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UPPER MIOCENE CALCAREOUS MICROFOSSILS (FORAMINIFERA AND OSTRACODA) FROM NORTHWESTERN ARGENTINA

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Abstract. Although the Neogene deposits of the Calchaquíes Valleys, northwestern Argentina, have been intensively studied, there are only a few works dealing with the calcareous microfauna. Thus, this study aims to provide detailed systematic descriptions of the calcareous microfauna recorded at the Playa del Zorro Alloformation and Chiquimil Formation, units exposed at the El Cajón Valley and Pampa Hill respectively, Catamarca Province. Also, an assessment of the paleoenvironment, based on the calcareous microfossil association was carried out for both units. As a result, a new species of the ostracod genus *Cyprideis* Jones was recognized, namely *Cyprideis calchaquiensis* nov. sp., which was found associated with *Perissocytheridea carrenoe* Nicolaidis & Coimbra, *Limnocythere* spp. and the foraminifera *Ammonia tepida* Cushman. The low diversity assemblage, the predominance of rounded sieve pores on the valve surface of *C. calchaquiensis* nov. sp., and the presence of abnormal tests of *A. tepida* point to a shallow stressed water body that suffered evaporation episodes, resulting in fluctuating salinity. Interestingly, close similarities were observed between the Playa del Zorro Alloformation and Chiquimil Formation with the upper section of the Yecua Formation, Bolivia. This affinity could be explained by the passive dispersal capacities of the ostracods and foraminifers, the ecological preferences of the recognized taxa and the proximity of the outcrops, assisted by the development of mega wetlands.

Key words. Miocene. Non-marine ostracods. Foraminifera. Paleoenvironments. Playa del Zorro Alloformation. Chiquimil Formation.

Resumen. MICROFÓSILES CALCÁREOS (FORAMINIFERA Y OSTRACODA) DEL MIOCENO SUPERIOR DEL NOROESTE ARGENTINO. Los depósitos neógenos que afloran en los Valles Calchaquíes han sido objeto de estudios intensivos, sin embargo, solo unos pocos trabajos tratan sobre la microfauna calcárea. El objetivo de este estudio es proveer descripciones sistemáticas detalladas de la microfauna registrada en la Aloformación Playa del Zorro y Formación Chiquimil, unidades expuestas en el valle El Cajón y el cerro Pampa respectivamente, provincia de Catamarca. Además, se realizó la evaluación del paleoambiente de ambas unidades, con base en la asociación de microfósiles. Como resultado, se reconoció una nueva especie de ostrácodo del género *Cyprideis* Jones, denominada *Cyprideis calchaquiensis* nov. sp., asociada con *Perissocytheridea carrenoe* Nicolaidis y Coimbra, *Limnocythere* spp. y con el foraminífero *Ammonia tepida* Cushman. La baja diversidad de la asociación, el mayor porcentaje de poros en tamiz redondeados sobre la superficie de las valvas de *Cyprideis calchaquiensis* nov. sp. y la presencia de conchillas anormales de *A. tepida* sugieren el desarrollo de un cuerpo de agua somero, estresado, que sufrió periodos de evaporación resultando en la fluctuación de la salinidad de sus aguas. Otro dato interesante es la similitud observada entre ambas unidades aquí estudiadas con los niveles superiores de la Formación Yecua, Bolivia, afinidad que podría explicarse por la capacidad de dispersión de foraminíferos y ostrácodos, las preferencias ecológicas de los taxones involucrados y la proximidad de los afloramientos, junto al desarrollo de mega humedales.

Palabras clave. Mioceno. Ostrácodos no marinos. Foraminíferos. Paleoambientes. Aloformación Playa del Zorro. Formación Chiquimil.

THE NEOGENE deposits that form the infill of a series of valleys in the Pampean Ranges geological province—extending from Cafayate, Salta Province, to Sierra de Belén, Catamarca Province, northwestern Argentina—have been the subject of intensive studies since the end of the 19th century focused on its rich fossil content, represented by mammals, molluscs, and plants (Herbst *et al.*, 2000; Bonini, 2014; Bonini *et al.*, 2017 and references therein, see below). However, little is known about its calcareous microfauna,

and most studies were carried out on outcrops of the San José Formation (Upper Miocene), Santa María Valley (Salta and Tucumán provinces), or are mentioned in unpublished reports and congress abstracts (*e.g.*, Vergani *et al.*, 1991; Gavrilloff & Bossi, 1992; Gavrilloff *et al.*, 1998; Grünwaldt & Morton, 2002; Leiva & Morton, 2002; Espíndola & Morton, 2004, 2008; Morton & Espíndola, 2006; Zamudio & Morton, 2016, 2017; Espíndola, 2019).

One of the first micropaleontological works with sys-

tematic descriptions of calcareous microfossils is that of Bertels & Zabert (1980). These authors described the ostracod *Cyprideis herbsti*, associated with *Ammonia parkinsoniana* (d'Orbigny, 1839) and "*Ammonia compacta*" (Hofker, 1964), from levels of the San José (Catamarca Province) and Saladillo (Tucumán Province) formations, Santa María Group. Also, from the upper portion of the San José Formation at Tucumán, Zabert (1984) described the foraminifer

Nonion demens f. *santamariana*. Charophytes were described from the San José Formation and the Playa del Zorro Alloformation (El Cajón Valley, Catamarca Province) by García & Herbst (1997). From the Río Salí Formation (Upper Miocene, Tucumán Province), Espíndola *et al.* (2017) described a non-marine ostracod assemblage represented by darwinulids and candonids. A summary of the recorded calcareous microfossil species is presented in Table 1.

TABLE 1 – Recorded microfossils at Miocene sites of the Calchaquíes Valleys, Argentina

Taxa/Stratigraphic unit	Saladillo Fm.	San José Fm.	Chiquimil Fm.	Río Salí Fm.	Playa del Zorro Allofm.
<i>Ammonia parkinsoniana</i>					
<i>Ammonia tepida</i>					
<i>Ammonia</i> sp.					
<i>Buccella frigida</i>					
<i>Nonion demens</i>					
" <i>Nonionella</i> " sp.					
<i>Protelphidium tuberculatum</i>					
<i>Trochammina</i> sp.					
<i>Chlamydotheca</i> sp.					
<i>Candona</i> sp.					
<i>Cyclocypris</i> sp.					
<i>Cyprinotus</i> cf. <i>trispinosus</i>					
<i>Heterocypris incongruens</i>					
<i>Ilyocypris</i> sp.					
<i>Neocyprideis</i> sp.					
<i>Cyamocytheridea ovalis</i>					
<i>Cyprideis herbsti</i>					
<i>Cyprideis salebrosa hartmanni</i>					
<i>Cyprideis similis</i>					
<i>Cyprideis</i> cf. <i>torosa</i>					
<i>Cyprideis</i> sp.					
<i>Perissocytheridea</i> sp.					
<i>Limnocythere</i> sp.					
<i>Limnocythere</i> cf. <i>reticulata</i>					
<i>Darwinula stevensoni</i>					
<i>Penthesilenula inca</i>					
<i>Vestalenula danielopoli</i>					

Data from Bertels & Zabert (1980); Zabert (1984); Vergani *et al.* (1991); Gavrilloff & Bossi (1992); Leiva & Morton (2001); Leiva (2002); Morton (2004); Espíndola *et al.* (2017); Zamudio & Morton (2019). Fm, Formation, Allofm., Alloformation.

