



Chitinoidellids from the Early Tithonian–Early Valanginian Vaca Muerta Formation in the Northern Neuquén Basin, Argentina



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ABSTRACT

As part of microfacies studies carried out on the Tithonian – Valanginian carbonate ramp of the Neuquén Basin, two stratigraphic sections of the Vaca Muerta Formation (Arroyo Loncoche and Río Seco de la Cara Cura) were chosen in order to analyze the chitinoidellid content and distribution. Calpionellids in the studied sections are relatively poorly preserved; hyaline calcite walls are often recrystallized making the systematic determination difficult. However, microgranular calcite walls seem to have resisted better the incipient neomorphism presented by the limestones of the Vaca Muerta Formation. Seven known species of Chitinoidellidae and four known species of Calpionellidae are recognized. The distribution of calpionellid species allows recognizing the Chitinoidella and Crassicollaria Zones in the Neuquén Basin. The Chitinoidella Zone correlates with the *Virgatospinctes mendozanus*–*Windhausenicerias internispinosum* Andean ammonite Zones, and can be divided into two subzones. The lower one is poorly defined, while the upper one can be assigned to the Boneti Subzone. The Crassicollaria Zone in the Neuquén basin needs a detailed revision, but data provided in this work enable its correlation at least with the *Corongoceras alternans* ammonite Zone. Similar associations were reported in Mexico and Cuba, showing good consistency between these regions. However, in the Neuquén Basin unlike the Tethys, chitinoidellids persist until the lower Berriasian.

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1. Introduction

Calpionellids are a useful biostratigraphic group of planktonic protozoa widely distributed in the Tethyan realm during the Late Jurassic – Early Cretaceous times (e.g. Remane, 1971; Grün and Blau, 1997; Michálik et al., 2009; Lakova and Petrova, 2013). Three families are recognized based on the ultrastructure of their lorica: Chitinoidellidae Trejo, 1980 (microgranular lorica), Semi-chitinoidellidae Nowak 1978 (combined microgranular and hyaline lorica), and Calpionellidae Bonet 1956 (hyaline loricas).

Reports of calpionellids from mid and high latitudes of the Southern Hemisphere are really rare, and these faunas were practically unknown for Argentina despite having been repeatedly sought by some researchers (e.g., Remane, 1985). Presence of

calpionellids in the Neuquén Basin was mentioned earlier by Fernández Carmona et al. (1996), Fernández Carmona and Riccardi (1998, 1999), and Kietzmann et al. (2011a), who report the presence of hyaline and microgranular forms. These reports represent the first record of calpionellids outside the Tethyan realm, but unfortunately without illustrations.

Affinities between the faunas of the Tethyan realm and the Neuquén Basin were known since the pioneering work of Darwin (1846). Mesozoic faunal exchange between the southeast Pacific and the Tethys were continuous through the Central Atlantic and around Australasia (Riccardi, 1991). Cosmopolitan faunas and floras would have been distributed through the so-called Hispanic Corridor (Smith, 1983), a narrow, embryonic Atlantic seaway hypothesized to have opened in Pliensbachian time, creating a shortcut connection between the Tethys and eastern Panthalassa (Aberhan, 2001). Tethyan influence in the Neuquén Basin has been noted in ammonite faunas (e.g., Riccardi, 1991; Zeiss and Leanza, 2008, 2010), bivalves (e.g., Damborenea, 2002), foraminifera and ostracodes (e.g. Ballent and Whatley, 2000; Ballent et al., 2011), nannoplankton floras (e.g. Bown and Concheyro, 2004), as well as

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other typical Tethyan microfauna, such as the microcrinoid *Saccocomma* (e.g. Kietzmann and Palma, 2009). Therefore, the presence of calpionellids in the Neuquén Basin is not unexpected, but its importance lies in the fact that it represents the southernmost record outside of the Tethys.

The purpose of this paper is to describe chitinoideid specimens from the Vaca Muerta Formation in two stratigraphic sections in the southern Mendoza sector of the Neuquén Basin. At the same time, their stratigraphic distribution and a preliminary long distance correlation is discussed. Although more detailed studies of this group in the Vaca Muerta Formation is needed to allow an accurate correlation with Tethyan biozones, the results of this paper are very valuable, and consistent with recently published stratigraphic data (Kietzmann et al., 2015; Riccardi, 2015; Iglesia Llanos et al., 2017; Ivanova and Kietzmann, 2016) that will allow establishing an increasingly robust chronostratigraphic scheme.

2. Geological setting

The Neuquén Basin was a retro-arc basin developed in Mesozoic times along the Pacific margin of South America (Fig. 1a). It has a triangular shape and is bounded by a metamorphic and volcanic basement to the east and by an immature volcanic arc to the west (Yrigoyen, 1991). Its stratigraphy was defined by Groeber (1946), and later Legarreta and Gulisano (1989) updated this framework emphasizing the importance of eustatic changes in the development of depositional sequences.

Different tectonic regimes exerted a first-order control in basin development and sedimentary evolution (Legarreta and Uliana, 1991, 1996). An extensional regime was established during Late Triassic – Early Jurassic. It was characterized by a series of narrow, isolated depocenters controlled by large transcurrent fault systems filled mainly with continental deposits of the Precuyo Group (Maceda and Figueroa, 1993; Vergani et al., 1995). The Early Jurassic – Late Cretaceous was characterized by a thermal subsidence regime with localized tectonic events, which led to the development of a shallow marine basin connected to the proto-Pacific Ocean by narrow passages within the volcanic arc (Legarreta and Uliana, 1996). Depocenters were filled by continental and marine siliciclastic, carbonate and evaporite successions (Cuyo, Lotena, and Mendoza Groups). Under these tectonic conditions, a series of marine sequences were developed throughout the basin during Late Jurassic – Early Cretaceous. These are included in the Mendoza Group (Stipanovic, 1969) or Mendoza Mesosequence (Legarreta and Gulisano, 1989) (Fig. 1b), also divided by Leanza (2009) into Lower, Middle and Upper Mendoza Subgroups. Finally, a compressive deformation regime was established during the Late Cretaceous and lasting throughout the Cenozoic alternating with extensional events (Ramos, 2010).

In the northern Neuquén Basin (southern Mendoza area, Fig. 1c) the lower Mendoza Subgroup includes continental deposits of the Tordillo Formation (Kimmeridgian–Early Tithonian?), basal to middle carbonate ramp deposits of the Vaca Muerta Formation (Early Tithonian – Early Valanginian) and middle to inner ramp oyster-deposits of the Chachao Formation (Early Valanginian), which form a homoclinal carbonate ramp system (e.g. Leanza et al., 1977; Legarreta and Kozłowski, 1981; Carozzi et al., 1981; Mitchum and Uliana, 1985; Kietzmann et al., 2014).

3. Studied sections and methods

As part of microfacies studies carried out on the Tithonian–Valanginian carbonate ramp of the Neuquén Basin, two stratigraphic sections of the Vaca Muerta Formation –Arroyo Loncoche (~280 m; Fig. 2) and Río Seco de la Cara Cura (~300 m; Fig. 3)–

were chosen in order to analyses the chitinoideid content and distribution. A total of 60 thin sections were studied under a petrographic transmitted light microscope. In these sections the Vaca Muerta Formation is characterized by a decimetre-scale rhythmic alternation of marlstones and limestones representing the most distal part of carbonate ramp system (Kietzmann et al., 2008, 2011b, 2014; Kietzmann and Palma, 2014). Ammonite data in the studied sections indicate an Early Tithonian to Early Valanginian age (Riccardi pers. comm.). Nannoplankton in the Arroyo Loncoche section has poorly resolution, however some important bioevents were recognized (Lescano and Kietzmann, 2010; Kietzmann et al., 2011a). Also seven calcareous dinocysts zones, previously proposed for the Tethyan Realm, were confirmed in the Vaca Muerta Formation by Ivanova and Kietzmann (2016) (Fig. 2).

