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Ammonites and stratigraphy of a Lower Bajocian (Middle Jurassic) section in Sierra Chacaico (Neuquén Basin, Argentina)

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Abstract

A Lower Bajocian section from southern Neuquén Basin (Argentina), with 3 faunal horizons (*sphaeroceroides*, *submicrostoma* and *giebeli* horizons) in the Singularis and Giebeli zones, is described. The Giebeli Zone is relatively thick in contrast with the section at Paso del Espinacito. The ammonite species *Chondromileia submicrostoma* (Gottsche) is quite variable and consists of large specimens. For the first time well preserved and complete macroconch specimens of *Emileia multiformis* (Gottsche) are described. It is shown that the lithostratigraphic and biostratigraphic boundaries are not coincident in the studied section.

Key words: Ammonites, Lower Bajocian, biostratigraphy, Argentina

Zusammenfassung

Aus dem Unter-Bajocium des südlichen Neuquén-Beckens (Argentinien) wird ein Profil mit drei Ammoniten-Faunenhorizonten (*sphaeroceroides*-, *submicrostoma*- und *giebeli*-Horizont) der Singularis- und Giebeli-Zonen beschrieben. Die Schichten der Giebeli-Zone sind recht mächtig im Vergleich zum Profil am Paso del Espinacito. Die Art *Chondromileia submicrostoma* (Gottsche) ist bemerkenswert variabel und beinhaltet großwüchsige Exemplare. Zum ersten Mal werden gut erhaltene, vollständige, makroconche Exemplare der Art *Emileia multiformis* (Gottsche) vorgestellt. Es wird gezeigt, dass die litho- und biostratigraphischen Grenzen im untersuchten Profil nicht miteinander übereinstimmen.

Schlüsselwörter: Ammoniten, Unter-Bajocium, Biostratigraphie, Argentinien

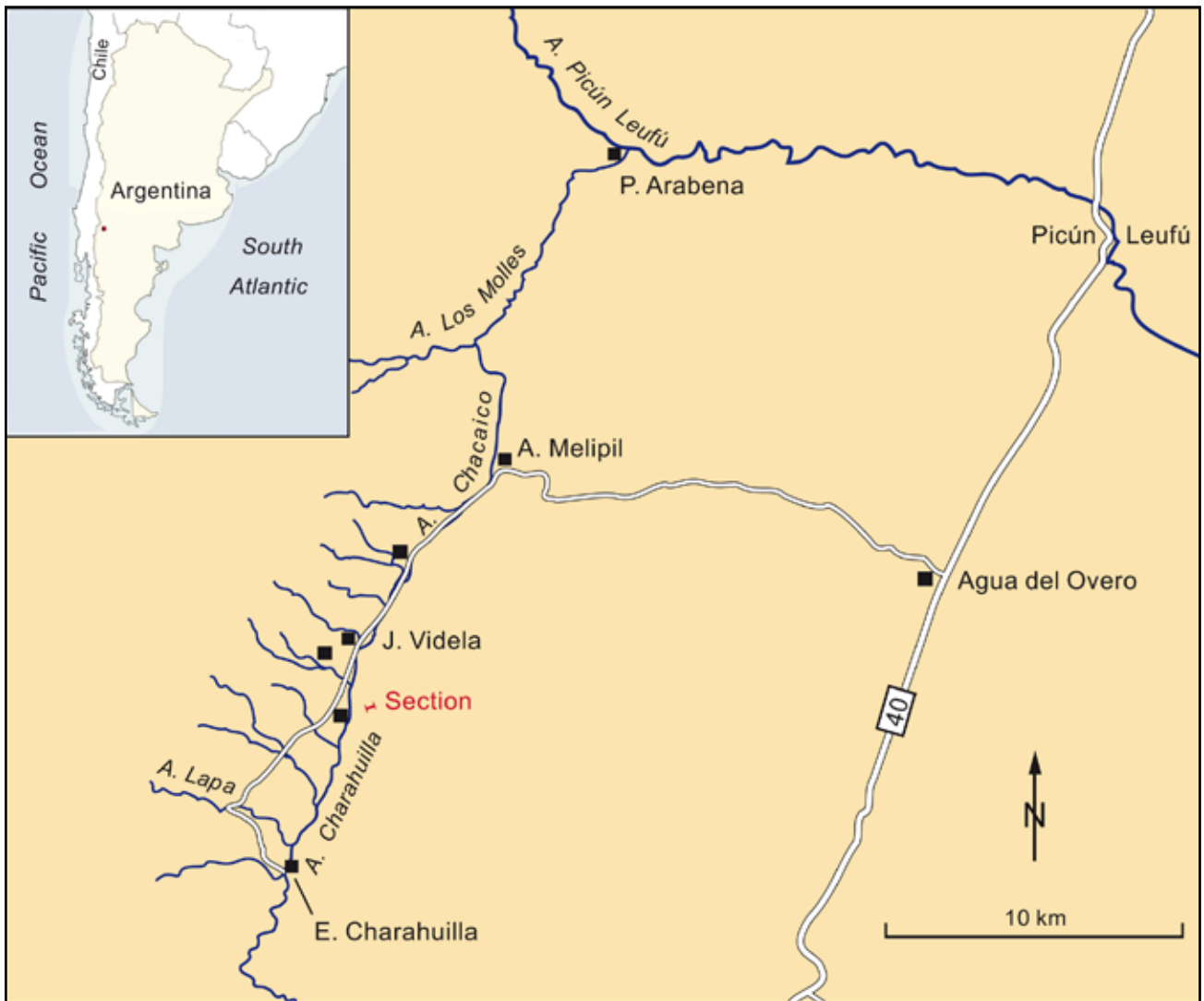
1. Introduction

Abundant fossiliferous Lower Bajocian outcrops exist in the "back-arc" Neuquén Basin in west-central Argentina (e.g. Westermann & Riccardi 1972, 1979; Gulisano 1992; Zavala 1996a, 1996b). The area south of Zapala (Neuquén Province), especially in Sierra Chacaico, is famous for its well exposed and thick outcrops containing rich Lower Bajocian ammonite faunas (for details see Westermann & Riccardi 1972, 1979). One of these outcrops – east of the road from Melipil to Charahuilla (Textfig. 1) and near the section Charahuilla-1 of Westermann & Riccardi (1979), as well as close to the section visited in 1994 by the fieldtrips of the 4th International Congress on Jurassic Stratigraphy and Geology (Gulisano & Gutiérrez Pleimling 1994: fig. 21, section 2) – was described by Volkheimer (1973; ammonite determination by AvH) and studied by one of us (AvH)

with preliminary comments in Hillebrandt (1973). We illustrate and describe the ammonites collected from levels included in the "Cura Niyeu Formation" *sensu* Volkheimer (1973; name no longer in use, see Section 3) of this section, where the strata of the Giebeli Zone are extremely thick. The presence of the ammonite genera *Chondromileia* and *Emileia* is of special interest, as they contribute to a better understanding of the evolution and infraspecific variation of these groups in the Neuquén Basin.

2. Material

In this paper, we describe and figure the material collected by Volkheimer (1973), supplemented by the bed-by-bed ammonite collection made by von Hillebrandt in 1971 and 1983. Overall, we studied about 80 specimens from about 10 succeeding ammonite



Textfigure 1: Geographical location of the section near Arroyo Charahuilla in Sierra Chacaico (Neuquén Basin, Argentina).

levels. The illustrated ammonites are kept in the La Plata Museum, Argentina, except of one specimen from another locality illustrated for comparison.

Abbreviations used in the text and figure captions:

- HT = Holotype
- LT = Lectotype
- var. = variety (used for varieties of infrasubspecific rank)
- MLP = Museo de la Plata, Argentina
- SMNS = Staatliches Museum für Naturkunde Stuttgart, Germany
- AvH = Axel von Hillebrandt, co-author

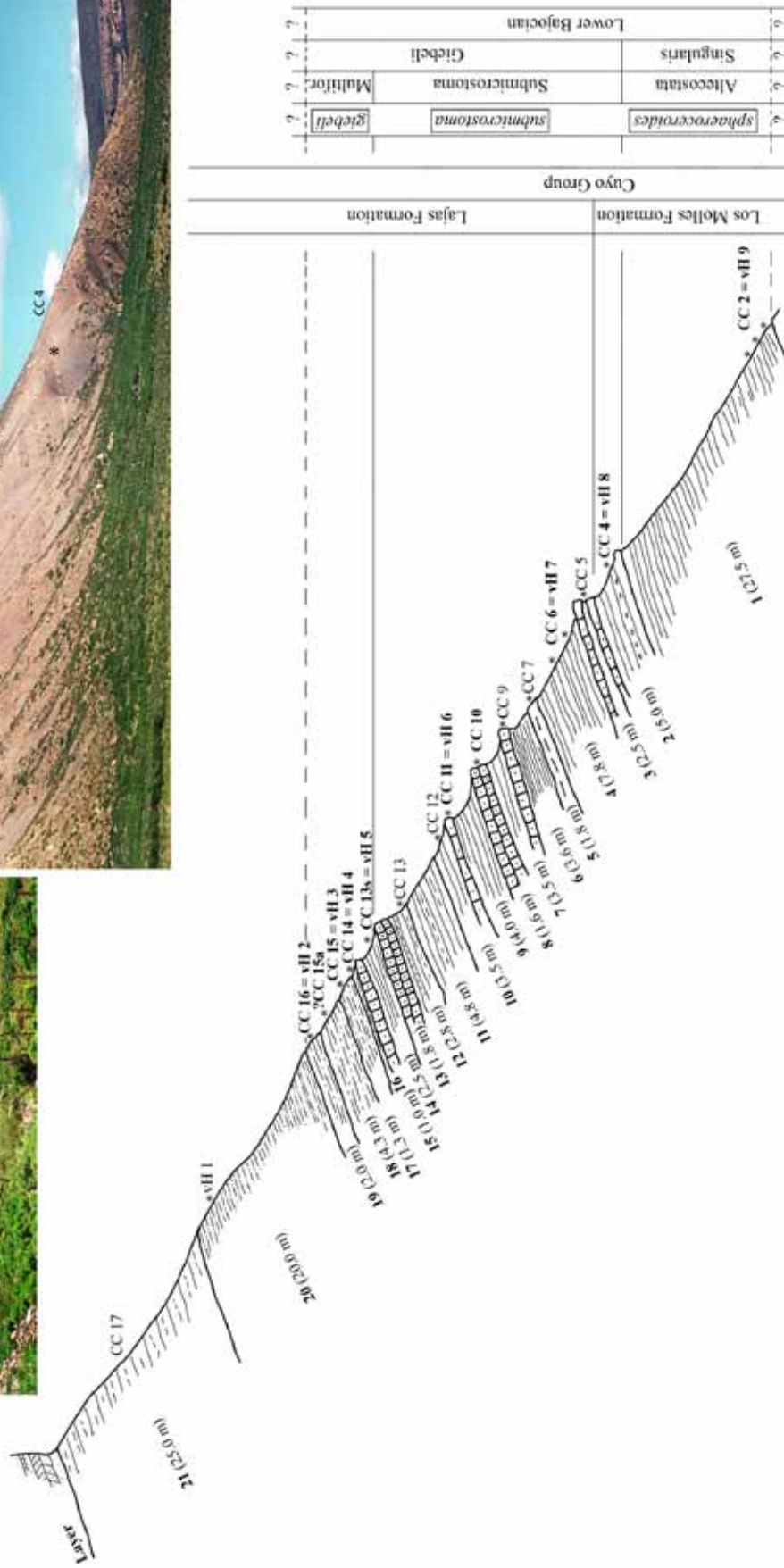
3. Section and litho-/sequence stratigraphy