This work aims to describe the calcareous microfossil assemblages retrieved from Miocene deposits at six sites in El Cajón Valley and Pampa Hill, Catamarca Province, and to discuss the paleoenvironmental conditions suggested by these microfauna.

GEOLOGICAL SETTING

The Neogene deposits studied herein are exposed in two areas in northwestern Catamarca Province: El Cajón Valley and Pampa Hill (Fig. 1). Bossi *et al.* (2001) considered these deposits synchronous and grouped them in the Santa María-Hualfín Basin. However, radioisotope dating carried out by Georgieff *et al.* (2012) suggested that the sedimentary sequence at the Santa María Valley is younger than that of the southern (Hualfín). As a result, these areas have been subdivided into separate basins (Bonini & Georgieff, 2013; Bonini, 2014; Bonini *et al.*, 2017).

The El Cajón Valley is a tectonic depression with a north-south direction, placed between the Quilmes/El Cajón Range to the east and the Chango Real Range to the west (Malizia *et al.*, 1990; Mortimer *et al.*, 2007). The sedimentary filling of the valley was first described by Turner (1973) as the Morterito Formation. Later, the sequence was redefined by Bossi *et al.* (1992) as three different units separated by angular unconformities, and thus considered alloformations. From base to top, these are Peñas Azules (Sequence I), Playa del Zorro (Sequence II), and El Totoral (Sequence III). The base of these Neogene deposits lies unconformably over the metamorphic Loma Corral Formation (Precambrian; Turner, 1973; Bossi *et al.*, 1992, 2000).

Part of the microfauna analyzed in this work was recorded in lacustrine levels of the Playa del Zorro Alloformation, which reaches 1,288 m and is known for its rich paleontological content (Bossi *et al.*, 1992; Esteban & Nasif, 1996; García & Herbst, 1997; Morton, 2004; Anzótegui *et al.*, 2007; Garralla *et al.*, 2016; Horn *et al.*, 2016; Zamudio & Morton, 2019). Bossi *et al.* (1992, 2000) recognized a lower section characterized mostly by dark olive green sandstones and green-yellowish diamictites, volcanic conglomerates, and reddish-brown medium sandstones (Subsequence IIa); a middle lacustrine section, composed mainly of yellow and dark-green siltstones with parallel and wavy stratification; interbedded with gypsum, calcareous concretions, and lami-

nated fine sandstone; abundant bivalves, gastropods, ostracods, fish scales, and plants (Subsequence IIb); finally, the upper section is represented by fine to medium sandstones that pass to coarse and conglomeratic sandstones (Subsequence IIc).

The Neogene deposits exposed on the western flank of Pampa Hill, southeast of the El Cajón Valley, are approximately 1,600 m thick and overlie the crystalline basement (Villavil-Quillay Basin; Bonini *et al.*, 2017). The sedimentary sequence is represented by (from base to top) the Las Arcas, Chiquimil, Andalhuala, and Corral Quemado formations (Bossi *et al.*, 1999; Bossi & Muruaga, 2009). The Chiquimil Formation, of interest in this work, starts with a thick and continuous layer of tephra (Quillay Tephra; Bossi *et al.*, 1999), and although variable, it is recognizable by an alternating succession of brown-yellowish fine sandstones, siltstones, and claystones. Muruaga (1998, 2001) divided the Chiquimil Formation, exposed at Hualfín and El Durazno Hill, into the members Los Baños, El Áspero, and El Jarillal. Although Bossi & Muruaga (2009) correlated this sequence with the Chiquimil Formation exposed at the Santa María Valley, they recognized the significant influence of the Farallón Negro Volcanic Complex in the El Áspero Member at Pampa Hill. Interbedded between the volcanic conglomerates and grey-greenish massive sandstones of the El Áspero Member at Pampa Hill, Moyano (2003) described a lacustrine level composed of green clays, siltstones, and laminated and massive sandstones. This lacustrine level is the source of the samples studied here.

According to the radioisotope dating carried out by Strecker *et al.* (1989), the sedimentation in the El Cajón Valley occurred at 10.7 ± 1.7 Ma. Above the lacustrine levels of the Playa del Zorro Alloformation, Bossi *et al.* (2000) dated a tuff, obtaining ages between 5.38 ± 0.07 – 6.04 ± 0.07 Ma. In the adjacent Santa María Valley, the Chiquimil Formation ranges in age between ~ 6.88 Ma—lower levels of the underlying Las Arcas Formation (Georgieff *et al.*, 2012)—and 5.50 ± 0.9 Ma—lower levels of the overlying Andalhuala Formation (Strecker *et al.*, 1989). To the southeast, at the Villavil-Quillay Basin, a differential depositional time was observed for the Chiquimil Formation: Latorre *et al.* (1997) reported 7.14 ± 0.02 Ma from a tuff at the lower strata of the Andalhuala Formation, and Sasso (1997) ob-

tained an age of 9.14 ± 0.09 Ma from the El Áspero Member (Chiquimil Formation). A summary of the dating of the Neogene outcrops in the Calchaquíes Valleys can be found in Bonini *et al.* (2017).

MATERIAL AND METHODS

A total of 77 samples from the Playa del Zorro Alloformation at Río Totoral and 30 from the Chiquimil Formation at Pampa Hill were processed following the standard methodology for calcareous microfossils. Each sample was weighed and immersed in a 20% hydrogen peroxide solution until the sediments were disaggregated, after which they were washed through a stack of sieves with a 250 μm , 177 μm , and 62 μm opening, and finally oven-dried at less than 70°C. A maximum of 30 g of sediment was analyzed for the picking of calcareous microfossils. Specimens were studied under a Leica M50 stereoscopic microscope and with transmitted light under a Leitz microscope. Selected specimens

were photographed with a JEOL JSM-5800-LV Scanning Electron Microscope at the Secretaría General de Ciencia y Técnica of the Universidad Nacional del Nordeste, Corrientes Province.

The suprageneric systematics followed Martin & Davis (2001) for ostracods and The World Foraminifera Database (2022) for foraminifers. Descriptive terminology used in ostracods followed Kesling (1951).

Abbreviations are L, length; H, height; and W, width. To avoid ambiguity, we have established a framework for the valves and carapace dimensions, which are shown in millimeters as follows: very small (<0.400); small (0.401 to 0.500); medium (0.501 to 0.700), large (0.701 to 0.900); very large (>0.900).

All the studied specimens are stored in the Universidad Nacional del Nordeste, Corrientes Province, Colección Paleontológica "Dr. Rafael Herbst", under the acronym CTES-PMP N° 3466-3765 (Preparados Micropaleontológicos).



Figure 1. 1, General setting of the Catamarca Province (dark grey), Argentina. 2, Location of the studied sites (black circles) at the El Cajón Valley and Pampa Hill, Calchaquíes Valleys, Catamarca Province. References: 1-4, Playa del Zorro Alloformation; 5-6, Chiquimil Formation. Scale bar= 10 km. (Satellite image Landsat/Copernicus, Google Earth accessed November 2022).

RESULTS

The registered associations displayed low diversity and high abundances (4,120 valves and carapaces of ostracods and 128 tests of foraminifera), represented by two species of Cytherideidae and two of Limnocytheridae (Podocopida, Cytherocopina, Cytheroidea). Only one species of foraminifera (order Rotaliida) was recovered.

