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The marine Jurassic of Argentina: a biostratigraphic framework

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In Argentina the best and most complete marine Jurassic succession is exposed between 32° and 39° S, along a N-S belt roughly coincident with the border with Chile. Here all stages, except the Kimmeridgian, are represented by marine facies. Ammonites have provided a biostratigraphic framework to date and correlate lithostratigraphic units and sequences, to reconstruct the history of the marine fill, and allow the development of other palaeontological and geological studies. Recent studies on the systematics and/or biostratigraphy of Andean ammonites have provided the basis for the presentation of a summary of the 45 ammonite zones of the Jurassic of west-central Argentina and to stress its significance in reconstructing the palaeogeographic evolution of that region.

Introduction

Jurassic rocks in Argentina are present over extensive areas (see Figure 1) and include a large variety of marine and continental facies (see Riccardi et al., 1992). South of 39°S marine Jurassic consists of Pliensbachian-Lower Toarcian and uppermost Jurassic strata, represented respectively in central and southern Patagonia. North of 39°S marine Jurassic is exposed along a N-S belt roughly coincident with the boundary between Argentina and Chile, up to 31°S where it becomes restricted to Chile.

The marine Jurassic generally rests unconformably on Upper Triassic (west-central Argentina) and Upper Jurassic volcanites (southern Patagonia) or on Upper Paleozoic (west-central Patagonia). Only in the Rio Atuel region (c. 35° S) does the Jurassic rest transitionally on marine Triassic (see Riccardi et al., 2004).

Thus the best and most complete Jurassic succession is exposed in west-central Argentina, i.e. the Aconcagua-Neuquen or, for short, the Neuquen Basin, where all stages, except the Kimmeridgian, are represented by predominantly marine and marginal-marine siliciclastics, with subordinate carbonates and evaporites. The various lithostratigraphical units (Figure 2) have been referred to the Precuyo-Cuyo (Rhaetian-Callovian), Lotena (Middle Callovian-Oxfordian), and Mendoza (Kimmeridgian-Barremian) groups.

Ammonites present in this succession have been extensively studied, especially in the last 35 years and, as a result, a fine biostratigraphic framework has been progressively developed and correlated with the European biochronological standard (see Riccardi et al., 1990a–c, 2000; Hillebrandt et al., 1992). This ammonite zonation has been used, to date and correlate not only lithostratigraphic units, but also stratigraphic discontinuities bounding sequences or genetic depositional units, and finally to reconstruct the history of the marine fill of the Neuquen Basin (see Legarreta and Gulisano, 1989; Legarreta and Uliana, 1996; Lanes, 2005; Vicente 2005,