Cyclostratigraphic data published by Kietzmann et al. (2015) allowed them to apply a floating orbital scale and obtain a minimum duration for ammonite biozones. Likewise, Iglesia Llanos et al. (2017) obtained a detailed magnetostratigraphic column for the Arroyo Loncoche section. Both floating data are very consistent with biostratigraphic scheme of Riccardi (2015).

4. Systematic paleontology

Calpionellids are relatively poorly preserved in the studied sections of the Vaca Muerta Formation. Hyaline calcitic walls are often recrystallized making the systematic determination difficult; however, microgranular calcitic walls seem to have resisted better the incipient neomorphism presented by the limestones of the Vaca Muerta Formation. Seven species of Chitinoideidae are recognized, as well as four species of Calpionellidae. On the basis of morphological features of lorica and collar construction recognized species are listed below.

Family Chitinoideidae Trejo, 1980

Genus *Chitinoideella* Doben, 1963

Chitinoideella boneti Doben, 1963

Fig. 4.1–10, Fig. 5.1–3

1963 *Chitinoideella boneti* n.sp.- Doben, p. 42, pl. 6, Figs. 1–5.

1985 *Chitinoideella boneti* Doben - Remane, p. 564, Fig. 13.

1997 *Chitinoideella boneti* Doben - Grün and Blau, p. 208, pl. I, Fig. 7

1998 *Chitinoideella boneti* Doben - Pop, pl. I, Fig. 3

2002 *Chitinoideella boneti* Doben - Reháková, p. 370, Fig. 2. 1–4

2010 *Chitinoideella boneti* Doben - Benzaggagh et al., Fig. 8.

2011 *Chitinoideella boneti* Doben - Sallouhi et al., pl. 1, Fig. 24

2013 *Chitinoideella boneti* Doben - Lakova and Petrova, pl. 1, Figs. 17–18, pl. 5, Figs. 21–23.

Material: Arroyo Loncoche section (L74, L100, L115, L155, L158, L171, L190), Río Seco de la Cara Cura (Lt36, Lt37, Lt51, Lt54, Lt57, Lt90).

Diagnosis: Microgranular calcitic, bell-shaped lorica with a large oral opening, slightly preoral constriction, and outwardly deflected collar. Aboral pole of lorica ends usually by a short caudal appendage. Dimensions are 55–83 µm in length and 40–50 µm in width, with a length/width ratio smaller than 1.5. It resembles *Tintinnopsella carpathica* (Murgeanu and Filipescu).

Occurrence and stratigraphic distribution: In the Tethys occurs in the Upper Tithonian Boneti Subzone of the *Chitinoideella* Zone. It was recognized in the Anatolian Peninsula, Eastern Europe (Carpathians, Balkanides), Venetian and Eastern Alps, Betic Cordillera of Spain, North of Africa (Morocco and Tunisia), Cuba and Mexico. In the Neuquén Basin was mentioned previously in the *Windhausenicerias internispinosum* ammonite Zone (lowermost

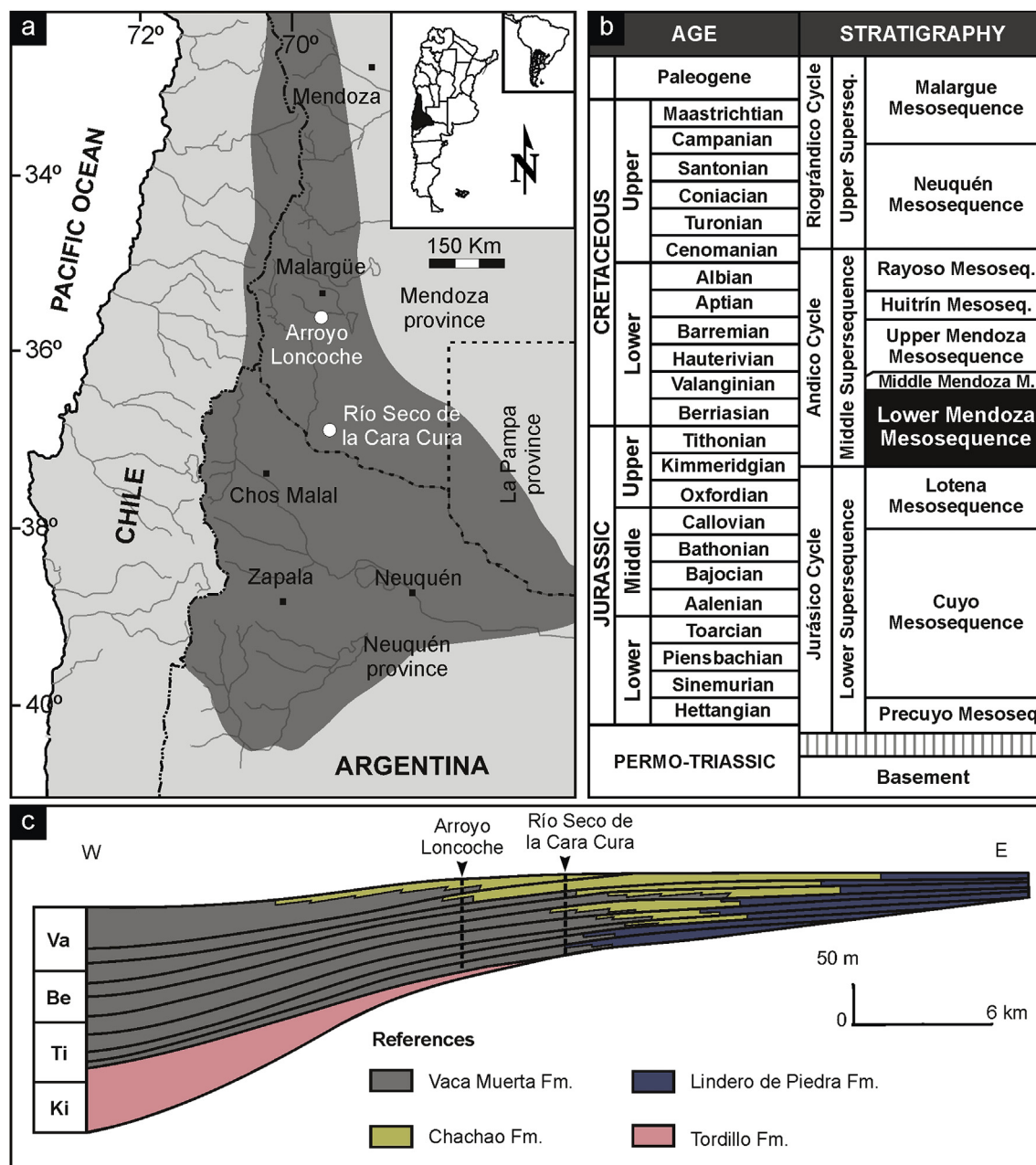


Fig. 1. A) Sketch map of the Neuquén Basin with detail of the studied localities. B) Stratigraphic chart for the Neuquén Basin showing Groeber's cycles and sequence stratigraphic subdivision after Legarreta and Culisano (1989). C) Lithostratigraphic subdivision of the Lower Mendoza Mesosequence or lower Mendoza Subgroup in Southern Mendoza. Modified from Kietzmann et al. (2014). Ki: Kimmeridgian, Ti: Tithonian, Be: Berriasian, Va: Valanginian.

Upper Tithonian) of the Northern Sierra de la Cara Cura (Fernandez-Carmona and Riccardi, 1998). In the studied sections, it was recognized from the base of the *Windhausenicerias internispinosum* to the *Argentiniceras noduliferum* ammonite Andean Zones (lowermost Upper Tithonian – uppermost Lower Berriasian).