All the studied samples were dominated by *Cyprideis calchaquiensis* nov. sp. The diversity of the rest of the species fluctuated along the stratigraphic profiles. However, subtle differences could be observed between the studied outcrops. In the Subsequence IIb (lacustrine) of the Playa del Zorro Alloformation at Río Totoral, although *Cyprideis* dominated along the section, it showed a marked reduction in diversity toward its upper levels (Fig. 2.1–4). A similar situation was observed at the studied levels of the Chiquimil Formation at Pampa Hill, but here the diversity was even lower, and only two samples yielded tests of *Ammonia tepida* (Fig. 2.5–6).

The gastropod *Heleobia* sp. and bivalves of the genus *Neocorbicula* Fischer, 1887 represent the associated macrofauna.

SYSTEMATIC PALEONTOLOGY

Class OSTRACODA Latreille, 1802

Subclass PODOCOPA Müller, 1894

Order PODOCOPIDA Sars, 1866

Suborder CYTHEROCOPINA Baird, 1850

Superfamily CYTHEROIDEA Baird, 1850

Family CYTHERIDEIDAE Sars, 1925

Subfamily CYTHERIDEINAE Sars, 1925

Genus *Cyprideis* Jones, 1857

Type species. *Candona torosa* Jones, 1850. Pleistocene, Great Britain.

Remarks. Because of its morphological plasticity and paleoenvironmental applications, the extant genus *Cyprideis* has been extensively studied. It first occurred in the late Oligocene–Early Miocene of Germany and is widely distributed in Eurasia and America (Ligios & Gliozzi, 2012). Whatley *et al.* (1998) amended the diagnosis of *Cyprideis* to include the numerous and diverse species found in the

Solimões Formation, Brazil, and equivalent units from Peru and Colombia. Later, Wouters & Martens (1999) included diagnostic characteristics from the appendages, and Tibert *et al.* (2003) identified the middle sulcus, the presence of sexual dimorphism, the hinge structure, and the reticulated pattern on the valve's surface as the main distinguishing features.

Cyprideis calchaquiensis nov. sp.

Figure 3.1–12

LSID urn:lsid:zoobank.org:act:A43F21B2-9A3C-4808-A85B-991A6AE892E2

2004 *Cyprideis* sp. Morton, 2004, p. 194, fig. 67d–e, i.

?2008 *Cyprideis* spp. Nicolaidis & Coimbra, p. 182, fig. 3G–O, fig. 4A–F.

2019 *Cyprideis* sp. Zamudio & Morton, p. 122, fig. 5a–d.

Type material. Holotype, male carapace, PMP-CTES 346; paratype, female right valve, PMP-CTES 3462; paratype, female left valve, PMP-CTES 3463; paratype, male carapace, PMP-CTES 3728; paratype, female left valve, PMP-CTES 3465; paratype, juvenile right valve, PMP-CTES 3466; paratype, female right valve, PMP-CTES 3730; paratype, male right valve, PMP-CTES 3467; paratype, juvenile left valve, PMP-CTES 3468; paratype, female carapace, PMP-CTES 3469; paratype, female carapace, PMP-CTES 3729.

Referred material. 3,492 carapaces and 264 valves, PMP-CTES 3487.

Derived name. After the Calchaquíes Valleys region.

Diagnosis. A *Cyprideis* species with the carapace in lateral view subrectangular (females) to elongated subtrapezoidal (males), anterodorsal sulcus shallow, with an anteromarginal ridge present and small anteroventral marginal denticles.

Description. Carapace large to very large and strongly dimorphic. In lateral view, adult female carapace with subrectangular outline, anterior margin rounded and posterior slightly convex to almost straight. Dorsal margin convex, ventral margin almost straight, with a small indentation in the oral region, better marked in the right valve. Greatest height towards the mid-length. Outline in dorsal view elongated ovoid, anteriorly acuminate and posteriorly somewhat truncated, greatest width at the posterior third. Adult male carapace elongated subtrapezoidal in lateral view, anterior margin evenly rounded, posterior margin dorsally

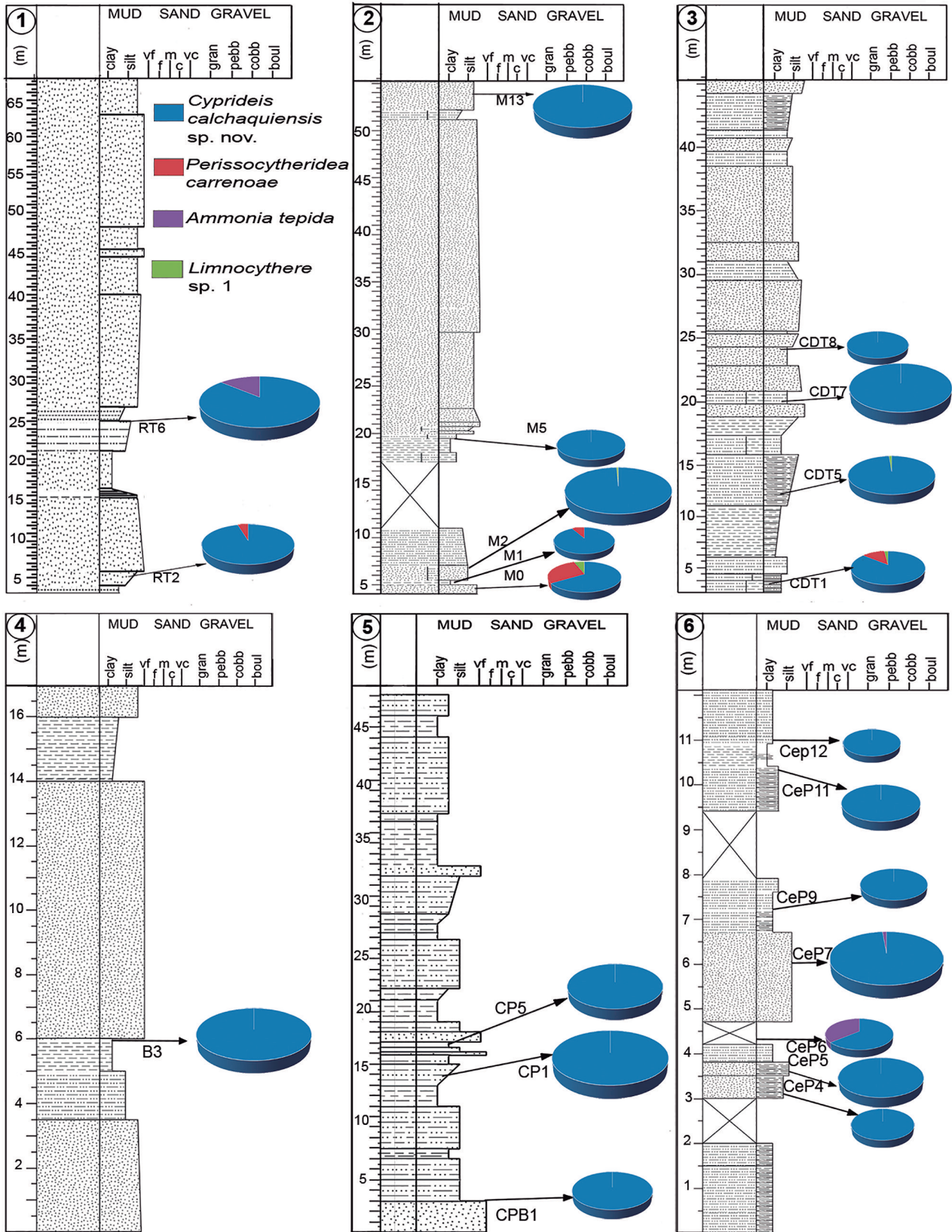


Figure 2. Schematic stratigraphic sections of 1-4, the Playa del Zorro Alloformation and 5-6, Chiquimil Formation. The relative abundance of the calcareous microfossils is shown along the profiles with pie charts.