3.1 Introductory remarks

The section described here is situated at the eastern slope of Charahuilla valley in Sierra Cha-

caico (Textfigs 1, 2). The outcrop was originally described as the type locality of the 126 m thick “Cura Niyeu Formation” (Volkheimer 1973; Quattrocchio & Volkheimer 1993; for a description of the complete site, we refer to Volkheimer 1973 and Hillebrandt 1973).

Gulisano et al. (1984), Gulisano & Gutiérrez Pleimling (1994), Zavala (1996a, 1996b), and Quattrocchio et al. (1996) studied in detail the lithology, sequence stratigraphy and palaeogeographic changes of the Cuyo Group in southern Neuquén Basin. The results presented by Zavala (1996a, 1996b) are of especial interest. This author measured twelve sections and identified depositional sequences of third and fourth order. In the east there are mainly fluvial deposits, while in the west coeval shallow marine sediments occur. The section studied here (Textfig. 3) is in the middle and is equivalent to section 3 of Zavala (1996b), which is found 7.5 km north of section 2, described in detail by Zavala (1996a). Both sections belong to the same series of outcrops, in which the same fourth-order sequences (JC4.1 and



Textfigure 2: Section (indicated by arrows; bars show the layers described here) east of road from Charahuilla to Chacaico (see Textfig. 1). The images show the section in the year 1971.

JC4.2) of the third-order sequence JC4 of the Los Molles and Lajas formations (sensu Zavala 1996a, 1996b) are exposed. For an interpretation of our section, see below (Section 3.3).

The name “Cura Niyeu Formation” *sensu* Volkheimer should be abandoned. We follow the authors mentioned above and use the name Lajas Formation for most of our section. However, to avoid confusion, in the labeling of the successive layers we follow Volkheimer (1973: layers 1 through 21). Volkheimer labeled each of the fossil-bearing beds with the prefix “CC”; however, as not all of the beds are mentioned in his paper, this numeration is not continuous. Hillebrandt labeled the beds in which he collected ammonites with the year, month and day [of collection] and “bed” [e.g. 711126/1].

3.2 Description of the section, lithostratigraphy and ammonite fauna

Cuyo Group (from bottom to top):

Los Molles Formation:

- **1** (27.5 m: alternating sequence of siltstones, marls and shales; basal 5 m with several layers of calcareous nodules containing ammonites)
(bed CC 2 = vH 711126/9)
Ammonites: *Sonninia altecostata* Tornquist var. *gracile* Tornquist [M] [Pl. 1, Figs 1, 3–5] ?*S. bodenbenderi* Tornquist [m] [Pl. 1, Fig. 2] [loose, from slightly deeper]
- **2** (5 m: marly or sandy siltstones, alternating with marls and sandstones. In its lower third, calcareous concretions with ammonites are common)
(bed CC 4 = vH 711126/8).
Ammonites: *Sonninia espinazitensis* Tornquist [M] [Textfig. 4; Pl. 1, Figs 6, 7]
S. altecostata Tornquist [M]
S. subdeltafalcata Tornquist [m] [mentioned by Volkheimer 1973]
Bivalves: *Pleuromya* sp., *Modiolus* sp.

Lajas Formation:

- **3** (2.5 m: calcareous sandstones up to 0.4 m, with interbedded sandy siltstones)
(bed CC 5).
- **4** (7.8 m: Alternation of partly sandy siltstones and shales, in its lower part with interbedded sandstones. Very fossiliferous in the uppermost 3 m)
(bed CC 6 = vH 711126/7).
Ammonites: *Chondromileia submicrostoma* (Gottsche) [M] [Pl. 2, Figs 1, 2]
C. submicrostoma (Gottsche) [m] [Pl. 2, Fig. 3] slightly higher within layer 4:
C. submicrostoma (Gottsche) [M] [Pl. 2, Figs 4, 5, 7, 8; Pl. 3, Figs 1–3]
C. submicrostoma (Gottsche) [m] [Pl. 2, Fig. 6] From between layers 6 and 7:
Sonninia espinazitensis Tornquist [M] [Pl. 3, Fig. 4]

- **5** (1.8 m: sandstone)
(bed CC 7).
- **6** (3.6 m: Alternation of siltstones, marls and sandstones)
- **7** (3.5 m: Alternation of siltstones, muddy sandstones and sandy, muddy marls; at the base beds of marls with numerous large *Sonniniids*)
(bed CC 9).
Ammonites: *Sonninia espinazitensis* Tornquist [M] [mentioned by Volkheimer 1973]
- **8** (1.6 m: sandstone)
(bed CC 10).
Ammonites: *Chondromileia submicrostoma* (Gottsche) [M] [Pl. 3, Figs 5–8, Pl. 4, Fig. 5]
? *Chondromileia/Emileia* [m] [Pl. 4, Figs 1–4]
- **9** (4.0 m: siltstones)
- **10** (3.5 m: Siltstones with interbedded calcareous sandstones (CC 12): at base siltstones (CC 11) with many ammonites in calcareous nodules):
(bed CC 11 = vH 711126/6)
Ammonites: *Sonninia espinazitensis* Tornquist [M] [Pl. 4, Fig. 6]
S. altecostata Tornquist [M] [Pl. 4, Fig. 7]
? *Emileia/Chondromileia* sp. [m] [Pl. 4, Figs 8, 9]
- **11** (4.8 m: Shales and siltstones, in the lower half banks of sandstone).
- **12** (2.8 m: siltstones with interbedded sandstones)
(bed CC 13):
Ammonites: *Sonninia* sp. [M] [mentioned by Volkheimer 1973]
- **13** (up to 1.8 m: banks of sandstones)
- **14** (2.5 m: sandy siltstones)
(bed CC 13s = vH 711126/5 [notice collection AvH: ca. 3 m below 26/4]).
Ammonites: *Emileia multiformis* (Gottsche) [M] [Pl. 5, Figs 7, 8]
? *Emileia/Chondromileia* sp. [m] [Pl. 5, Figs 1, 2, 4–6]
Lytoceras aff. *subfrancisci* Sturani *posterum* Gottsche [M] [Pl. 5, Fig. 3]
- **15** (1.0 m: calcareous and marly sandstones).
- **16** (0.6 m: sandy siltstones)
(bed CC 14 = vH 711126/4 [collection notice AvH: ca. 2 m below 26/3]).
Ammonites: *Emileia multiformis* (Gottsche) [M] [Pl. 6, Figs 1–4]
? *Chondromileia/Emileia* sp. [m] [Pl. 7, Figs 3, 6]
- **17** (1.3 m: sandy siltstones)

Formation (Cuyo Group)	Sequence (Zavala 1996b)	Layer	Volkheimer (CC) Hillebrandt [vH]	Faunal Horizon	Subzone	Zone	Stage
Lajas Formation	JC4.2	21 (25.0 m)	CC 17	?			Lower Bajocian
		20 (20.0 m)	[vH 1]				
		19 (2.0 m)	CC 16 [vH 2]	<i>Chondromileia giebeli</i>	Emileia multiformis	<i>Chondromileia giebeli</i>	
		18 (4.3 m)	?CC 15a				
		17 (1.3 m)	CC 15 [vH 3]				
		16 (0.6 m)	CC 14 [vH 4]				
		15 (1.0 m)					
		14 (2.5 m)	CC 13s [vH 5]				
		13 (1.8 m)					
		12 (2.8 m)	CC 13	<i>Chondromileia submicrostoma</i>	<i>Chondromileia submicrostoma</i>	<i>Chondromileia giebeli</i>	
		11 (4.8 m)					
		10 (3.5 m)	CC 12 CC 11 [vH 6]				
		9 (4.0 m)					
		8 (1.6 m)	CC 10				
		7 (3.5 m)	CC 9				
		6 (3.6 m)					
		5 (1.8 m)	CC 7	<i>Ps. sphaeroc.</i>	<i>S. altecostata</i>	<i>Ps. singularis</i>	
4 (7.8 m)	CC 6 [vH 7]						
3 (2.5 m)	CC 5	<i>Ps. sphaeroc.</i>	<i>S. altecostata</i>	<i>Ps. singularis</i>			
2 (5.0 m)	CC 4 [vH 8]						
Los Molles Formation	JC4.1	1 (27.5 m)	CC 2 [vH 9]	<i>Ps. sphaeroc.</i>	<i>S. altecostata</i>	<i>Ps. singularis</i>	

Textfigure 3: Chart of bio-, chrono-, litho- and sequence stratigraphy of the described section.

