

Aalenian (Jurassic) to Berriasian (Cretaceous) chronostratigraphic zonation and guide ammonites of the Central Andes (Argentina, Chile, Peru)

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Key words: Neuquén Basin, Tarapacá Basin, chronostratigraphy, zonation, biohorizons, Ammonoidea (Cephalopoda), Aalenian to Berriasian.

Abstract. In the Central Andes there are developed two marine basins with an extensive Jurassic record: the Neuquén (or Central Andean) Basin and the Tarapacá Basin. Their Jurassic and Lower Cretaceous ammonite successions have been studied extensively for more than 150 years, producing detailed chronostratigraphic scales based on ammonite zones and biohorizons. The ammonite faunas include Andean lineages, and cosmopolitan, Tethyan, Caribbean, North American, and Indo-Madagascan elements. This paper presents the results of a revision of the zonation of the interval Aalenian-Berriasian. Before presenting the results, this paper emphasizes the distinction between, and the convenient nomenclature for, biozones, zones, standard zones, and biohorizons.

The *scissum* Hz. (new) is introduced in the lower (-most?) Manflasensis Zone (Aalenian). The Rotundum Subzone (new) with base at the *cf.-leptus* Hz., is introduced for the upper part of the Rotundum Zone (Bajocian). The Gulisanoi Zone (Bathonian) is standardized by designation of the *cf.-aspidoides* Hz. (new) as its base. The Chacaymelahuensis Zone (new) with base at the “*prahecquense*” Hz. (new) is introduced for the Callovian. The Cubanensis Zone (Oxfordian) is introduced to replace nominally, or to rename, the inconveniently named “Passendorferia” Zone. The Tarapacaense Zone (Oxfordian) is standardized by designation of the *tarapacaense* Hz. (new) as its base. The Tithonian Malarguensis Zone (formerly subzone) is here emended and standardized by designation of the *malarguensis* Hz. as its base; this zone replaces the unviable Mendozanus Zone. The Zitteli Zone is standardized by designation of the widely recorded *perlaevis* Hz. as its base. The Fascipartita Subzone (Internispinosum Zone) is standardized by designation of the *internispinosum-beta* Hz. (new) as its base. The Alternans Zone is standardized by designation of the *vetustum* Hz. as its base, and the Koeneni Zone (uppermost Tithonian) by designation of the *striolatus* Hz. as its base.

INTRODUCTION

Two main marine basins developed during the Jurassic in the Central Andes (Cecioni, Charrier, 1974; Westermann, Riccardi, 1985; Uliana, Biddle, 1988; Parent, 2006; *cf.* Vicente, 2005): (1) the Tarapacá Basin (Fig. 1A, B; northern Chile, and southern Peru which does not include type localities, see Westermann *et al.*, 1980 for a detailed map), and separated by the Antofagasta Land (2) the Neuquén or (Cen-

tral Andean) Basin (Fig. 1C; west central Argentina and central Chile). Lithostratigraphic classifications are rather well established for the region (*e.g.*, Benavides-Cáceres, 1962; Vicente, 1981; Pérez, 1982; Gulisano *et al.*, 1984; Palacios-Moncayo, 1995; Legarreta, Uliana, 1996; León-Lecaros *et al.*, 2000; Howell *et al.*, 2005; Charrier *et al.*, 2007).

The Neuquén and Tarapacá basins are narrow and longitudinal with Andean orientation, and formed behind volcanic arcs (see Groeber, 1952; Gröschke *et al.*, 1988; Spalletti

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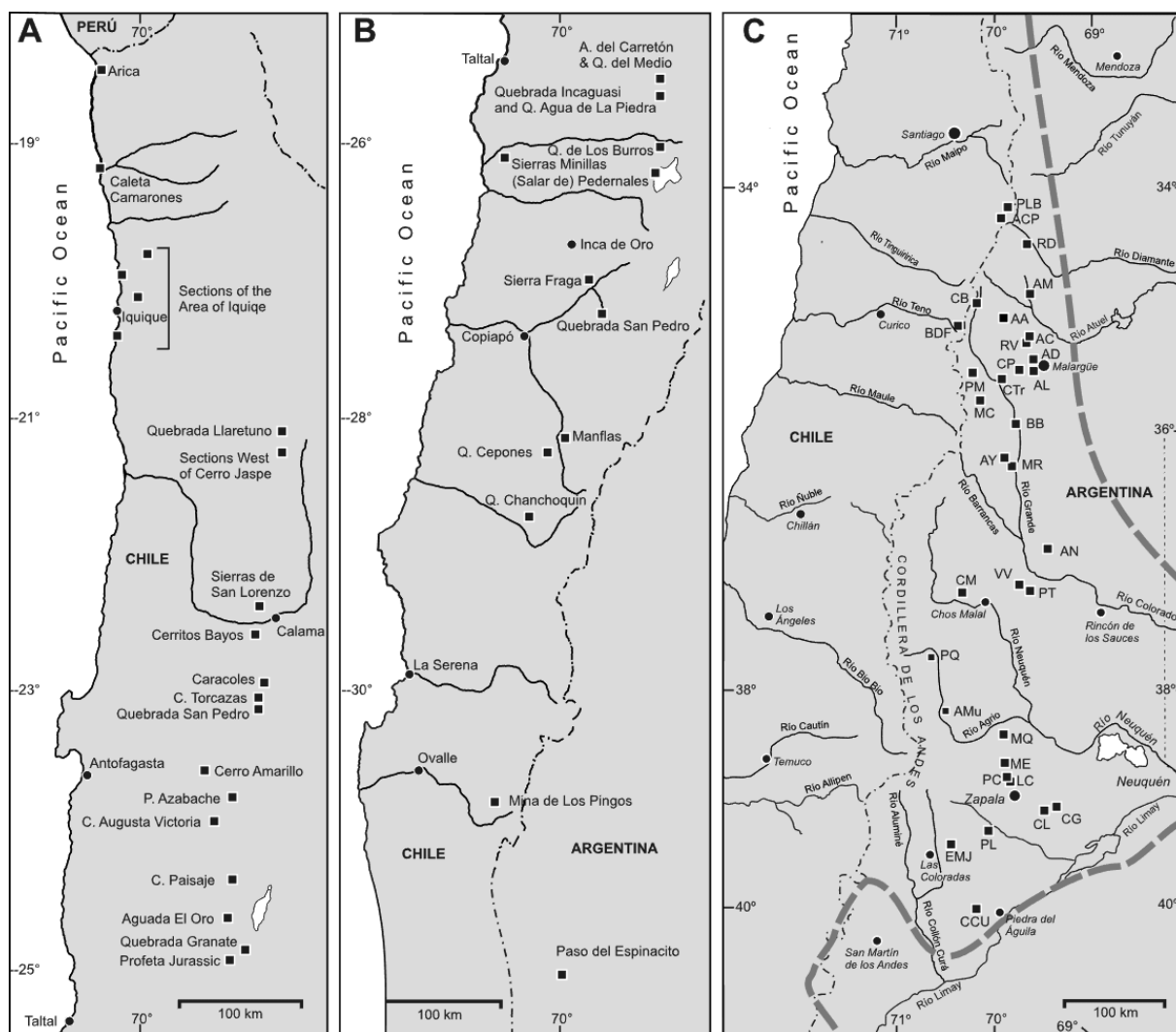


Fig. 1. Localities cited in text on recent geography

A. Northern Chile (northern Tarapacá Basin). **B.** Central Chile pars (southern Tarapacá Basin). **C.** Central Chile (pars) and West-central Argentina (Neuquén Basin, gray broken line). A and B based on Hillebrandt, Gröschke (1995), Gygi, Hillebrandt (1991), and Hillebrandt (2001); C based on Parent, Garrido (2021). **Key localities Neuquén Basin (C):** PLB: Paso Los Bayos, ACP: Arroyo Cruz Piedra; RD: Río Diamante, AM: Arroyo de la Manga, CB: Cajón del Burro-Río Choicas, BDF: Baños del Flaco, AC: Arroyo Cieneguita, RV: Rodeo Viejo, AD: Arroyo del Durazno, AL: Arroyo Loncoche, PM: Paso Montañés, CP: Casa Pincheira, MC: Molinos Colgados, BB: Bardas Blancas (Molinos Colgados), AY: Arroyo del Yeso, MR: Mallín Redondo, AN: Aguada del Naco, VV: Vega de la Veranada, PT: Pampa Tril, CM: Chacay Melehué, AMu: Arroyo Mulichinco, PQ: Puerta Quintuco; MQ: Mallín Quemado, ME: Manzano Escondido, PC: Portada Covunco, LC: Los Catutos, CG: Cerro Granito (La Amarga), CL: Cerro Lotena, PL: (Puente) Picún Leufú, EMJ: Estancia María Juana, CCu: Carrín Curá.

et al., 2000; Hillebrandt, 2001; Franzese *et al.*, 2003; detailed review in Spalletti, 2013) which must have controlled the faunal migrations. The stratigraphic record of the Palaeopacific platforms, west of the volcanic arcs, has been lost by subduction of the Pacific and Southamerican plates. These basins were connected with the Indo-Madagascan region by the Mozambique Corridor (Cecioni, Charrier, 1974; Enay, Cariou, 1997; Parent, 2006; Parent *et al.*, 2011a, 2017a), and with the Tethys by the Caribbean Corridor (Enay, 1980; Westermann, Riccardi, 1985; Westermann, 1992). In palaeobiogeographical terms both basins belong to the Andean

Province, and the faunas are composed of local lineages, and cosmopolitan, Tethyan, Caribbean and north American elements (Westermann, Riccardi, 1985; Gygi, Hillebrandt, 1991; Westermann, 1992; Parent, 2006; Parent *et al.*, 2017a). From the Oxfordian onwards there are elements of the Indo-Madagascan region. Westermann and Riccardi (1985) concluded that the degree of endemism increases towards the south. This pattern or gradient could explain the apparent absence in the Neuquén Basin of certain Tethyan genera which do occur in the Tarapacá Basin, like *Gregoryceras* Spath, 1924 and *Ochetoceras* Haug, 1885. However, this is

still provisional since genera like *Taramelliceras* Del Campa, 1904 and *Passendorferia* Brochwicz-Lewiński, 1973 have been recorded in the Neuquén Basin but not (yet?) in the Tarapacá Basin. The connection with the Indo-Madagascan region through the Mozambique Corridor produces a different pattern. For example, the genus *Catutosphinctes* Leanza, Zeiss, 1992, which evolved from Indo-Madagascan *Katrolliceras* Spath, 1924 (see Parent *et al.*, 2011a), occurs abundantly all through the Tithonian of the Neuquén Basin but is rare in the Tarapacá Basin. On the other hand, it must be taken into consideration that local absences must be related to the lack of record, in one basin, of certain horizons which do occur in the other basin, or in different regions of them (see Parent, 2006; Parent, Garrido, 2015 for details).

The abundantly recorded ammonites (Cephalopoda, Ammonoidea) in both basins have provided an excellent basis for chronostratigraphic classification of the successions and regional and intercontinental time-correlation, allowing the reconstruction of the Jurassic-Cretaceous geologic history of western South America with appreciable detail. The advancement of chronostratigraphy typically develops from the refinement of the local scales and the time-correlation with the Primary International Chronostratigraphic Scale. In the last 20 years there have been many advances in these respects, mainly by the introduction of biohorizons which have led to significant refinement of the Middle to Upper Jurassic and Lower Cretaceous chronostratigraphic scales. The description of ammonite assemblages and the recognition of intraspecific variability typical of the ammonoids are key factors leading to the identification of lineages and also to advancements in time-correlation of the Andean successions.

The aim of this paper is to summarize and update the current state of the ammonite zonation of the interval Aalenian-Berriasian in the Central Andes. The present revision of published data has led to the definition of new biohorizons and zones, and slight changes in the subdivision as well as the standardization of some zones/subzones.

Abbreviations used through the text and figures: [M]: macroconch (female); [m]: microconch (male); HT: holotype; LT: lectotype; Z.: zone; Sz.: subzone; Hz.: biohorizon

BIOSTRATIGRAPHY AND CHRONOSTRATIGRAPHY: DEFINITIONS AND NOMENCLATURE

The following units of the independent biostratigraphic and chronostratigraphic classifications are distinguished:

- a. biozone: body of rock characterized by its fossil content (e.g., *Pressulus* Biozone);
- b. chronostratigraphic zone (zone hereafter): sheet of rock (one or more strata) bounded by two time-planes and recognized by its fossil content (e.g., *Pressulus* Zone);
- c. standard chronostratigraphic zone: a chronostratigraphic zone defined by an ammonite bio-horizon as its base, thus forming a succession of standard zones without gaps or overlaps; and
- d. ammonite horizon or biohorizon, a bed or series of beds characterized by a fossil assemblage within which no further stratigraphical differentiation of fauna can be distinguished (e.g., *pressulus* Horizon).

The biohorizons, as the shortest distinguishable biostratigraphic subdivision, must be considered time-planes for any practical purpose; and in this sense they are the base for the elaboration of chronostratigraphic classifications from the biostratigraphy of the fossil successions. Indeed, the biohorizon is the empirical, observable link between bio- and chronostratigraphic classifications. Further discussion about the meaning and nomenclature of these units can be found in Gabilly (1971), Callomon (1985, 1995), Cariou, Hantzpergue (1997), Garrido, Parent (2013), Parent *et al.* (2015), Schweigert (2015), and Page (2017). In this paper 'Horizon' and 'Biohorizon' are used interchangeably but always in the sense of Callomon (1985). This biostratigraphic unit must be distinguished from the 'Horizon' in the French style which are sub-subzones (see discussion in Page, 2017).

The zones are characterized by ammonite assemblages, the guide-species, and thereafter recognized by them in other localities than the type. The index-species has the sole function of providing a name to the zone, and can be typical of the zone or rare in it, it only needs to at least occur in the zone. Zones and biozones are not zoological but stratigraphic units, thus the use of the complete name of the index species for naming of the zone is not only unnecessary, but also inconvenient, leading to misinterpretations. The capital in the name of zones and biozones calls the attention to this fact. Additionally, the generic assignation of species is frequently changed. Furthermore, the use of the complete species name leads to misinterpretations, such as that the zone, or biozone, corresponds to the total range (of existence) of this single species. This latter is a fact that will never be known, we have only the recorded-range changing constantly as new discoveries come at hand. Some biozones are defined under this feature, as total range biozones, but they can have local meaning only. It is worth noting that the first and/or last occurrences are nothing but taphonomic artifacts, created by a large number of factors related to, e.g., the ecology of the species, the local environments, the diagenetic and taphonomic processes, and the chances and efforts of sampling. The concurrence of at least some of these factors makes any first and/or last occurrence a fluctuating point in the time at every locality. At least this is the condition that should be assumed for interpretation of the biostratigraphic charts which are the base for chronostratigraphy and our efforts should be concentrated in the horizons defined by the co-occurrence of several species or morphotypes.

For example, the *Pressulus* (Standard Chronostratigraphic) Zone (Lower Oxfordian, see below) does not include the whole range of beds yielding *Peltoceras* *pressulus* (Leanza, 1947). This range of beds, for example in Vega de la Veranada (Parent, Garrido, 2015: levels VV-M-15 to 23), is the *Pressulus* (First Occurrence) Biozone (Parent, 2006: 57). Thus, the base of the *Pressulus* Biozone is defined by the first occurrence of *P. pressulus*, which naturally would have different ages in other localities where it occurs. The base of the *Pressulus* Zone is the *pressulus* Hz. selected as time-plane marker, and the zone ranges up to the base of the *Pseudokranaus* Zone.

THE AMMONITE ZONATION OF THE NEUQUÉN-TARAPACÁ BASINS

The Jurassic zonation was summarized by Hillebrandt *et al.* (1992) and Riccardi (2008), and the Berriasian by Aguirre-Urreta *et al.* (2007) and Parent *et al.* (2011b, 2015). These summaries are based on a large number of studies impossible to cite at length. Thus, the references cited through the text are mainly those where the units discussed were introduced, plus few others which otherwise contain lists of references not possible to cite herein.

The complete zonation discussed below, with its sub-zones and bio-horizons (= horizons), as well as their time-correlation with the Tethyan Standard are shown in the Figures 2, 3. The number of localities cited in the text is large, they are indicated in the maps of Fig. 1.

Since details of the characteristic ammonite assemblages or guide species have been published in a large number of papers, we present herein a compilation of sets of modified refigurations (at half natural size, $\times 0.5$) of most of the characteristic morphotypes. The ammonites are mostly selected from the literature and, as far as possible well-preserved adults, female and male if available.

The subspecies category is not accepted here (see Parent, 2021). For the cases in which two or more subspecific names are used in the literature for succeeding forms of a single species, they are considered and noted as transients; or morphs if their time succession is not proved or they are coeval.

AALENIAN

Time-correlation with the Tethyan standard was discussed by Hillebrandt and Westermann (1985) and Hillebrandt *et al.* (1992).

Stage	Tethyan standard zonation	Central Andes		
		Zone	Subzone	Horizon
CALLOVIAN	Lamberti	Dimorphosus		
		Primus		schilleri
	Athleta	Patagoniensis		cf. lairensis
				cf. isabellae
	Coronatum	"Coronatum"		* patagoniensis
	Anceps	Chacaymelehuensis (new)		
	Gracilis	Proximum		* "praehequeuse" (new)
BATHONIAN	Bullatum	Bodenbenderi		
		Gottschei		
	Discus	Steinmanni	Gerthi	jupiter
	Retrocostatum		Steinmanni	* crassus
				gulisanoi
	Bremeri			
	Morrisi			
BAJOCIAN	Subcontractus	Sofanus		
	Progracilis			
	Aurigerus			
	Zigzag	Gulisanoi		* cf. aspidoides (new)
	Parkinsoni	Intersertus		
	Garantiana	Magnum		
	Niortense	Rotundum	Rotundum (new)	* cf. leptus
AALENIAN	Humphriesianum	"Humphriesianum"	Dehmi	dehmi
			Chilense	caracolense
	Sauzei	Giebeli	"Romani"	
	Laeviscula		Blancoensis	blancoensis
	Ovale		Multiformis	giebeli
	Discites		Submicrostoma	submicrostoma
	Concavum		Altecostata	sphaeroceroideis
AALENIAN	Bradfordiense	Singularis	Zitteli	singularis
	Murchisonae	Malarguensis	Maubeugei	* maubeugei
	Opalinum		Mendoza	mendoza
			Compressa	compressa
		Groeberi		
AALENIAN		Manflasensis		
				scissum (new)

Fig. 2. Andean ammonite chronostratigraphic zonation of the interval Aalenian-Callovian

Time-correlation between the Andean and the Tethyan zonations is approximate, the broken lines indicate non-standard zones. The height of the units is arbitrarily drawn from equal-heighted European zones. The (bio-) horizons have speculative position within the zones or subzones, save those marked with an asterisk which are base of standard zones or subzones. The Tethyan zonation is mainly based on Schweigert (2015)

MANFLASENSIS ZONE [HILLEBRANDT, WESTERMANN, 1985]

Stage	Tethyan standard zonation	Central Andes		
		Zone	Subzone	Horizon
BERRIASIAN	Boissieri	Damesi		★ <i>transgrediens</i>
	Occitanica	Noduliferum		
	Jacobi			
TITHONIAN	Durangites	Koeneni		★ <i>noduliferum</i> ★ <i>compressum</i> ★ <i>planulatum</i> ★ <i>koeneni</i> ★ <i>striolatus</i>
	Microcanthum	Alternans		★ <i>azulense</i> ★ <i>bardense</i> ★ <i>vetustum</i> ★ <i>catutiosensis</i>
	Ponti	Internispinosum	Fascipartita Rafaeli	★ <i>internispinosum-β</i> (new) ★ <i>internispinosum-α</i>
	Fallauxi	Proximus		★ <i>folculatum</i>
	Semiforme	Zitteli		★ <i>erinoides</i> ★ <i>perlaevis</i>
	Darwini	Malarguensis		★ <i>malarguensis</i>
	Hybonotum	Picunleufuense		★ <i>picunleufuense-γ</i> ★ <i>picunleufuense-β</i> ★ <i>picunleufuense-α</i>
KIMMERIDGIAN	Beckeri			
	Cavouri			
	Acanthicum			
	Divisum			
	Strombecki			
	Platynota			★ <i>off-janus</i>
OXFORDIAN	Planula			
	Bimammatum	Desertorus		
	Bifurcatus	Tarapacaense		★ <i>tarapacaense</i> (new)
	Transversarium	Cubanensis		
	Plicatilis	Pseudokranaus		
	Paturattensis	Pressulus		★ <i>pressulus</i>
	Minax	Eugenii		

Fig. 3. Andean ammonite chronostratigraphic zonation of the interval Oxfordian-Berriasian

Time-correlation between the Andean and the Tethyan zonations is approximate, the broken lines indicate non-standard zones. The height of the units is arbitrarily drawn from equal-heighted European zones. The (bio-) horizons have speculative position within the zones or subzones, save those marked with an asterisk which are base of standard zones or subzones. The Tethyan zonation is mainly based on Schweigert (2015)

- *Index species*: *Bredya manflasensis* Westermann in Hillebrandt and Westermann, 1985.
- *Type locality*: Not originally designated but from the text of Hillebrandt, Westermann (1985) it should be Manflas in northern Chile.
- *Guide species* (Figs. 4, 5): *B. manflasensis*, *Bredya delicata* Westermann, 1985, *Leioceras chilense* Westermann, 1985, and late *Sphaerocoeloceras brocchiiformis* Jaworski, 1926.
- *Horizons*: *scissum* Hz. (new). It is defined from an assemblage collected from a single coquinoïd level (0.5–0.7 m thickness) of yellowish brown, fine calcareous sandstone in the section of Picún Leufú (type locality) described by Westermann and Riccardi (1975), corresponding to their level/sample 207, and to the level A1 of Gründel *et al.* (2004). Characteristic fauna (Fig. 4): the index species *Tmetoceras scissum* (Benecke, 1865), *Hildatoides* n. sp. aff. *retrocostatum* Hillebrandt, 1987, *Bredya* cf. *manflasensis* (cf. Hillebrandt, Westermann, 1985: pl. 4: 1–4), and *Phylloceras* cf. *trifoliatum* Neumayr, 1871.

The *T. scissum* (Fig. 4C–E), abundant, seems to be typical of the species (e.g., Callomon, Chandler, 1994: pl. 5: 2, 3; Rulleau *et al.*, 2001: pl. 16: 4; Schweigert, 2018: pl. 13: 2); with narrower umbilicus and higher flanks relative to the Andean specimens figured by Westermann, Riccardi (1972). The largest observed specimen would be more than 50 mm in diameter at the peristome. The specimens from the next overlying level show slight differences: more evolute, less densely ribbed and stiffer primary ribs (Fig. 4J).

H. n. sp. aff. *retrocostatum* (Fig. 4F–H) differs from the Middle Toarcian species described by Hillebrandt (1987) by its rounded venter (slightly fastigate in some specimens), the smaller adult size (although these could be microconchs), and the later onset of the coarse lateral ribbing, from about 15–18 mm in diameter.

B. cf. *manflasensis* (Fig. 4I) is an early form of the genus, maintaining a resemblance to evolute earliest Aalenian *Hammatoceras* Hyatt, 1867 (e.g., Callomon, Chandler, 1994: pl. 3; Rulleau *et al.*, 2001: pl. 25: 2, pl. 26: 1). A late ontogenetic stage of well-formed lateral clavi (Fig. 4I₁) compares well with the earlier stage of some early Aalenian macroconch *Bredya subinsignis* (Oppel, 1856), e.g., Schweigert (2018: pl. 13: 3).