truncated and sharply rounded towards the ventral region; dorsal margin slightly convex, ventral margin sinuous, with a delicate concavity near the anterior region. Subelliptic outline in dorsal view, with acuminate ends. In both sexes, left valve greater than the right valve, overlap at all margins. A very poorly developed flange is observed in the anterior margin, accompanied by approximately 9–11 small and regularly spaced denticles at the anteroventral margin of both valves, which are best seen in interior view. A subtle anteromarginal ridge is also present. Anterodorsal sulcus shallow, somewhat anteriorly inclined. Valves surface punctated, without preferential arrangement except towards the ventral margin where the punctae are parallel to the margin. Narrow inner lamella with numerous marginal pore canals widened at the base, simple or bifurcated, and a well-developed selvage continuous between the anterior and posterior margins. Hinge generotypic is represented in the right valve by a long and thickly crenulate anterior element with 13–15 denticles, some with a heart shape, a very short crenulate anteromedial sulcus, and a postero-medial element with 4–6 denticles. Left valve with complementary elements. Central muscular scar is typical for the genus.

Dimensions (mm) of the figured specimens. L= 0.99, H= 0.55 (Fig. 3.1); L= 0.88, H= 0.49 (Fig. 3.2); L= 1.00, H= 0.53, W= 0.4 (Fig. 3.3); L=1.08, H= 0.5, W= 0.39 (Fig. 3.4); L= 0.93, H= 0.53 (Fig. 3.5); L= 0.69, H= 0.4 (Fig. 3.6); L= 0.96, H= 0.55 (Fig. 3.8); L=0.87, H= 0.45 (Fig. 3.9); L= 0.55, H= 0.34 (Fig. 3.10); L= 0.94, W= 0.47 (Fig. 3.11); L= 0.92, W= 0.45 (Fig. 3.12).

Remarks. A combination of diagnostic characters for discriminating species of *Cyprideis* defined by Sandberg (1964) and later by Whatley *et al.* (1998) and Gross *et al.* (2014) was followed here, *i.e.*, shape of the valves in lateral view, stable ornament patterns, presence/absence of marginal denticulation, and development of the inner lamella and marginal pore canals. *Cyprideis calchaquiensis* nov. sp. is comparable to *C. multidentata* Hartmann, 1955 and *C. salebrosa hartmanni* Ramírez, 1967, two recent species commonly found in Argentina and Brazil. The outline in lateral view of the valves of *C. calchaquiensis* nov. sp. and *C. salebrosa hartmanni* is very similar; in both species the male valves are elongated subtrapezoidal with a sinuous ventral margin, whereas the females are subrectangular. However, the marginal denti-

cles recognized in *C. calchaquiensis* nov. sp. are missing in *C. salebrosa hartmanni*. As stated by Sandberg (1964, p. 37) for the species *C. salebrosa* van den Bold, 1963 "even the most strongly ornamented variant from Pliocene of Trinidad has no marginal denticulations". Thus, we considered this as a key difference between both aforementioned species. Also, the anterior margin in females seems less expanded anteriorly in the Miocene species. On the other hand, *C. multidentata* presents 5–6 marginal denticles and a strong posteroventral spine in the right valve of juveniles and adults. In comparison, the marginal denticles of the species described here are more numerous and more tightly arranged but less developed, and no posteroventral spine was found in any of the specimens examined. Moreover, differences can be observed in the outline of the valves in lateral view of *C. multidentata*, which are more elongated and less high, in the stronger anterodorsal sulcus and in the broader calcified inner lamella of this species.

Cyprideis camacho Rossi de García, 1966, a fossil species from the Miocene Entre Ríos Formation (northeastern Argentina), also presents anteromarginal denticles; however, as in *C. multidentata*, these are less abundant and widely spaced. Moreover, the outline of the valves in lateral view of *C. camacho* and *C. multidentata* is very similar, as is the strong anterodorsal sulcus. Thus, this combination of features allows differentiating *C. calchaquiensis* nov. sp. from *C. camacho*.

Some of the specimens figured by Nicolaidis & Coimbra (2008) as *Cyprideis* spp., from the Middle–Late Miocene of Bolivia, seem to be related to *C. calchaquiensis* nov. sp. Common features between both species are the anterior marginal denticles (Nicolaidis & Coimbra, 2008, figs. 3G, I, N and 4E), an anterodorsal ridge, and the outline of the male valves in lateral view, except for the ventral margin which is almost straight. Differences can be observed in the lateral outline of some of the female valves figured by these authors (2008, fig. 3), which seem to be more elongated, except those in figure 4B–C.

C. pachamama Martínez-García *et al.*, 2017 from the Middle–Late Miocene of Ecuador is another species with small marginal denticles, although they are more abundant. Differences can also be observed in the female valve outline in lateral view, which is comparatively higher with the

dorsal margin more arched and the posterior margin truncated, giving it a stockier appearance, whereas in dorsal view the posterior margin seems less rounded. The dorsal margin of the right male valves appears to be continuously inclined from its greatest height towards the posterior margin, while the sinuous ventral margin is less visible.

Stratigraphic and geographic distribution. Late Miocene of the Playa del Zorro Alloformation; Río Totoral and Playa del Zorro; El Cajón Valley; Chiquimil Formation; Pampa Hill; in Catamarca Province, Argentina. This species is probably also present in the Middle–Late Miocene of the Yecua Formation, Bolivia (Nicolaidis & Coimbra, 2008).

Genus *Perissocytheridea* Stephenson, 1938

Type species. *Cytheridea matsoni* Stephenson, 1935. Middle Miocene, Mississippi, USA.

Perissocytheridea carrenoae Nicolaidis & Coimbra, 2008

Figure 3.13–20

2008 *Perissocytheridea carrenoae* Nicolaidis & Coimbra, p. 180, fig. 3A–F.

Referred material. 131 carapaces and 4 valves. Additional material, CTES-PMP 3489 (Fig. 3.13–20).

Description. Small carapace, sexually dimorphic, outline in lateral view elongated subtrapezoidal, females shorter than males. Anterior margin widely and homogeneously rounded and extended ventrally, dorsal margin straight, sloping towards the posterior margin, which is rounded in the right valve and dorsally truncated in the left valve. Ventral margin slightly concave anteriorly, obscured by a posteriorly pointed alar process. Greatest height at the eye tubercle. The left valve is larger than the right valve, overlapping slightly at all margins. Outline in dorsal view oval in males, with the posterior margin rounded, ellipsoidal in females, with the posterior margin extended and narrowly rounded; anterior margin compressed in both genera. Greatest width at the posterior third. Valves with two anterodorsal well-developed sulci. Hinge antimerodont with all the elements crenulated. Central muscle scar formed by four individual scars arranged vertically, increasing in size towards the ventral margin; the top scar is the smallest, almost triangular, followed by two elongated and flattened scars, and ending

with a larger circular fourth scar. Frontal scar C-shape. Surface of the valves is ornamented by a polygonal reticule of slender *muri*, in some specimens with smooth *solae* whereas in others the *solae* are pitted on the central surfaces of the valves. There is no preferential arrangement of the reticule, except anteriorly where it becomes parallel to the margin.