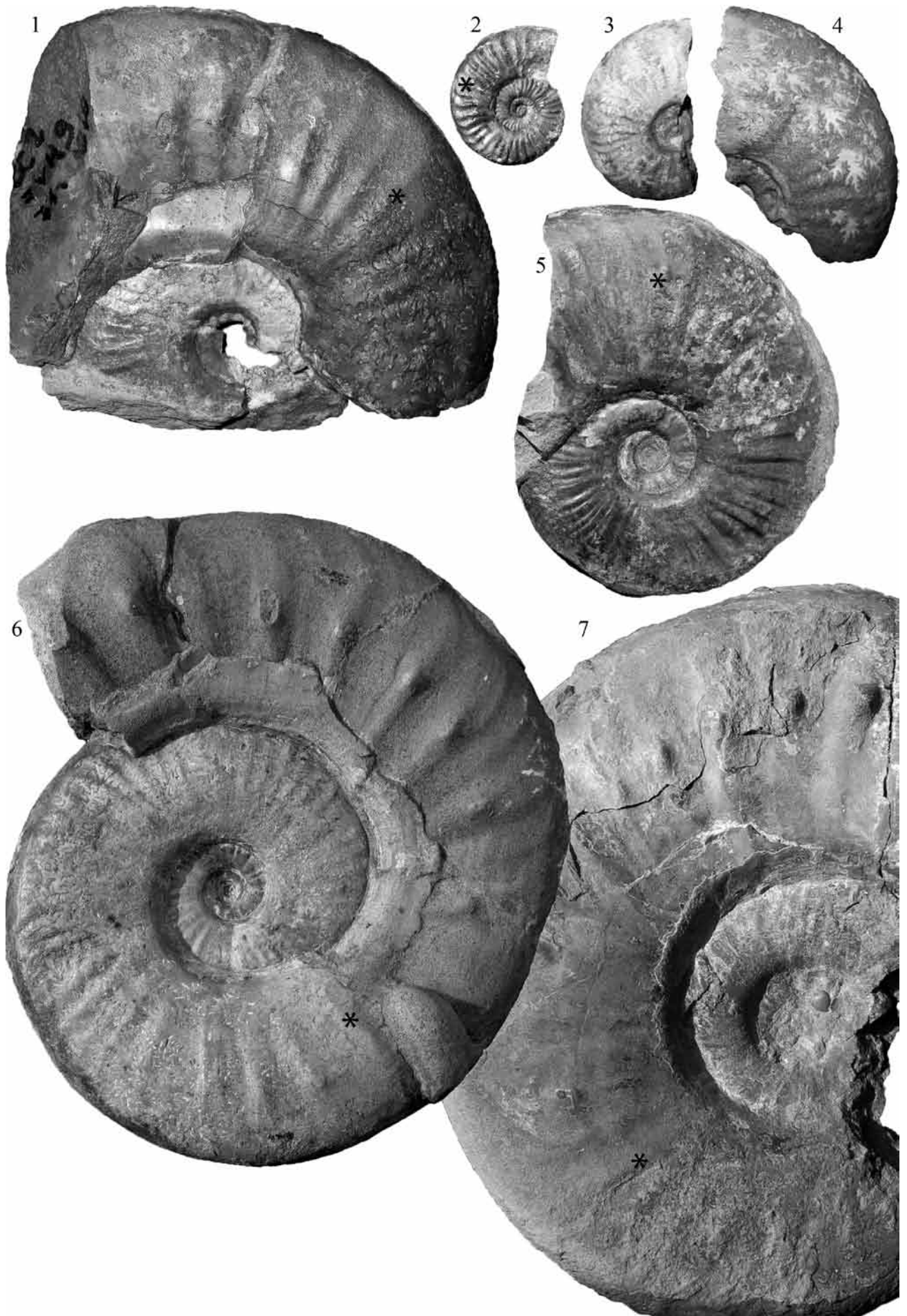


Plate 1

(bed CC 15 = vH 711126/3 = vH 831209/3).

Ammonites: *Chondromileia giebeli* (Gottsche) [M] [Pl. 7, Figs 4, 5, 7, 8]
C. submicrostoma (Gottsche) [M] [Pl. 8, Figs 1, 2]
Emileia multififormis (Gottsche) [m] [Pl. 7, Fig. 9]

- **18** (4.3 m: siltstones, partly sandy)
 [most probably ammonites labeled by AvH as "CC 15a" are from here]:
 Ammonites: ?*Emileia/Chondromileia* sp. [m] [Pl. 8, Figs 3–6]
- **19** (2 m: siltstones to silty sandstones)
 (= bed CC 16 = vH 711126/2).
 Ammonites: *Sonninia* sp. [mentioned in field-book of AvH, lost]
Emileia aff. *constricta* Imray [M] [Pl. 8, Figs 7–9 (found loose ca. 1–2 m below layer 19)]
- **20** (20 m: sandy and clayish siltstones, at top horizon with bivalves)
 (= vH 711126/1).
 Bivalves: *Modiolus* sp., *Trigonia* sp., *Camptonectes* sp., *Entolium* sp., *Ctenostreon* sp.
- **21** (25 m: Alternation of sandstones)
 (= CC 17).

3.3 Interpretation of the lithologic succession

Our section starts in the upper part of the Los Molles Formation (JC4.1) and the main part belongs to the lower part (JC4.2) of the Lajas Formation, and is overlain by cross-bedded sandstones (JC5) of the Lajas Formation, interpreted by Zavala (1996a, 1996b) as estuarines.

Sequence JC4.1 (ammonite horizons CC 2 and CC 4) is formed by off-shore marine claystones and ends with lower delta front sandstones (Zavala 1996b). Sequence JC4.2 starts with c. 3 meters of sandstones, interpreted as an estuarine channel fill, which are followed by a series of coarsening-upward facies with sigmoidal tidal-bundles which are interpreted as tidal sand-waves. Ammonite beds CC 6 to CC 11 occur within these sequences. They are sharply overlain by off-shore marine claystones with ammonite bed CC 12 and are followed by a foresetting set of delta-front deposits related to input-dominated deltaic systems (Zavala 1996a, 1996b) with ammonite bed CC 13. Stream mouth-bar deposits show gently deepening foreset beds and lack any tidal influence (bed CC 13s). The sequence ends

with sandstones and claystones of a delta plain origin, where ammonite horizons (CC 14 to CC 16) occur in the lower part, whilst in the upper part (CC17, without ammonites), swamp deposits are common.

Sequence JC4.2 has been interpreted as a platform sequence. The platform evolution started with sandstones of estuarine channels, which are followed (1) by a transgressive surface and tidal sandwaves (TST), and (2) a maximum flooding surface and an input dominated sandy deltaic system with, and (3) a delta plain (HST). This platform area cannot have been the biotope of the ammonites found there and they must have been washed ashore. Fully marine biotope conditions are proved by complete internal casts of endobenthic marine bivalves.

Sequence stratigraphy and lithostratigraphy on the one hand and bio-/chronostratigraphy (see Section 5 below) on the other hand do not precisely match (Textfig. 4). This is not surprising, as most of the ammonites lived on the continental shelf area and not at the place of burial. The boundary between the Singularis and Giebeli zones is lower down in the section within off-shore marine claystones. The boundary between the Submicrostoma and Multififormis subzones corresponds to a change from an input-dominated deltaic system to stream mouth-bar deposit.

4. The ammonite fauna

4.1 Family Sonniniidae Buckman, 1892

4.1.1 Genus *Sonninia* Bayle, 1879

Type species: *Waagenia propinquans* Bayle, 1878

Remarks: For an emended usage of *Sonninia* and related (sub-)genera, see exhaustive discussion in Dietze et al. (2005).

Sonninia altecostata Tornquist, 1898 [M]
 (Pl. 1, Figs 1, 3–5; Pl. 4, Fig. 7)

- *v 1898 *Sonninia altecostata* Tornquist – Tornquist: p. 19, pl. 2, fig. 4; pl. 3, fig. 1 [LT]
- v 1898 *Sonninia gracilis* Tornquist – Tornquist: p. 21, pl. 4, fig. 4
- v 1898 *Sonninia curviflex* Tornquist – Tornquist: p. 22, pl. 4, fig. 3
- v 1972 *Sonninia (Papilliceras) espinazitensis* Tornquist, 1898 ♀ – Westermann & Riccardi: p. 77, pl. 20, figs 1, 2

Plate 1: (1, 3–5) *Sonninia altecostata* Tornquist var. *gracile* Tornquist [M]; (1) MLP 33739, (3) MLP 33741, (4) MLP 33742. (5) MLP 33743. (2) ?*S. bodenbenderi* Tornquist [m]; MLP 33740. (1–5) Cuyo Group, Los Molles Formation, Layer 1 [CC 2 = vH 711126/9]; Lower Bajocian, Singularis Zone, Altecostata Subzone, *sphaeroceroides* horizon. (6–7) *Sonninia espinazitensis* Tornquist [M]; Cuyo Group, Los Molles Formation, Layer 2 [CC 4 = vH 711126/8]; Lower Bajocian, Giebeli Zone, Submicrostoma Subzone, *submicrostoma* horizon. (6) MLP 33744 [pathogenic bubble probably caused by an injury of the shell followed by an infection of the epithelium [Keupp in litt.]]; (7) MLP 33745. – All specimens: x1; * = beginning of the body chamber.

