatible with the previous studies, a future multi-proxy approach using the ostracod valve chemistry (stable isotope and trace element analyses) as a tool may lead to make high-resolution paleoenvironmental/paleoclimatic interpretations along the ACS.

Conclusion

By the evaluation of 11 determined ostracod taxa along with accompanying assemblages and lithology, a detailed paleoenvironmental approach is proposed along the ACS.

The fauna at the lower parts of ACS (possibly deposited during the Northgrippian, Middle Holocene) mainly indicates freshwater to oligohaline, oligotrophic, and relatively deep lacustrine conditions alternating with short lake shrinkage terms. The volcanic material at the top of this part includes a superabundant ostracod assemblage, which is related to a possible maar formation and the deepening of the lake. At the upper part of the ACS (most probably Meghalayan in age, Late Holocene), the lacustrine environment is represented by shallow, saline, and warmer conditions.

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