Dimensions (mm) of the figured specimens. L= 0.6, H= 0.3 (Fig. 3.13); L= 0.61, H= 0.34 (Fig. 3.14); L= 0.59, W= 0.26 (Fig. 3.15); L= 0.6, H= 0.34 (Fig. 3.16); L= 0.45, H= 0.27 (Fig. 3.17); L=0.48, H= 0.27 (Fig. 3.18); L=0.59, H= 0.3 (Fig. 3.19); L= 0.6, W= 0.26 (Fig. 3.20).

Remarks. The specimens studied here are strongly similar to *Perissocytheridea carrenoae* described by Nicolaidis & Coimbra (2008) from the Miocene of the Yecua Formation (Bolivia). However, two differences between these specimens must be mentioned: 1) the overall size of the Bolivian specimens is smaller than the Argentinean ones, *i.e.*, average in females L= 0.45 mm and L= 0.56 mm, respectively; 2) the ornamentation pattern is stronger in the Argentinean specimens. However, this could be due to differential preservation between both assemblages. A second-order reticulation, similar to the Argentinean material, can be observed in the specimen in figure 3D of Nicolaidis & Coimbra (2008). *Perissocytheridea colini* Evangelista-Nogueira & Feijó-Ramos, 2016, from the Oligocene–Miocene Pirabas Formation, northeastern Brazil, has a more truncated posterodorsal margin and punctuated valves.

Stratigraphic and geographic distribution. Late Miocene of the Playa del Zorro Alloformation, at Río Totoral and El Cajón Valley, Catamarca Province, Argentina; Middle–Late Miocene, Yecua Formation at the Chaco Basin, Bolivia (Nicolaidis & Coimbra, 2008).

Family LIMNOCYThERIDAE Klie, 1938

Genus *Limnocythere* Brady, 1867

Type species. *Cythere inopinata* Baird, 1843. Recent, Great Britain.

Limnocythere spp.

Figure 4.1–4

Referred material. 28 carapaces and six valves. Additional

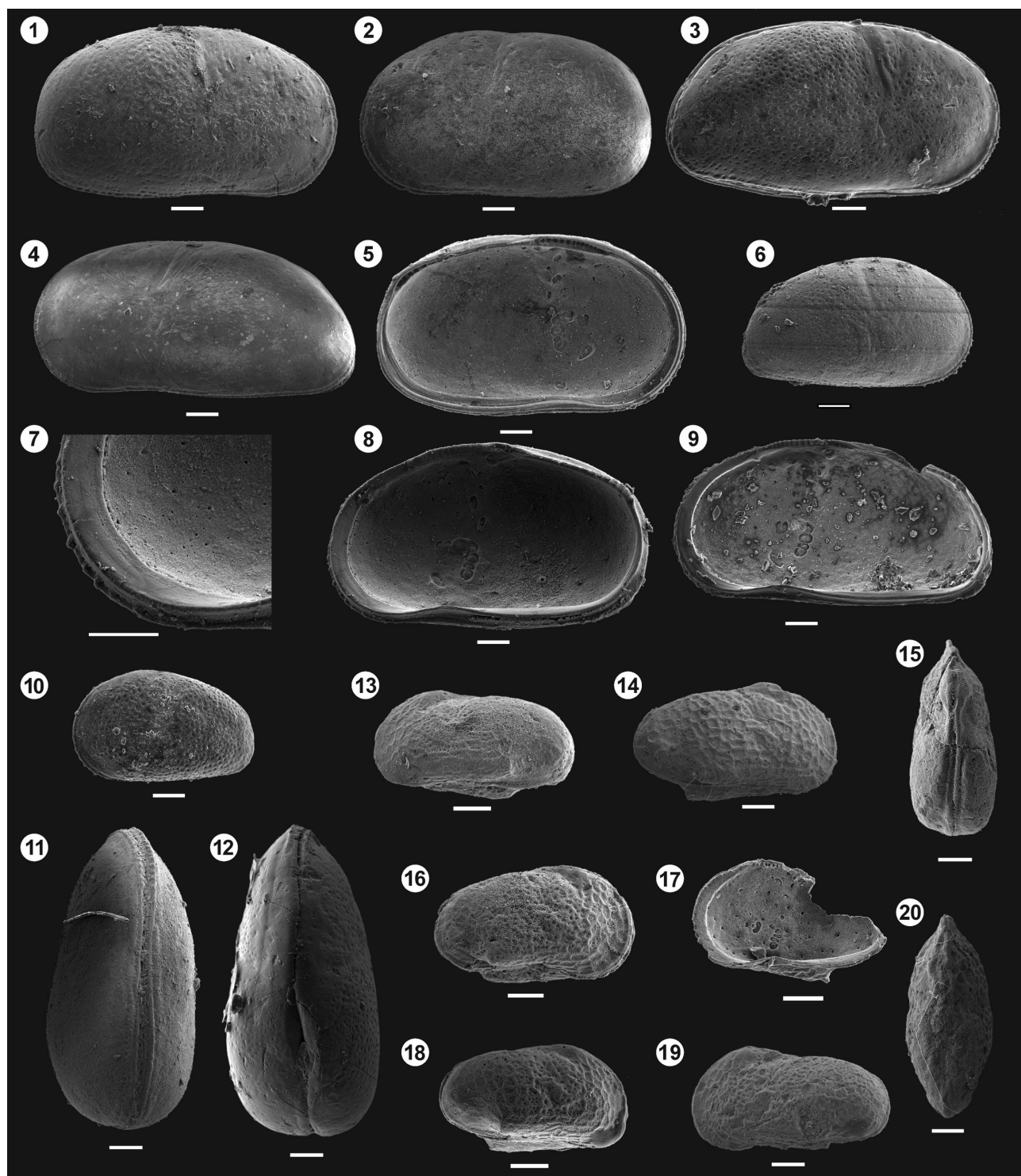


Figure 3. Ostracoda from the Playa del Zorro Alloformation and Chiquimil Formation, at studied sites. 1–12, *Cyprideis calchaquiensis* nov. sp. 1, female right valve, external view, PMP-CTES 3462; 2, female left valve, external view, PMP-CTES 3463; 3, holotype, male carapace, right lateral view, PMP-CTES 3464; 4, male carapace, left lateral view, PMP-CTES 3728; 5, female left valve, internal view, PMP-CTES 3465; 6, juvenile right valve, external view, PMP-CTES 3466; 7–8, female right valve, internal view and detail of the anterior margin with denticles, PMP-CTES 3730; 9, male right valve, internal view, PMP-CTES 3467; 10, juvenile left valve, external view, PMP-CTES 3468; 11, female carapace, ventral view, PMP-CTES 3469; 12, female carapace, dorsal view, PMP-CTES 3729. 13–20, *Perissocytheridea carrenoae* Nicoladis & Coimbra, 2008. 13, male carapace, left lateral view, PMP-CTES 3470; 14, female carapace, right lateral view, PMP-CTES 3471; 15, female carapace, dorsal view, PMP-CTES 3752; 16, female carapace, right lateral view, PMP-CTES 3754; 17, fragmented right valve, internal view, PMP-CTES 3753; 18, female carapace, right lateral view, PMP-CTES 3472; 19, male carapace, left lateral view, PMP-CTES 3473; 20, male carapace, dorsal view, PMP-CTES 3474. Scale bar= 0.01 mm.

material CTES-PMP 3488.