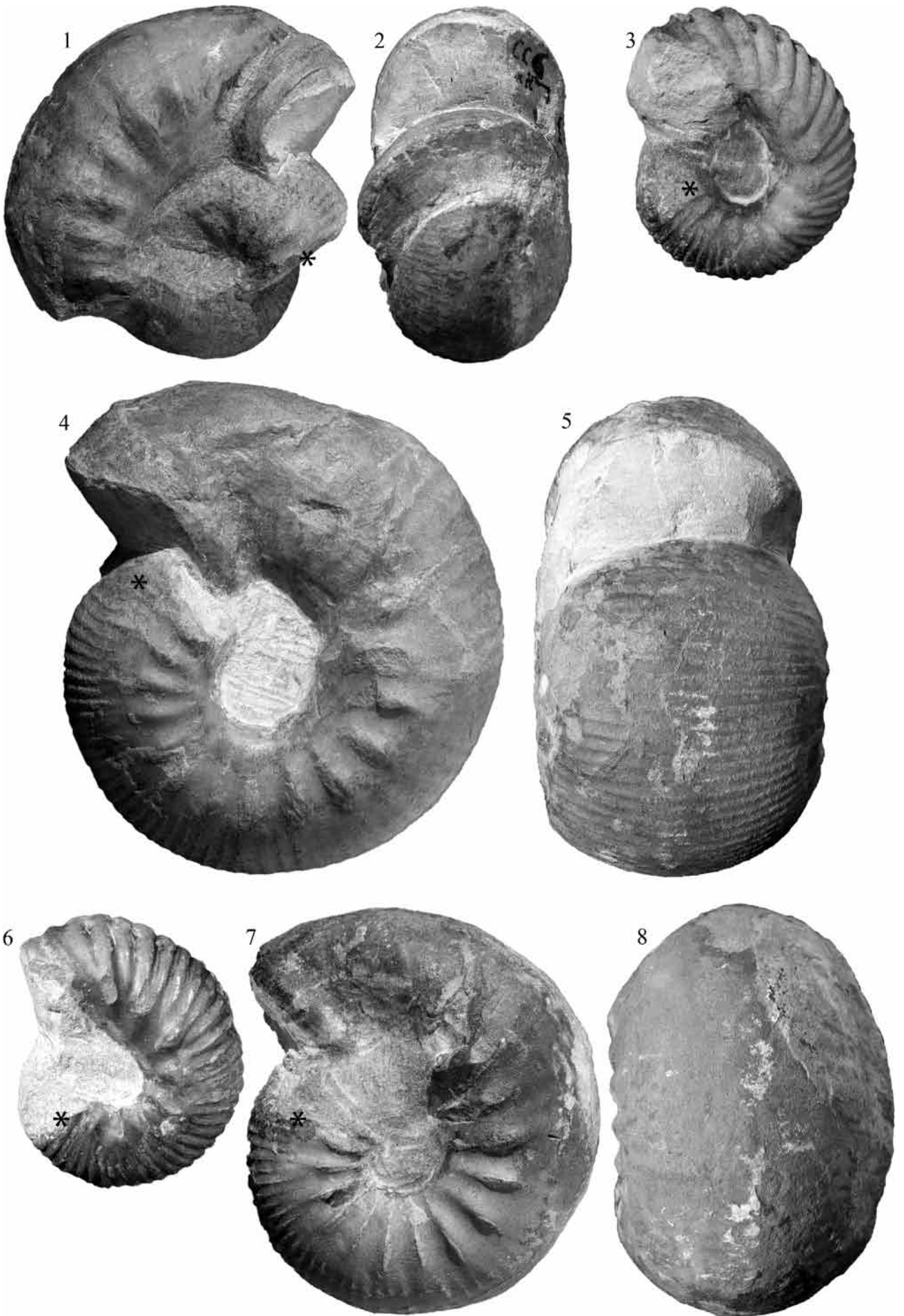


Plate 2

- v 1972 *Sonninia (Papilliceras) espinazitensis* (?subsp.) *altecostata* Tornquist ♀ – Westermann & Riccardi : p. 77, pl. 22, figs 1 [LT refigured], 2 [with further synonymy and extensive discussion]
- v 2001 *Sonninia altecostata* Tornquist – Hillebrandt: p. 56, 58
- v 2010 *Sonninia altecostata* Tornquist – Dietze et al.: p. 91–95; pl. 4, fig. 3, pl. 5, figs. 1–3
- v 2012 *Sonninia altecostata* Tornquist – Dietze & Hillebrandt, p. 29, 31, pl. 3, fig. 1

Material: 8 specimens from Charahuilla, layers 1 and 10.

Remarks: Two of our specimens (Pl. 1, Figs 1, 5) from the base of layer 1 (CC 2 = vH 9) show the typical high whorls of the medium stage of *S. altecostata* var. *gracile* Tornquist (see re-illustration of the holotype in Westermann & Riccardi 1972, pl. 20, fig. 1). With the exception of this special feature these finds are very close to topotypes of *S. altecostata* described by Dietze et al. (2010) from the Paso del Espinacito section and to the lectotype of the species; the typical dense ribbing with small papillae at about the mid-height of the flanks continues on the evolute body chamber. The small specimens figured on Pl. 1, Figs. 3–4 show the sculpture of the nucleus.

Between layers 2 (CC 4 = vH 8) and 10 no specimens of the morphospecies *S. altecostata* were recorded. Only in layer 10 (CC 11 = vH 6) the morphospecies *S. altecostata* (Pl. 4, Fig. 7) reappears, now in about the same number as *S. espinazitensis* (Pl. 4, Fig. 6), although the papillae are now higher on flanks and the inner whorls are less densely ribbed.

Sonninia espinazitensis Tornquist, 1898 [M]
(Textfig. 4; Pl. 1, Figs 6, 7; Pl. 3, Fig. 4; Pl. 4, Fig. 6)

- *v 1898 *Sonninia espinazitensis* Tornquist – Tornquist: p. 20, pl. 3, figs 2 [HT], 3; pl. 4, fig. 1
- v 1972 *Sonninia (Papilliceras) espinazitensis* Tornquist, 1898, ♀ – Westermann & Riccardi: p. 77, pl. 20, fig. 3 [HT refigured]; pl. 21, fig. 1; pls 23–26 [with further synonymy and extensive discussion]
- v 1992 *Sonninia (Papilliceras) espinazitensis* Tornquist, ♀ – Westermann: p. 140, 247; pl. 54, figs. 1, 2
- v 2001 *Sonninia espinazitensis* Tornquist – Hillebrandt: p. 53–54, 56–58
- v 2010 *Sonninia espinazitensis* Tornquist – Dietze et al.: p. 91–95; pl. 7, figs 1–5; pl. 10, fig. 3

Material: 20 specimens from Charahuilla, layers 2, 4, and 10.

Remarks: The first representatives of the *S. espinazitensis* morphospecies occur in layer 2 (CC 4 = vH 8; Textfig. 4, Pl. 1, Figs 6, 7). The innermost and median whorls are densely ribbed without clearly

discernible papillae. The papillae set on at the end of the phragmocone and continue to the end of the body chamber. The ribbing becomes more or less widely spaced on the body chamber, with papillae occurring about mid-height of flanks. There is a gradual transition from *S. altecostata* var. *gracile*, present in layer 1, the older specimens showing higher whorls sections at middle growth and a more densely ribbed body chamber.

The next rich level with sonniniids is represented by layer 10 (CC 11 = vH 6). The specimens of *S. espinazitensis* are almost identical to those from layer 2 with exception of the slightly higher position of papillae on flanks and less dense ribbing on phragmocone (cf. Pl. 1, Figs 6, 7 and Pl. 4, Fig. 6). One specimen found between layers 6 and 7 (Pl. 3, Fig. 4) resembles specimens from layer 10.

Comparisons and conclusions: The specimens of *S. altecostata* from layer 10 (Pl. 4, Fig. 7), in contrast to those of *S. espinazitensis* (Pl. 4, Fig. 6) from the same level, exhibit more evolute coiling and a denser ribbing on the body chamber, with ribs that curve forward slightly above the row of papillae and reach the keel. However, intermediate morphs exist. Hence, the morphospecific distinction between the taxa used herein is purely artificial, but helpful to describe in short individual characters. As already indicated by Westermann & Riccardi (1972) and confirmed by Dietze et al. (2010), *S. altecostata* and *S. espinazitensis* are part of a chronocline with higher shell plasticity in younger representatives. Although it can be observed that the assemblages from the different levels (layers 1, 2 and 10) differ from each other in a characteristic way, we refrain separating them at specific level. They are considered as morphologically variable transients within a chronocline in the sense of Bather (1927) – or to quote Waagen (1869): “Mutationen” with “Varietäten” within the “Formenreihe/Collectivart” (see Dietze et al. 2005).

Aptychi: The large example of the species illustrated on Textfig. 4 shows one aptychus valve still at the end of the body chamber. As in the aptychi described by Morton (1973), the apex is towards the aperture and the harmonic margin facing the ventral part of the whorl, although closer to the venter at the apical angle. For a description of similar material we refer to Morton (1973), who described aptychi from the Lower Bajocian of Scotland. The shell described here consists of black calcite and has fine folds and in contrast to the specimens described by Morton (1973) shows a – slightly – shiny, black surface. This could be an argument against its classification as a true *Cornaptychus* – the presumed aptychus of *Sonninia* according to Arkell (1957: L439). In contrast to



Textfigure 4: *Sonninia espinazitensis* Tornquist [M] with its aptychus [*Cornaptychus* s.l.] *in situ*; Cuyo Group, Los Molles Formation, Layer 2 [CC 4 = vH 711126/8]; Lower Bajocian, Giebeli Zone, Submicrostoma Subzone, *submicrostoma* horizon; MLP 33738. – Scale bar: 10 cm; * = beginning of the body chamber.

the specimens described by Morton (1973) our find shows a black shiny surface, possibly due to a high organic content. Typical cornaptychi exhibit coarse folds in contrast to the material figured here and by Morton (1973) and Westermann & Riccardi (1972).

Several similar forms have been classified as *Laevicornaptychus* by Trauth (1936), but the latter genus must be regarded as a *nomen nudum* because it is lacking a type species (Moore & Sylvester-Bradley in Arkell 1957). Later, Gaşiorowski (1962) emended

the latter genus but still failed designating a type species. Thus, we keep this aptychus tentatively in *Cornaptychus* s.l.

?*Sonninia bodenbenderi* Tornquist, 1898 [m]
(Pl. 1, Fig. 2)

- *v 1898 *Sonninia bodenbenderi* Tornquist – Tornquist: p. 24, pl. 5, fig 9 [HT]
v 1972 *Sonninia* cf. *espinazitensis* Tornquist ♂ [*S. bodenbenderi* Tornquist, 1898] – Westermann & Riccardi: p. 90, pl. 22, figs 3[HT refigured]–5
v 1992 *Sonninia* (*Papilliceras*) cf. *espinazitensis* Tornq., ♂ – Westermann: pl. 54, fig. 4 [non HT as mentioned, but Westermann & Riccardi 1972, pl. 22, fig. 5 refigured]

Material: 1 specimen from Charahuilla, layer 1.

Remarks: Westermann & Riccardi (1972) and Dietze et al. (2010) assumed that the group of ?*S. bodenbenderi/subdeltafalcata* is the corresponding microconch of the *S. espinazitensis/altecostata* group. It should be noted that in ?*S. subdeltafalcata* (see Westermann & Riccardi 1972, pl. 21, fig. 4; pl. 22, fig. 3) about each second or third rib does not originate at the umbilical seam and begins below the middle flank. However, we do not have enough material to decide if these two taxa are conspecific.