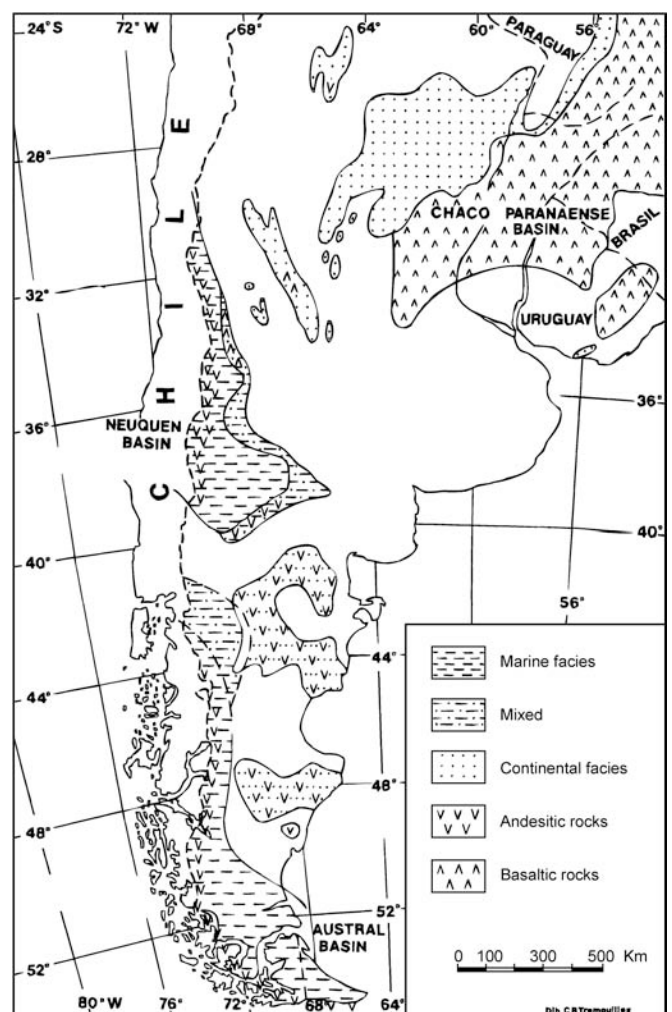


Figure 1 Distribution of Jurassic rocks in Argentina (modified from Stipanovic, 1996).

2006), where the Mesozoic accounts for a large percentage of the Argentine oil and gas production. The same zonation has been found applicable to the marine units exposed in west-central and southern Patagonia, notwithstanding their sparse and poorly preserved faunal record. Additionally ammonite biostratigraphy has provided the basis to biostratigraphic zonations based on other fossil groups, as well as to other paleontological and geological studies, e.g. to document evidence of phyletic gradualism, punctuated equilibrium, and heterochronic processes in Middle Jurassic taxa, to build a Lower Jurassic magnetostratigraphic composite section, to propose an isotope stratigraphy for the Pliensbachian, and to date evidences of a Toarcian global oceanic anoxic event (Riccardi 1985, 2000, 2005; Iglesia Llanos and Riccardi, 2000; Valencio et al., 2005). A number of studies on the systematics and/or biostratigraphy of Andean

System/Series/Stage		Group/Formation		
JURASSIC	UPPER	Tithonian	Mendoza	Vaca Muerta
		Kimmeridgian		Tordillo
		Oxfordian	Lotena	Auquilco La Manga
	MIDDLE	Callovian		Lotena
		Bathonian		Tabanos (Lajas)
		Bajocian		Chacay Melehue,
		Aalenian		Tres Esquinas,
		Toarcian		Los Molles
	LOWER	Pliensbachian	Precuyo - Cuyo	Puesto Araya
		Sinemurian		El Freno
		Hettangian		
		TRIASSIC (Rhetian)		Arroyo Malo

Figure 2 Simplified lithostratigraphic column, west-central Argentina.

ammonites, mostly published in the last 15 years, provided the basis for this summary of the ammonite biostratigraphy of the Jurassic of west-central Argentina and its significance to reconstruct the paleogeographic evolution of that region.

Ammonite biostratigraphy

Thus far, 45 biozones have been recognized in the Jurassic of west-central Argentina, 22 in the Lower Jurassic, 14 in the Middle Jurassic and 9 in the Upper Jurassic (Oxfordian and Tithonian). Data analysis included below is based on genera rather than species, as most genera are restricted to one zone. Ranges and means of genera (total = 137) longevity, when analyzed in terms of Andean ammonite zones, give a mean longevity of 1.4.

Using Remane (2000) and Ogg (2004)'s numerical dates, estimation for the average duration of an Argentine Jurassic Zone gives mean longevity for a genus of 0.8 to 1.3 million years. When the Lower, Middle and Upper (restricted to Oxfordian and Tithonian) Jurassic are discriminated, mean genera longevities are, respectively, of 0.6–1.3, 1.0–1.5, and 1.2 million years. Values for the different stages range from 0.5 (Hettangian), 0.7–1.5 (Callovian), and 0.8–1.0 (Tithonian) to 3.5–4.5 (Sinemurian) and 2.0–2.7 (Oxfordian), as expected, considering that the last two include relatively poorly preserved and/or studied faunas.