Chitinoidella hegarati Sallouhi et al., 2011

Fig. 4.11–13; Fig. 5.4

2011 *Chitinoidella hegarati* n. sp. - Sallouhi, Boughdiri, and Cordey

Material: Arroyo Loncoche section (L115, L171, L190), Río Seco de la Cara Cura (Lt37, Lt51, Lt54, Lt57).

Diagnosis: Microgranular calcitic, fairly isometric bell-shaped to polygonal lorica with parallel lateral edges. Conical aboral pole terminating in a caudal appendage (rounded in oblique sections). Large oral opening surrounded by a collar outwardly deflected in its distal extremity, its lower part being small and cylindroid with a small preoral constriction.

Parallel to fairly rounded lateral flanks converge to the oral part through a shoulder-like structure. For axial sections, Dimensions are 50–65 µm in length and 38–43 µm in width, with a length/width ratio between 1.2 and 1.5. The maximum width can be measured by the middle of the lorica. It resembles *Tintinnopsella remanei* Borza.

Occurrence and stratigraphic distribution: In the Tethys occurs in the Upper Tithonian Boneti Subzone of the *Chitinoidella*

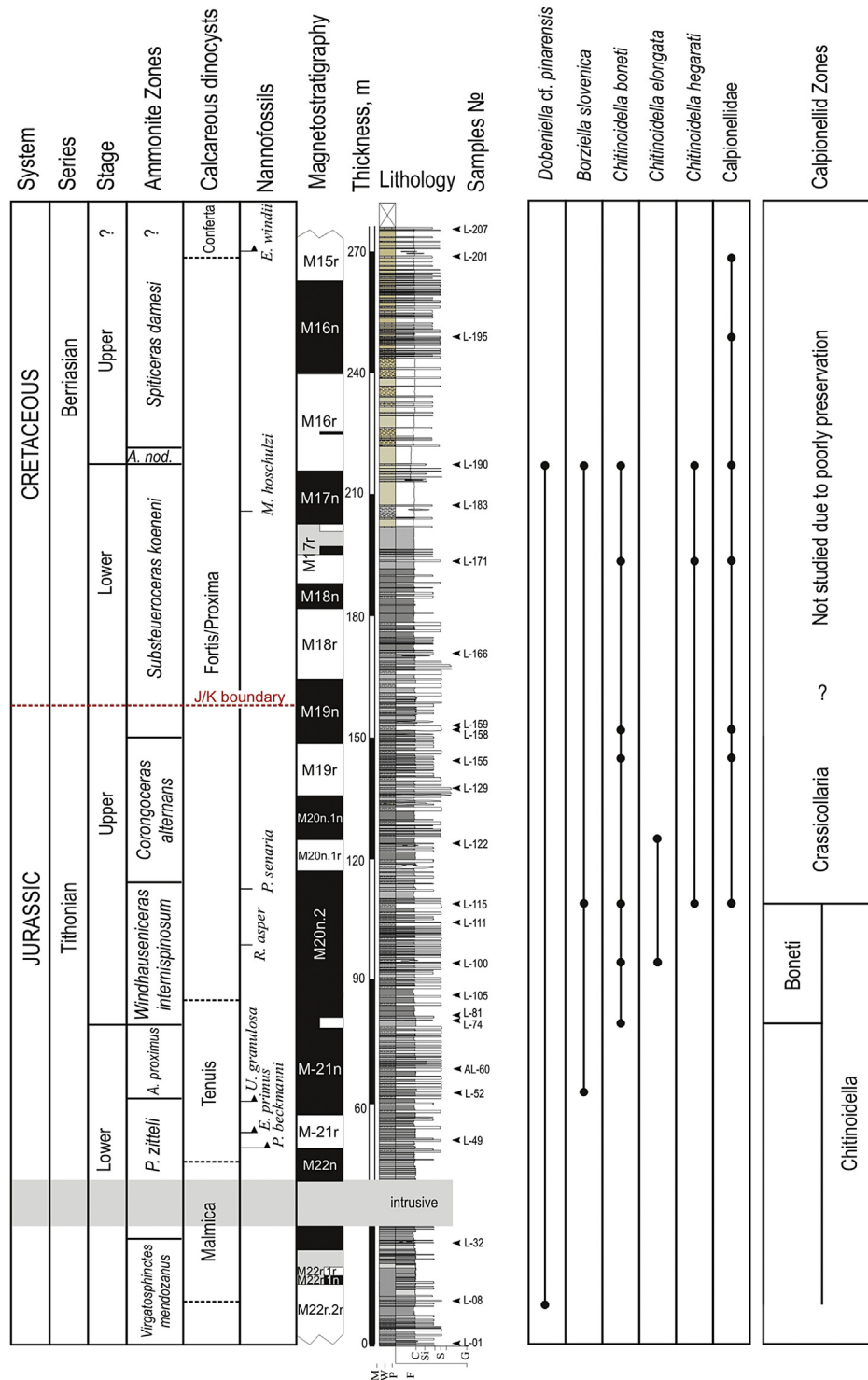


Fig. 2. Arroyo Loncoche section showing Stages based on Andean Ammonite Zones (Riccardi, 2015), calcareous dinocysts Zones (Ivanova and Kietzmann, 2016), Nanofossil bio-events (Lescano and Kietzmann, 2010; Kietzmann et al., 2011a), magnetostratigraphy (Iglesia Llanos et al., 2017), lithologic log, sample location, chitinoideids distribution and calpionellid zones.

Zone. It was recognized in Venetian and Eastern Alps, and North of Africa (Morocco and Tunisia). In the studied sections, it was recognized from the upper *Windhausenicerias internispinosum* ammonite Zone to the *Argentinerias noduliferum* ammonite Zone (lowermost Upper Tithonian – uppermost Lower Berriasian).

Chitinoideella elongata Pop, 1997

Fig. 4.14–15, Fig. 5.5–6

- 1997 *Chitinoideella elongata* Pop - Pop, Fig. 1: 2, 2 photos 3–4.
 2002 *Chitinoideella elongata* Pop - Reháková, p. 2, Figs. 5–8.
 2013 *Chitinoideella elongata* Pop - Lakova and Petrova, pl. 1, Figs. 20–21, pl. 5, Figs. 24–25.