The stratigraphic position of the *scissum* Hz. in the lower part of the Manflasensis Zone is suggested by (1) the presence of early *Bredya* belonging to a species of the Manflasensis Zone and recalling early Aalenian forms of Europe, (2) the morphology of the specimens of *T. scissum* matching the earliest Tethyan representatives (cf. Callomon, Chandler,

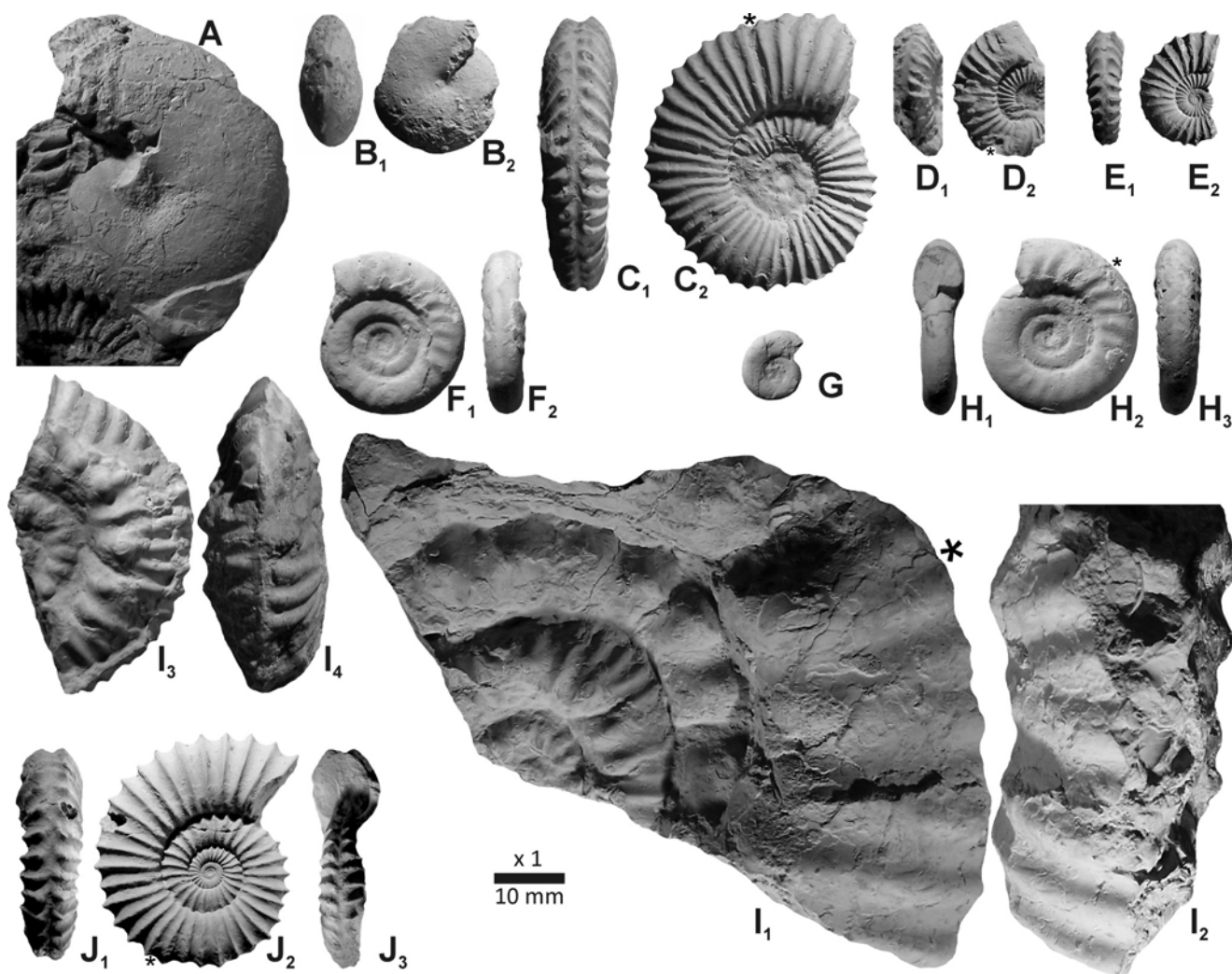


Fig. 4. Characteristic ammonite-assemblage of the Andean *scissum* Hz. (new) in Picún Leufú, bed-A1 of Gründel *et al.* (2004: fig. 1)

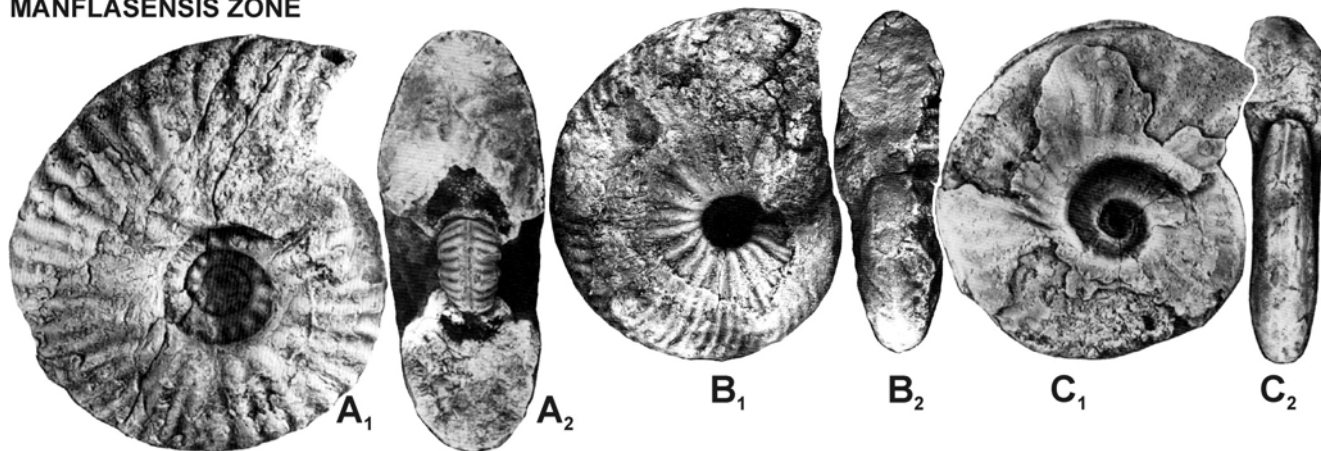
A, B. *Phylloceras* cf. *trifoliatum*; a juvenil (A; MOZ-PI-6630) and a small phragmocone (B; MOZ-PI-6631). **C–E.** *Tmetoceras scissum* (Benecke); an adult macroconch (C; MOZ-PI-6627), a juvenil? with incomplete bodychamber (D; MOZ-PI-6628), and inner whorls (E; MOZ-PI-6629). **F–H.** *Hildaitoides* n. sp. aff. *retrocostatum* Hillebrandt; an adult, [M?] phragmocone (F; MOZ-PI-6632), a juvenil (G; MOZ-PI-6633), and an adult [M?] with part of the bodychamber (H; MOZ-PI-6634). **I.** *Bredya* cf. *manflasensis* Westermann (MOZ-PI-6636), an adult macroconch with part of the bodychamber. **J.** *Tmetoceras scissum* (Benecke), an adult macroconch (MOZ-PI-6635) from the next overlying level. All natural size (x1). Asterisk at last septum, base of the bodychamber. All the specimens belong to the collections of the Museo Provincial de Ciencias Naturales “Prof. Dr. Juan A. Olsacher”, Zapala (MOZ-PI)

1994; Fernandez-Lopez *et al.*, 1999), and (3) because in the immediately overlying levels occur ammonites of the Manflasensis Zone (to be published elsewhere). The occurrence of *Hildaitoides* in the Lower Aalenian is interesting, for the genus was hitherto known only from the Middle Toarcian of Chile and Argentina (see Hillebrandt, 1987). Fragments of phylloceratids indicate the remarkable occurrence of adults larger than 250–300 mm in diameter. The large gastropod *Eucycloscala?* sp. (in Gründel *et al.*, 2004) is very abundant.

GROEBERI ZONE [WESTERMANN, RICCARDI, 1979]

- *Index species*: *Westermanniceras groeberi* (Westermann, Riccardi, 1972).
- *Type locality*: Not originally designated but from the text of Westermann, Riccardi (1979) it should be Bardas Blancas, Argentina.

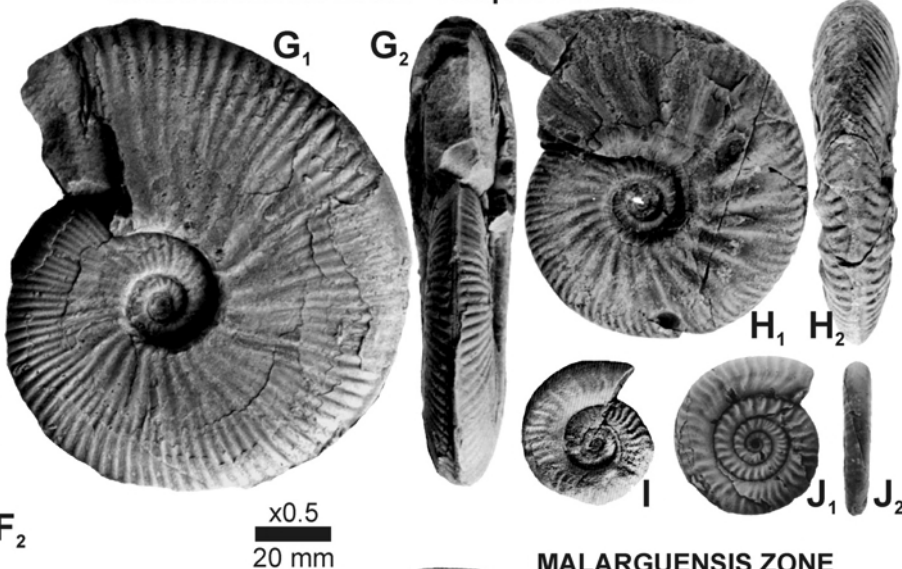
MANFLASENSIS ZONE



GROEBERI ZONE



MALARGUENSIS ZONE - Compressa Subzone



MALARGUENSIS ZONE - Mendoza Subzone

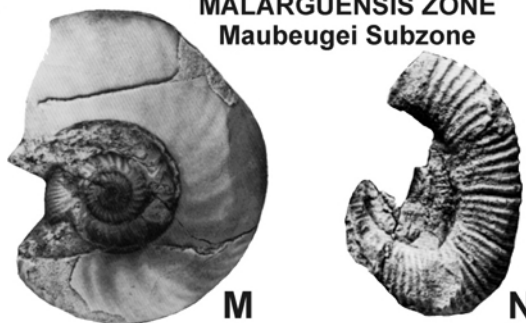
MALARGUENSIS ZONE
Maubeugei Subzone

Fig. 5. Guide species

Manflasensis Z. **A.** *Bredya manflasensis*, HT, Manflas. **B.** *Bredya delicata*, HT, Manflas. **C.** *Leioceras chilense*, HT, Manflas. – Groeberi Z. **D.** *Euaptetoceras jenseni*, HT, Quebrada El Asiento. **E.** *Westermanniceras groeberi*, adult specimen, Las Yeseras. **F.** *Podagrosiceras athleticum*, HT, Los Molles.

Malarguensis Z., Compressa Sz. **G.** *Planammatoceras tricolore*, HT, Cerro Tricolor. **H.** *Puchenquia compressa*, HT, Poti Malal. **I.** *Fontannesia? austroamericana*, complete specimen, Quebrada El Asiento. **J.** *F.? austroamericana*, HT, Cerro Tricolor.

Malarguensis Z., Mendoza Sz. **K.** *Puchenquia mendoza*, HT, Poti Malal. **L.** *Eudmetoceras jaworskii*, HT, Cerro Tricolor.

Malarguensis Z., Maubeugei Sz. **M.** *Podagrosiceras maubeugei*, adult [M], Portezuelo El Padre. **N.** *Tmetoceras cf. flexicostatum*, adult specimen, Quebrada El Asiento.

All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A–D, I and M, modified from Westermann (1985); E and J, modified from Westermann, Riccardi (1972); F, modified from Maubeuge, Lambert (1955); G, H and K, L, modified from Westermann, Riccardi (1982)

- *Guide species* (Fig. 5): *Euaptetoceras jenseni* (Westermann, 1985), *W. groeberi*, *Podagrosiceras athleticum* Maubeuge, Lambert, 1955.

MALARGUENSIS ZONE [WESTERMANN, RICCARDI, 1979]

- *Index species*: *Puchenquia malarguensis* (Burckhardt, 1903).
The zone has been subdivided by Hillebrandt, Westermann (1985) in three subzones:

Compressa Subzone [Hillebrandt, Westermann, 1985]

- *Index species*: *Puchenquia compressa* Westermann, Riccardi, 1982.
- *Type locality*: Not designated.
- *Guide species* (Fig. 5): *P. compressa*, *P. malarguensis*, *Tmetoceras* cf./aff. *scissum*, *Planammatoceras tricolore* Westermann, Riccardi, 1982, *Fontannesia austroamericana* Jaworski, 1926.
- *Horizons*: *compressa* Hz. (Hillebrandt, 2001).

Mendoza Subzone [Hillebrandt, Westermann, 1985]

- *Index species*: *Puchenquia mendoza* Westermann, Riccardi, 1982.
- *Type locality*: Not originally designated but from the text of Hillebrandt, Westermann (1985) it should be Pederuales, Chile.
- *Guide species* (Fig. 5): *P. mendoza*, *P. malarguensis*, *Tmetoceras* cf./aff. *scissum*, *P. tricolore*, *Eudmetoceras jaworskii* Westermann, 1964.
- *Horizons*: *mendoza* Hz. (Hillebrandt, 2001).

Maubeugei Subzone [Hillebrandt, Westermann, 1985]

This was formerly established as a bio-horizon by Hillebrandt, Westermann (1985: 21), later in Hillebrandt *et al.* (1992) it was considered as a subzone. It is the highest subzone of the Malarguensis Zone, with its base, here designated, at the *maubeugei* Hz. According to the standard nature of the Malarguensis and Singularis zones, as well as their sub-

zones, the Maubeugei Subzone naturally ranges up to the base of the Zitteli Subzone which is the base of the Singularis Zone (Lower Bajocian). In this way the gap shown in Hillebrandt (2001: table 1) is covered by the property of the standard scales, and it is perfectly possible, if necessary, to introduce new subzones or zones by insertion.

- *Index species* (Fig. 5): *Podagrosiceras maubeugei* Westermann, Riccardi, 1979. This species has been considered by Riccardi (2000) as a junior synonym of *P. athleticum*. However, both forms show significant differences in ornamental ontogeny: *P. maubeugei* is more inflated and coarsely ribbed from the inner whorls, whereas *P. athleticum* is more finely and densely ribbed. On the other hand, *P. athleticum* seems to occur in a lower stratigraphic position. Thus, for the time being both species should be considered different, or perhaps transients.
- *Type locality*: Quebrada Caballo Muerto, Chile.
- *Guide species*: *P. maubeugei*, early *Sonninia amosi* Westermann, Riccardi, 1972, *E. jaworskii*, *Tmetoceras* cf. *flexicostatum* Westermann, 1964.
- *Horizons*: *maubeugei* Hz.

BAJOCIAN

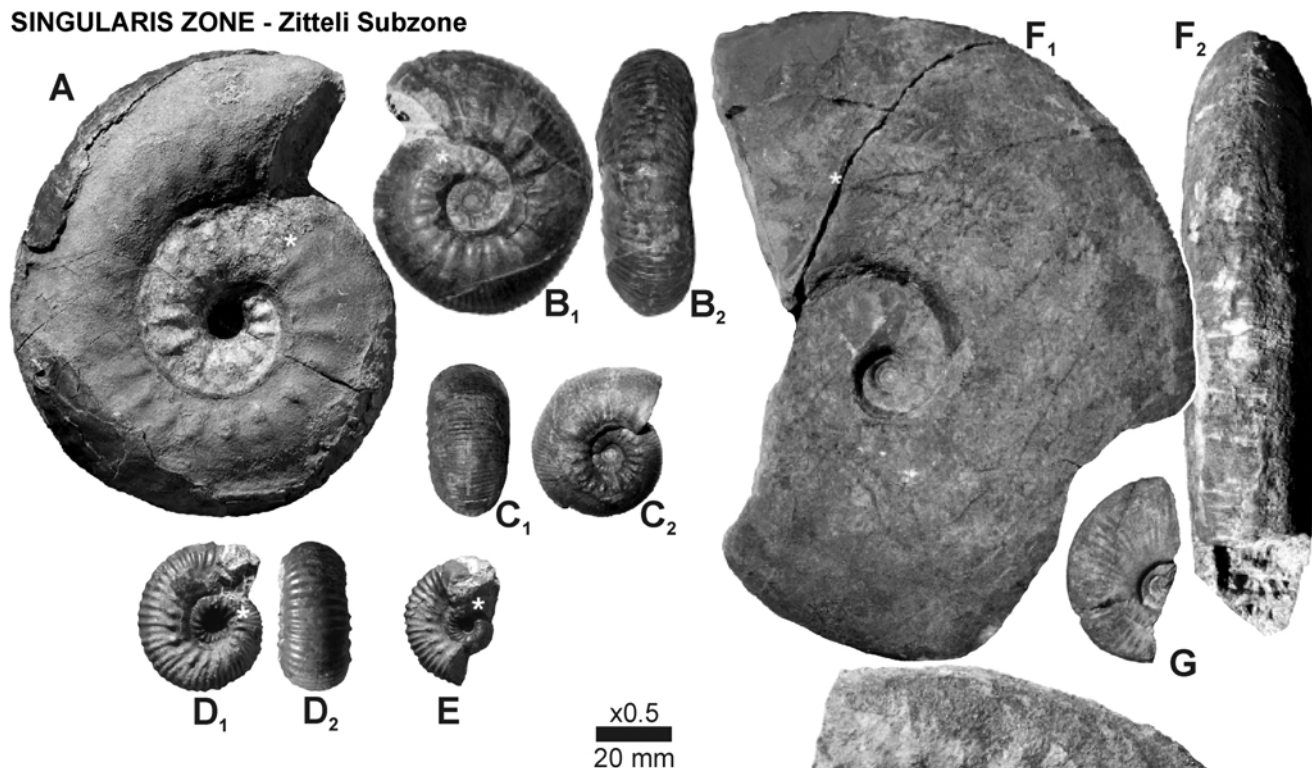
Time-correlation with the Tethyan standard was recently discussed by Hillebrandt (2001), Dietze *et al.* (2010, 2012), Dietze, Hillebrandt (2012, 2019).

SINGULARIS ZONE [WESTERMANN, RICCARDI, 1979]

- *Index species*: *Pseudotoites singularis* (Gottsche, 1878).
This zone is currently subdivided in two subzones:

Zitteli Subzone [Dietze *et al.*, 2010]

- *Index species*: *Fissiloboceras zitteli* (Gottsche, 1878).
- *Type locality*: Paso del Espinacito, Argentina.
- *Guide species* (Fig. 6): *F. zitteli* (highly variable species with at least three characteristic morphs: argentinicum, intumescens, andinum, as varieties in Dietze *et al.*, 2010), *P. singularis* (= *Pseudotoites crassus* Westermann, Riccardi, 1979, = *Pseudotoites argentinus* Arkell, in Arkell, Playford, 1954).
- *Horizons*: *singularis* Hz. (Hillebrandt, 2001).

SINGULARIS ZONE - Zitteli Subzone**SINGULARIS ZONE - Altecostata Subzone****Fig. 6. Guide species.**

Singularis Z., Zitteli Sz. **A.** *Pseudotoites argentinus*, adult [M], Manflas. **B., C.** *Pseudotoites singularis* [M] (B: adult, C: inner whorls), Portezuelo El Padre. **D., E.** *Pseudotoites singularis-argentinus* [m], Manflas. **F., G.** *Fissiloboceras zitteli* [M] (F: adult from Manflas, G: nucleus from Paso del Espinacito). Singularis Z., Altecostata Sz. **H.** *Pseudotoites sphaeroceroideus*, adult [M], Manflas. **I., J.** *Sonninia altecostata* [M] (I: nucleus from Paso del Espinacito, J: adult from Manflas).

All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A–F, H, and J, modified from Dietze, Hillebrandt (2012); G, I modified from Dietze *et al.* (2010)

Altecostata Subzone

[Dietze *et al.*, 2010]

- *Index species*: *Sonninia altecostata* Tornquist, 1898.
- *Type locality*: Paso del Espinacito, Argentina.
- *Guide species* (Fig. 6): *S. altecostata*, *Pseudotoites sphaeroceroides* (Torquist, 1898).
- *Horizons*: *sphaeroceroides* Hz. (Hillebrandt, 2001).

GIEBELI ZONE

[WESTERMANN, RICCARDI, 1979]

- *Index species*: *Chondromileia giebeli* (Gottsche, 1878).
- This zone is currently subdivided in three subzones:

Submicrostoma Subzone

[Westermann, Riccardi, 1979]

- *Index species*: *Chondromileia submicrostoma* (Gottsche, 1878).
- *Type locality*: Not designated.
- *Guide species* (Fig. 7): early *Emileia multiformis* (Gottsche, 1878), *C. submicrostoma*, late *Pseudotoites sphaeroceroides* (e.g., Dietze, Hillebrandt, 2019: pl. 11: 3, 7), *Pseudotoites transatlanticus* (Tornquist, 1898), *Sonninia espinazitensis* Tornquist, 1898, late *Sonninia altecostata*.
- *Horizons*: *submicrostoma* Hz. (Hillebrandt, 2001).

Multiformis Subzone

[Westermann, Riccardi, 1979]

- *Index species*: *Emileia multiformis* (Gottsche, 1878).
- *Type locality*: Not designated.
- *Guide species* (Fig. 7): typical *E. multiformis*, *C. giebeli*.
- *Horizons*: *giebeli* Hz. (Hillebrandt, 2001).

Blancoensis Subzone

[Westermann, Riccardi, 1979]

- *Index species*: *Dorsetensia blancoensis* Westermann, Riccardi, 1972.
- *Type locality*: Not designated.
- *Guide species* (Fig. 8): *D. blancoensis* and *Dorsetensia mendozai* Westermann, Riccardi, 1972.

“HUMPHRIESIANUM” ZONE

A standard zone in Europe, recognized in the Andes by characteristic ammonites (see Westermann, Riccardi, 1979; Hillebrandt, 2001). The stratigraphic content is different, so that it seems better to name the Andean zone as “Humphriesianum Zone”.

- *Index species*: *Stephanoceras humphriesianum* (Sowerby, 1825).

This zone in the Andean basins is currently subdivided in two subzones:

“Romani” Subzone

A standard subzone in Europe, recognized in the Andes by characteristic ammonites (see Westermann, Riccardi, 1979; Hillebrandt, 2001). The stratigraphic content is different, so that it seems better to name the Andean subzone as “Romani Subzone”.

- *Index species*: *Dorsetensia romani* (Oppel, 1862).
- *Andean reference section/locality*: In the Andean basins the section to refer to this subzone is at Salar de Pedernales, Chile (Westermann, Riccardi, 1979).
- *Guide species* (Fig. 8): *D. romani*, *Dorsetensia liostraca* (Buckman, 1892), *Stephanoceras pyritosum* (Quenstedt, 1886).

Chilense Subzone

[Westermann, Riccardi, 1979]

- *Index species*: *Duashnoceras chilense* (Hillebrandt, 1977).
- *Type locality*: Not designated.
- *Guide species* (Fig. 8): *D. chilense*, *Duashnoceras caracolense* (Westermann, Riccardi, 1979), *Teloceras chacayi* Westermann, Riccardi, 1979.
- *Horizons*: *caracolense* Hz. (Hillebrandt, 2001).