4.2 Family Otoitidae Mascke, 1907

4.2.1 Genus *Emileia* Buckman, 1898

Type species: *Ammonites brocchii* J. Sowerby, 1818.

Diagnosis: Moderately-sized sphaeroconic macroconchiate ammonite with strong and prominent primaries and gradual coiling in all ontogenetic stages. Microconchs [=Otoites] lappeted.

Emileia multiformis Gottsche, 1878 [M]
(Pl. 5, Figs 7, 8; Pl. 6, Figs 1–4, Pl. 7, Figs 1, 2)

- *v 1878 *Stephanoceras multiforme* sp. nova – Gottsche: p. 13, pl. 2, figs 5–6, 7 [HT], 8, pl. 3, figs. 1, 4

- 1898 *Sphaeroceras multiforme* Gottsche sp. – Tornquist: p. 27
*v 1979 *Emileia* (*Emileia*) *multiformis* (Gottsche, 1878) ♀ – Westermann & Riccardi: p. 122, pl. 3, figs 1, 2 [NT] 3–5, pl. 4, figs. 1–2 [with further synonymy and extensive discussion]
v 1992 *Emileia* (*E.*) *multiformis* (Gott.) – Westermann: pl. 55, figs 4–5
v 2001 *Emileia multiformis* (Gottsche) – Hillebrandt: p. 54
v 2010 *Emileia multiformis* (Gottsche) – Dietze et al.: p. 92, 94, 96–95; pl. 6, figs 4, 6, pl. 8, fig. 3

Material: 4 specimens from Charahuilla, layers 14 and 16; 1 specimen from Aguada Profeta (Northern Chile, loc 10 in Hillebrandt 2001).

Description and remarks: The final diameters of the complete specimens illustrated by us are similar. In contrast, other morphological features show some variability, excepting the prominent short primary ribs:

One specimen (MLP 33766, Pl. 5, Figs 7, 8) is very close to the incomplete phragmocones of the variety “*Stephanoceras*” *multiforme* var. *macromphalum* figured by Gottsche (1878, pl. 2, figs 6a, b; pl. 3, figs 1a, b; both lost) from Paso del Espinacito (San Juan Province, Argentina). The specimen figured by us seem to be a complete example of this variety. The neotype of the species *E. multiformis*, selected by Westermann & Riccardi (1979, pl. 3, figs 2a, b) is too small for a proper interpretation. However, distances between primary ribs of that specimen are close to those shown in our specimen. Whorl section and umbilicus uncoiling are closer to those for the holotype (Gottsche 1878, pl. 2, figs 7a, b) of this species.

In specimen MLP 33767 (Pl. 6, Figs 1, 2) the phragmocone is not preserved and therefore comparison with Gottsche’s type material, which consists only of incomplete phragmocones, is difficult. The dense ribbing of the body chamber suggests a similarity with Gottsche’s “Typus” [= HT] of the species *E. multiformis* (Gottsche 1878, pl. 2, figs 7a, b; specimen lost) or with the variety *E. multiformis* var. *micromphalum* (Gottsche 1878, pl. 2, figs 5a, b; refigured by Westermann & Riccardi 1979, pl. 3, figs 3a–c). The ribbing of the specimens figured by Gottsche is much denser compared to the variety *E. multiformis* var. *macromphalum*.

The specimen MLP 33768 (Pl. 6, Figs 3, 4) reminds

Plate 3 (p. 130): (1–3, 5–8) *Chondromileia submicrostoma* (Gottsche) [M]; (1) MLP 33751, (2–3) MLP 33752, (5–6) MLP 33754; (7–8) MLP 33753. (4) *Sonninia espinazitensis* Tornquist [M]; MLP 33761. (1–8) Cuyo Group, Lajas Formation; (1–3) Layer 4 [CC 6 = vH 711126/7]; (4) between layers 6 and 7; (5–8) Layer 8 [CC 10; no vH collection number]; (1–8) Lower Bajocian, Giebeli Zone, Submicrostoma Subzone, *submicrostoma* horizon. – All specimens: x1; * = beginning of the body chamber.

Plate 4 (p. 131): (1–4, 8–9) ?*Chondromileia/Emileia* [m]; (1–2) MLP 33756; (3–4) MLP 33757, (8–9) MLP 33758. (5) *Chondromileia submicrostoma* (Gottsche); MLP 33755. (6) *Sonninia espinazitensis* Tornquist [M]; MLP 33760, (7) *Sonninia altecostata* Tornquist [M]; MLP 33759. (1–9) Cuyo Group, Lajas Formation. (1–5) Layer 8 [CC 10; no vH collection number]; (6–9) Layer 10 [CC 11 = vH 711126/6]. (1–9) Lower Bajocian, Giebeli Zone, Submicrostoma Subzone, *submicrostoma* horizon. – All specimens: x1.

Plate 5 (p. 132): (1–2, 4–6) ?*Chondromileia/Emileia* [m]; (1–2) MLP 33762; (4–5) MLP 33763; (6) MLP 33764. (3) *Lytoceras* aff. *subfrancisci* Sturani *posterum* Gottsche [M]; MLP 33765. (7–8) *Emileia multiformis* (Gottsche) [M]; MLP 33766. (1–8) Cuyo Group, Lajas Formation; layer 14 [CC 13s = vH 711126/5. Lower Bajocian, Giebeli Zone, Multiformis Subzone, *giebeli* horizon. – All specimens: x1.

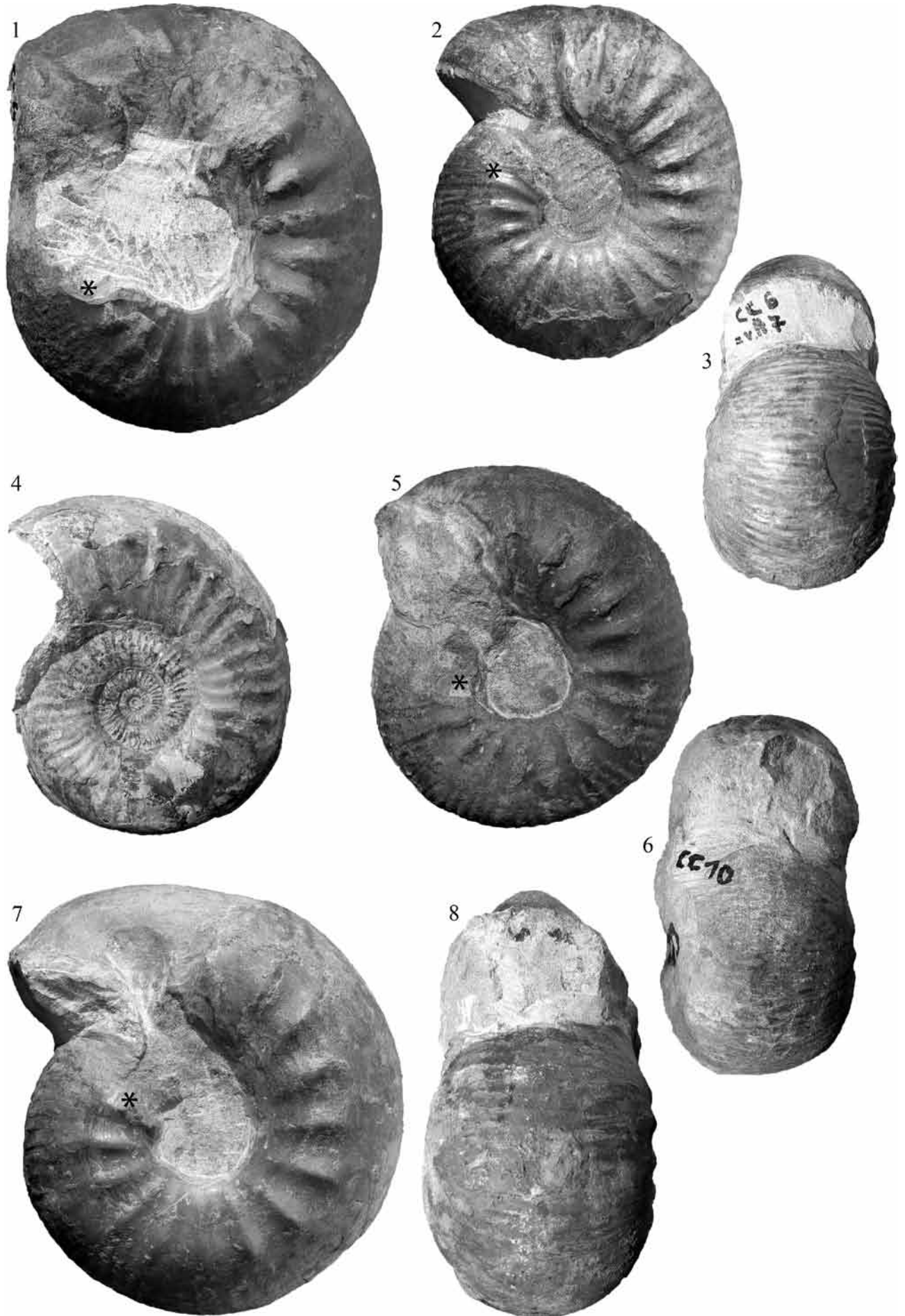
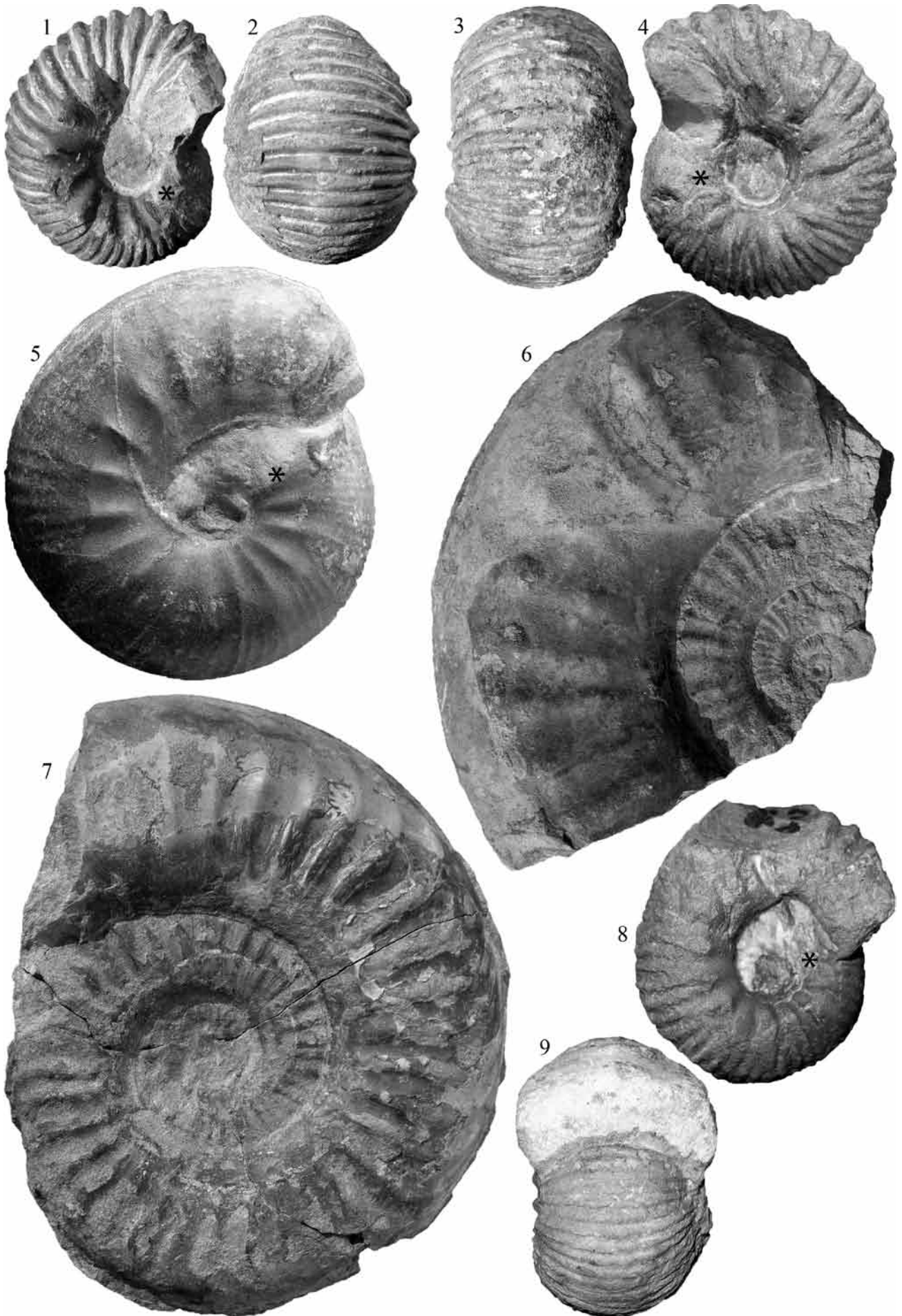