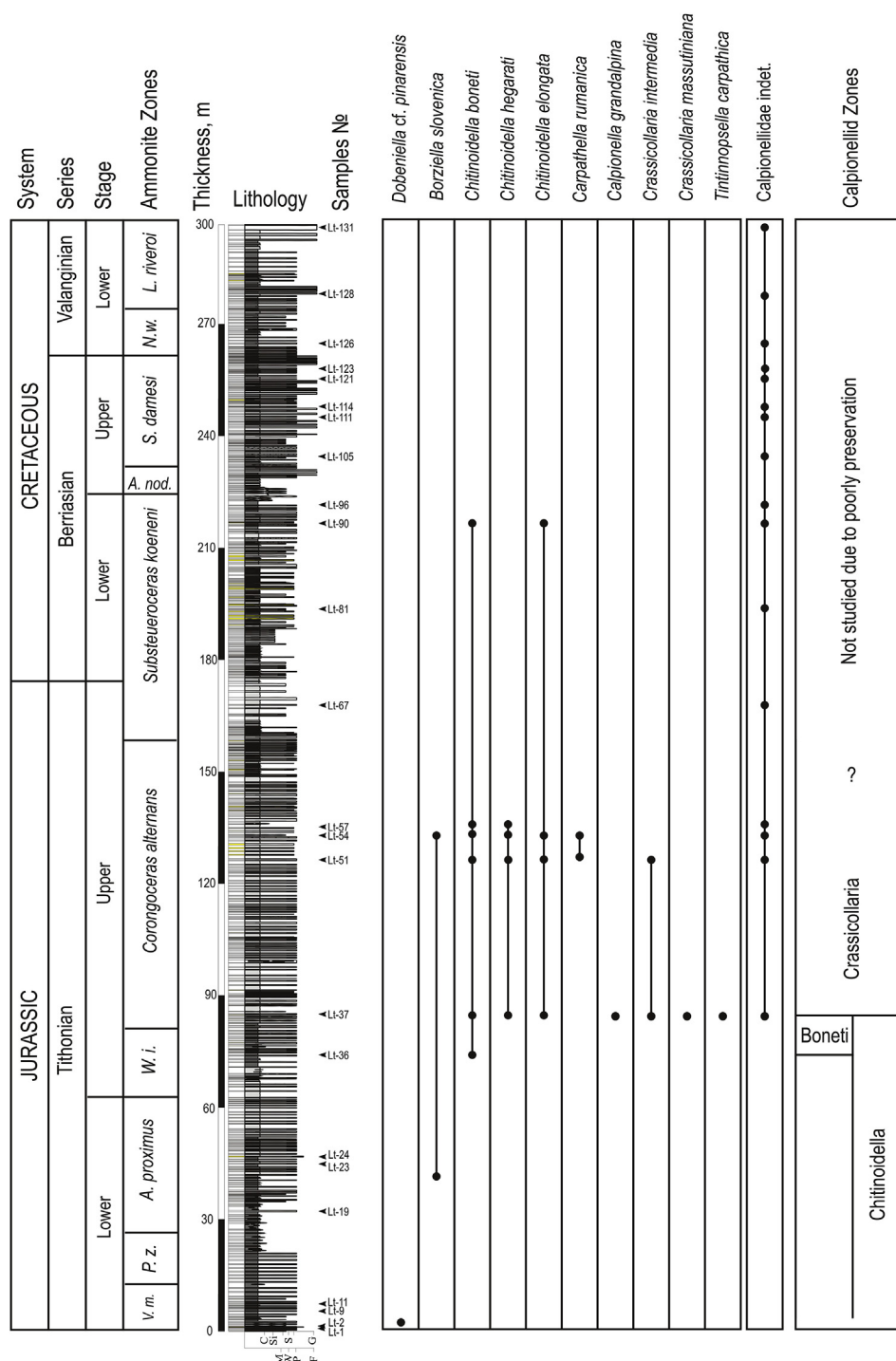


Fig. 3. Río Seco de la Cara Cura section showing Stages based on Andean Ammonite Zones (Riccardi, 2015), lithologic log, sample location, chitinoideid distribution and calpionellid zones.

Material: Arroyo Loncoche section (L100, L122), Río Seco de la Cara Cura (Lt37, Lt51, Lt54, Lt90).

Diagnosis: Cylindrical lorica with a conical aboral ended by caudal appendage and an outwardly deflected collar. The lorica length is 84–105 μm , and its width is 44–55 μm . Length/width ratio is 1.9. Its shape resembles that of *Tintinnopsella longa* (Colom).

Occurrence and stratigraphic distribution: In the Tethys occurs in the Upper Tithonian, Boneti Subzone (Chitinoideella Zone) of the Carpathians. In the studied sections was recognized from the

upper *Windhauseniceras internispinosum* ammonite Zone to the *Corongoceras alternans* ammonite Zone (Upper Tithonian).

Genus *Borziella* Pop, 1997

Borziella slovenica (Borza, 1966)

Fig. 4.16–18; Fig. 5.7–8

1969 *Chitinoideella slovenica* n. sp. - Borza, pl. LXVI, Figs. 8-9.

1997 *Borziella slovenica* (Borza) - Pop, Fig. 2, potos 14-15.

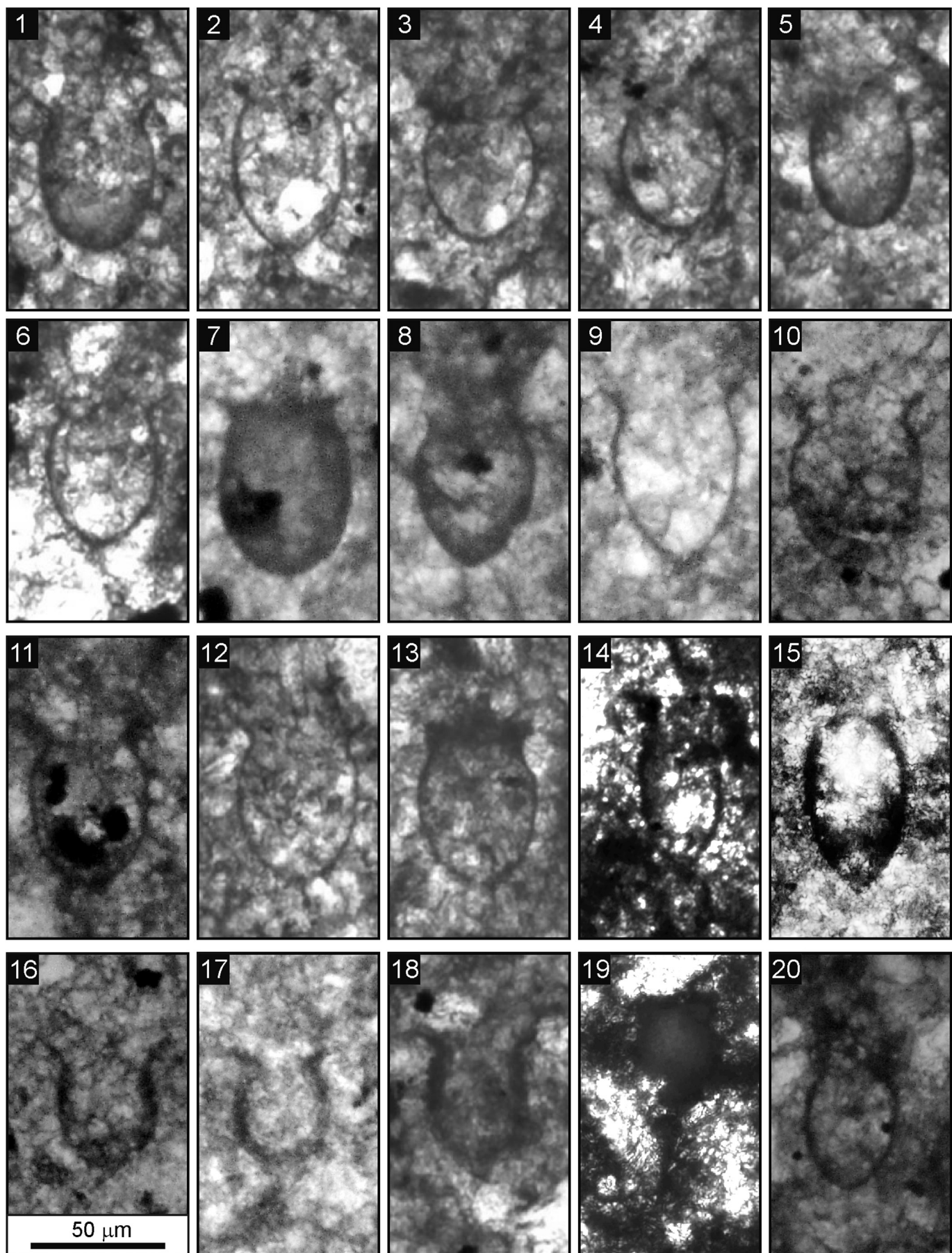
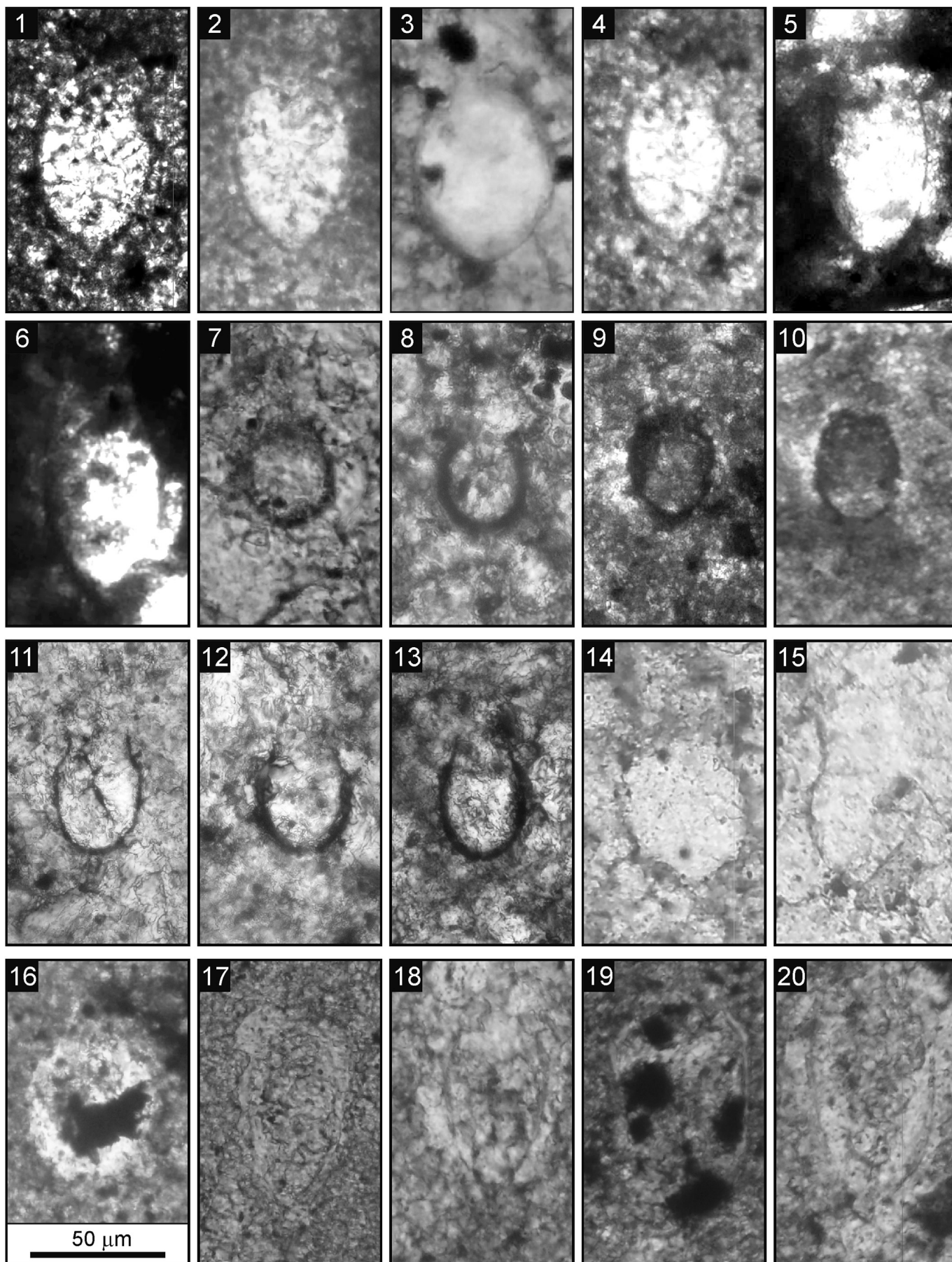