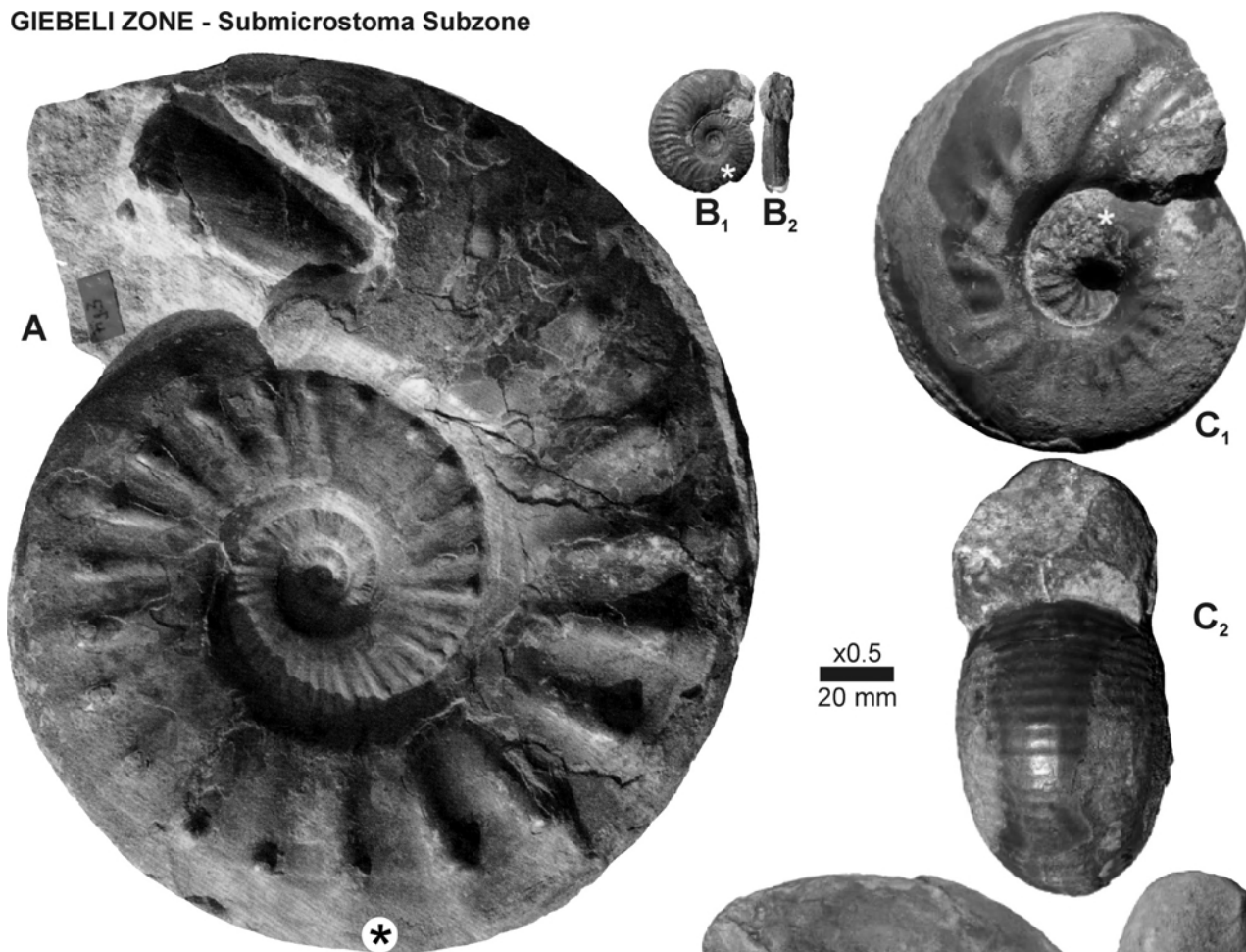
ROTUNDUM ZONE

[HALL, WESTERMANN, 1980]

Introduced for North America, recognized in the Andes by Westermann, Riccardi (1979). The paper by Hall, Westermann (1980) was accepted early in 1979 but printed later.

- *Index species*: *Megasphaeroceras rotundum* Imlay, 1961.
- This zone is currently subdivided in two subzones.

GIEBELI ZONE - Submicrostoma Subzone



GIEBELI ZONE - Multiformis Subzone



Fig. 7. Guide species

Giebeli Z., Submicrostoma Sz. **A, B.** *Sonninia espinazitensis* (A: adult [M] from Sierra Chacaico, B: adult [m] from Manflas). **C.** *Chondromileia submicrostoma*, adult [M], Manflas.

Giebeli Z., Multiformis Sz. **D.** *Chondromileia giebeli*, adult [M], Charahuilla. **E, F.** *Emilia multiformis*, Portezuelo El Padre (E: adult [m], F: adult [M]).

All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, modified from Schweigert (2008); B, C, E, F, modified from Dietze, Hillebrandt (2019); D, modified from Westermann, Riccardi (1979)

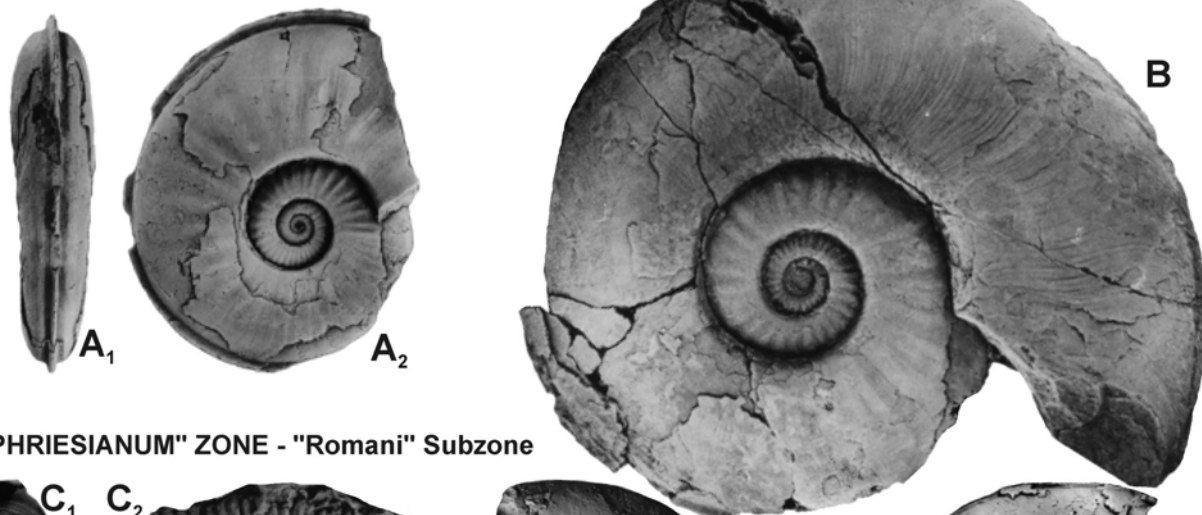
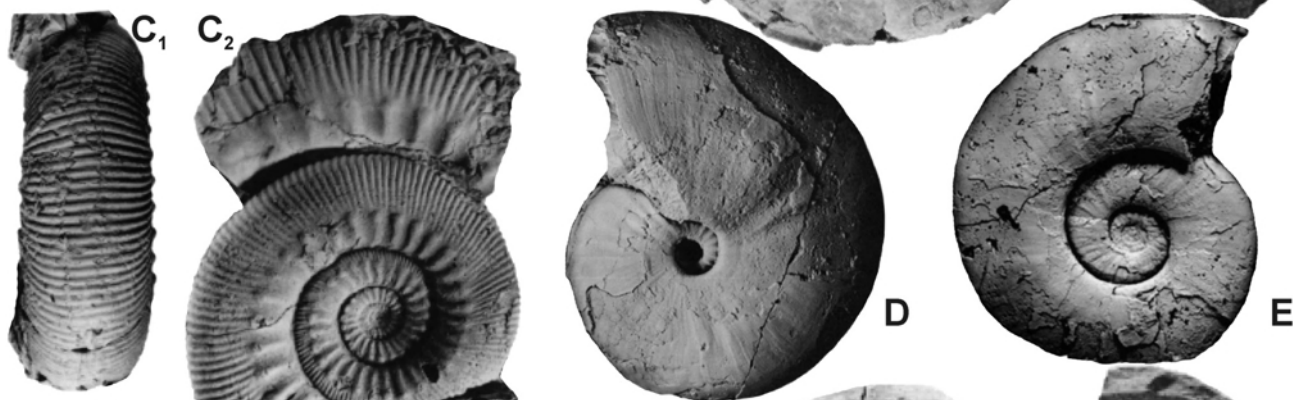
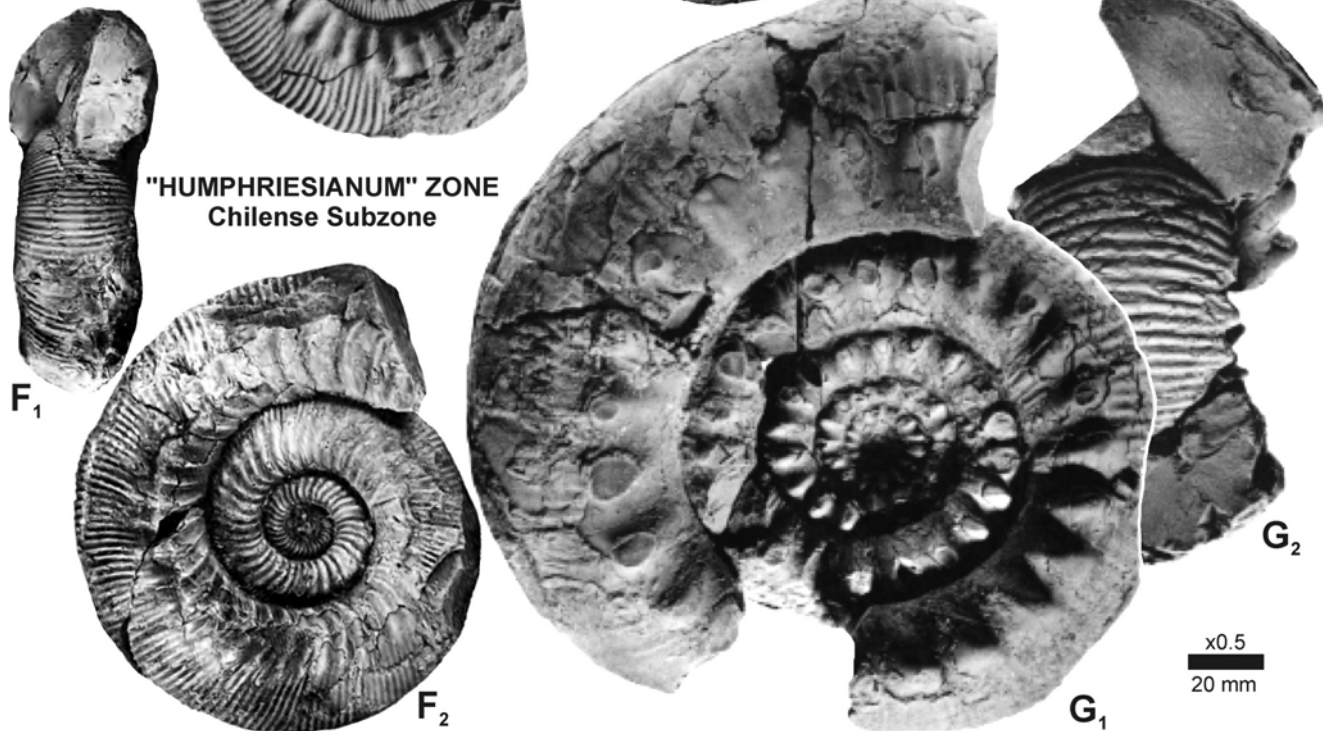
GIEBELI ZONE - Blancoensis Subzone**"HUMPHRIESIANUM" ZONE - "Romani" Subzone****"HUMPHRIESIANUM" ZONE
Chilense Subzone**

Fig. 8. Guide species

Giebeli Z., Blancoensis Sz. **A.** *Dorsetensia blancoensis*, HT, Arroyo de La Manga. **B.** *Dorsetensia mendozai*, adult [M], Arroyo Blanco. "Humphriesianum" Z., "Romani" Sz. **C.** *Stephanoceras pyritosum*, adult [M], Salar de Pedernales. **D.** *Dorsetensia liostraca*, [M] phragmocone, Salar de Pedernales. **E.** *Dorsetensia romani*, [M] phragmocone, Salar de Pedernales. "Humphriesianum" Z., Chilensel Sz. **F.** *Duashnoceras chilense*, HT, Cordillera Domeyko. **G.** *Teloceras chacayi*, adult [M], Chacay Melehué. All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, B, D, E, modified from Westermann, Riccardi (1972); C, G, modified from Westermann, Riccardi (1979); F, modified from Hillebrandt (1977)

Dehmi Subzone [Westermann, Riccardi, 1979]

- *Index species*: *Lupherites dehmi* (Hillebrandt, 1977).
- *Type locality*: Not designated.
- *Guide species* (Fig. 9): *L. dehmi*, *Duashnoceras chilense* (Hillebrandt, 1977), *Duashnoceras profetaense* Hillebrandt, 2001.
- *Horizons*: *dehmi* Hz. (Hillebrandt, 2001).

Rotundum Subzone [new]

This standard subzone is here introduced for the upper part of the Rotundum Zone with base at the *cf.-leptus* Hz. This subzone corresponds to the unnamed interval shown in the table 12.2 of Hillebrandt *et al.* (1992), between the Dehmi Subzone (below) and the Magnum Zone (above).

- *Index species*: *M. rotundum*.
- *Type locality*: Quebrada Aguada del Minero (westernmost part of the Profeta syncline, see Hillebrandt, 2001), Chile.
- *Guide species* (Fig. 9): *Megasphaeroceras spissum* Riccardi, Westermann, 1991a, *Leptosphinctes cf. leptus* Buckman, 1920 (most likely a new genus considering the distinctive form of the lappets in males and ribbing with prosocline curved ribbing).
- *Horizons*: *cf.-leptus* Hz. (as *leptosphinctes* Hz. in Hillebrandt, 2001; there is no way to name a horizon from a genus name). The type locality is here designated at Quebrada Aguada del Minero (westernmost part of the Profeta syncline, see Hillebrandt, 2001), Chile.

MAGNUM ZONE [HILLEBRANDT ET AL., 1992]

- *Index species*: *Megasphaeroceras magnum* Riccardi, Westermann, 1991a.
- *Type locality*: Not designated.
- *Guide species* (Fig. 10): for the time being only the index species. A varied, yet poorly known fauna occurs

in northern Chile (Fernandez-Lopez *et al.*, 1994; Hillebrandt, 2001), including forms of, or close to, the genera *Cadomites*, *Leptosphinctes*, *Prorsisphinctes*, *Lupherites*, *Oppelia*, and *Spiroceras*.

INTERSERTUS ZONE [FOR THE LOBOSPHINCTES HORIZON/ASSEMBLAGE OF RICCARDI ET AL., 1989]

There is no formal definition for this zone in the literature. It seems the first use was in the table 1 of Riccardi *et al.* (1989), later in the table 12.2 of Hillebrandt *et al.* (1992). It is currently known from Chacay Melehué (Riccardi *et al.*, 1989), Vega de la Veranada (Parent *et al.*, 2020), and Quebrada San Pedro (Fernandez-Lopez *et al.*, 1994).

- *Index species*: *Lobosphinctes intersertus* Buckman, 1923.
- *Type locality*: Chacay Melehué, Argentina.
- *Guide species* (Fig. 10): *L. intersertus*.

BATHONIAN

Time-correlation with the Tethyan standard was discussed by Riccardi *et al.* (1989), Gröschke, Hillebrandt (1994), Riccardi, Westermann (1999), and Parent *et al.* (2020).

GULISANOI ZONE [MORPHOCERAS ASSEMBLAGE OF RICCARDI, WESTERMANN, 1999]

- *Index species*: *Morphoceras gulisanoi* Riccardi, Westermann, 1999.
- *Type locality*: Agua del Ñaco (Sierra de Reyes), Argentina.
- *Guide species* (Fig. 10): *M. gulisanoi*, *Oxycerites cf. aspidoides* (Oppel, 1857) [large involute adults with middle whorls inflate and evolute].
- *Remarks*. At the type locality the guide species are associated with fragmentary *Procerites* (Riccardi, Westermann, 1999) in a single bed, thus here considered a faunal bio-horizon: the *cf.-aspidoides* Hz. (new). This horizon

ROTUNDUM ZONE - Dehmi Subzone

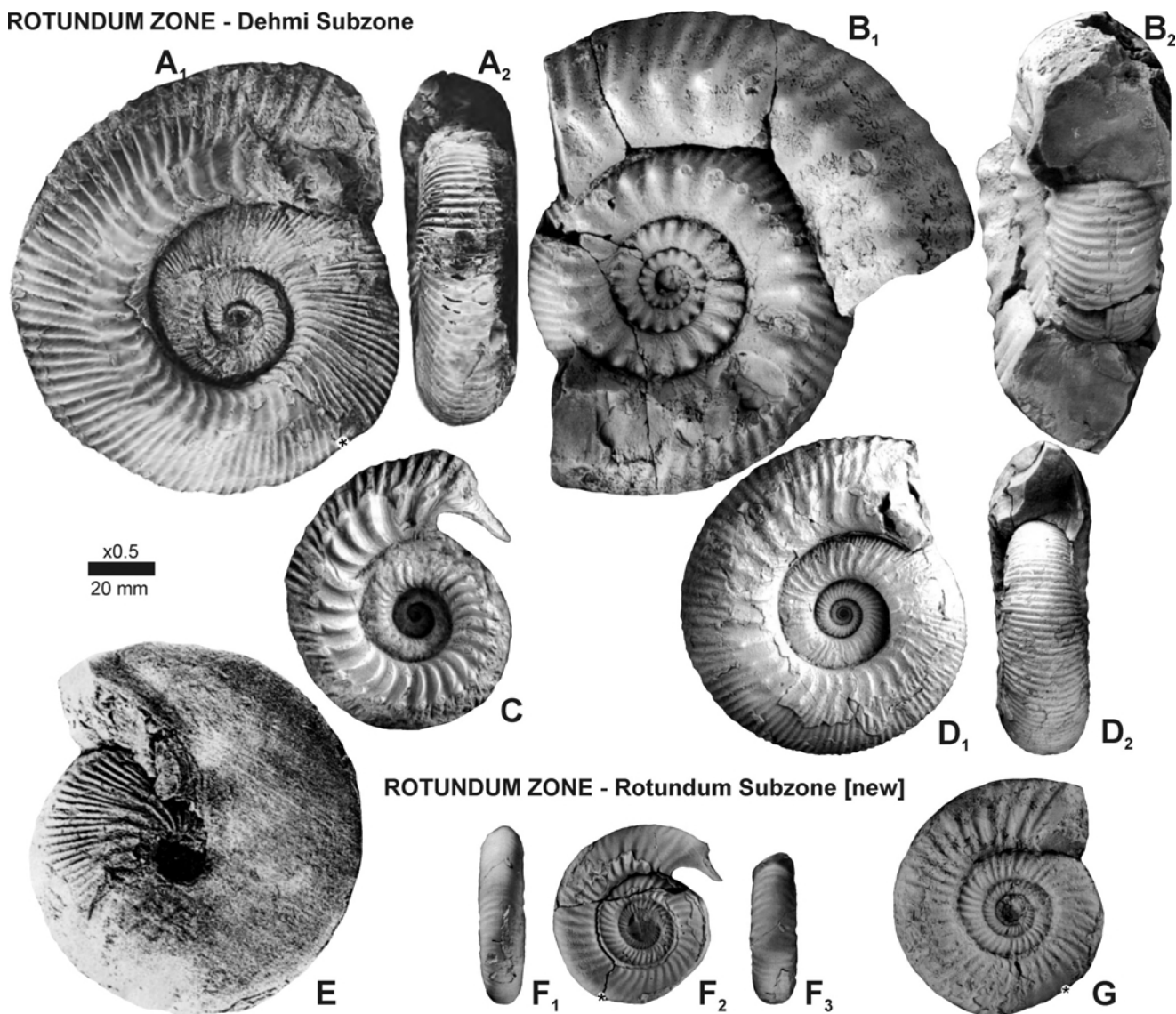


Fig. 9. Guide species

Rotundum Z., Dehmi Sz. **A.** *Lupherites dehmi*, HT, Cordillera Domeyko. **B.** *Duashnoceras profetaense*, HT, Aguada del Minero. **C.** *Duashnoceras chilense* (D, [M] phragmocone, Cerro Agua de Piedra; C, [m], Agua del Minero). Rotundum Z., Rotundum Sz. **E.** *Megasphaeroceras spissum*, HT, Quebrada El Profeta. **F.** *Leptosphinctes* cf. *leptus*, Aguada del Minero (G, adult [M]; F, adult [m]). All reduced to half natural size (x0.5). Asterisk at last septum. A, modified from Hillebrandt (1977); B, D, F, G, modified from Hillebrandt (2001); E, modified from Riccardi, Westermann (1991a)

is here designated the base of the Gulisanoi Zone which then becomes standard, and ranges up to the base of the non-standard Sofanus Zone. The Gulisanoi Zone seems to be, at least in part, time-equivalent or slightly younger than the “ammonite assemblage with ?*Zigzagiceras*” of Gröschke, Hillebrandt (1994).

The name Gulisanoi Zone is misleading since Parent (1998) established the *gulisanoi* Hz. in the Upper Bathonian (see further details in Parent *et al.*, 2020); it will be convenient to rename the Gulisanoi Zone for avoiding confusion.

– Horizons: cf.-*aspidoides* Hz. (new).

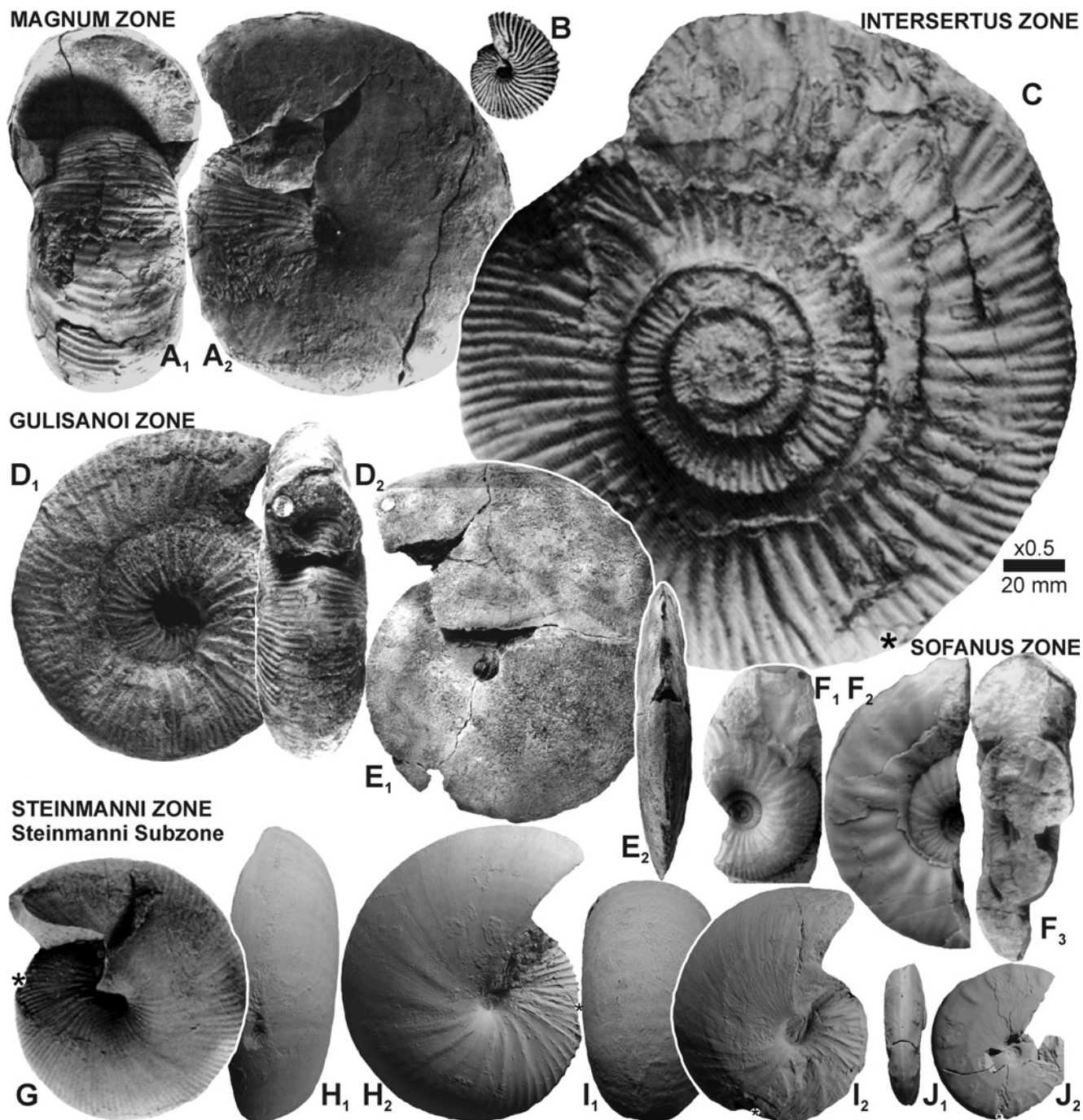


Fig. 10. Guide species

Magnum Zone. **A, B.** *Megasphaeroceras magnum*, Chacay Melehué (A, HT; B: adult [m]).