Plate 3



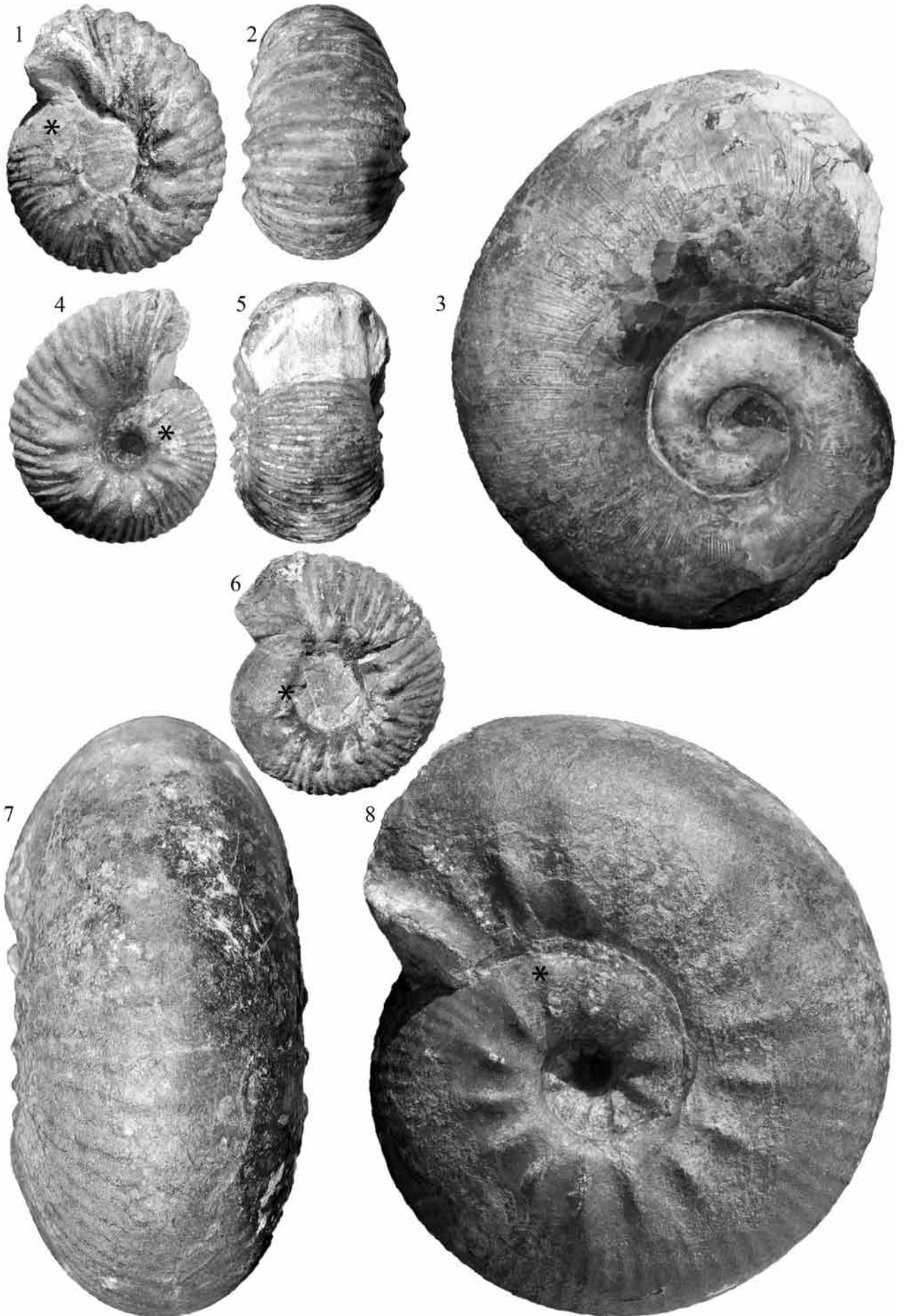


Plate 5

at first sight *Emileia polyschides* Opper, known mainly from the northern margin of the Tethys. However, a closer examination showed some significant differences. Although the primaries in both *E. multiformis* and *E. polyschides* are coarse and relatively well spaced, in *E. multiformis* they are prominent only in the lower third of the flanks, whilst primaries in *E. polyschides* are coarse and prominent also on the upper flank, especially on the body chamber (cf. Westermann 1964, pl. 7, figs 1, 2). The final diameter of *E. polyschides* is larger than in *E. multiformis* (15–16 cm vs. 12–13 cm).

An additionally specimen (SMNS 70022, Pl. 7, Figs 1, 2) from the Giebeli Zone (Multiformis Subzone) of Aguada Profeta in Northern Chile (Hillebrandt 2001: 54) shows a very broad whorl section, as in the specimen figured by Gottsche (1878, pl. 2, figs 5a, b) as *E. multiformis* var. *micromphalum* but with a more evolute umbilicus – as figured by Gottsche's (1878, pl. 2, figs 6a, b and pl. 3, figs 1a, b) *E. multiformis* var. *macromphalum*.

Despite these morphological differences, all illustrated specimens belong to *E. multiformis*. Characteristic and common features are the relatively small final diameter – as compared to the “European” species of this genus –, the coarse and prominent primaries restricted to the lower part of the flanks and the broadly oval whorl section, although the last feature differs slightly in an undescribed fauna of *E. multiformis* (Hillebrandt 2001) from the Giebeli Zone of Manflas (Chile).

Emileia aff. *constricta* Imlay [M]
(Pl. 8, Figs 7–9)

- aff. 1964 *Emileia constricta* Imlay, n. sp. – Imlay: p. B40, pl. 11, figs 1–8
aff. 1992 *Emileia constricta* Imlay, ♀ – Westermann (ed.): pl. 28, figs 4a, b

Material: 2 specimens from Charahuilla, layer 19.

Comparison and remarks: Two specimens (MLP 33776, MLP 33777, Pl. 8, Figs 7–9) differ clearly from the *E. multiformis* assemblage of our section: (1) final diameter is larger; in the specimen figured on Pl. 8, Figs 8–9 about 1/4 to 1/3 of the final whorl is missing, so that the original diameter of the complete ammonite was about 15 cm; (2) primaries are less prominent and become weaker higher on the flanks; (3) body chamber whorl section is high-oval and not broadly rounded oval.

For these features the best fitting nominal species we could find in the literature is *Emileia constricta* Imlay. The name-bearing constrictions of this taxon are pathogenic and thus not diagnostic for the species. Although the holotype of *E. constricta* shows

a denser ribbing when compared with our material, the illustrated paratypes (Imlay 1964, pl. 11, figs. 3, 8) show a similar ribbing style and width of umbilicus and whorl sections are also quite comparable.

E. brocchii (Sowerby) differs by a clearly more depressed whorl section. *E. arkelli* Maubeuge exhibits a more rounded whorl section and more prominent primaries. All other nominal species in the literature show less morphological resemblance.

4.2.2 Genus *Chondromileia* Westermann & Riccardi, 1979

Type species: *Stephanoceras giebeli* Gottsche, 1878.

Diagnosis: Moderately-sized, sphaeroconic, dimorphic ammonite with macroconchs of *Emileia*-like appearance, but with prominent primaries restricted to inner part of flank and sudden egression of body chamber in the adult stage. Microconchs lappeted.