Fig. 4. Chitinoideidellids from the Tithonian–Berriasian Vaca Muerta Formation at the Arroyo Loncoche section. **1–10**) *Chitinoideidella boneti* Doben (samples L74, L100, L190). **11–13**) *Chitinoideidella hegarati* Sallouhi, Boughdiri, and Cordey (samples L171, L190). **14–15**) *Chitinoideidella elongata* Pop (samples L100, L122). **16–18**) *Borziella slovenica* (Borza) (samples L52, L115, L190). **19–20**) *Dobeniella* cf. *pinaensis* (Furazola Bermudez and Kreisel) (samples L8, L190).



- 1998 *Borziella slovenica* (Borza) -Pop, pl. 1, Figs. 16–17.
 2002 *Borziella slovenica* (Borza) - Reháková, Fig. 2. 1–4
 2011 *Borziella slovenica* (Borza) - Sallouhi et al., pl. 1, Figs. 18, 20–21
 2013 *Borziella slovenica* (Borza) - Lakova and Petrova, pl. 1, Figs. 9–10.

Material: Arroyo Loncoche section (L52, L115, L190), Río Seco de la Cara Cura (Lt23, Lt54).

Diagnosis: Ovoid to spheroidal lorica with rounded aboral pole. The lorica length is 40–48 μm , and its width is 28–32 μm . The preoral segment of the lorica bears a small constriction followed by a relatively short outwardly deflected collar similar to *Tintinnopsella remanei* Borza or *Lorenziella hungarica* Knauer type.

Occurrence and stratigraphic distribution: In the Tethys occurs in the uppermost Lower Tithonian Dobeni Subzones of the Chitinoidea Zone. It was recognized in Easter Europe (Carpathians and Balkanides), Eastern Alps, Anatolian Peninsula, and North of Africa (Morocco and Tunisia). In the studied sections, it was recognized in the *Aulacosphinctes proximus* to the *Argentiniceras noduliferum* ammonite Zones (uppermost Lower Tithonian–uppermost Lower Berriasian).

Genus *Carpathella* Pop, 1998
Carpathella rumanica Pop, 1998
 Fig. 5.9–13

- 1998 *Carpathella rumanica* n. sp. - Pop, Fig. 2, photos 1–5.
 2002 *Carpathella rumanica* Pop - Reháková, Figs. 2.13–16.

Material: Río Seco de la Cara Cura (Lt51, Lt54).

Diagnosis: Ovoidal lorica with a rounded aboral pole. The preoral segment of the lorica bears slight constriction forming a characteristic “shoulder”. The collar is short and cylindrical, with a diameter commonly smaller than the maximum width of the lorica. The lorica length is 38–42 μm , and its width is 34–36 μm . This species strongly resembles *Calpionella alpina* Lorenz.

Occurrence and stratigraphic distribution: In the Tethys occurs in the uppermost Lower Tithonian Dobeni Subzone of the Chitinoidea Zone. It was recognized in Easter Europe (Carpathians), and North of Africa (Tunisia). In the studied sections, it was recognized from the *Corongoceras alternans* ammonite Zone (Upper Tithonian).

Genus *Dobeniella* Pop, 1997
Dobeniella cf. *pinaraensis* (Furazola Bermudez and Kreisel, 1973)
 Fig. 4.19–20; Fig. 5.14–15

- 1973 *Chitinoidea pinaraensis* n. sp. - Furazola Bermudez and Kreisel, pl. 1, Figs. 5–6.

Material: Arroyo Loncoche section (L8, L190), Río Seco de la Cara Cura (Lt2).

Description: Ovoid lorica with a sub-rounded aboral pole ended by a caudal appendage, which is approximately a half of the total length of the lorica. The oral segment of the lorica ends with a composite collar. The outer ring of the collar is large and deflected outwardly. The inner piece of the collar is cylindrical and larger than the outer one. The lorica length is 68–122 μm , and its width is

39–44 μm .