Intersertus Z. **C.** *Lobosphinctes intersertus*, adult [M], Chacay Melehué.

Gulisanoi Z. **D.** *Morphoceras gulisanoi*, HT, Agua del Naco. **E.** *Oxyerites* cf. *aspidoides*, phragmocone, Agua del Naco.

Sofanus Z. **F.** *Bullatimorphites sofanus*, adult [M], Profeta Jurassic.

Steinmanni Z., Steinmanni Subz., all from Chacay Melehué. **G.** *Lilloettia steinmanni*, adult [M]. **H.** *Iniskinites gulisanoi*, adult [M]. **I.** *Eurycephalites belgranoi*, HT. **J.** *Alcidellus* aff. *obsoletoides*, adult [M].

All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, B, modified from Riccardi, Westermann (1991a); C, G, modified from Riccardi *et al.* (1989); D, E: modified from Riccardi, Westermann (1999); F, modified from Gröschke, Hillebrandt (1994); H, J, modified from Parent *et al.* (2020)

SOFANUS ZONE [GRÖSCHKE, HILLEBRANDT, 1994]

This zone is based on the “ammonite assemblage with *Rugiferites sofanus*” of Gröschke, Hillebrandt (1994). As indicated by Gröschke, Hillebrandt (1994: table 1) it corresponds, at least in part, to the so called “*Cadomites*-*Tulitidae* mixed assemblage” of Riccardi *et al.* (1989). This latter assemblage includes *Bullatimorphites sofanus*, e.g. Riccardi *et al.*, 1989: pl. 2:1, as *Tulites*? (*Rugiferites*?) cf. *davaiacensis* (Lissajous, 1923) *sensu* Sandoval (1983).

- *Index species*: *Bullatimorphites sofanus* (Boehm, 1912). The holotype (Boehm, 1912: pl. 35: 2) from Keeuw, collected without stratigraphic control (Westermann, 1992: 259), perfectly matches the Middle Bathonian specimens figured by Sandoval (1983: pl. 66: 2; 67: 2, 3).
- *Type locality*: Quebrada del Profeta.
- *Guide species* (Fig. 10): *B. sofanus*. Gröschke, Hillebrandt (1994) reported the index species associated, in two localities, with *Cadomites*? sp. or spp. and *Iniskinites* sp. However, for the time being the Sofanus Zone is a non-standard Zone derived from the local stratigraphic range of the guide species, and ranging up to the base of the standard Steinmanni Zone.

STEINMANNI ZONE [RICCARDI ET AL., 1989]

- *Index species*: *Lilloettia steinmanni* (Spath, 1928).

This zone was recently subdivided in two standard subzones (Parent *et al.*, 2020):

Steinmanni Subzone [Parent *et al.*, 2020]

- *Index species*: *Lilloettia steinmanni* (Spath, 1928).
- *Type locality*: Chacay Melehué, Argentina.
- *Guide species* (Fig. 10): *L. steinmanni* (mostly restricted to this subzone, later passing to its later transient *Lilloettia australis* Riccardi, Westermann, 1991a; see Parent *et al.*, 2020), *Iniskinites gulisanoi* Riccardi, Westermann, 1991a, early *Iniskinites crassus* Riccardi, Westermann, 1991a (small adult size and narrow umbilicus), *Eurycephalites belgranoi* Parent *et al.*, 2020, *Alcidellus* aff. *obsoletoideus* Riccardi *et al.*, 1989.
- *Horizons*: *gulisanoi* Hz. (Parent, 1998).

Gerthi Subzone [Parent *et al.*, 2020]

- *Index species*: *Stehnocephalites gerthi* (Spath, 1928).
- *Type locality*: Chacay Melehué, Argentina.
- *Guide species* (Fig. 11): *S. gerthi*, *L. australis*, *I. crassus* (larger adult size and wider umbilicus), *Choffatia jupiter* (Steinmann, 1881), *Choffatia* aff. *subbakeriae* (d’Orbigny, 1850), *Choffatia irregularis* Parent *et al.*, 2020, *Alcidellus* n. sp. aff. *tenuistriatus* (Grossouvre, 1888), *Prohectoceras blanazense* Elmi, 1967.
- *Horizons*: *crassus* Hz. (Parent, 1998), base of the standard subzone; *jupiter* Hz. (Riccardi *et al.*, 1989).

CALLOVIAN

Time-correlation with the Tethyan standard was discussed by Riccardi *et al.* (1989), Hillebrandt, Gröschke (1995), Parent (2006), and Parent, Garrido (2015), and most recently by Dietl *et al.* (2021).

GOTTSCHKEI ZONE [RICCARDI ET AL., 1989].

Formerly named Vergarensis Zone, renamed by Parent (1998), see details in Westermann *et al.* (2002: 509) and Garrido, Parent (2013).

- *Index species*: *Eurycephalites gottschei* (Tornquist, 1898).
- *Type locality*: Chacay Melehué, Argentina.
- *Guide species* (Fig. 12): *E. gottschei* (early transient *gottschei*, late transient *latumbilicatus*), latest *I. crassus* (small adults with wide umbilicus), *Kheraicerus bullatum* (d’Orbigny, 1846).

BODENBENDERI ZONE [RICCARDI ET AL., 1989]

- *Index species*: *Neuquenicerus bodenbenderi* (Tornquist, 1898).
- *Type locality*: Chacay Melehué, Argentina.
- *Guide species* (Fig. 12): *N. bodenbenderi*, *Eurycephalites rotundus* (Tornquist, 1898), *Eurycephalites extremus* (Tornquist, 1898).

STEINMANNI ZONE - Gerthi Subzone

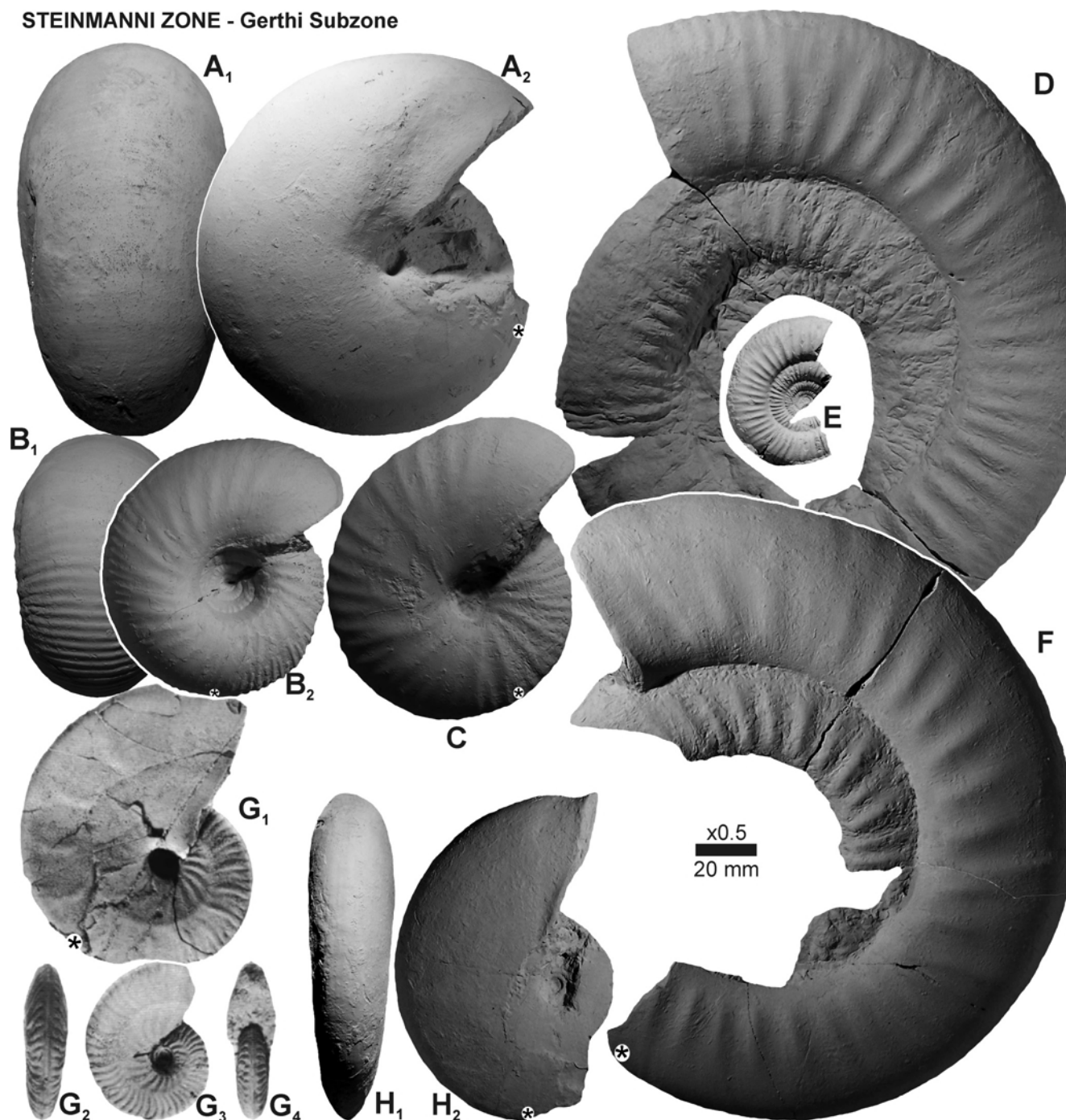


Fig. 11. Guide species

Steinmanni Z., Gerthi Sz. **A.** *Lilloettia australis*, adult [M], Chacay Melehué. **B.** *Stehnocephalites gerthi*, adult [M], Chacay Melehué. **C.** *Iniskinites crassus*, adult [M], Chacay Melehué. **D, E.** *Choffatia* aff. *subbakeriae* (D, adult [M]; E, inner whorls), Chacay Melehué. **F.** *Choffatia jupiter*, adult [M], Chacay Melehué. **G.** *Prohectioceras blanazense*, adult [M], Caracoles. **H.** *Alcidellus* n. sp. aff. *tenuistriatus*, adult [M], Chacay Melehué.

All reduced to half natural size (x0.5). Asterisk at last septum. A–F, H modified from Parent *et al.* (2020); G, modified from Riccardi *et al.* (1989)

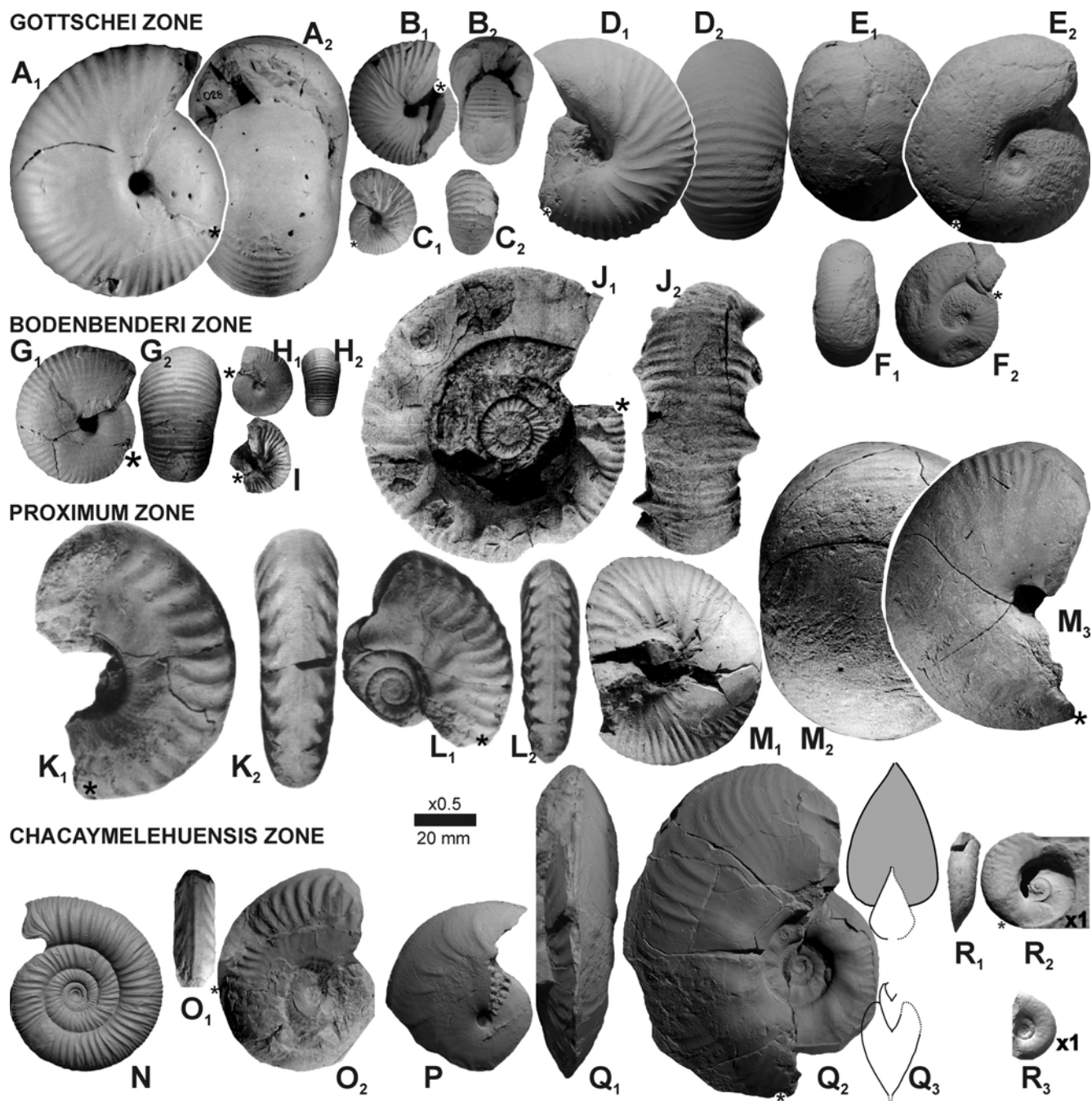


Fig. 12. Guide species

Gottschei Z. **A–C.** *Eurycephalites gottschei* (A, adult [M]; B, juv. [M]; C, adult [m]). **D.** *Iniskintes crassus*, adult [M]. **E, F.** *Kheraicerias bullatum* (E, adult [M]; F, adult [m]).

Bodenbenderi Z. **G–I.** *Euryc. rotundus* (G, subadult [M]; H, juv. [M]; I, adult [m]). **J.** *Neuquenicerias bodenbenderi*, adult [M].

Proximum Z. **K.** *Hecticoceras ardescicum*, adult [M]. **L.** *Hect. proximum*, adult [M]. **M.** *Euryc. extremus*, adult [M].

Chacaymelehuensis Z. **N.** “*Choffatia*” [nov. gen.] sp. A, adult [m]. **O.** *Hect. “prahecuense”*, subadult [M]. **P.** *Oxycerites* aff. *oppeli*, phragmocone. **Q, R.** *Pseudosonninia chacaymelehuensis* (Q, HT; R, adult [m]).

All from Chacay Melehué, except E, F from V. Veranada. All reduced to half natural size (×0.5). Asterisk at last septum. A–D, G–I, M, modified from Parent (1998); E, MOZ-PI-11218/2; F, MOZ-PI-11823; J, modified from Riccardi, Westermann (1991b); K, L, modified from Riccardi *et al.* (1989); N, O, Q, R, modified from Parent *et al.* (2019b); P, MOZ-PI-3553/6

PROXIMUM ZONE [RICCARDI ET AL., 1989]

- *Index species*: *Hecticoceras proximum* Elmi, 1967.
- *Type locality*: Chacay Melehué, Argentina.
- *Guide species* (Fig. 12): *H. proximum*, *Hecticoceras boginense* (Peticlerc, 1915), *Hecticoceras ardescicum* Elmi, 1967, *E. extremus*.

CHACAYMELEHUENSIS ZONE [NEW]

Represented in Chacay Melehué by the topmost 6 m of shales of the Los Molles Fm (Parent *et al.*, 2019b), with base in the “*prahecuense*” Hz. (new). The Chacaymelehuensis Zone would correspond, approximately, to the “Jason” Zone of Hillebrandt, Gröschke (1995: fig. 2).

- *Index species*: *Pseudosonninia chacaymelehuensis* Parent *et al.*, 2019b.
- *Type locality*: Chacay Melehué, Argentina.
- *Guide species* (Fig. 12): *P. chacaymelehuensis*, *P. aff. chacaymelehuensis*, *Oxycerites aff. oppeli* Elmi, 1967, *Hecticoceras* “*prahecuense*” (Peticlerc, 1915).
- *Horizons*: “*prahecuense*” Hz. (new). This bio-horizon corresponds to the faunal level B in the section of Parent *et al.* (2019b: fig. 1B) with *H. “prahecuense”*, *P. aff. chacaymelehuensis*, *Araucanites* n. sp. A (large macroconchs, involute and with inflated, smooth bodychamber) and “*Choffatia*” [nov. gen.] sp. A.

“CORONATUM ZONE” [HILLEBRANDT, GRÖSCHKE, 1995]

Rocks with ammonites of this age seem to be rather scarce in the Andean basins (Gröschke, Hillebrandt, 1985; Gröschke, Zeiss, 1990). In those papers several species of oppeliids and perisphinctids have been described which could likely be Coronatum Zone in age (see summary in Parent, 2006), e.g., *Hecticoceras atakamense* Gröschke, Zeiss, 1990, *Hecticoceras aff. hartmanni* Zeiss, 1956, *Reineckeia cf. euactis* Steinmann, 1881, *Rehmanni reissi* Steinmann, 1881, and *Rehmannia stehni* (Zeiss, 1956). However, no assemblages have been monographed, and no chronostratigraphic units have been defined for the time being.

PATAGONIENSIS ZONE [PARENT, 2006]

This zone is derived from the *Patagoniensis* Biozone, and standardized by means of the designation of the *patagoniensis* Hz. as its base by Garrido, Parent (2013).

- *Index species*: *Rehmannia patagoniensis* (Weaver, 1931).
- *Type locality*: Manzano Escondido, Argentina.
- *Guide species* (Fig. 13): *R. patagoniensis*, *Choffatia cf. isabellae* Bonnot *et al.*, 2008, *Hecticoceras cf. lairensis* (Waagen, 1875), *Peltoceras retrospinatum* Gérard, Con-taut, 1936, *Araucanites prereyesi* Parent, 2006.
- *Horizons*: *patagoniensis* Hz. (Riccardi, Westermann, 1991b), *cf.-isabellae* Hz. (as *choffatia* Hz. in Parent, 2006), *cf.-lairensis* Hz. (as *hecticoceras* Hz. in Parent, 2006).

PRIMUS ZONE [HILLEBRANDT, GRÖSCHKE, 1995]

- *Index species*: *Peltoceratoides primus* (Hillebrandt, Gröschke, 1995), the microconch described as *Rursiceras convexum* Hillebrandt, Gröschke, 1995.
- *Type locality*: Aguada El Oro, Chile.
- *Guide species* (Fig. 14): *P. primus*, *Choffatia schilleri* Parent, Garrido, 2015, *Hecticoceras aff. lairensis* (Waagen, 1875).
- *Horizons*: *schilleri* Hz. (Parent, Garrido, 2015).

DIMORPHOSUS ZONE [HILLEBRANDT, GRÖSCHKE, 1995]

See discussion of the time-correlation of the Andean Dimorphosus and Eugenii zones with the Tethyan upper Lambert and Mariae/Minax zones, respectively, in Parent, Garrido (2015: 209, fig. 38).

- *Index species*: *Peltoceratoides dimorphosus* (Hillebrandt, Gröschke, 1995), the microconch seems to be *Rursiceras convexum* Hillebrandt, Gröschke, 1995.
- *Type locality*: Cerro Amarillo, Chile.
- *Guide species* (Fig. 14): *P. dimorphosus*, *Euaspidoceras cf. depereti* (Collot, 1917) and its probable microconch *Miosphinctes* sp. A (in Hillebrandt, Gröschke, 1995: pl. 6: 9), *Jaspeiceras philippii* Gröschke, Kossler, 1999.