Dimensions (mm) of the figured specimens. L= 0.53, H= 0.32 (Fig. 4.1); L= 0.65, H= 0.37 (Fig. 4.2); L= 0.69, H= 0.4 (Fig. 4.3); L= 0.67, H= 0.36 (Fig. 4.4).

Remarks. The recovered material is poorly preserved, which hindered its taxonomic features. There seem to be two species of *Limnocythere*, one with evenly rounded anterior and posterior margins and with a rounded subrectangular outline (Fig. 4.1–2), and the other with an acuminate posteroventral margin and subrectangular outline (Fig. 4.3–4). There are several species in the literature with an acuminate posteroventral margin. Among these, *Limnocythere* sp. (Cusminsky *et al.*, 2005), a recent Patagonian species, differs in having a more acuminate posteroventral margin. Another species is *Limnocythere ruipunctifinalis* Palacios-Fest *et al.*, 2016, found in late Quaternary shallow freshwater bodies of the Argentinean Puna. However, this species has a subtrapezoidal outline, no reticulum is observed, and the posterior margin is markedly truncated. In lateral view, the other morphotype recognized here resembles *Limnocythere fosteri* Palacios-Fest *et al.*, 2016. Nevertheless, the scarcity

and poor preservation of the specimens prevented a better approximation.

Stratigraphic and geographic distribution. Late Miocene of the Playa del Zorro Alloformation, at Río Totoral and El Cajón Valley, Catamarca Province, Argentina.

Phylum FORAMINIFERA d'Orbigny, 1826
Class GLOBOTHALAMEA Pawlowski *et al.*, 2013
Order ROTALIIDA Delage & Hérouard, 1896
Family AMMONIIDAE Saidova, 1981

Genus *Ammonia* Brünnich, 1771

Type species. *Nautilus beccarii* Linnaeus, 1758. Miocene–Recent, Mediterranean Sea.

Ammonia tepida Cushman, 1926

Figure 4.5–9

Referred material. 128 tests.

Dimensions (mm) of the figured specimens. L= 0.24, H= 0.20 (Fig. 4.5); L= 0.3, H= 0.26 (Fig. 4.6); L= 0.28, H= 0.22 (Fig. 4.7);

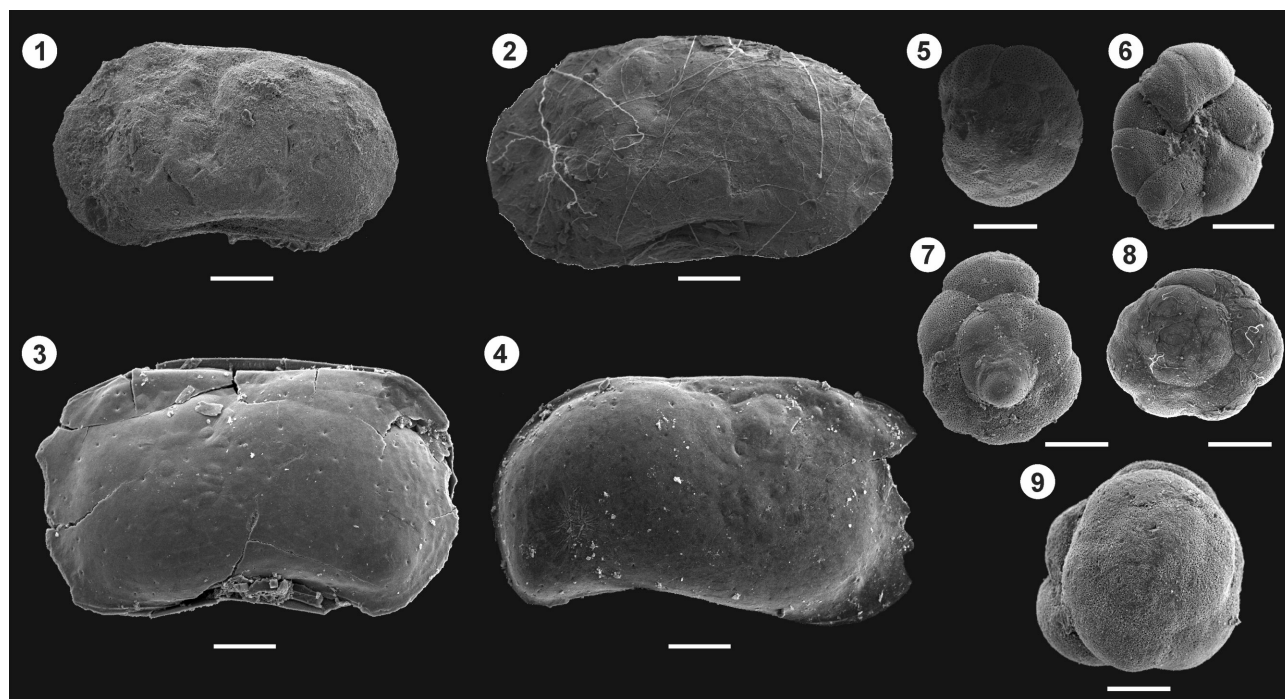


Figure 4. Ostracoda and foraminifera from the Playa del Zorro Alloformation and Chiquimil Formation, at studied sites. 1–4, *Limnocythere* spp., 1, carapace, external view, CTES-PMP 3764; 2, carapace, external view, CTES-PMP 3765; 3, carapace, external view, CTES-PMP 3761; 4, right valve, external view, CTES-PMP 3763. 5–9, *Ammonia tepida*, 5, spiral view, CTES-PMP 3748; 6, umbilical view, CTES-PMP 3744; 7, spiral view, CTES-PMP 3750; 8, spiral view, CTES-PMP 3746; 9, spiral view, CTES-PMP 3476. Scale bar= 0.01 mm.

L= 0.23; H= 0.28 (Fig. 4.8); L= 0.32, H= 0.30 (Fig. 4.9).

Remarks. The absence of a button in the umbilical area, an unornamented test, and the presence of six chambers in the last whorl placed the specimens studied here under the species *Ammonia tepida*. Some specimens presented abnormal development, *i.e.*, deviations in the test construction concerning the diagnostic morphological characteristics of the species (Ballent & Carignano, 2008). These abnormalities included distorted arrangements, aberrant sizes, and additional chambers.

Stratigraphic and geographic distribution. Worldwide. In this work: Late Miocene, Playa del Zorro Alloformation, at Río Totoral and Playa del Zorro, El Cajón Valley and Chiquimil Formation, Pampa Hill, Catamarca Province, Argentina.

DISCUSSION

All the taxa recovered in this study (*i.e.*, *Ammonia tepida* and the genera *Cyprideis*, *Perissocytheridea*, and *Limnocythere*) have living representatives, and therefore, paleoenvironmental inferences by comparison with their living relatives could have a high level of reliability.