Occurrence and stratigraphic distribution: In the Tethys occurs in the Upper Tithonian Boneti Subzone of the Chitinoidea Zone. It was recognized in Easter Europe (Carpathians), as well as in Cuba. In the studied sections, it was recognized from the *Virgatospinctes mendozanus* and the *Argentiniceras noduliferum* Ammonite Zones (Lower Tithonian – uppermost Lower Berriasian).

Family Calpionellida Bonet, 1956
 Genus *Calpionella* Lorenz, 1902

Calpionella alpina Lorenz, 1902
 (Fig. 5.16)

- 1902 *Calpionella alpina* n.sp. - Lorenz, pl. 9, Fig. 1.
 1932 *Calpionella alpina* Lorenz - Cadisch, pl. 1, Figs. 1–9, pl. 2, Figs. 12–15, pl. 3 Figs. 22–23.
 1964 *Calpionella alpina* Lorenz - Remane, pl. 1, Figs. 1–21, pl. 5, Fig. 2.
 1973 *Calpionella alpina* Lorenz - Furazola Bermúdez and Kreisel, pl. 3, Figs. 6–7.
 1985 *Calpionella alpina* Lorenz - Remane, Figs. 6a, 18.1–3.
 1999 *Calpionella alpina* Lorenz - Lakova et al., pl. 1, Fig. 9.
 2013 *Calpionella alpina* Lorenz - Lakova and Petrova, pl. 2, Figs. 12–16

Material: Río Seco de la Cara Cura (Lt37).

Diagnosis: Ovoidal lorica with a rounded aboral pole. The preoral segment of the lorica bears slight constriction forming a characteristic “shoulder”. The collar is short and cylindrical, with a diameter commonly smaller than the maximum width of the lorica. The lorica length is 50–90 μm , and its width is 40–70 μm . The length/width ratio is <1.25.

Occurrence and stratigraphic distribution: This species is known from the whole of the Tethyan area, and its stratigraphic range is Upper Tithonian–Berriasian. In the Neuquén Basin was mentioned previously in Tithonian and Berriasian levels (Fernandez-Carmona et al., 1996; Fernandez Carmona and Riccardi, 1999). In the studied sections, it was recognized at the base of the *Corongoceras alternans* ammonite Andean Zones (Upper Tithonian), as well as poorly preserved specimens in Berriasian levels.

Genus *Crassicollaria* Remane, 1962
Crassicollaria intermedia (Durand-Delga, 1957)
 (Fig. 5.17–18)

- 1957 *Calpionella intermedia* n.sp. - Durand Delga, pl. 1, Fig. 2.4.
 1963 *Calpionella intermedia* Durand Delga - Boller, pl. 1, Figs. 1–9, pl. 2, Fig. 34.
 1964 *Crassicollaria intermedia* (Durand-Delga) - Remane, pl. 2, Figs. 19–35, pl. 5, Figs. 16–17.
 1973 *Crassicollaria intermedia* (Durand-Delga) - Furazola Bermúdez and Kreisel, pl. 3, Figs. 1–2.
 1985 *Crassicollaria intermedia* (Durand-Delga) - Remane, Figs. 11.1–18, 18.14–15
 2013 *Crassicollaria intermedia* (Durand-Delga) - Lakova and Petrova, pl. 5, Figs. 44–46

Material: Río Seco de la Cara Cura (Lt37).

Fig. 5. Chitinoideids and calpionellids from the Tithonian–Berriasian Vaca Muerta Formation at the Río Seco de la Cara Cura section. **1–3** *Chitinoidea boneti* Doben. (samples Lt36, Lt37, Lt90). **4** *Chitinoidea hegarati* Sallouhi, Boughdiri, and Cordey (sample Lt37). **5–6** *Chitinoidea elongata* Pop (samples Lt51, Lt90). **7–8** *Borziella slovenica* (Borza) (samples Lt23, Lt54). **9–13** *Carpathella rumanica* Pop (samples Lt51, Lt54). **14–15** *Dobeniella* cf. *pinaraensis* (Furazola Bermúdez and Kreisel) (sample Lt2). **16** *Calpionella alpina* Lorenz (sample Lt2). **17–18** *Crassicollaria intermedia* (Durand-Delga) (sample Lt2). **19** *Crassicollaria massutiniana* (Colom) (sample Lt2). **20** *Tintinnopsella carpathica* (Murgeanu and Filipescu) (sample Lt2).

Diagnosis: Ovoidal elongated or cylindrical, its aboral part ends by a short caudal appendage. The lorica length is 91–108 μm , and its width is 45–51 μm . The large oral opening is surrounded by a short cylindrical collar, the preoral segment of the lorica displays a more or less pronounced swelling.

Occurrence and stratigraphic distribution: This species is known from the whole of the Tethyan area, and its stratigraphic range is Upper Tithonian. In the studied sections, it was recognized at the base of the *Corongoceras alternans* ammonite Andean Zones (Upper Tithonian).

Crassicollaria massutiniana (Colom, 1948)
(Fig. 5.19)

1948 *Calpionella massutiniana* n.sp. - Colom, pl. 11, Fig. 45.

1962 *Crassicollaria massutiniana* (Colom) - Remane, p. 15.

1964 *Crassicollaria massutiniana* (Colom) - Remane, pl. 3, Figs. 17–40, pl. 5, Figs. 21–22.

1973 *Crassicollaria massutiniana* (Colom) - Furrazola Bermúdez and Kreisel, pl. 3, Fig. 5.

2013 *Crassicollaria massutiniana* (Colom) - Lakova and Petrova, pl. 5, Figs. 47–48.

Material: Río Seco de la Cara Cura (Lt37).

Diagnosis: Ovoidal elongated or cylindrical, its aboral part ends by a short caudal appendage. The lorica length is 80–97 μm , and its width is 53–59 μm . The large oral opening is surrounded by a short cylindrical collar, the preoral segment of the lorica displays a more or less pronounced swelling.

Occurrence and stratigraphic distribution: This species is known from the whole of the Tethyan area, and its stratigraphic range is Upper Tithonian. In the studied sections, it was recognized at the base of the *Corongoceras alternans* ammonite Andean Zones (Upper Tithonian).

Genus *Tintinnopsella* Colom, 1948

Tintinnopsella carpathica (Murgeanu and Filipescu, 1933)
(Fig. 5.20)

1933 *Calpionella carpathica* n.sp. - Murgeanu and Filipescu, pl. 1, Fig. c.

1947 *Tintinnopsella carpathica* (Murgeanu and Filipescu) - Colom, pl. 19, Figs. 4–5.

1957 *Tintinnopsella carpathica* (Murgeanu and Filipescu) - Durand Delga, pl. 1, Fig. 5.

1964 *Tintinnopsella carpathica* (Murgeanu and Filipescu) - Remane, pl. 4, Figs. 23–25.

1973 *Tintinnopsella carpathica* (Murgeanu and Filipescu) - Furrazola Bermúdez and Kreisel, pl. 4, Fig. 1.

1985 *Tintinnopsella carpathica* (Murgeanu and Filipescu) - Remane, Figs. 12, 18.21–24.

2013 *Tintinnopsella carpathica* (Murgeanu and Filipescu) - Lakova and Petrova, pl. 5, Figs. 38–45.

Material: Río Seco de la Cara Cura (Lt37).

Diagnosis: Hyaline calcitic, bell-shaped lorica with a large oral opening, slightly preoral constriction, and outwardly deflected collar. Aboral pole of lorica ends usually by a short caudal appendage. Dimensions are 40–70 μm in length and 70–120 μm in width.

Occurrence and stratigraphic distribution: This species is known from the whole of the Tethyan area, and its stratigraphic range equals that of the family Calpionellidae. In the Neuquén Basin was mentioned previously in Tithonian and Berriasian levels (Fernandez-Carmona et al., 1996; Fernandez Carmona and Riccardi, 1999). In the studied sections, it was recognized its small form at

the base of the *Corongoceras alternans* ammonite Andean Zones (Upper Tithonian), as well as poorly preserved specimens in Berriasian levels.