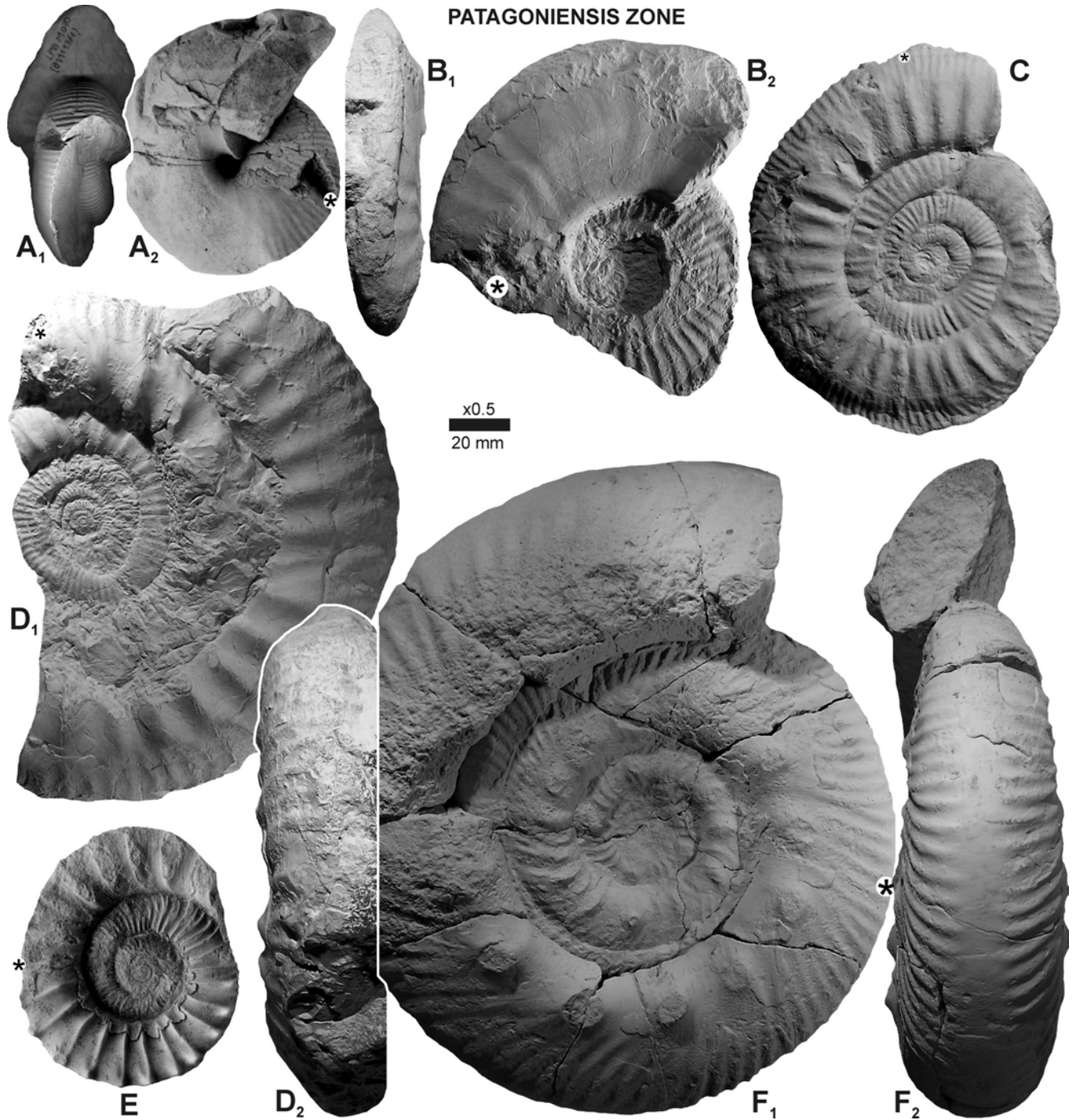
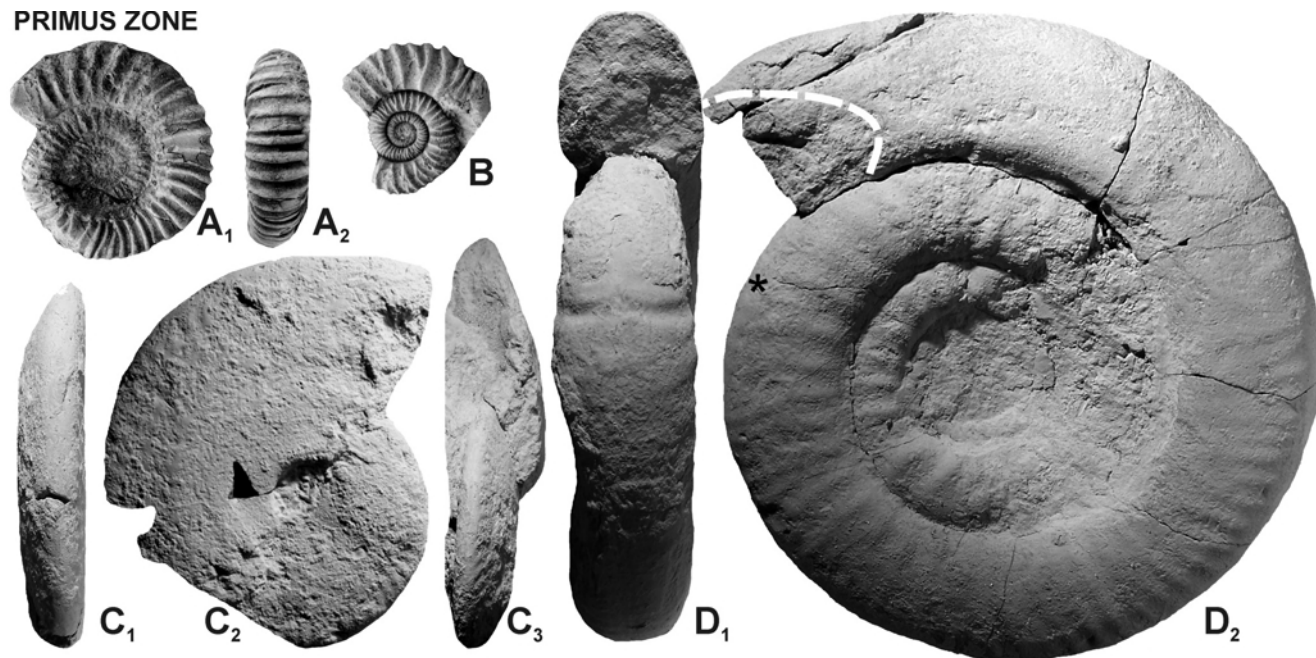


Fig. 13. Guide species

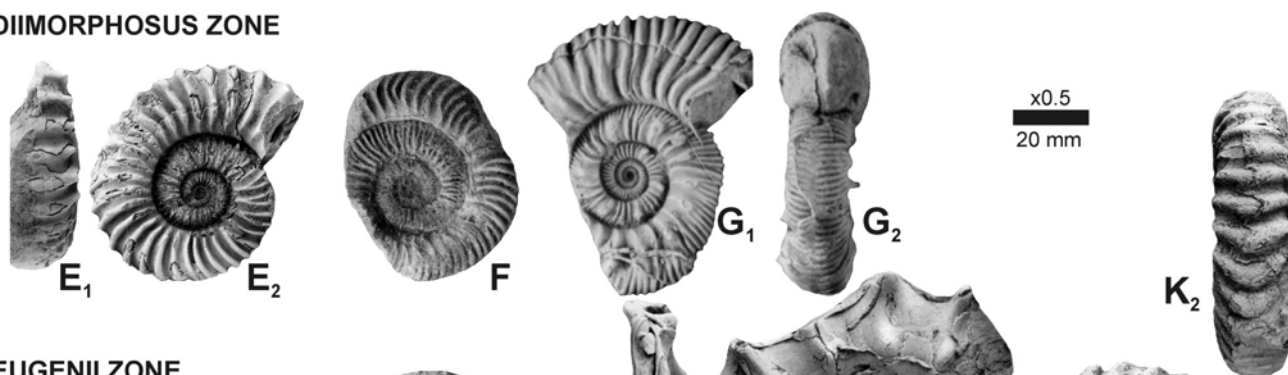
Patagoniensis Z. **A.** *Araucanites prereyesii*, HT, Cerro Amarillo. **B.** *Hecticoceras* cf. *lairensis*, adult [M], Manzano Escondido. **C.** *Choffatia* cf. *isabellae* (C, adult [M] phragmocone; D, adult [M]), Manzano Escondido. **E.** *Peltoceras retrospinatum*, adult [M], Cerro Amarillo. **F.** *Rehmannia patagoniensis*, adult [M], Picún Leufú.

All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, E, modified from Hillebrandt, Gröschke (1995); B, C, modified from Parent (2006); D, MOZ-PI-6820; F, modified from Garrido, Parent (2013)

PRIMUS ZONE



DIIMORPHOSUS ZONE



EUGENII ZONE

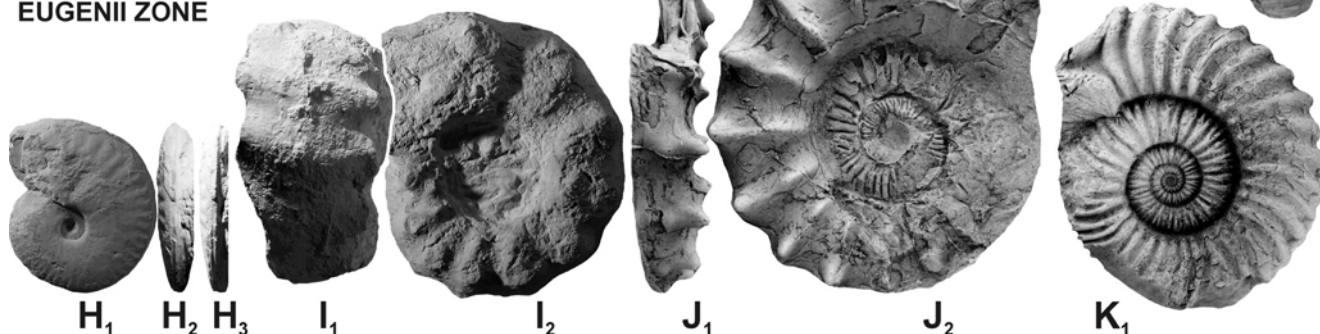


Fig. 14. Guide species

Primus Z. **A, B.** *Peltoceratoides primus* (A, HT, Aguada del Carretón; B, adult [m], Cerro Paisaje). **C.** *Hecticoceras* aff. *lairense*, adult [M], Vega de la Veranada. **D.** *Choffatia schilleri*, HT, V. de la Veranada.

Dimorphosus Z. **E, F.** *Peltoceratoides dimorphosus* (E, HT, Aguada Colorada; F, adult [m], Cerro Amarillo). **G.** *Jaspeiceras philippii*, adult [M], Cerro Jaspe. – Eugeniei Z. **H.** *Neoprioceras girardoti*, adult [M], V. de la Veranada. **I.** *Euspidoceras* cf. *subbabeum*, phragmocone, V. de la Veranada. **J, K.** *Peltoceratoides eugeniei* (J, adult [M], K, adult [m], P. Azabache/Cerro la Ballena).

All reduced to half natural size (x0.5). Asterisk at last septum. A, B, E, F, J, K, modified from Hillebrandt, Gröschke (1995); C, D, H, I, modified from Parent, Garrido (2015); G, modified from Gröschke, Kossler (1999)

OXFORDIAN

Time-correlation with the Tethyan standard was discussed by Gygi, Hillebrandt (1991), Hillebrandt, Gröschke (1995), Parent (2006), Parent *et al.* (2006a), and Parent, Garrido (2015).

EUGENII ZONE [HILLEBRANDT, GRÖSCHKE, 1995]

- *Index species*: *Peltoceratoides eugenii* (Raspail, 1842).
- *Type locality*: Puerto Azabache-Cerro La Ballena? (Hillebrandt, Gröschke, 1995: 13).
- *Guide species* (Fig. 14): *P. eugenii* (its probable local microconch is *Rursiceras ballenaensis* Hillebrandt, Gröschke, 1995), *Jaspeiceras philippii* Gröschke, Kosler, 1999, “*Perisphinctes*” [nov. gen.] n. sp. A, compressed morphotypes (in Parent, Garrido, 2015), *Euaspidoceras* cf. *subbabeaunum* (Sintzov, 1888 *sensu* Jeannel, 1951), *Neoprioceras girardoti* (De Loriol, 1902).

PRESSULUS ZONE [PARENT, 2006]

This zone was derived from the *Pressulus* Biozone, and standardized by means of the designation of the *pressulus* Hz. as its base (Parent, Garrido, 2015).

- *Index species*: *Peltoceratoides pressulus* (Leanza, 1947).
- *Type locality*: Chacay Melehué, Argentina.
- *Guide species* (Fig. 15): *P. pressulus*, *Euaspidoceras ajax* (Leanza, 1947), *Cubasphinctes* aff. *durangensis* (Burckhardt, 1912), “*Perisphinctes*” n. sp. A, inflated morphotypes (in Parent, Garrido, 2015), *Veranadaites palmicostatus* Parent, Garrido, 2015.
- *Horizons*: *pressulus* Hz. (Parent, Garrido, 2015).

PSEUDOKRANAUS ZONE [PARENT, 2006]

This zone is derived from the *Pseudokranaus* Biozone.

- *Index species*: *Subvinalesphinctes pseudokranaus* Parent *et al.*, 2006a.
- *Type locality*: Chacay Melehué, Argentina.
- *Guide species* (Fig. 16): *S. pseudokranaus*, *Subvinalesphinctes? prophetae* (Gygi, Hillebrandt, 1991), *Cubasphinctes durangensis*.

CUBANENSIS ZONE [=PASSENDORFERIA Z. IN PARENT, 2006]

This zone is derived from the *Passendorferia* Biozone. The name is changed merely for meeting the requirement of naming zones from specific names.

- *Index species*: *Cubasphinctes cubanensis* (O’Connell, 1920).
- *Type locality*: Mallín Quemado, Argentina.
- *Guide species* (Fig. 16): *Passendorferia* cf. *teresiformis* (Brochwicz-Lewinski, 1973), *C. cubanensis*.

TARAPACAENSE ZONE [PARENT, 2006]

This zone is derived from the *Tarapacaense* Biozone, and standardized here by the designation of the *tarapacaense* Hz. (new) as its base.

- *Index species*: *Euaspidoceras tarapacaense* Parent, 2006.
- *Type locality*: Aguada del Carretón, Chile.
- *Guide species* (Fig. 16): *E. tarapacaense*, *Perisphinctes andium* Steinmann, 1881, *Gregoryceras perplanatum* Gygi, Hillebrandt, 1991.
- *Horizons*: *tarapacaense* Hz. (new). This horizon is defined from the bed 3 of the section of Aguada del Carretón (Gygi, Hillebrandt, 1991: fig. 11) by the assemblage of *E. tarapacaense* (the microconch would be *Miosphinctes* sp. B in Gygi, Hillebrandt, 1991: pl. 3: 6; see Parent, 2006), *Perisphinctes andium*, and *Gregoryceras perplanatum*.

DESERTORUS ZONE [PARENT, 2006]

This zone is derived from the *Desertorus* Biozone.

- *Index species*: *Lithacosphinctes desertorus* (Stehn, 1923).
- *Type locality*: Aguada del Carretón, Chile.
- *Guide species* (Fig. 17): *L. desertorus*, *Ochetoceras mexicanum* (Burckhardt, 1912).
- *Remarks*. Förster, Hillebrandt (1984: pl. 1) have figured and briefly discussed a collection of aspidoceratids collected north of Quebrada El Profeta (N Chile) and assigned to *Orthaspidoceras* Spath, 1925 and *Cubaspidoceras* cf. *caribeanum* Myczyński, 1976, respectively. A. v. Hillebrandt has kindly sent us casts of the specimens, and the specimens properly were later sent to us for study, currently in the State Museum of Natural His-

PRESSULUS ZONE

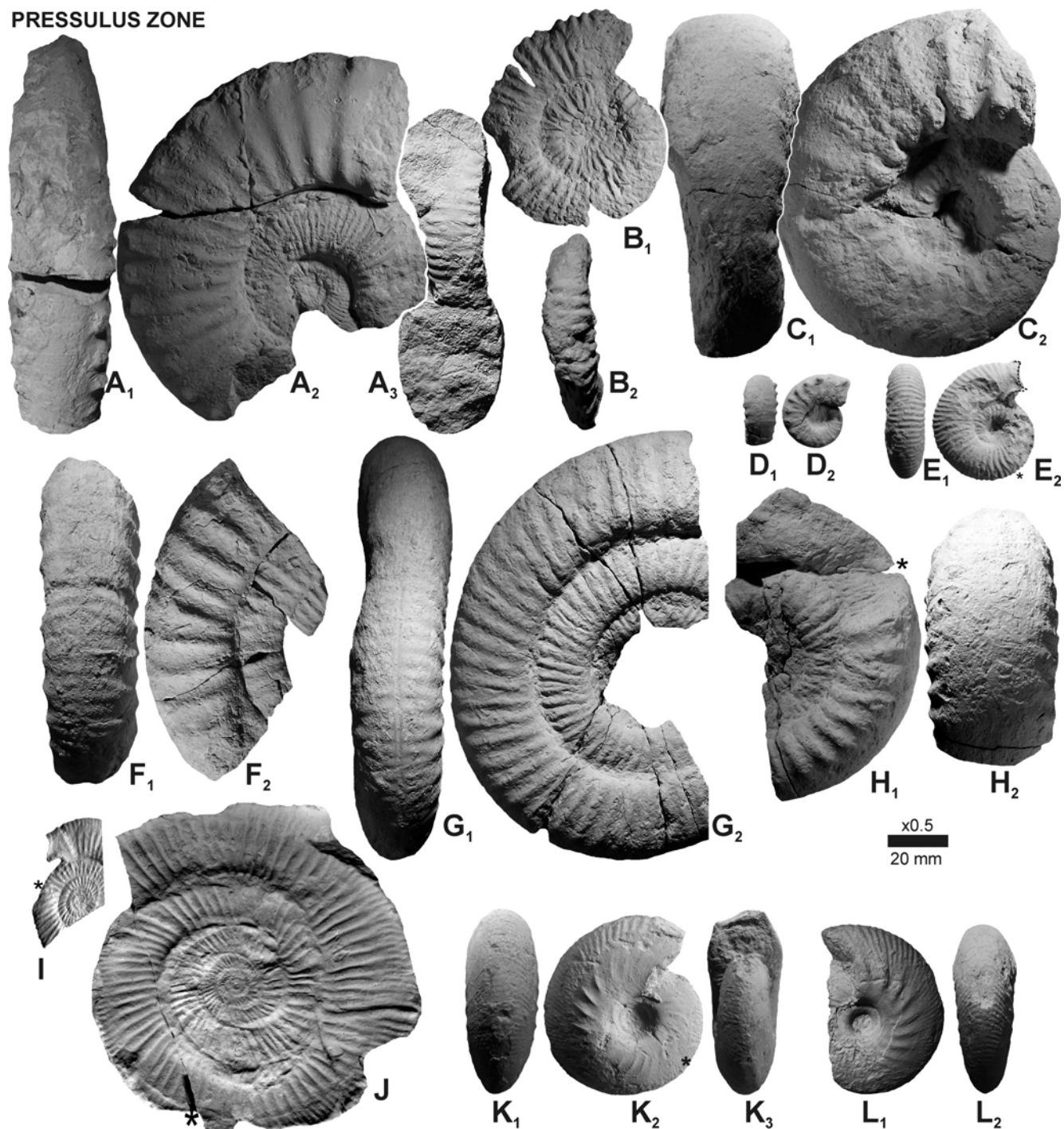
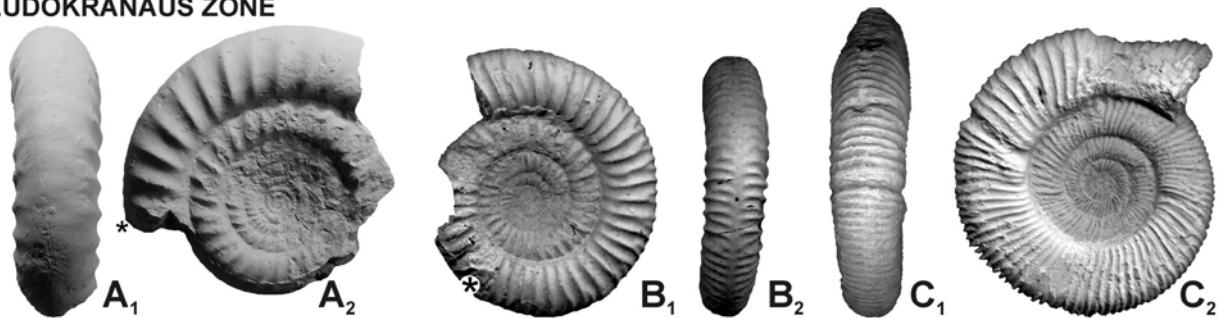


Fig. 15. Guide species

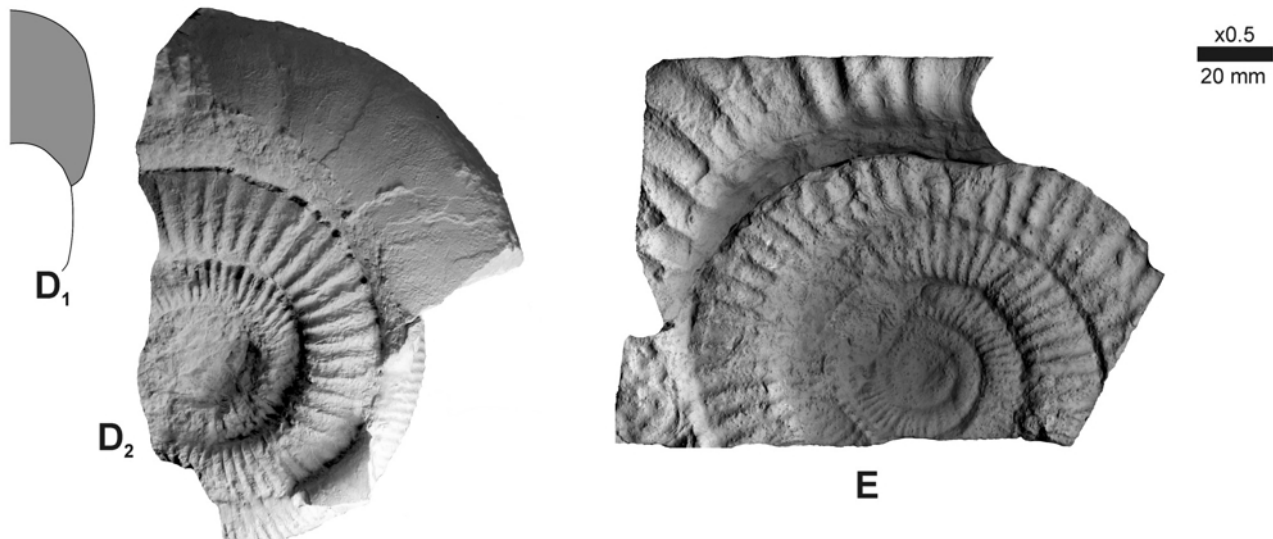
Pressulus Z. **A, B.** *Peltoceratoides pressulus* (A, adult [M]; B, adult [m]). **C–E.** *Euaspidoceras ajax* (C, adult [M]; D, inner whorls [M]; E, adult [m]). **F–H.** “*Perisphinctes*” nov. sp. A (in Parent and Garrido 2015) (F, adult [M] coarsely ribbed morphotype; G, adult [M] phragmocone; H, adult [M]). **I, J.** *Cubasphinctes* aff. *durangensis* (I, adult [m]; J, adult [M]). **K, L.** *Veranadaites palmicostatus* (K, HT; L, adult [M], paratype).

All from V. Veranada, except I, J from Rahucó (Cerro Caicayén). All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A–H, K, L, modified from Parent, Garrido (2015); I, J, modified from Parent (2006)

PSEUDOKRANAUS ZONE



CUBANENSIS ZONE



TARAPACAENSE ZONE



Fig. 16. Guide species

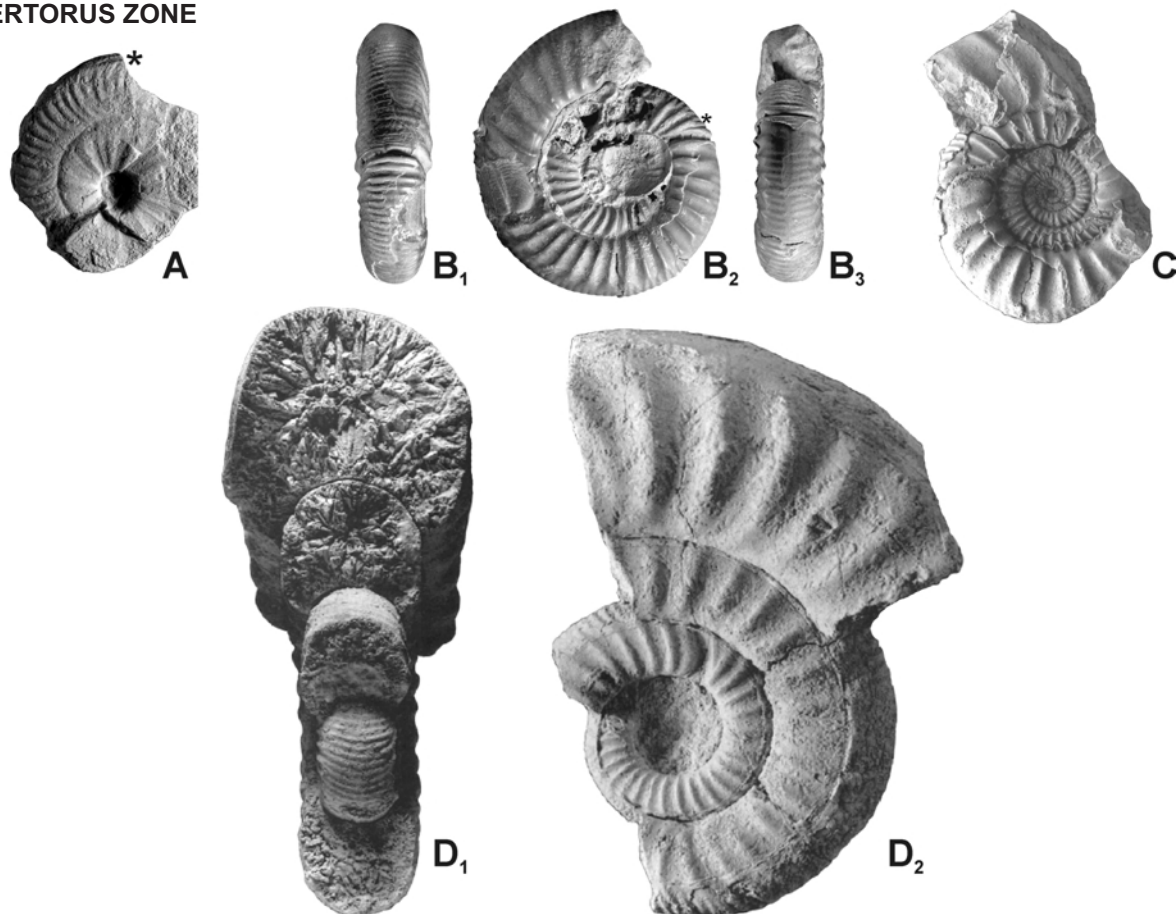
Pseudokranaus Z. **A.** *Subvinalesphinctes pseudokranaus*, HT, Ch. Melehué. **B.** *Subvinalesphinctes prophetae*, adult [m], Ch. Melehué. **C.** *Cubasphinctes durangensis*, adult [M], Quebrada Sandón.