Chondromileia submicrostoma
(Gottsche, 1878) [M]

(Pl. 2, Figs 1, 2, 4, 5, 7, 8; Pl. 3, Figs 1–3, 5–8; Pl. 4, Fig. 5; Pl. 8, Figs 1, 2)

- * v 1878 *Stephanoceras submicrostoma* sp. nova – Gottsche: p. 15, pl. 3, fig. 3 [LT]
v 1898 *Sphaeroceras submicrostoma* Gottsche sp. – Tornquist: p. 27
v 1979 *Emileia (Chondromileia) giebeli submicrostoma* (Gottsche, 1878) ♀ – Westermann & Riccardi: p.135; pl. 6, fig. 4, pl. 7, figs 2, 3 [LT refigured], 4, 5, pls 8, 9 [with further synonymy and extensive discussion]
v 1992 *Emileia (Chondromileia) giebeli submicrostoma* (Gott.) – Westermann (ed.): pl. 56, figs 1, 2
v 2001 *Emileia (Chondromileia) giebeli submicrostoma* (Gottsche) – Hillebrandt: p. 55, pl. 1, fig. 3
v 2010 *Chondromileia submicrostoma* (Gottsche) – Dietze et al.: p. 91–94, 98, pl. 6, figs 1–3, pl. 8, fig. 4.

Material: 16 specimens from Charahuilla, layers 4 and 8.

Description: Most specimens show only the body chambers, often laterally crushed and damaged near the aperture. The phragmocone is preserved, totally or in part, in few specimens. Characteristic features of *C. submicrostoma* – prominent, relatively wide spaced primaries, secondaries still visible on body chamber and a broad-oval whorl section – are well developed. Size of complete specimens varies from 69 mm (Pl. 8, Figs 1, 2) to 100 mm (Pl. 2, Figs 4–5). There are relatively compressed shells (Pl. 3,



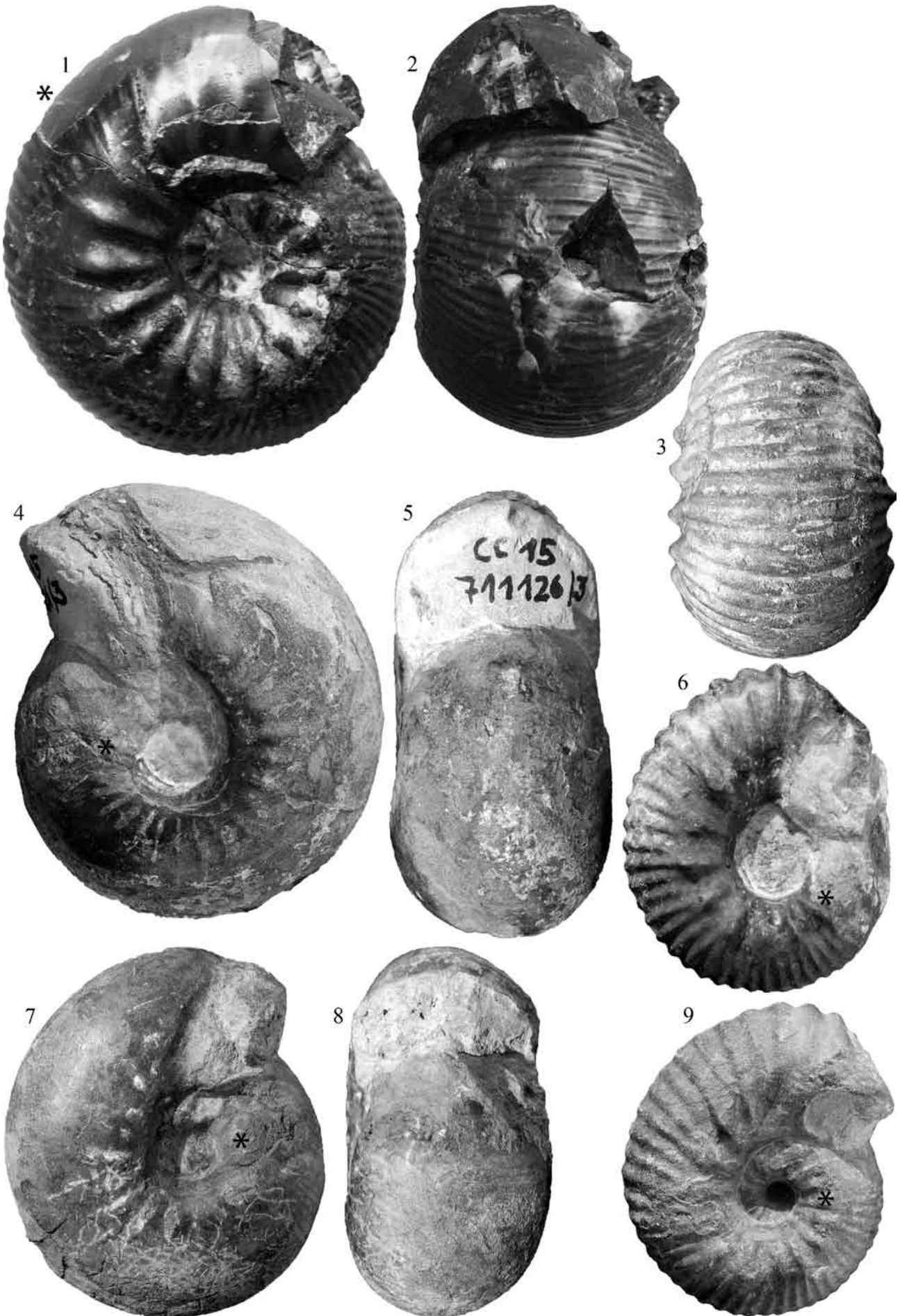


Plate 7

Figs 5, 6; Pl. 4, Fig. 5) resembling *C. giebeli*, to relatively broad shells (Pl. 2, Figs 4, 5, 7, 8), but consistently with a more depressed whorl section and a less curved venter than in *C. giebeli*. The primaries are relatively well recognizable but variable (e.g. compare Pl. 3, Fig. 2 with Pl. 3 Fig. 7). Due to their incomplete preservation it is impossible to determine the number of primaries on the last whorl.

Comparison: The *C. submicrostoma* specimens of the Charahuilla/Chacaico area are remarkably larger than those from Paso del Espinacito, from where the type material comes (cf. also the figured specimens from both areas in Westermann & Riccardi 1979, pls 7–9). The reason for this size differences may be ecological and in view of the otherwise identical morphology of both associations we dismiss the possibility that they belong to different (bio-)species.

Of great interest is the striking similarity of this large-sized *C. submicrostoma* fauna and some specimens of *Emileia multiformis*. Common and typical features for both groups are the prominent, short primaries. However, as already pointed out by Westermann & Riccardi (1979: 126), *C. submicrostoma* exhibits extremely involute nuclei – although this feature cannot be seen in our material –, and a sudden egression of the adult body chamber. This and the larger adult size of *E. multiformis* are the best features to distinguish both taxa. The similarity of both taxa suggests a possible common ancestor, probably in the genus *Docidoceras*. This probable relationship has been pointed out in Westermann & Riccardi (1985).

Chondromileia giebeli (Gottsche, 1878) [M]
(Pl. 7, Figs 4, 5, 7, 8)

- *v 1851 *A. bullatus* Gieb. nec d'Orb. – Giebel: p. 246
- *v 1878 *Stephanoceras giebeli* sp. nova – Gottsche: p. 15, pl. 4, fig. 1 [HT]
- v 1898 *Sphaeroceras giebeli* Gottsche sp. – Tornquist: p. 27
- v 1979 *Emileia (Chondromileia) giebeli giebeli* (Gottsche, 1878) ♀ – Westermann & Riccardi: p. 134; pl. 6, figs 1 [HT refigured], 2–3, pl. 7, fig. 1 [with further synonymy and extensive discussion]
- v 1992 *Emileia (Chondromileia) giebeli giebeli* (Gott.) s.s. – Westermann: pl. 55, fig. 7
- v 2001 *Emileia (Chondromileia) giebeli giebeli* (Gottsche) – Hillebrandt: p. 53, 56, pl. 1, fig. 1
- v 2008a *Emileia (Chondromileia) giebeli* (Gottsche). – Riccardi: p. 633, figs 7.5, 7.6
- v 2008b *Emileia (Chondromileia) giebeli* (Gottsche). – Riccardi: p. 330, figs 6.5, 6.6

- v 2010 *Chondromileia giebeli* (Gottsche). – Dietze et al.: p. 91–94, 98, pl. 8, figs 1, 2, 4, 7

Material: 3 specimens from Charahuilla, layer 17.

Description: The two figured specimens have complete body chambers with small relicts of phragmocone. They are very close to the specimens figured by Westermann & Riccardi (1979, pl. 6, figs 2a–c, pl. 7, figs 1a–b) from a nearby Charahuilla section. Characteristic are the compressed body chamber and the dense and fine ribbing, which fades out on the body chamber with exception of the low primaries.