5. Stratigraphic distribution and biozonation

In the studied sections seven known species of Chitinoideidae and four known species of Calpionellidae are recognized: *Chitinoidea boneti* Doben, *Chitinoidea hegarati* Sallouhi, Boughdiri, and Cordey, *Chitinoidea elongata* Pop, *Borziella slovenica* (Borza), *Carpathella rumanica* Pop, *Dobeniella* cf. *pinaraensis* (Furazola Bermúdez and Kreisel), *Crassicollaria intermedia* Durand Delga, *Crassicollaria massutiniana* (Colom), *Calpionella alpina* Lorenz, and *Tintinnopsella carpathica* (Murgeanu and Filipescu). However, both families show different preservation grades due to neomorphism of limestones, showing better preservation potential those of microcrystalline wall (chitinoideids).

In the Tethyan Realm chitinoideids attained a dominant position in the plankton during the later Early Tithonian until the Late Tithonian (Fallauxi to Microcanthum ammonite Standard Zones), when they were replaced by hyaline calpionellids (e.g. Borza, 1969, 1984; Remane, 1985; Benzaggagh and Atrpos, 1995; Reháková and Michalík, 1997; Reháková, 2002; Sallouhi et al., 2011; Lakova and Petrova, 2013). In the Neuquén Basin the first chitinoideid specimen has been recognized within the *Virgatospinectes mendozanus* to the *Argentineroceras noduliferum* Andean Ammonite Zones.

The Andean *Virgatospinectes mendozanus* Zone has been correlated differently by diverse methodologies: Ammonite biostratigraphy suggest that this zone correlates with the uppermost Darwini?–Semiforme Standard Zones (Riccardi, 2008; 2015), however, this interval starts with a reverse polarity and attains a polarity pattern that comprises more than just normal polarity. Cyclostratigraphic data provided by Kietzmann et al. (2015) suggests its correlation with the lower part of the Fallauxi Standard Zone (following the absolute scale of Gradstein et al., 2012), but detailed magnetostratigraphy carried out by Iglesia Llanos et al. (2017) would indicate its correlation with the uppermost Hybnotum–Darwini Standard Zone. The Andean *Argentineroceras noduliferum* ammonite Zone is correlated by ammonite biostratigraphy, cyclostratigraphy and magnetostratigraphy to the uppermost Occitanica–lowermost Boissieri Standard Zone (uppermost Early Berriasian to lowermost upper Berriasian) (Riccardi, 2015; Kietzmann et al., 2015; Iglesia Llanos et al., 2017). However, other biostratigraphic postures suggest its correlation with the Early Berriasian Jacobi–Occitanica Standard Zones (Vennari et al., 2014).

The first hyaline calpionellid in the Neuquén Basin appears in the transition between the *Windhausenoceras internispinosum* and *Corongoceras alternans* ammonite Zones, corresponding to the uppermost part of the Microcanthum Standard Zone (Zeiss and Leanza, 2008, 2010; Riccardi, 2015; Kietzmann et al., 2015; Iglesia Llanos et al., 2017) similarly to the Tethys area (e.g. Remane, 1985; Lakova and Petrova, 2013).

The present distribution of calpionellid species allows recognizing two of the calpionellid standard zones in the Neuquén Basin:

5.1. Chitinoidea zone

In the Tethys, the first occurrence (FO) of microgranular chitinoideids defines the lower boundary of the Chitinoidea zone, whereas the upper boundary coincides with the FO of *Praetintinnopsella andrusovi* Borza or the FO of Calpionellidae Bonet (Borza, 1984; Lakova and Petrova, 2013). The Chitinoidea zone is divided into two interval subzones: Dobeni Subzone (Grandesso, 1977) and Boneti Subzone (Borza, 1984). After the systematic revision of chitinoideids, Pop (1997) defined their lower

boundaries at the FO of *Longicollaria dobeni* (Borza) for the Dobeni Subzone, and at the FO of *Chitinoidea boneti* Doben for the Boneti Subzone. Another subdivision of this zone was given by Řehánek (1990), Grün and Blau (1997), and Sallouhi et al. (2011). However, Lakova et al. (2016) consider two allocated chitinoideid subzones as sufficient.

In the Neuquén Basin *Longicollaria dobeni* (Borza) was not recognized. However, *Dobeniella* cf. *pinaraensis* (Furazola Bermudez and Kreisel), and *Borziella slovenica* (Borza), which is a typical component of the Dobeni Subzone, represent to the first occurrence of chitinoideids in the Vaca Muerta Formation (*Virgatospinctes mendozanus*–*Aulacosphinctes proximus* Zones). The FO of *Chitinoidea boneti* Doben indicate the base of the Boneti Subzone, and coincides approximately with the base of the *Windhausenicerias internispinosum* ammonite Zone. The FO of hyaline calpionellids occurs in the transition between the *Windhausenicerias internispinosum* and *Corongoceras alternans* ammonite Zones.

The interval between the FO of *Dobeniella* cf. *pinaraensis* (Furazola Bermudez and Kreisel) and the FO of *Chitinoidea boneti* Doben could be assigned to the Dobeni Subzone. However, this interval should be studied in more detail to establish more precisely its correlation with the Tethyan subzone. On the other hand, the interval between the FO of *Chitinoidea boneti* Doben and the FO of hyaline calpionellids can be assigned to the Boneti Subzone. It is noteworthy that similar low-diversity associations are represented in Mexico and Cuba, where the Dobeni Subzone is also poorly represented, and the Boneti Subzone is well defined (Pszczółkowski and Myczyński, 2010; López-Martínez et al., 2015).

5.2. Crassicollaria zone

The Crassicollaria Zone was defined by Alleman et al. (1971) between the FO of hyaline-walled calpionellids and the “explosion” of the spherical form of *Calpionella alpina* Lorenz. This zone is known from practically the whole of the Tethyan area, and was divided into two or three subzones by different authors (see Lakova and Petrova, 2013).

In the Neuquén basin this zone needs a detailed revision, but data provided in this work indicate a typical association of *Tintinnopsis carpathica* (Murgeanu and Filipescu), *Calpionella alpina* Lorenz, *Crassicollaria intermedia* Durand Delga and *Crassicollaria massutiniana* Colom. The lower boundary is determined by the FO of Calpionellidae and coincides with the transition between the *Windhausenicerias internispinosum* and *Corongoceras alternans* ammonite Zones. Its upper boundary is not defined in the present work. A similar association was reported by López-Martínez et al. (2013a, b, 2015) in Mexico, which again shows good consistency between the two regions.

6. Discussion

The distribution of calpionellids in the studied sections of the Vaca Muerta Formation show good similarities with the calpionellid zones in the Tethys. However, chitinoideids show a wider temporal distribution, since Tethyan chitinoideids are restricted to the uppermost Lower Tithonian and Upper Tithonian (Fallauxi–lowermost Microcanthum ammonite Standard Zones). Therefore, the presence of chitinoideids as down as the *Virgatospinctes mendozanus* Zone would support the cyclostratigraphic data by Kietzmann et al. (2015) of a correlation with the Fallauxi Standard Zone, but magnetostratigraphic scale by Iglesia Llanos et al. (2017) seems to be a stronger argument for an older position.