Accuracy in the correlation of the local ammonite zonation with the European standard zones varies throughout the different stages, as it is closely related to biogeographic changes, which in turn were controlled by changes in sea-level and in migration routes of seaways between the Tethys and eastern Pacific oceans (see Riccardi, 1991).

Lower Jurassic

Hettangian and Sinemurian fossil assemblages are only present in the Rio Atuel area (c. 35° S). Pliensbachian and Toarcian assemblages are present in west-central Argentina from 30° to 40° and have also been recorded from west-central Patagonia.

Hettangian

Rhaetian and Hettangian ammonites were recorded and figured by Riccardi et al. (see 2004). The Hettangian fauna and biostratigraphy was also described by Hillebrandt (2000).

1. *Psiloceras rectocostatum* Assemblage Zone. Originally defined from northern Chile (see Hillebrandt, 2000), was extended to the Rio Atuel area, where specimens comparable to the nominal species occur (see Riccardi et al., 2000, 2004). Early Hettangian, Late Plicatulus and Early Johnstoni Subzones of the Planorbis Zone. Ammonites coeval to the Planorbis Subzone have yet to be documented, but they might be represented by c. 80 m, apparently unfossiliferous, between levels with *Choristoceras* cf. *marshi* Hauer (Rhaetian) and *P.* cf. *rectocostatum* Hill. Loose material, compara-

STAGES	STANDARD ZONES	ARGENTINA
TOARCIAN	AALENSIS	22. Dumortieria
	PSEUDORADIOSA	-----
	DISPANSUM	21. <i>P. tenuicostatum</i>
	THOUARSENSE	20. <i>Phymatoceras</i>
	VARIABILIS	19. <i>C. chilensis</i>
	BIFRONS	18. <i>P. pacificum</i> 17. <i>P. largaeense</i>
	SERPENTINUM	16. <i>D. hoelderi</i>
PLIENSBACHIAN	TENUICOSTATUM	15. TENUICOSTATUM
	SPINATUM	14. <i>F. disciforme</i>
	MARGARITATUS	13. <i>F. fannini</i>
	DAVOEI	12. <i>A. behrendseni</i>
	IBEX	11. <i>E. meridianus</i>
SINEMURIAN	JAMESONI	10. <i>M. externum</i>
	RARICOSTATUM	9. <i>M. chilcaense</i>
	OXYNOTUM	8. <i>Orthechioceras</i> - <i>Paltechioceras</i>
	OBTUSUM	-----
	TURNERI	?
	SEMICOSTATUM	7. <i>Coroniceras</i> - <i>Arnioceras</i>
HETTANGIAN	BUCKLANDI	6. " <i>Vermiceras</i> " 5. <i>B. canadensis</i> 4. <i>S. peruvianus</i>
	ANGULATA	3. <i>D. reissi</i> 2. <i>K. bayoensis</i>
	LIASICUS	1. <i>P. rectocostatum</i>
	PLANORBIS	-----

Figure 3 Correlation chart for the Lower Jurassic of west-central Argentina (Duration of stages from Remane, 2000).

ble with *Psiloceras erugatum* Buck. and *P. pressum* Hill., is indicative of the lower to middle part of the Planorbis Zone (see Riccardi et al., 2004).

2. **Kammerkarites bayoensis Assemblage Zone.** Defined from northern Chile (Hillebrandt, 2000) in Argentina, it appears to be present in the Rio Atuel region (as “*Psiloceras* Assemblage Zone” in Riccardi et al., 1991), with *K. cf. bayoensis* Hill. *K. cf. chinchillaensis* Hill. (MLP 22245), *P. cf. crassicoatum* (Guex) (MLP 22247) (Figure 4.1), *P. sp.* (MLP 22248), and “*Alsatites cf. liasicus* (d’Orb.)”. Middle Hettangian, Early Liassic Zone.