Passendorferia Z. **D.** *Cubasphinctes cubanensis*, adult [M], Mallín Quemado. **E.** *Passendorferia* cf. *teresiformis*, adult [M], Arroyo Mulichinco.

Tarapacaense Z. **F, G.** *Euaspidoceras tarapacaense* (F, HT, A. del Carretón; G: adult [m], A. del Carretón). **H.** *Gregoryceras perplanatum*, HT, A. del Carretón. **I.** *Perisphinctes andium*, adult [m?], Q. del Profeta.

All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, B, modified from Parent *et al.* (2006); C–E, modified from Parent (2006); F–I: modified from Gygi, Hillebrandt (1991)

DESERTORUS ZONE



aff.-janus Horizon

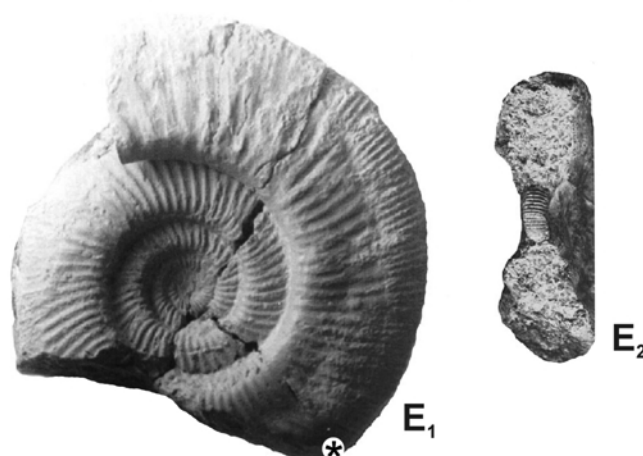


Fig. 17. Guide species

Desertorus Z. **A.** *Ochetoceras mexicanum*, adult [M], Aguada del Carretón. **B–D.** *Lithacosphinctes desertorus* (B, HT from Caracoles; C, adult macroconch from Quebrada del Medio; D: adult [M] from Quebrada del Medio). – *aff.-janus* Hz. **E.** *Lithacosphinctes aff. janus*, adult [M], Chacay Melehué. All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, E, modified from Parent *et al.* (2006); B–D, modified from Gygi, Hillebrandt (1991)

tory, Stuttgart. According to G. Schweigert (pers. comm. 12/12/21), this fauna includes very early *Physodoceras* Hyatt, 1900 (Förster, Hillebrandt, 1984: pl. 1: 1, 2, 4–6), and *Cubaspidoceras* cf./aff. *caribeanum* (Förster, Hillebrandt, 1984: pl. 1: 7, 8). Additionally, the specimen in pl. 1: 3 of Förster, Hillebrandt (1984), could be assigned to *Benetticeras* Checa, 1985. This fauna could likely belong to the Desertorus Zone.

KIMMERIDGIAN

Recently, the base of the Kimmeridgian has been moved down to include the *bimammatum* Hz., just overlying the *berrense* Hz. of the Oxfordian Hypselum Zone (Wierzbowski *et al.*, 2016). For matters of comparison the former boundary at the base of the Platynota Zone is also shown in Figure 3. The Kimmeridgian is poorly represented by marine deposits in the Andean basins (Gröschke *et al.*, 1988; Legarreta, Uliana, 1996). There seem to be just two ammonite records:

1. *aff.-janus* Horizon (Parent, 2006). This bio-horizon currently stands isolated, occurring in just two close localities (Rahucó and Chacay Melehué), and would lie in some part of the upper Planula to Platynota zones interval. Such a position was concluded (Parent *et al.*, 2006a) on the basis of the strong resemblance of *Lithacosphinctes* aff. *janus* (Choffat, 1893) with *Lithacosphinctes* *janus* as described by Hantzpergue (1989: pl. 7: a–c) and other similar representatives of the genus.
- *Index and guide species* (Fig. 17): *L. aff. janus*.
- *Type locality*: Chacay Melehué, Argentina.
2. Gröschke *et al.* (1988: fig. 1) figured an aspidoceratid from northern Chile as *Orthaspidoceras*. According to G. Schweigert (pers. comm. 12/12/21) this specimen belongs to the genus *Benetticeras* and could be early Kimmeridgian in age; and according to A. Scherzinger (pers. comm. 12/12/21) a very similar *Benetticeras* sp. occurs in the Kimmeridgian of Hungary. The latter originates from a bed the age of which is Divisum Zone or younger.

TITHONIAN

Time-correlation with the Tethyan standard was discussed by Leanza (1981), Parent *et al.* (2006b, 2011a, 2015), Vennari (2016), and Aguirre-Urreta *et al.* (2019). Additional information was given by Salazar, Stinnesbeck (2015) and Salazar *et al.* (2020).

PICUNLEUFUENSE ZONE [PARENT *ET AL.*, 2011b]

- *Index species*: *Indansites picunleufuense* (Parent *et al.*, 2011b).
- *Type locality*: Picun Leufú, Argentina.
- *Guide species* (Fig. 18): *I. picunleufuense*, *Choicensisphinctes platyconus* Parent *et al.*, 2011b, *Catutosphinctes guenenakenensis* Parent *et al.*, 2011b, and early *Cieneguiticeras perlaevis* (Steuer, 1897).
- *Horizons* (recently reviewed in Parent *et al.*, 2019a): *picunleufuense-alpha* Hz., *picunleufuense-beta* Hz., *picunleufuense-gamma* Hz.

MALARGUENSIS ZONE [ZEISS, LEANZA, 2010]

This standard zone is derived from the Malarguensis Subzone of Leanza, Zeiss (2010), here introduced to replace the unviable Mendozanus Zone introduced by Burckhardt (1903). The base of the Malarguensis Zone is here designated at the *malarguensis* Hz.

- *Index species*: *Indansites malarguensis* (Spath, 1931).
- *Type locality*: The Malarguensis Subzone (Zeiss, Leanza, 2010) lacked a definition and type locality/section designation. For the present redefinition as a standard zone, we establish Casa Pincheira as the type locality of the Malarguensis Zone, as this is the type locality of the *malarguensis* Hz. (Parent *et al.*, 2011a).
- *Guide species* (Fig. 19): early *Choicensisphinctes erinoides* (Burckhardt, 1903), early *Pseudolissoceras zitteli* (Burckhardt, 1903), *I. malarguensis*, *Choicensisphinctes burckhardti* (Douvillé, 1910), *Catutosphinctes windhausenii* (Weaver, 1931).
- *Horizons*: *malarguensis* Hz. (Parent *et al.*, 2011a).
- *Remarks*. The Mendozanus Zone (type locality: Cajón del Burro-Río Choicas) should have been renamed since “*Virgatites*” *mendozanus* Burckhardt, 1911 is the microconch of *C. erinoides*, thus a junior synonym (discussion in Parent *et al.*, 2011a). On the other hand, the overlap and even inversion of the stratigraphic ranges of the guide species *C. erinoides* (including its microconch “*V.*” *mendozanus*) and *P. zitteli* (see Weaver, 1931; Suero, 1951; Parent *et al.*, 2011a, b; Vennari, 2016), prevents the distinction of the Mendozanus and Zitteli zones, as derived from their respective biozones (see discussion in Parent *et al.*, 2011a, b, 2015). However, the guide assemblages listed above and below (under Zitteli Zone) allow a con-

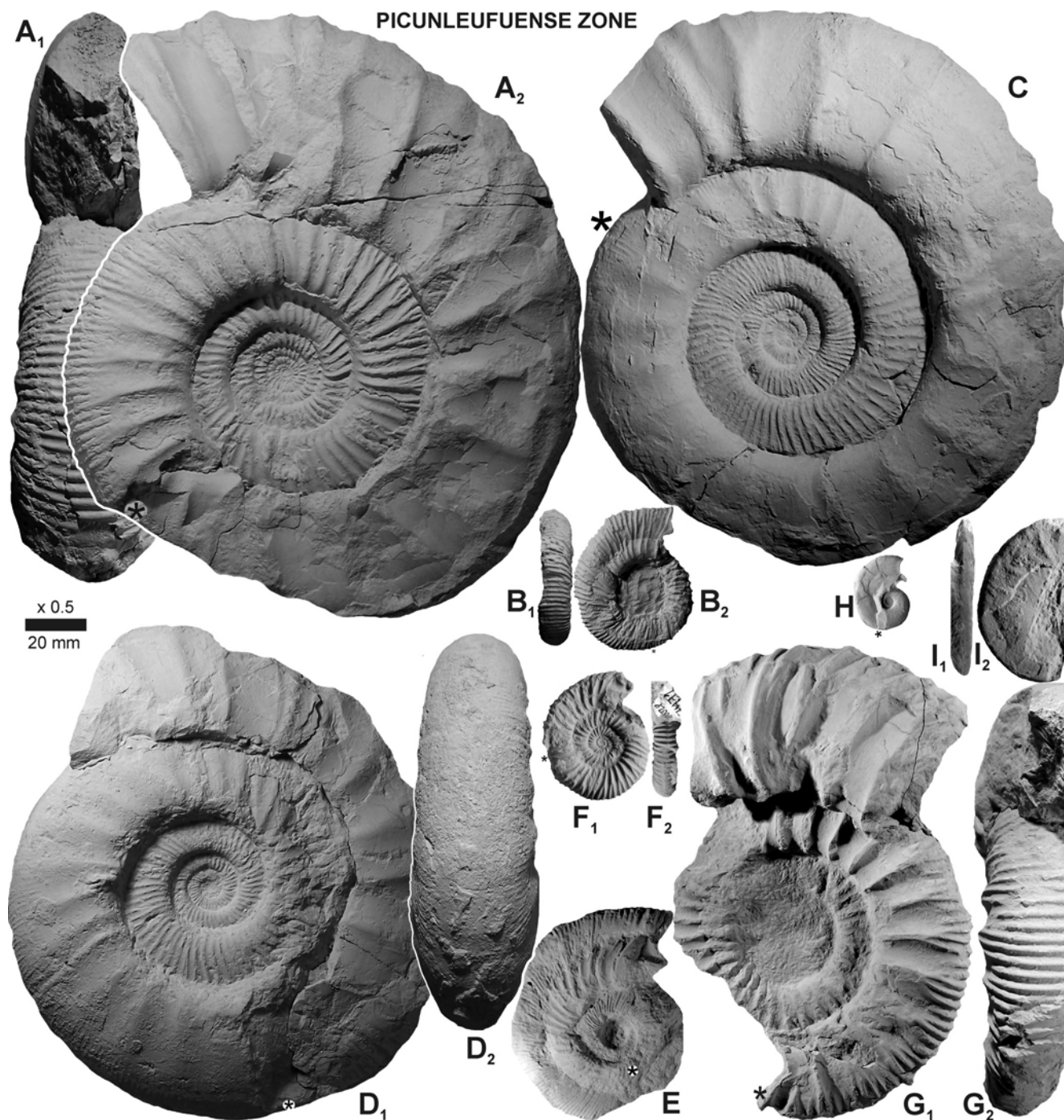


Fig. 18. Guide species

Picunleufuense Z. **A, B.** *Indansites picunleufuense* transient alpha (A, adult [M]; B, adult [m]), Picún Leufú. **C.** *Indansites picunleufuense* transient gamma, adult [M], Est. María Juana. **D, E.** *Choicensisphinctes platyconus* (D, adult [M] from Pampa Tril; E, adult [m] from Picún Leufú). **F, G.** *Catutosphinctes guenenakenensis* (F, adult [m]; G, adult [M]), Picún Leufú. **H, I.** *Cieneguiticeras perlaevis* (H, adult [m]; I, adult [M] phragmocone), Picún Leufú. All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, B, E–I, modified from Parent *et al.* (2011a); C, modified from Parent *et al.* (2018); D, modified from Parent *et al.* (2017)

MALARGUENSIS ZONE

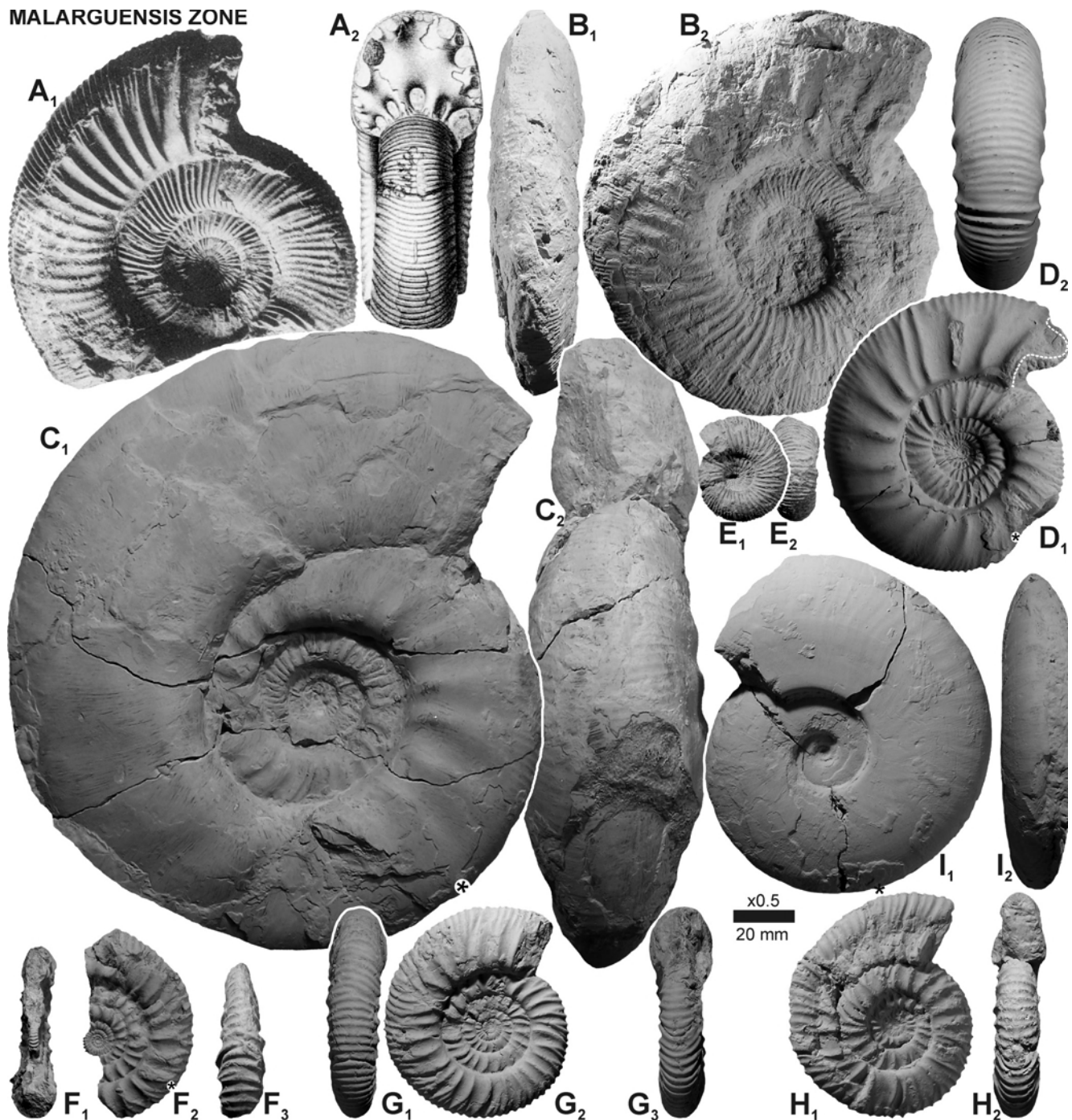


Fig. 19. Guide species

Malarguensis Z. **A.** *Indansites malarguensis*, HT, Casa Pincheira. **B.** *Choicensisphinctes burckhardtii*, adult [M], Pampa Tril. **C–E.** *Choicensisphinctes erinoides*, early transient (C, adult [M]; D, adult [m]; E, nucleus), Cerro Lotena. **F–H.** *Catutosphinctes windhauseni* (F, adult [m], Cerro Granito-I; G, [M] phragmocone, Cerro Granito-I; H, adult [M?] phragmocone), Cerro Lotena. **I.** *Pseudolissoceras zitteli*, early transient, adult [M], Cerro Granito-II.

All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, modified from Burckhardt (1900, 1903); B, modified from Parent *et al.* (2015); C, MOZ-PI-9382/1; D, MOZ-PI-9382/2; E, MOZ-PI-7127/2; F, MOZ-PI-8407; G, MOZ-PI-8408; H, MOZ-PI-4316

fidest distinction of the succeeding faunas (which can be subdivided by several bio-horizons, work in progress).

The alternative zonation proposed by Groeber (1946) of the succession of the Pseudolictor, Choicensis, and Zitteli zones was adopted by Leanza (1973) but soon abandoned, returning (Leanza, 1980) to the former zonation of Burckhardt (1903). Following the paper by Leanza (1980) the succession of the Mendozanus and the Zitteli zones was widely adopted. However, the ammonites described by Leanza (1980: 6) were collected by A. Windhausen without stratigraphic control (discussion in Parent *et al.*, 2011a), and the ammonites were stratigraphically assigned by their identity, but not by direct observation of their positions in the sequence. This is the reason by which the “Mendozanus Zone” fauna Leanza (1980) described appeared to perfectly underlie the first records of *P. zitteli*. This problem was profusely studied in the ammonite successions all through the basin (Parent *et al.*, 2011a, b, 2013, 2015, Garrido *et al.*, 2018), including the very rich sequences of the transect Cerro Lotena-Cerro Granito in the southern Picún Leufú Subbasin (Parent, Garrido, 2021: appendix 1).

Unfortunately the solution proposed by Vennari (2016) consisting of the renaming of the Mendozanus Zone as the Andesensis Zone with a Primordialis Subzone at its base, cannot be accepted because: (1) “*Pseudinvoluticeras*” *primordialis* Vennari, 2016 is a perfect subjective synonym of *C. platyconus* (see Garrido *et al.*, 2018), thus of Picunleufuense Zone age, and (2) *Virgatosphinctes andesensis* Douvillé, 1910 is an invalid species for it was based on two specimens from unknown locality and horizon (see Parent *et al.*, 2011a for details). Specimens matching those figured by Douvillé (1910: pl. 17: 3, 4, paratype and holotype, respectively) can be collected all through the stratigraphic range of *P. zitteli* and they are indistinguishable from the microconch of late *C. erinoides*, i.e. “*V.*” *mendozanus* (!).

The Malarguensis Subzone of Zeiss, Leanza (2010) was introduced in a table, with no explanation, and considered by Vennari (2016: fig. 19) as valid. As Garrido *et al.* (2018) pointed out, the Malarguensis Subzone, considering the stratigraphic range of the index-guide species (*I. malarguensis*), has a stratigraphic position rather equivalent to that of the *malarguensis* Hz. of Parent *et al.* (2011a). Thus, in replacement of the problematic Mendozanus Zone we here re-define the Malarguensis Subzone as a standard zone with

base at the *malarguensis* Hz., overlying the Picunleufuense Zone.

ZITTELI ZONE [BURCKHARDT, 1903]

This zone is here standardized by designation of the widely recorded *perlaevis* Hz. as its base.

- *Index species*: *P. zitteli*.
- *Type locality*: Cajón del Burro-Río Choicas.
- *Guide species* (Fig. 20): late *P. zitteli*, *C. perlaevis*, late *C. erinoides* (see Parent, Garrido, 2021), *Pasottia andina* Parent *et al.*, 2008, *Catutosphinctes* n. sp. aff. *guenenakenensis*, *Physodoceras* sp. A (in Parent *et al.*, 2011a, b, 2015).
- *Horizons*: *perlaevis* Hz., *erinoides* Hz.
- *Remarks*. The stratigraphic range of *P. zitteli* includes most of the Malarguensis and Zitteli zones, but the latter zone is defined by its base at the *perlaevis* Hz. If this bio-horizon is not recorded or recognized in a given section, the zone could be recognized by the guide ammonites listed above.

PROXIMUS ZONE [GROEBER, 1946]

See Garrido *et al.* (2018: 19) for the history of the zone.

- *Index species*: *Catutosphinctes proximus* (Steuer, 1897).
- *Type locality*: Not designated.
- *Guide ammonites* (Fig. 21): *C. proximus*, *Indansites* n. sp. aff. *picunleufuense*, *Pseudhimalayites subpretiosus* (Uhlig, 1878), distinguished from the earlier records in the Zitteli Zone by the less densely tuberculated macroconch, *Cieneguiticeras falculatum* (Steuer, 1897).
- *Horizons*: *falculatum* Hz. (Parent *et al.*, 2011b).

INTERNISPINOSUM ZONE [WEAVER, 1931]

- *Index species*: *Windhauseniceras internispinosum* (Krantz, 1926).