The genus *Cyprideis* has a fossil record dating back to the Upper Oligocene (Tibert *et al.*, 2003), consequently, it has the potential for paleosalinity studies of sediments up to 10 Ma. However, each taxon may have a particular salinity range (Boomer & Eisenhauer, 2002). Two species commonly recorded in Quaternary and Recent South American sites are *C. salebrosa hartmanni* and *C. multidentata*, both very similar to *C. calchaquiensis* nov. sp. *Cyprideis salebrosa hartmanni*, a euryhaline species, was found living in the muddy sand margin of the hipohaline Armazém Lagoon and a marginal lagoon at the Sepetiba Bay, in mixohaline shallow waters of Brazil (Ornellas & Würdig, 1983; Dias-Brito *et al.*, 1988; Coimbra *et al.*, 2007). In Argentina, this species was recorded in vegetated permanent, hipo-oligohaline, high-alkalinity water bodies (Ramírez, 1967; Laprida, 2006). Kihn (2017) reported *C. salebrosa hartmanni* as the only species present in sites with the highest degree of eutrophication at the Bahía Blanca estuary. There are also abundant records in Late Pleistocene–Holocene sediments from the Buenos Aires and Entre Ríos provinces, where *C. salebrosa hartmanni* was found associated with oligo-mesohaline

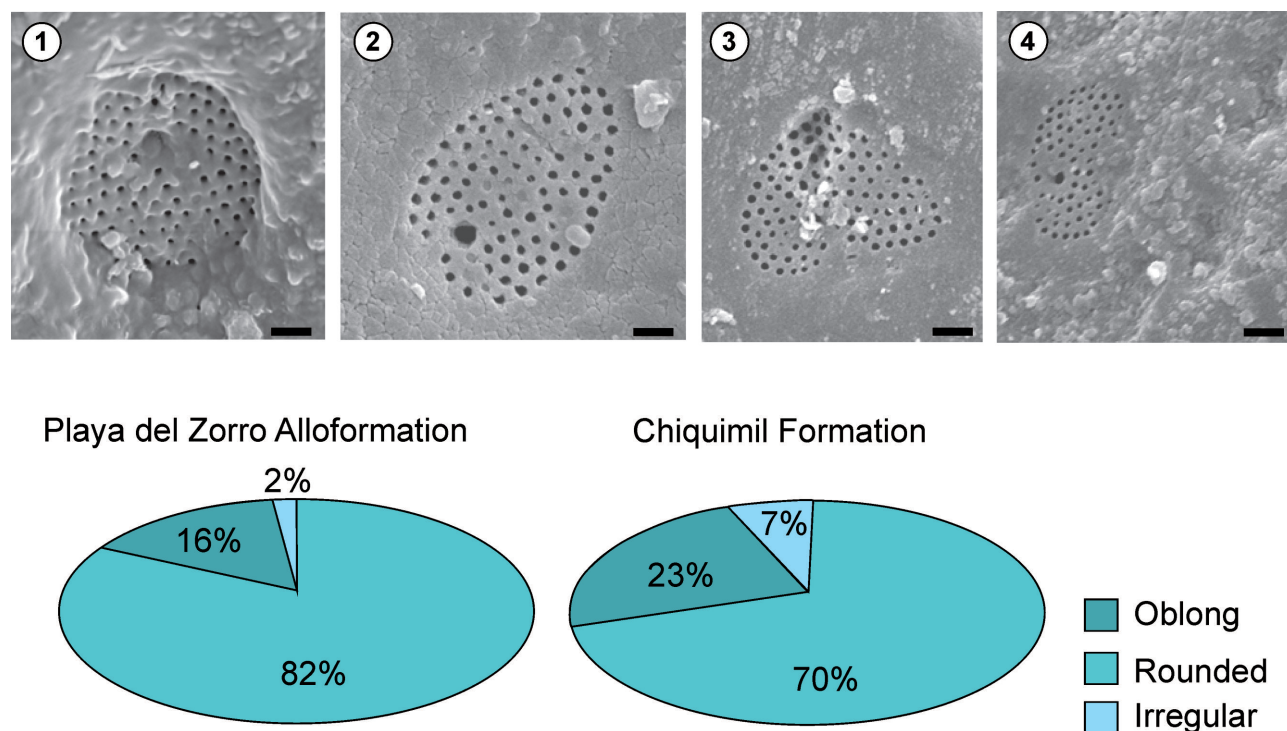


Figure 5. Types of sieve pores of *Cyprideis calchaquiensis* nov. sp. and their proportion at both studied sections. 1, rounded, 2, oblong, 3–4, irregular. Scale bar= 0.002 mm.

ostracods (Zabert & Herbst, 1986; Cusminsky *et al.*, 2006; Laprida & Valero-Garcés, 2009) or with more brackish/marine microfauna (*e.g.*, Bertels-Psotka & Martínez, 1990, 1997; Whatley *et al.*, 1997; Ferrero, 1996, 2009; Ramos *et al.*, 2019; Flores *et al.*, 2021), often being the dominant species. Recently, D'Ambrosio *et al.* (2020) registered an assemblage of *Limnocythere* spp. and juveniles of *C. salebrosa*, in a Middle Holocene saline lake at the Jujuy Province. Similarly, *C. multidentata* is known as a living and Quaternary fossil species from Brazil and Argentina. Records of this species include estuarine environments of oligo-mesohaline to polyhaline waters, lagoons, and littoral marine environments (*e.g.*, Dias-Brito *et al.*, 1988; Bertels-Psotka & Martínez, 1990; Laprida, 2006), and is considered to be more tolerant to euhaline waters (Coimbra *et al.*, 2007).

A commonly used morphological feature of the genus *Cyprideis* when reconstructing the paleoenvironmental conditions is the development of nodes on the carapace surface (*e.g.*, van Harten, 1975, 1996; Keyser & Aladin, 2004; Frenzel *et al.*, 2016; Meyer *et al.*, 2017). In this study, no nodes were observed on the valve surface of *C. calchaquiensis* nov. sp. On the other hand, Rosenfeld & Vesper (1977) recognized a relationship between salinity and the shape (roundness) of the sieve pores of *C. torosa*. Subsequently, this relationship was applied successfully to reconstruct paleosalinities (*e.g.*, Gliozzi & Mazzini, 1998; Frenzel *et al.*, 2016; Pint *et al.*, 2017). Three shapes of sieve pores can be determined according to their length-height ratio: rounded ($L/H > 1.5$), oblong ($L/H < 1.5$), and irregular (highly variable in shape). Rounded pores are dominant at low salinities (0.7–1.8‰), oblong ones predominate at 15–17‰, and irregular ones at higher salinities (50–80‰) (Rosenfeld & Vesper, 1977; Pint *et al.*, 2017). In this sense, a total of 512 sieve pores (57 valves from both the Playa del Zorro Alloformation and Chiquimil Formation) were analyzed in this study, resulting in a prevalence of rounded pores at both sections (Fig. 5), suggesting oligohaline waters.

Living and fossil species of *Perissocytheridea* are typically found in brackish to euhaline waters, inhabiting together with both freshwater and marine species in littoral environments, estuaries, lagoons, lakes, etc., since the Upper Cretaceous (Dias-Brito *et al.*, 1988; Whatley *et al.*, 1997; Piovesan *et al.*, 2014; Evangelista-Nogueira & Feijó-Ramos,

2016). Several studies on the ostracod assemblages from Brazilian estuarine and lagoonal systems (see Coimbra *et al.*, 2007, tab. III and references therein) combined with environmental parameters data (such as temperature, pH, salinity, substrate), allowed the recognition of four ostracod groups. The mixohaline assemblage (corresponding to the polyhaline and mesohaline groups) comprises *C. multidentata*, *C. salebrosa hartmanni*, *Minicythere heinii* Ornellas, 1974, *Perissocytheridea kroemmelbeini* Pinto & Ornellas, 1970, and *Cytherura purperae* Ornellas & Fallavena, 1978. As in the present study, *Perissocytheridea* has been recorded in association with species of *Cyprideis*, and also with the foraminifera *Ammonia* (*e.g.*, Keyser, 1977; Würdig, 1983; Laprida, 2006; Nicolaidis & Coimbra, 2008), and is considered indicative of meso-polyhaline environments (Ornellas, 1974).