3. **Discamphiceras reissi Assemblage Zone.** Defined from northern Chile (Hillebrandt, 2000), a few of the included species appear to be present in the Rio Atuel (as lower part of the “*Waehneroceras-Schlotheimia* Assemblage Zone” in Riccardi et al., 1991), i.e. *Kammerkarites cf. diploptychoides* Guex (MLP 22249) and *Storhoceras cf. frigga* (Wahner) (MLP 22251) (Figure 4.2). Middle Hettangian, Late Liassic Zone.

4. **Sunrisites peruvianus Assemblage Zone.** Zone defined from northern Chile (Hillebrandt, 2000). Only one species of those included in this zone appears to be present in the Rio Atuel area (as upper part of the “*Waehneroceras-Schlotheimia* Assemblage Zone” in Riccardi et al., 1991), i.e. *Schlotheimia? cf. cachinensis* Hill. (MLP 22250, 22252) (Figure 4.3), which occurs together with *Paracaloceras cf. coregonense* (Sow.). Middle to Late Hettangian, Late Liassic and Early Angulata Zones.

5. **Badouxia canadensis Assemblage Zone.** Originally introduced for the Upper Hettangian of the Taseko Lakes, Canada, is represented in the Rio Atuel area (see Riccardi et al., 1991). In northern Chile (Hillebrandt, 2000) it has been divided into two subzones, from below, the *Schlotheimia cuevitensis* and *Paracaloceras varaense* Subzones.

In Argentina, the *B. canadensis* assemblage includes, besides the nominal species species (Figures 4.4–5), *Paracaloceras cf. rursicostatum* Frebold, *Angulaticeras cf. marmoreum* (Oppel), and *Paracaloceras sp.* Hettangian (? to Sinemurian), Late Angulata (? to Early Bucklandi) Zones.

6. “**Vermiceras Assemblage Zone**”. Introduced by Riccardi et al. (see 1991) on the basis of “*Vermiceras cf. gracile* (Spath) and *Vermiceras spp.*”, and considered by Hillebrandt (2000) as equivalent to the upper part of the *P. varaense* Subzone, *Canadensis* Zone (see above). As indicated by Hillebrandt (2000), material compared with *V. gracile* (see Figures 4.6–7) could in fact be referred to *Paracaloceras varaense* Hill., but this would imply that this species ranges well above the last record of *B. canadensis*, *P. cf. rursicostatum*, and *A. cf. marmoreum*. Therefore, distinction of two biozones on the basis of this (and other?) Arietitidae cannot be ruled out. Resolution of this issue must await a systematic study, now underway, of the Arietitidae present in the area. (?Hettangian to) Sinemurian, (?Late Angulata to) Early Bucklandi Zone(s).

Sinemurian

Sinemurian ammonites in Argentina are restricted to the Rio Atuel region, and were figured by Riccardi et al. (1991). Late Sinemurian material was described by Hillebrandt (2002) in a monographic study, where he recognized eleven ammonite horizons, four equivalent to the Obtusum Sandard Zone, two to the Oxynotum S.Z., and five to the Raricostatum S.Z. Thus far only three of the last five have been found in Argentina.

7. **Coroniceras-Arnioceras Assemblage Zone.** Replacement name for the “*Agassiceras* Assemblage Zone” of Riccardi et al. (see 1991, 2000). With *Coron-*

iceras (C.) cf. alcinoe (Rey.) (Figures 4.8–9), *Coroniceras spp.* and *Pseudaetomoceras? cf. arcuatum* Hill. (MLP 22262), and poorly preserved material referable, in part, to *Arnioceras spp.* Early Sinemurian, Bucklandi and Semicostatum (?to Obtusum) Zones. *Pseudaetomoceras arcuatum* was used by Hillebrandt (2000) to recognize a faunal horizon at the Hettangian-Sinemurian boundary, overlying the *B. canadensis* Zone and underlying a succession characterized by Arietitidae of the Bucklandi Zone. In the Arroyo Malo section material comparable to this species is present in levels well above the last *Badouxia*, following levels containing material comparable, in part, with *P. varaense* (see above under “*Vermiceras Assemblage Zone*”).