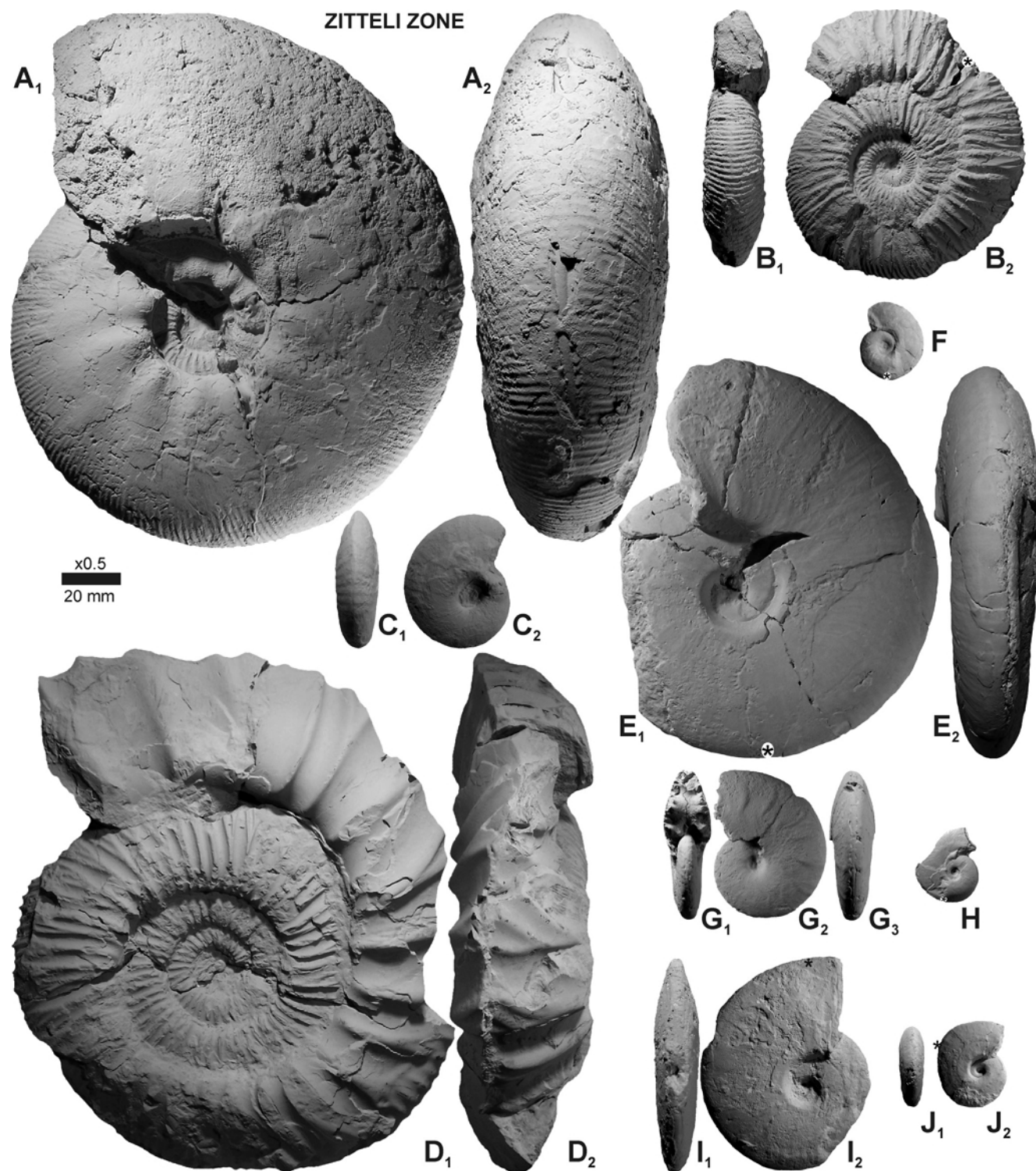


Fig. 20. Guide species

Zitteli Z. **A, B.** *Choicensisphinctes erinoides* transient gamma (A, adult [M]; B, adult [m]), Pampa Tril. **C.** *Physodoceras* n. sp. A, phragmocone, Pampa Tril. **D.** *Catutosphinctes* n. sp. aff. *guenenakenensis*, adult [M], Cerro Lotena. **E, F.** *Pseudolissoceras zitteli* (E, adult [M] from Cerro Lotena; F, adult [m] from Portada Covunco). **G, H.** *Cieneguiticeras perlaevis* (G, adult [M] from Pampa Tril; H, adult [m] from Portada Covunco). **I, J.** *Pasottia andina* (I, HT; J, adult [m]), Cerro Granito-I (La Amarga). All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, C and G, modified from Parent *et al.* (2015); B, modified from Parent *et al.* (2017); D, MOZ-PI-7520-A; E, MOZ-PI-7452; F and H, modified from Parent *et al.* (2013); I, J: modified from Parent *et al.* (2008)

PROXIMUS ZONE

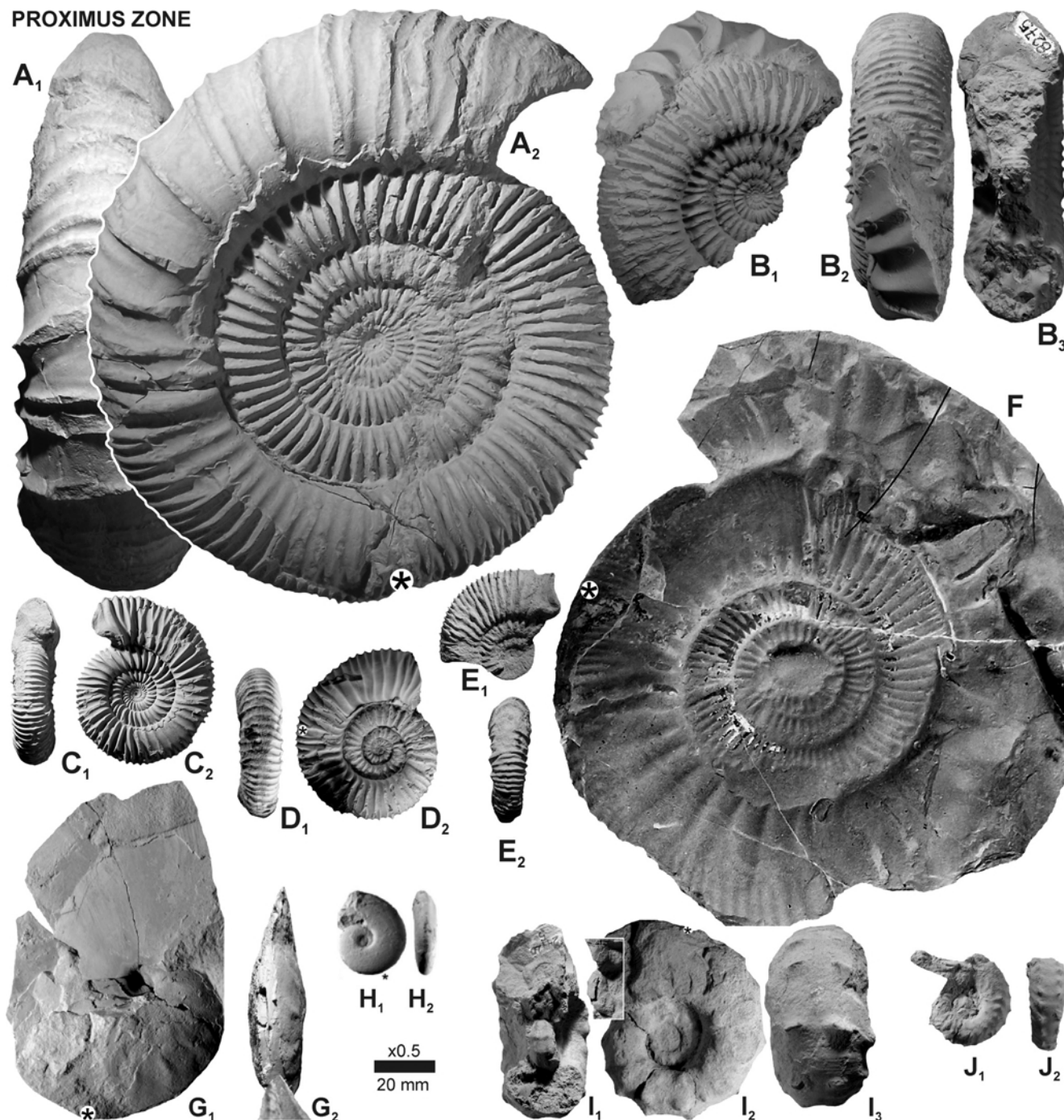


Fig. 21. Guide species

Proximus Z. **A–D.** *Catutosphinctes proximus* (A, large adult [M] from Cerro Lotena; B, small adult [M] from C. Lotena; C, small adult [m] from C. Lotena; D, Lectotype, Arroyo Cieneguita). **E, F.** *Indansistes* n. sp. aff. *picunleufuense* (E, adult [m] from Cerro Lotena; F, adult [M] from A. Cieneguita). **G, H.** *Cieneguiticeras falculatum* (G, adult [M]; H, adult [m]), A. Cieneguita. **I, J.** *Pseudhimalayites subpretiosus* (I, adult [M]; J, adult [m]), Arroyo Cieneguita. All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, MOZ-PI-1383; B, MOZ-PI-8275; C, MOZ-PI-9999/1; D, modified from Parent (2003a); E, MOZ-PI-9999/2; F, modified from Parent *et al.* (2011b); G, H, modified from Parent *et al.* (2010)

This zone has been subdivided by Leanza, Zeiss (1992) into two subzones:

Rafaeli Subzone [Leanza, Zeiss, 1992]

This subzone is derived from the Rafaeli Sub-biozone of Leanza, Zeiss (1992). The *internispinosum-alpha* Hz. is its base, and thus the base of the standard Internispinosum Zone (Parent *et al.*, 2015, 2017b).

- *Index species*: *Catutosphinctes rafaeli* Leanza, Zeiss, 1992.
- *Type locality*: Los Catutos, Argentina.
- *Guide species* (Fig. 22): *C. rafaeli*, early *W. internispinosum*.
- *Horizons*: *internispinosum-alpha* Hz.

Fascipartita Subzone [Leanza, Zeiss, 1992]

This subzone is derived from the Fascipartita Sub-biozone, and here standardized by designation of the *internispinosum-beta* Hz. (new) as its base.

- *Index species*: *Zapalia fascipartita* Leanza, Zeiss, 1990.
- *Type locality*: Los Catutos, Argentina.
- *Guide species* (Fig. 23): *Z. fascipartita*, *Zapalia triplex* Zeiss, Leanza, 2010, *Indansites zapalensis* (Zeiss, Leanza, 2010), late *W. internispinosum*, *Catutosphinctes araucanensis* (Leanza, 1980), *Aspidoceras euomphalum* Steuer, 1897.
- *Horizons*: *internispinosum-beta* Hz. (new), and *catutosensis* Hz. (Zeiss, Leanza, 2010). The *quinchoai* Hz. (Zeiss, Leanza, 2010) is based on specimens collected loose in the field, even including a large macroconch of *P. steinmanni* (Haupt, 1907), with ventral tubercles, from the *internispinosum-alpha* Hz. (see details in Parent *et al.*, 2013). Thus, the *quinchoai* Hz. is not accepted here.

We here introduce the *internispinosum-beta* Hz. (new), which is defined in Cerro Lotena, Argentina, in the bed CL-70 (in Parent, Garrido, 2021: figs. 3, 4), and characterized by the assemblage of *C. araucanensis* (Fig. 23C, D), *W. internispinosum* transient beta (Fig. 23A, B; see also Parent, Garrido, 2021), and *Corongoceras huarpense* Parent, Garrido (2021: fig. 21E).

ALTERNANS ZONE [LEANZA, 1945]

This zone is here standardized by the designation of the *vetustum* Hz. as its base (as characterized in Arroyo Cieneguita, the type locality of the horizon, see Parent *et al.*, 2011b).

- *Index species*: *Steueria alternans* Gerth, 1921.
- *Type locality*: this was not designated explicitly; it was based on the study of the succession of Mallín Redondo, Argentina. It seems possible to consider zones and standard-zones as different units and so they could have different type localities (Arroyo Cieneguita would be the type locality of the Alternans Standard Zone).
- *Guide species* (Fig. 24): *S. alternans* (including three morphotypes: *alternans*, *spinulosa*, and *inaequicostata*, see Parent *et al.*, 2011b), *Corongoceras mendozanum* (Behrendsen, 1891), *Catutosphinctes inflatus* (Leanza, 1945), *Parodontoceras calistoides* (Behrendsen, 1891), *Blanfordiceras vetustum* (Steuer, 1897), *Krantziceras azulense* (Leanza, 1945).
- *Horizons*: *vetustum* Hz., *bardense* Hz., *azulense* Hz.

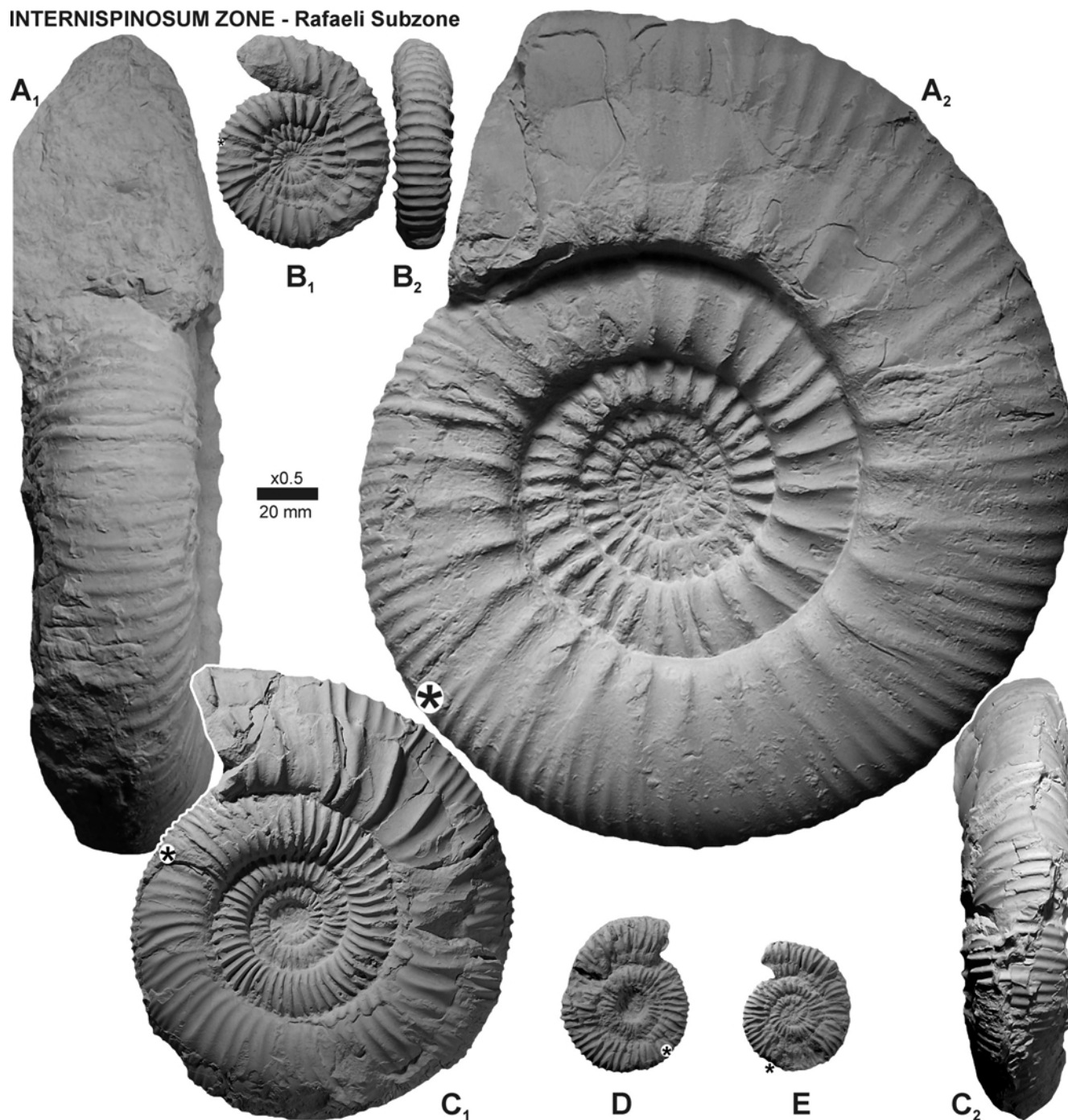
KOENENI ZONE [GERTH, 1925]

This zone is here standardized by the designation of the *striolatus* Hz. as its base.

- *Index species*: *Substeueroceras koeneni* (Steuer, 1897).
- *Type locality*: not designated.
- *Guide species* (Fig. 25): *S. koeneni*, *Choicensisphinctes striolatus* (Steuer, 1897), *Parodontoceras discoidalis* (Gerth, 1925), *Krantziceras planulatum* (Vennari *et al.*, 2012), *Himalayites* cf. *treubi* Boehm, 1904 (in Parent *et al.*, 2015).
- *Horizons*: *striolatus* Hz., *koeneni* Hz., *planulatum* Hz. (see Parent *et al.*, 2011b, 2015).

BERRIASIAN

Time-correlation of the Andean successions with the Tethyan standard was discussed by Leanza (1981), Aguirre-Urreta *et al.* (2007), and Parent *et al.* (2015, 2017b), among others. Additional information was given by Salazar,

INTERNISPINOSUM ZONE - Rafaeli Subzone**Fig. 22. Guide species**

Internispinosum Z., Rafaeli Sz. **A, B.** *Windhausenicerias internispinosum* transient CG-II-98 in Parent, Garrido, 2021 (A, adult [M]; B, adult [m]), Cerro Granito-II. **C–E.** *Catutosphinctes rafaelli* (C, adult [M] from Cerro Lotena; D, adult [m] from Portada Covunco; E, adult [m] from Portada Covunco). All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, B, modified from Parent, Garrido (2021); C, MOZ-PI-9391; D, E, modified from Garrido *et al.* (2018)

INTERNISPINOSUM ZONE - Fascipartita Subzone

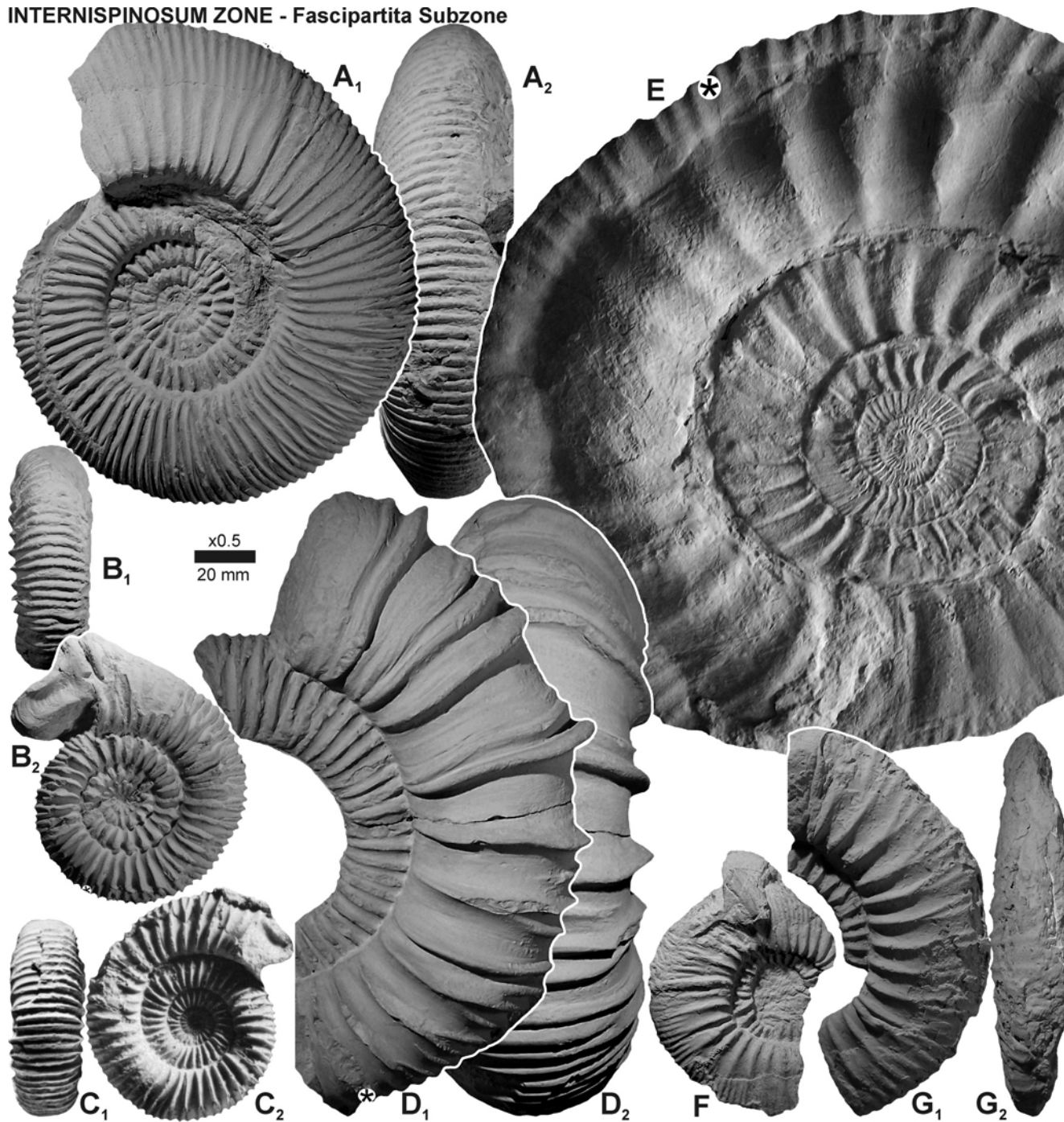


Fig. 23. Guide species

Internispinosum Z., Fascipartita Sz. **A, B.** *Windhauseniceras internispinosum* transient beta (A, adult [M]; B, adult [m]), Cerro Lotena. **C, D.** *Catutosphinctes araucanensis* (C, HT; D, adult [M]), Cerro Lotena. **E.** *Zapalia fascipartita*, adult [M], Los Catutos. **F.** *Indansites zapalensis*, adult [M], Cerro Granito-II. **G.** *Zapalia triplex*, adult [M], Cerro Granito-II.

All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, B, modified from Parent, Garrido (2021); C, modified from Leanza (1980); D, MOZ-PI-7657; E, modified from Parent *et al.* (2017); F, MOZ-PI-5801/3; G, MOZ-PI-5801/2

ALTERNANS ZONE

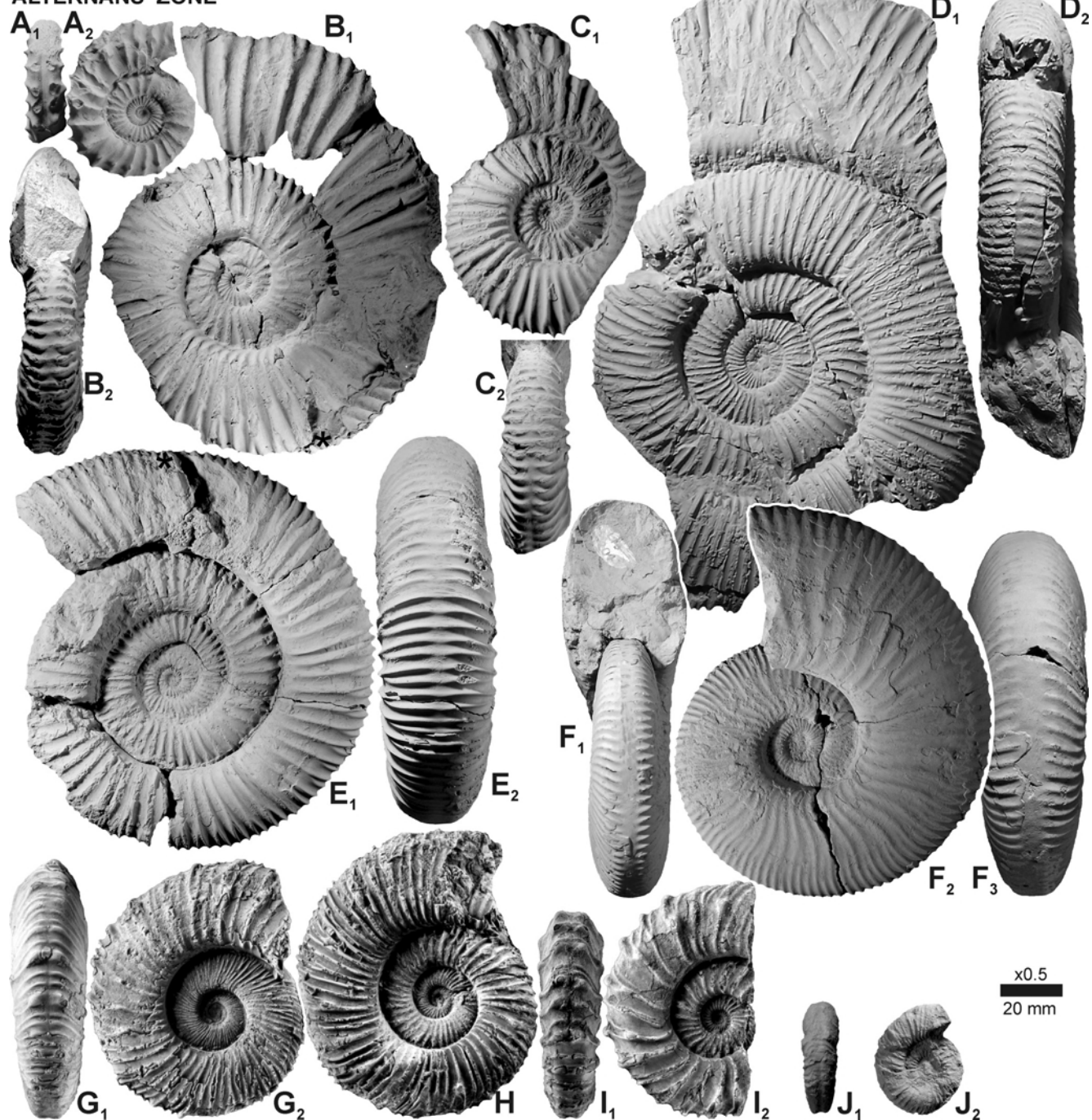


Fig. 24. Guide species

Alternans Z. **A, B.** *Corongoceras mendozanum* (A, adult [m]; B, adult [M]), Arroyo Cieneguita. **C.** *Blanfordiceras vetustum*, adult [M], A. Cieneguita. **D.** *Krantziceras azulense*, adult [M], Pampa Tril. **E.** *Catutosphinctes inflatus*, adult [M], Pampa Tril. **F.** *Parodontoceras calistoides*, adult [M], Casa Pincheira. **G–J.** *Steueria alternans* (G, morph inaequicostata from A. Durazno; H, morph spinulosa from A. Durazno; I, HT from A. Durazno; J, adult [m] from Portada Covunco).