The available data on the timing of the first appearances of chitinoideids in the Tethys are rather scarce (Lakova and Petrova, 2013), and in many Tithonian sections of the Tethyan Realm the

earliest species of Chitinoideidae (from Dobeni Subzone) were not registered, only the upper Boneti Subzone of Chitinoidea Zone being documented (Enay and Geyssant, 1975; Lugo, 1975; Cecca et al., 1989; Benzaggagh et al., 2010; Boughdiri et al., 2006; López-Martínez et al., 2013a, b, 2015). Even though the Dobeni Subzone would correlate with the Fallauxi–Ponti Santard Zones (e.g., Benzaggagh and Atrpos, 1995; Michalik et al., 2009; Benzaggagh et al., 2010), Keisser-Weidich and Schairer (1990) reported some chitinoideid sections from the Hybonotum Standard Zone in Northern Calcareous Alps, and also Platonov et al. (2014) place the base of the Chitinoidea Zone close to ammonites from this zone.

On the other hand, López-Martínez et al. (2015) reported chitinoideids at higher position than the Remanei Subzone in Mexico. Nevertheless, the presence of chitinoideids up to Early Berriasian in the Neuquén Basin could be explained by reworking of Late Tithonian deposits in marginal positions of the basin during Berriasian times or by differences related to ecological controls. Although the upper *Substeueroceras koeneni* and *Argentinerias noduliferum* Zones represent deposits of forced regressions, sedimentological and seismic data indicate an aggradational low-gradient depositional system, with high sedimentation rates, and no evidence of large erosion features (Mitchum and Uliana, 1985; Kietzmann et al., 2014, 2016; Gonzalez et al., 2016). Therefore, this hypothesis cannot be rejected, but it seems unlikely.

The development of microgranular calpionellids in the Tethys occurred at two specific times, during Tithonian (chitinoideids) and Early Albian (precollomiellids), with a time gap of ~20 Ma (e.g., Remane, 1985; Řeháková and Michalik, 1997; Řeháková, 2002; Núñez-Useche et al., 2016). That allows Řeháková and Michalik (1997) and Řeháková (2002) to speculate about similar paleoclimatic and paleoceanographic conditions during both time intervals, probably in connection with supersaturation of calcium carbonate in sea-water chemistry. Řeháková et al. (2016) show that calpionellid diversity maxima and crises may coincide either with metal poisoning or with salinity changes, as well as global climate changes by active volcanoes. Indeed, different triggers have been proposed for crises in marine biocalcification, such as changes in nutrient levels, temperature, and seawater chemistry, etc. Weissert and Erba (2004) indicate that whereas increased nutrient availability could have affected biocalcification, changes in palaeotemperature do not appear to be as significant with respect to carbonate production in the Late Jurassic–Early Cretaceous. In fact, stable isotopic data published by Scasso et al. (2005) from the Vaca Muerta Formation show similar values to those of the Tethys, and surface water temperature of 25–30 °C.

Weissert and Erba (2004) relate biocalcification crises with volcanic activity and decrease in pH and carbonate ion concentration of surface waters. Also, it is important to keep in mind that Late Jurassic–Early Cretaceous times were characterized by high calcification, elevated PCO₂ and lower pH than modern oceans (Hönisch et al., 2012). On the other hand, the eastern margin of the Pacific Ocean was associated with an active subduction zone and a volcanic arc, so it is very likely that the waters chemistry of the Pacific were oversaturated in Ca²⁺ and Mg²⁺, which could have favored the proliferation of porcelaneous forms, as in the case of other microfossils. For example, hyaline and porcelaneous foraminifera have different mechanism for tests calcification, with different ranges in pH conditions and Mg/Ca ratios (de Nooijer et al., 2009). In any case, these argumentations are only speculative and more detailed and regional studies are needed in order to understand the chitinoideid distribution, as well as the application of Tethyan calpionellid standard zones in the Neuquén Basin.

Although it is still necessary to carry out further studies in other stratigraphic sections of the Neuquén Basin in order to establish the applicability of the biostratigraphy based on calpionellids, standard

calpionellids zones were recognized previously in the subsurface of the basin (see González Tomassini et al., 2015), but since these are unpublished reports by the author, they have not yet been properly demonstrated. The presence of *Tintinnopsella*, *Crassicollaria* and *Calpionella* forms in the *Corongoceras alternans* and *Substeuerceras koeneni* ammonite Zones were also reported in other sections of the Vaca Muerta Formation by Fernández Carmona et al. (1996), and indicate that conditions for hyaline calpionellids were also favorable at these latitudes.

The definition of the Boneti Subzone of the Chitinoidea Zone allowed a valuable anchorage of Andean ammonite zones to biozones in the Tethys. Correlation of the *Windhausenicer* *internispinosum* Zone with the *Simplisphinctes* Subzone of the *Microcanthum* Zone of the Standard Zonation was originally proposed by Leanza (1945) and later confirmed by Zeiss and Leanza (2008, 2010) on the basis of the presence of the genus *Simplisphinctes* Tavera. These conclusions were also ratified by Fernández Carmona and Riccardi (1998), who reports for the first time *Chitinoidea boneti*, C. cf. *pinarensis*, and *Chitinoidea* spp. in the *W. internispinosum* Zone, from the northern part of Sierra de la Cara Cura. Also the Chitinoidea Zone was recognized in the subsurface (El Trapial block, see González-Tomassini et al., 2015), which would indicate that at least the Boneti Subzone it is a well-defined subzone in the Neuquén basin.

The presence of large forms of *Calpionella alpina* Lorenz, *Crassicollaria* sp. and *Tintinnopsella* sp. in association with ammonites of the *Corongoceras alternans* and lowermost part of the *Substeuerceras koeneni* Zones were reported by Fernández Carmona et al. (1996) for the Aconcagua Subbasin. Besides the small form of *Calpionella alpina* Lorenz, together with large forms of *Tintinnopsella carpathica* (Murgeanu and Filipescu), was reported at Chacay Melehue (Fernández Carmona and Riccardi, 1999) with ammonites of the *Substeuerceras koeneni*–*Argentiniceras noduliferum* Zones, which allows to Riccardi (2015) to confirm the extension of the *Substeuerceras koeneni* Zone into the Berriasian. These data, and those presented in this work, strongly suggest that the study of calpionellids will contribute to clarify the doubts that still seem to be with some correlations between the Andean and Tethyan ammonite zones. New detailed studies in other stratigraphic sections along the basin, will allow establishing with more precision the applicability of the Berriasian–Valanginian calpionellid zones. So far, the biggest difference with Tethys is the persistence of chitinoideids into Berriasian levels.

7. Conclusions

The distribution of eleven known species of chitinoideids and calpionellids allows recognizing the Chitinoidea and Crassicollaria Zones in the Neuquén Basin. The Chitinoidea Zone correlates with the *Virgatosphinctes mendozanus*–*Windhausenicer* *internispinosum* Andean Ammonite Zones, and can be divided into two subzones, of which the upper one can be assigned to the Boneti Subzones. The lower subzone is represented only by *Dobeniella* cf. *pinaraensis* and *Borziella slovenica*, and corresponds with the *Virgatosphinctes mendozanus*–*Aulacosphinctes proximus* Andean ammonite Zones. The Boneti Subzone includes *Chitinoidea boneti*, *Ch. hegarati*, *Ch. elongata*, *Borziella slovenica*, and *Dobeniella* cf. *pinaraensis*, and corresponds to the *Windhausenicer* *internispinosum* Andean ammonite Zones.

The Crassicollaria Zone contains of *Tintinnopsella carpathica*, *Calpionella alpina*, *Crassicollaria intermedia*, and *Cr. massutiniana*. Although in the Neuquén Basin this zone needs a detailed revision, data provided in this work indicate its correlation at least with the *Corongoceras alternans* ammonite Zone.

Species distribution of chitinoideids and calpionellids in the

Neuquén Basin show some differences with the Tethys, particularly chitinoideids that persists until the Early Berrisian, but also show good similarity with the Tithonian–Berriasian in Mexico and Cuba.

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