8. **Orthechioceras-Paltechioceras Faunule.** Replacement name for the “*Epophioceras* Faunule” of Riccardi (see Riccardi et al., 1991, 2000). Equivalent to three ammonite horizons defined by Hillebrandt (2002), i.e., from below, Horizon with *Orthechioceras*

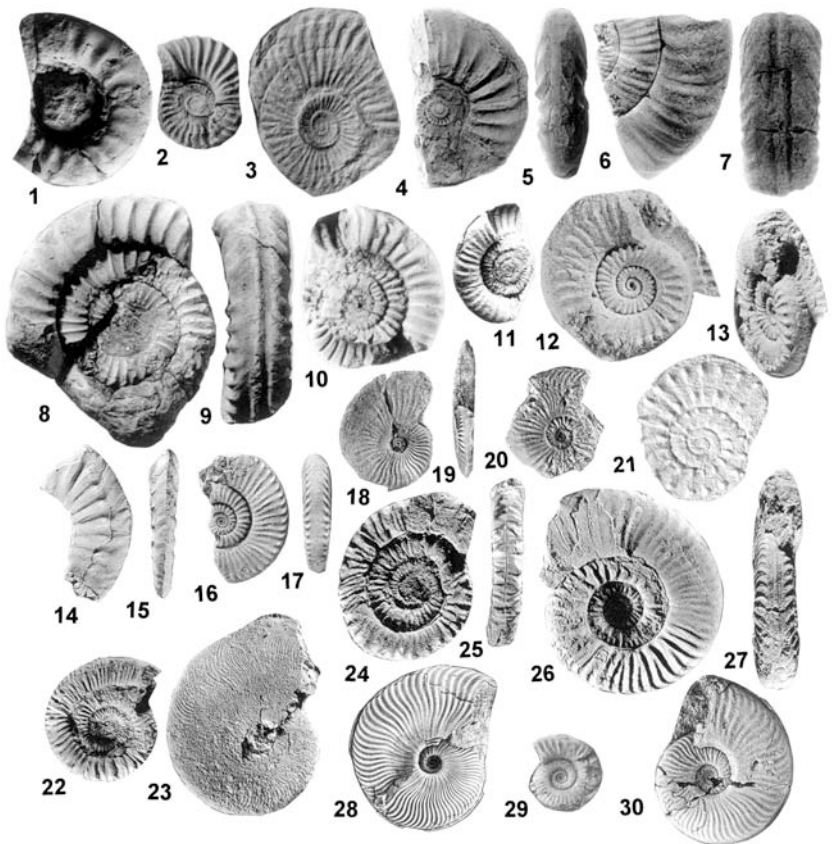


Figure 4 Lower Jurassic ammonites. Hettangian: 1, *Psiloceras cf. crassicoatum* (Guex) (MLP 22247), 2, *Storhoceras cf. frigga* (Wahner) (MLP 22251), 3, *Schlotheimia? cf. cachinensis* Hill. (MLP 22250), 4–5, *Badouxia canadensis* (Freb.) (MLP 22255); Sinemurian: 6–7, *cf. Paracaloceras varaense* Hill. (MLP 22259), 8–9, *Coroniceras (C.) cf. alcinoe* (Rey.) (MLP 22264), 10, *Orthechioceras incaguasiense* Hill. (TUB 790210/2a/2), 11, *Paltechioceras cf. tardecrescens* (Hauer) (TUB 790210/5/1), 12–13, *Miltoceras chilcaense* Hill. (TUB 790212/2/2), 14–15, *Meridiceras cf. externum* Hill. (TUB 790213/3/4), 16–17, *Eoamalthus parameridianus* Hill. (TUB 790209/6/1), 18–19, *Austromorphites behrendseni* (Jaw.) (SIPUB 65A), 20, *Fanninoceras cf. latum* McLearn (TUB 841206/3a), 21, *Canavaria (Tauromenicerus) sp.* (J 21661a); Toarcian: 22, *Peronoceras pacificum* Hill. (CPBA 17529), 23, *Harpoceras subplanatum* (Oppel) (CPBA, 17601), 24–25, *Collina chilensis* Hill. (CPBA 17459), 26–27, *Phymatoceras cf. pseudoerbaense* (Gabilly) (CPBA 16514), 28, *Phlyseogrammoceras? tenuicostatum* (Jaw.) (TUB 790222/2), 29, *Dumortieria cf. pusilla* (Jaw.) (TUB 680109/13), 30, *Pleydellia cf. lotharingica* (Branco) (TUB 680109/10). Repositories: CPBA, Universidad de Buenos Aires; J, Naturh. Museum Basel; MLP, Museo de la Plata; SIPUB, Universität Bonn; TUB, Technische Universität Berlin; Figs. 10–21, 28–30, in part modified, from Hillebrandt, 1987, 2002, 2006; 22–27, modified from Alvarez, 1996. All figures $\times 0.28$, except figures 1–3, 10–13, 21, $\times 0.56$.