All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A–C, F–H, modified from Parent *et al.* (2011b); D, E, modified from Parent *et al.* (2015); I, modified from Parent (2001); J, modified from Parent *et al.* (2013)

KOENENI ZONE

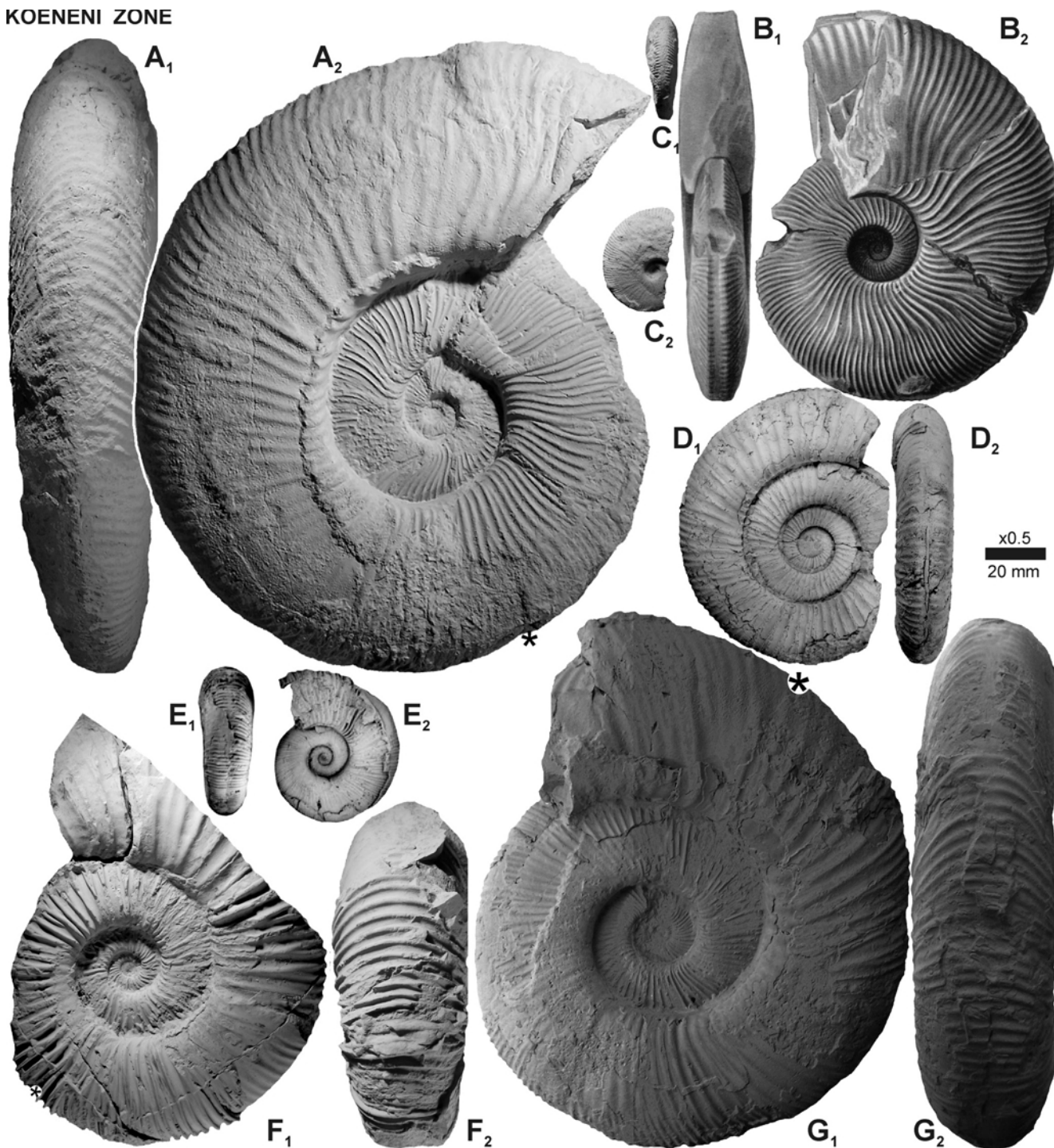


Fig. 25. Guide species

Koeneni Z. **A.** *Substeuerocheras koeneni*, adult [M], Mallín Quemado. **B., C.** *Parodontoceras discoidalis* (B, HT by monotypy, Bardas Blancas; C, nucleus, A. Cieneguita). **D.** *Krantziceras planulatum*, HT, Real de las Coloradas. **E–G.** *Choicensisphinctes striolatus* (E, lectotype, A. de la Manga; F, adult [M], P. Tril; G: adult [M], Cajón de Almanza).

All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, C, modified (with additional preparation) from Parent *et al.* (2011b); B, modified from Gerth (1925); D, modified from Vennari *et al.* (2012); E, modified from Parent (2003); F, modified from Parent *et al.* (2015); G, MOZ-PI-6389

Stinnesbeck (2015) and Salazar *et al.* (2020). The base of the Berriasian (the so-called Jurassic-Cretaceous boundary) is currently a strongly discussed issue. What we can say from the Andean records is that, out of endemic or local forms, the last late Tithonian himalayitids occur in the Andes in the Koeneni Zone (see Parent *et al.*, 2011b, 2015; Parent, Garrido, 2021), below a succession of mostly endemic forms but also including abundant *Subthurmannia boissieri* (Pictet, 1867) which indicates the late Berriasian in the Tethys. Furthermore, *S. boissieri* in some localities of the Andes belongs to an assemblage clearly comparable with coeval assemblages of the Boissieri Zone from southeastern Spain (see Parent *et al.*, 2015, 2017b). Thus, in the Andes, the interval uppermost Koeneni-Noduliferum zones must include a horizon of the same age as the base of the Berriasian in its type locality in the southern Tethys – certainly yet not much studied.

NODULIFERUM ZONE [LEANZA, 1945]

This is widely accepted as the lower zone of the Andean Berriasian (Leanza, 1981; Aguirre-Urreta *et al.*, 2007; Parent *et al.*, 2011b); standardized by means of the definition of its base at the *compressum* Horizon (Parent *et al.*, 2015: 89).

- *Index species*: *Argentiniceras noduliferum* (Steuer, 1897).
- *Type locality*: this was not designated explicitly but was based on the study of the succession of Arroyo del Yeso, Argentina which is also the type locality of the *noduliferum* Hz.
- *Guide species* (Figs. 26, 27): *A. noduliferum*, *Krantziceras compressum* Parent *et al.*, 2011b, *Substeueroceras permulticostatum* (Steuer, 1897), *Groebericeras bifrons* Leanza, 1945, *Raimondiceras alexandrense* Howlett, 1989.
- *Horizons*: *compressum* Hz., *noduliferum* Hz.
- *Remarks*. The *compressum* Hz., the base of the standard Andean Berriasian, is characterized by the association of compressed and evolute morphotypes of *K. compressum* (similar to the holotype), weakly ornamented macro- and microconchs of *G. bifrons*, and evolute and coarsely ornamented macroconchs of *S. fraternum* as illustrated by Leanza (1945) and Parent *et al.* (2011b, 2015). The stratigraphic ranges of most of these species are expanded by new discoveries, but the association of the cited morphotypes is a robust marker. In some levels above the *compressum* Hz. occur some of these species among others which characterize the zone, but not in

the combination of the morphotypes which define the biohorizon.

DAMESI ZONE [GERTH, 1921]

The zone was apparently introduced by Gerth (1921). Spath (1924: 88) adopted the unit as “zone of *Spiticeras damesi*” in his “Spiticeratan Age of the Infravalangian” but without any explanation or discussion. A little later, a detailed description was given by Gerth (1925). The Damesi Zone was standardized by the designation of the *transgrediens* Hz. as its base (Parent *et al.*, 2015: 89, inadvertently labelled “Transgrediens” Zone).

- *Index species*: *Spiticeras damesi* (Steuer, 1897).
- *Type locality*: not designated.
- *Guide species* (Fig. 28): *S. damesi*, *Spiticeras fraternum* (Steuer, 1897), *Subthurmannia boissieri* (Pictet, 1867), *Cyaniceras transgrediens* (Steuer, 1897).
- *Horizons*: *transgrediens* Hz.

FINAL REMARKS

The Andean zonation by ammonites shows the Aalenian, Bajocian, Upper Bathonian, Callovian, Oxfordian, Tithonian, and Berriasian finely subdivided. The lower and middle parts of the Bathonian remain poorly known, mainly because it seems to be poorly represented by marine rocks with ammonites. The Kimmeridgian is mainly represented by continental rocks in the Neuquén and Tarapacá basins, but there are some promising although sparse records.

The elaboration of successions of ammonite biohorizons has proven to be the most effective way for refining the zonal scales, and especially as the tools for the highest resolution possible in stratigraphy for time-correlation. The results available have even provided successful tools in oil exploration.

Time-correlation of the Andean Scale with the Primary Standard Scale is always difficult because of the regional dominance of local groups. However, the fluctuating connection with the Tethys through the Caribbean Corridor, opened windows of faunal exchange allowing closer comparisons in some time intervals. The lack of record of the former Pacific platforms of western South America and of the eastern part of the Caribbean Corridor (northwestern Africa) are major problems for full understanding of the relationships between the Andean and Tethyan faunas, and so time-correlation.

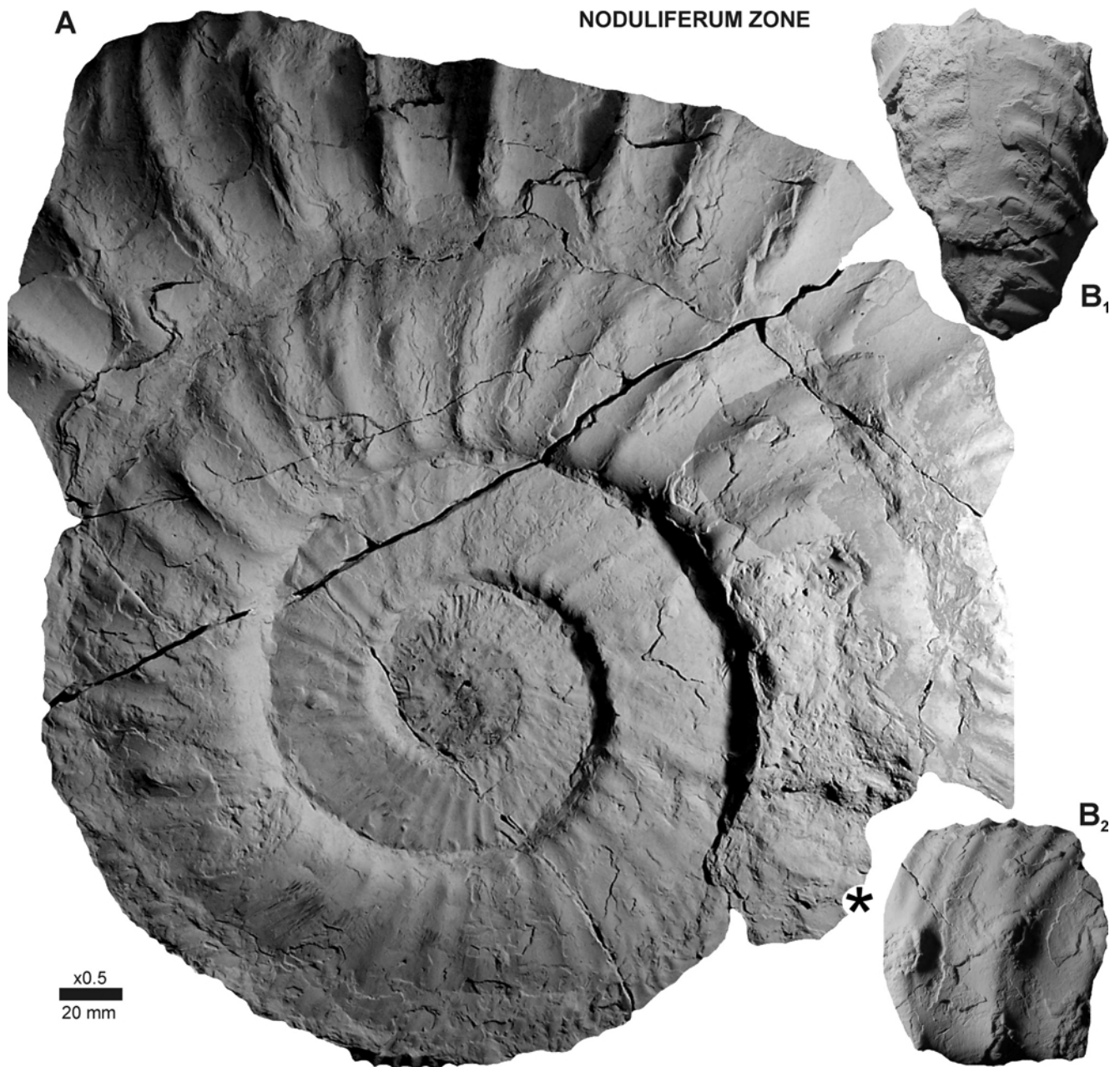


Fig. 26. Guide species

Noduliferum Z. **A, B.** *Argentiniceras noduliferum* (A, adult [M] with the last half whorl of bodychamber preserved; B, portion of adult [M] bodychamber showing the ventral sculpture and relative inflation), Pampa Tril
All reduced to half natural size ($\times 0.5$). Asterisk at last septum. All modified from Parent *et al.* (2015)

NODULIFERUM ZONE

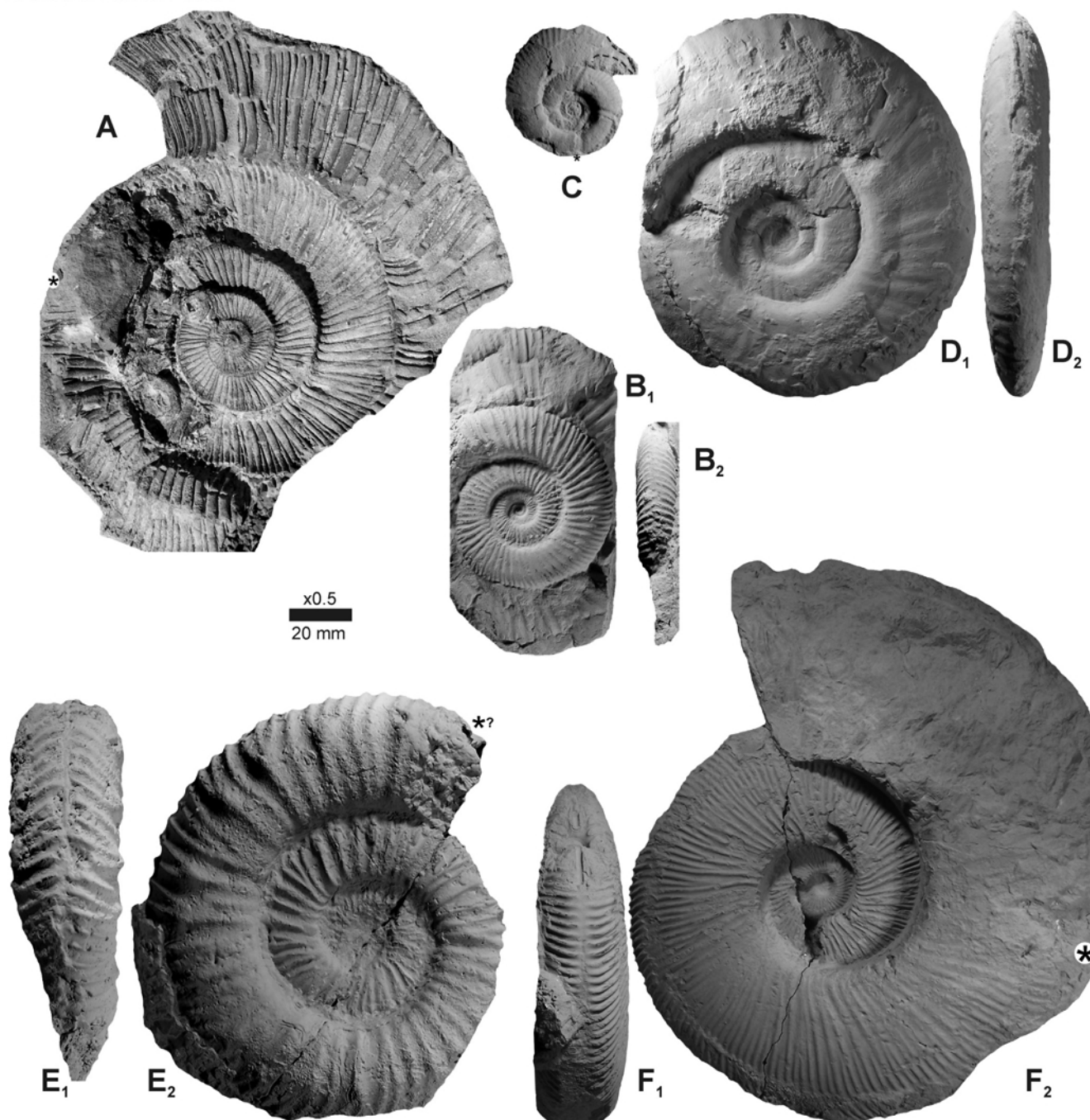


Fig. 27. Guide species

Noduliferum Z. **A, B.** *Krantziceras compressum* (A, adult [M], Pampa Tril; B, HT, Arroyo Cieneguita). **C, D.** *Groebericeras bifrons* (C, adult [m], Pampa Tril; D, adult [M], Mallín Quemado). **E.** *R. alexandrense*, adult [M], Pampa Tril. **F.** *Substeuoceras permulticostatum*, adult [M], Mallín Quemado. All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A, C, E, modified from Parent *et al.* (2015); B, modified from Parent *et al.* (2011b); D, F, modified from Garrido, Parent (2017)

DAMESI ZONE

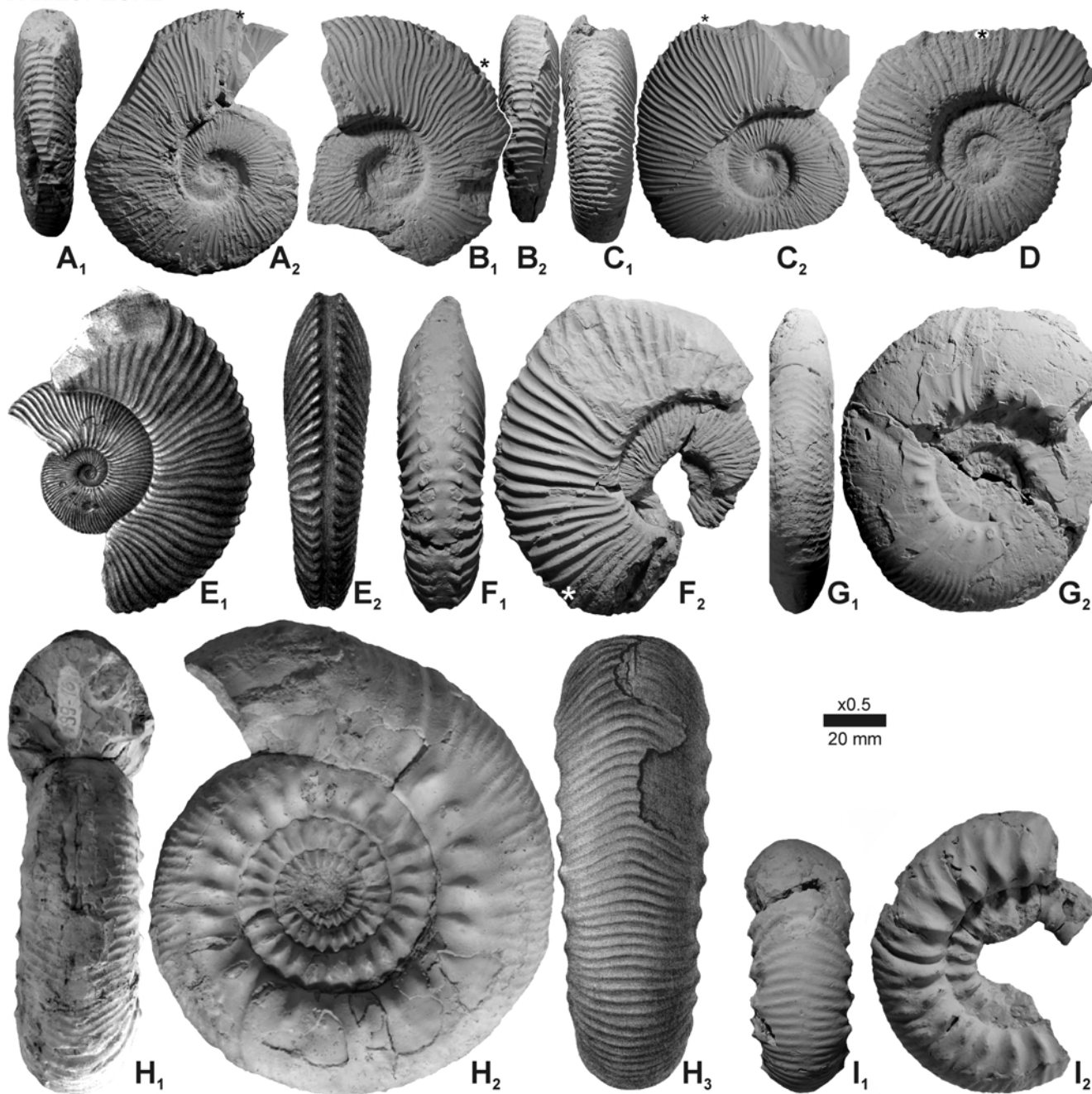


Fig. 28. Guide species

Damesi Z. **A–D.** *Subthurmannia boissieri*, adult macroconchs from Pampa Tril. **E, F.** *Cuyanicerias transgrediens* (E, HT by monotypy, Arroyo Alberjillo; F, adult [M], Casa Pincheira). **G.** *Spiticerias fraternum*, adult [M], Pampa Tril. **H, I.** *Spiticerias damesi* (H, Holotype by monotypy, adult [M], Arroyo Alberjillo; I, adult [M] phragmocone, Sierra Azul, Mendoza).

All reduced to half natural size ($\times 0.5$). Asterisk at last septum. A–D, modified from Parent *et al.* (2017); E, modified from Steuer (1897); F, LPB-199 (Laboratorio de Paleontología, Universidad Nacional de Rosario); G, modified from Parent *et al.* (2015); I, LPB-503. H₁, H₂, Institut für Geowissenschaften der Universität Göttingen (GZG-499-16), H₃, modified from Steuer (1897)

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