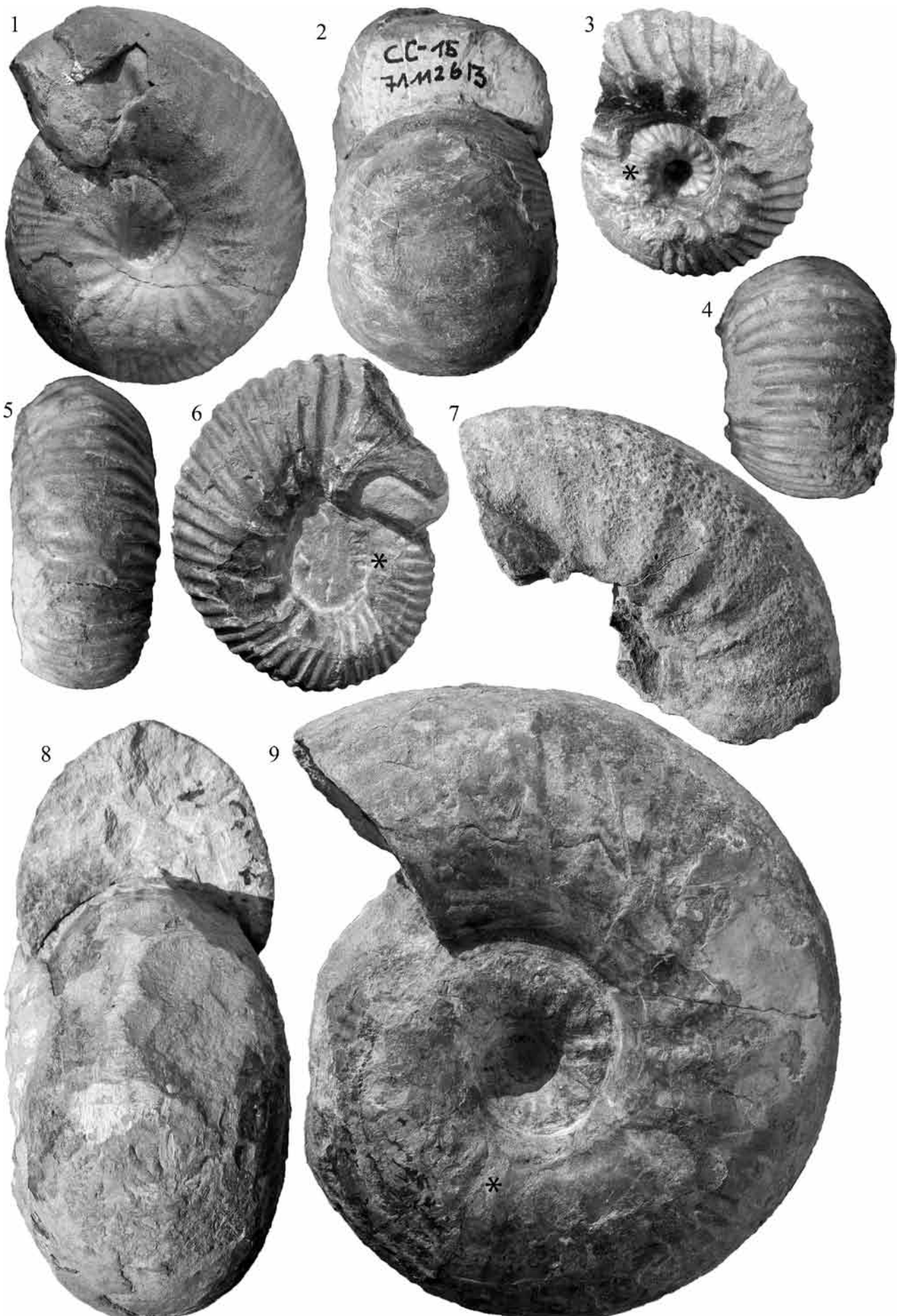
Remarks: As in *S. altcostata* and *S. espinazitensis*, *C. submicrostoma* and *C. giebeli* represent transients or succeeding chronospecies within the same chronocline. *C. submicrostoma* occurring stratigraphically earlier, and *C. giebeli* stratigraphically later. Westermann & Riccardi (1979) therefore regarded both taxa as chrono-subspecies, whilst Dietze et al. (2010) regarded them as chronospecies. These results are confirmed here. However, in contrast to the *S. altcostata/espinazitensis* group, morphological plasticity in *Chondromileia* is lower: only rarely the morphology of *C. submicrostoma* is mixed with that of *C. giebeli* – see the somewhat intermediate morphs figured on Pl. 4, Fig. 5 and Pl. 8, Figs 1, 2. Hillebrandt (2001, pl. 1, figs 1, 3) figured specimens of macroconchiate *C. submicrostoma* (pl. 1, figs 3A, B) and *C. giebeli* (pl. 1, figs. 1A–C) from the Submicrostoma resp. Multiformis subzones of Northern Chile. These specimens show excellently the involute phragmocone and the sudden egression of the body chamber, characteristic for the genus *Chondromileia*.

4.2.3 Remarks on the microconchiate Otoitidae

Due to incomplete preservation of most of microconchiate otoitids from the studied section and taking into account the great similarity between *Chondromileia* [m] and *Emileia* [m], we are not able to say to which of the genera belong most of our specimens. The characteristic differences – extremely involute inner whorls and sudden egression of the body chamber in the genus *Chondromileia* (Westermann & Riccardi 1979) – cannot be observed in most of our microconchs. Due to the egression of the body chamber we identify two specimens (Pl. 2,

Plate 7 (p. 135): (1–2) *Emileia multiformis* (Gottsche) [M]; Aguada Profeta (upper course of Quebrada del Profeta, Northern Chile (Hillebrandt 2001: 54); Giebeli Zone, Multiformis Subzone, *giebeli* horizon; SMNS 70022 (3, 6) ?*Emileia/Chondromileia* [m]; MLP 33769. (4–5, 7–8) *Chondromileia giebeli* (Gottsche) [M]; (4–5) MLP 33770; (7–8) MLP 33771. (9) *Emileia multiformis* (Gottsche) [m]; MLP 33772. (3–9) Cuyo Group, Lajas Formation; (3, 6) layer 16 [CC 14 = vH 711126/4]. Lower Bajocian, Giebeli Zone, Multiformis Subzone. (4–5, 7–9) layer 17 [CC 15 = vH 711126/3 = vH 831209/3]; Lower Bajocian, Giebeli Zone, Multiformis Subzone, *giebeli* horizon. – all specimens: x1.

Plate 8 (p. 137): (1–2) *Chondromileia submicrostoma* (Gottsche) [M]; MLP 33773; Cuyo Group, Lajas Formation, layer 17 [CC 15 = vH 711126/3]. (3–6) ?*Emileia/Chondromileia* [m]; (3–4) MLP 33774; (5–6) MLP 33775; Cuyo Group, Lajas Formation, layer 18 [CC 15a]. (7–9) *Emileia* aff. *constricta* Imlay [M]; Cuyo Group, Lajas Formation, layer 19 [CC 16 = vH 711126/2]; (7) MLP 33776; (8–9) MLP 33777. (1–9) Giebeli Zone, Multiformis Subzone, *giebeli* horizon. – All specimens: x1.



Figs 3, 6) as *C. submicrostoma* [m]. One specimen (Pl. 7, Fig. 9) shows the more regular egression of the body chamber and the less involute inner whorls of *Emileia multiformis* [m]. The best determination we can give for all other microconchiate otoitids (Pl. 4, Figs 1–4, 8, 9; Pl. 5, Figs 1, 2, 4–6; Pl. 7, Figs 3, 6; Pl. 8, Figs 3–6) is ?*Emileia/Chondromileia* [m].

4.3 Remarks on other taxa

In contrast to the section of Paso del Espinacito (Dietze et al. 2010), phylloceratids are totally missing and lytoceratids are very rare. This is not surprising, because these groups normally had a pelagic life-style and did not inhabit shallow deltaic environments. The sole specimen of *Lytoceras* aff. *subfrancisci posterum* (Pl. 5, Fig. 3) appears exotic among the remaining ammonite fauna.

5. Bio- and chronostratigraphy

As in Hillebrandt (2001) and Dietze et al. (2010), the beds are subdivided into the standard chronostratigraphic zones and subzones of the Andean Province (Westermann & Riccardi 1972, 1979; Riccardi 1992, 2008a, 2008b; Hillebrandt 2001). Within this chronostratigraphical scheme we describe the smallest distinguishable biostratigraphic units that can be recognized as faunal horizons (*sensu* Calomon 1985).

5.1 Aalenian

According to Hillebrandt & Westermann (1985: 18) and Gulisano & Gutierrez Pleimling (1994), lower parts of the Los Molles Formation in the area have yielded Aalenian ammonites (*Tmetoceras* sp., *Planmatoceras* sp., and *Puchenquia* sp.).

5.2 Bajocian

5.2.1 Singularis Zone

Zitteli Subzone

Beds of this subzone have not been recorded in our section. Westermann & Riccardi (1972, 1979) described from a section near the junction of Arroyo Los Molles and Arroyo Picún Leufú an abundant ammonite fauna from this subzone.

Altecostata Subzone

Horizon of *Pseudotoites sphaerocerooides*: The lower parts of Layer 1 (CC 2 = vH 711126/9) belong to this faunal horizon. Although we could not prove the index species *Ps. sphaerocerooides* itself, the sonniid fauna with typical specimens of *Sonninia alteco-*

stata (incl. var. *gracilis*) is characteristic enough for identifying this horizon (Hillebrandt 2001; Dietze et al. 2010; Dietze & Hillebrandt 2012).

5.2.2 Giebeli Zone

Submicrostoma Subzone

Horizon of *Chondromileia submicrostoma*: The layers 2 (CC 4 = vH 711126/8) to 13 are assigned to this faunal horizon. The sonniid fauna has changed from a nearly exclusively *S. altecostata* ammonite fauna in the lower parts of layer 2 to a *S. espinazitensis* dominated fauna from layer 2 upwards. This evolutionary replacement of the *S. altecostata* group by the *S. espinazitensis* group marks the beginning of the *C. submicrostoma* horizon (Dietze et al. 2010). From the middle part of layer 4 (CC 6 = vH 711126/7) upwards the ammonite fauna consists mostly of *C. submicrostoma*, the index of this faunal horizon (Hillebrandt 2001; Dietze et al. 2010). In the basal part of layer 10 (CC 11 = vH 711126/6) another fauna with *S. espinazitensis* – now with a large plasticity forming also the morphospecies *S. altecostata* – occurs within the *C. submicrostoma* horizon.

Multiformis Subzone

Horizon of *Chondromileia giebeli*: The strata from layers 14 (CC 13s) to 19 yield the *C. giebeli* horizon. We assign to this horizon layers 14 to 16 (CC 14 = vH 711126/4) because of its predominant fauna of macroconchiate *Emileia multiformis* (Westermann & Riccardi 1979; Dietze et al. 2010). We refrain from naming a new horizon for layers 14–16 for several reasons: (1) we do not have enough material to assure that there are two different horizons, one of them with *E. multiformis* (resp. *C. giebeli*) dominating. (2) Westermann & Riccardi (1979: 93) described from a nearby section a common occurrence of *E. multiformis* and *C. giebeli*, and with *C. giebeli* even lower in the section. (3) These ammonites are most likely allochthonous elements, which were deposited by high tides to their places of burial (see Section 3.3). Because of (1) and (3) we refrain also from naming a new horizon for layer 19, on the base of only two occurrences of *E. aff. constricta*.

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