Limnocythere is a non-marine genus with species that can withstand a wide range of environmental conditions and oligo-mesohaline salinity (Würdig, 1983; Meisch, 2000; Laprida, 2006). The poor preservation and scarcity of the recovered material hampered the systematic assessment and made determining the species' (paleo)autoecology difficult. Nonetheless, the presence of *Limnocythere* spp. corresponds to the inferred paleoenvironment and is frequently associated with species of *Cyprideis* (*e.g.*, Bertels-Psotka & Martínez, 1990, 1997; Ferrero, 1996; Laprida, 2006; Calvo-Marcilese *et al.*, 2019, 2022; D'Ambrosio *et al.*, 2020).

Despite being almost entirely marine, there are several records of fossil and living foraminifera in athalassic waters around the world. The genus *Ammonia*, a cosmopolitan benthic foraminifer, has inhabited marginal marine environments and waters with fluctuating salinity, temperature, and nutrient input since the Early Miocene (see Consorti *et al.*, 2021 and references therein). Especially *A. tepida* is a recurrent component of stressed paralic, athalassic, or estuarine environments with hypersaline conditions, low-oxygen and nutrient-rich bottoms (*e.g.*, Cann & De Deckker, 1981; Walton & Sloan, 1990; Almogi-Labin *et al.*, 1992, 1995; Debenay *et al.*, 2000; Murray, 2006; Riedel *et al.*, 2011; Pint *et al.*, 2017; Calvo-Marcilese *et al.*, 2019, 2022). Almogi-Labin *et al.* (1992) recorded a living association of *A. tepida*, *Cyprideis torosa*, gastropods, and fish remains in a shallow hypersaline lake in Israel, subject to seasonal variation in temperature, water level, and salinity. These

authors noted a high rate of abnormal tests in *A. tepida* due to stress conditions, including deformed chambers, changes in coiling direction, twin specimens, and distorted shape. Calvo-Marcilese *et al.* (2019) recorded an assemblage with a remarkable abundance of *A. tepida*—and scarce *Elphidium excavatum* Terquem, 1875—in the endorheic saline basin Salinas del Bebedero, San Luis Province, Argentina. Although ostracods such as *Cyprideis salebrosa hartmanni* and *Limnocythere aff. staplini* Gutentag & Benson, 1962 were also present in the studied samples, they were not found coexisting. Recently, Calvo-Marcilese *et al.* (2022) reported a Holocene assemblage of *A. tepida*, *E. excavatum*, *C. salebrosa*, and *Limnocythere cusminskyae* Ramón-Mercau *et al.*, 2014, from an archaeological site at Laguna Mar Chiquita, Córdoba Province, Argentina. It is important to note that in all these cited cases, the water bodies were more than 100 km from the nearest sea coast. Pint *et al.* (2017) pointed out that a low diversity assemblage of marginal marine taxa, plus the presence of abnormal foraminiferal tests in a higher proportion than 10%, could be used as an indicator of athalassic saline paleoenvironments. The presence of foraminifera in these particular environments seems to be related to birds traveling from open marine environments to saline lakes in more arid areas (Alve & Goldstein, 2014; Pint *et al.*, 2017).

The abnormal development registered in foraminifera tests is generally caused by variations in the environmental conditions and there are plenty of examples in the literature (*e.g.*, Cann & De Deckker, 1981; Almogi-Labin *et al.*, 1992; Boltovskoy *et al.*, 1991; Stouff *et al.*, 1999; Geslin *et al.*, 2000, 2002; Ballent & Carignano, 2008; Carignano & Ballent, 2009; Melis & Covelli, 2013; Pint *et al.*, 2017). The cause of these aberrant tests seems to be related to fluctuations in salinity, and Geslin *et al.* (2000) recognized four types of abnormal tests produced in natural environments: 1) a swell in the spiral side near the proloculus, 2) abnormal size/shape of the cameras (plus abnormal arrangement in hypersaline environments), 3) growth in two whorls (double/triple tests); and 4) complex forms. The *Ammonia tepida* specimens studied here showed a protuberance near the proloculus (Fig. 4.7), an abnormal shape of the last camera (Fig. 4.8), and an abnormal arrangement (Fig. 4.9), confirming a stressed paleolake for the studied beds, at least during part of its development.

The plant paleocommunities recorded at Playa del Zorro Alloformation and Chiquimil Formation were represented by lacustrine and xerophytic elements together with riparian forests, which indicate a warm and seasonally arid climate (Mautino, 2011; Garralla *et al.*, 2012, 2016). Furthermore, Garralla *et al.* (2012) proposed a close relationship between both units' paleoflora and fossil mollusks. This information is consistent with the composition and structure of the calcareous microfossil assemblages, which indicate a rather shallow lacustrine paleoenvironment with evaporation episodes resulting in fluctuating salinities (from oligo to at least mesohaline waters).

An interesting point of the studied microfauna is the close similarity between both the Playa del Zorro Alloformation and Chiquimil Formation associations, with those from the upper part of the Yecua Formation (Chaco Basin, Late Miocene, Bolivia), studied by Nicolaidis & Coimbra (2008). These authors recognized two distinct microfossil associations in the section: 1) a lower part, composed of freshwater ostracods as *Cypria aff. aqualica* Sheppard & Bate, 1980, *Darwinula sp.* and *Ilyocypris? sp.*, together with *Cyprideis spp.*; and 2) upper levels characterized by *Cyprideis spp.*, *Perissocytheridea carrenoae*, and *Ammonia tepida* with deformed tests, together with the gastropod *Heleobia spp.*, typical of brackish waters. According to Tineo *et al.* (2014), the sedimentological and paleontological characteristics of the Yecua Formation are indicative of lowland freshwater shallow lakes and rivers, with alternating flood-drought cycles. The presence of shared species between the three units (*i.e.*, Playa del Zorro Alloformation, Chiquimil, and Yecua formations) can be explained by the proximity of the outcrops and the passive dispersal capabilities of both ostracods and foraminifers via birds and other animals (*e.g.*, Serramo Lopez *et al.*, 1999; Green *et al.*, 2008; Vanschoenwinkel *et al.*, 2008; Alve & Goldstein, 2010; Pint *et al.*, 2017). Also, Tineo (2018) proposed the development of an intercontinental mega wetland system occupying part of South America during Miocene times, which could have connected several basins and provided diverse dispersal routes.

CONCLUSIONS

The analysis of the calcareous microfauna associations recovered at Playa del Zorro Alloformation, El Cajón Valley

and Chiquimil Formation, Pampa Hill, Catamarca Province, allowed the description of a new ostracod species, *Cyprideis calchaquiensis* nov. sp. The clear dominance of *Cyprideis calchaquiensis* nov. sp. and the presence of monospecific foraminifers with abnormal tests suggest a non-marine shallow lacustrine paleoenvironment with fluctuating oligo to mesohaline waters. To date, non-truly marine microfossils have been recorded in the Miocene of the Calchaqués Valleys. The presence of foraminifers should not be considered *per se* as evidence of marine incursions without consideration of their diversity and the accompanying micro, macrofauna, and flora, but it does constitute informative data about the salinity conditions of the waters.

The close relationship between the microfauna studied in this work and the registered in the upper levels of the Yecua Formation (Bolivia), can be explained by the passive dispersal abilities known for foraminifera and ostracods, assisted by the development of interconnected wetlands.

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