incaguasiense and *Plesechioceras domeykoense*, Horizon with *Paltechioceras* cf. *romanicum*, and Horizon with *Paltechioceras oosteri* and *P. cf. tardecrescens*. This faunule is characterized by *O. incaguasiense* Hillebrandt (MLP 22263) (Figure 4.10), *P. domeykoense* Hill., *P. cf. romanicum* (Uhlrig), *P. oosteri* (Dumortier) and *P. cf. tardecrescens* (Hauer) (Figure 4.11). Late Sinemurian, *Raricostatum* Zone.

Pliensbachian

Pliensbachian ammonites are widespread and well known in west-central Argentina (see Riccardi et al., 1991). Pliensbachian material, mostly from the Río Atuel area, was described and figured by Hillebrandt (2006).

9. ***Mitoceras chilcaense* Assemblage Zone.** Introduced by Hillebrandt (2006) for an assemblage typically represented in the Río Atuel region. Equivalent to the “*Mitoceras* Faunule” of Riccardi (see Riccardi et al., 1990a, 2000), with *M. chilcaense* Hill. (Figure 4.12–13), *M. reductispinosum* Hill., *M.?* sp. A, *Tropidoceras? hamulatum* Hill., *T. cf. aff. demonense* (Gemm.). Early Pliensbachian, Early Jamesoni Zone. The regional Pliensbachian strato-type was defined (Westermann and Riccardi, 1989) at the base of this zone, Río Atuel.

10. ***Meridiceras externum* Assemblage Zone.** Introduced by Hillebrandt (2006) for an assemblage typically represented in the Río Atuel region. Equivalent to the lower part of the “*Dubariceras* Assemblage Zone” of Riccardi et al. (1990a) or “*Tropidoceras* Zone or Assemblage Zone” of Hillebrandt (1987) and Riccardi et al. (2000). It consists of *M. cf. externum* Hill. (Figures 4.14–15), *M. celericrescens* Hill., *M. amolanasense* Hill., *M. densicostatum* Hill., *Tropidoceras* cf. *demonense* (Gemm.), *T. flandrini* cf. *flandrini* (Dum.), *T. f. cf. obtusum* (Futt.), *T. cf. mediterraneum* (Gemm.), *T. cf. ex gr. zitteli* Fuc., *T. atuelense* Hill., *Andicoeloceras* sp. A., *Dubariceras argentinicum* Hill., *Liparoceras* (L.) cf. *cheltiense* (Murch.), *Phylloceras hebertinum* (Rey.), *Partschiceras striatocostatum* (Meneg.), *Juraphyllites libertus australis* Hill., *J. sp. A.* Early Pliensbachian, Late Jamesoni and Early Ibex Zones.

11. ***Eoamalthus meridianus* Assemblage Zone.** Introduced by Hillebrandt (1987, 2006) for northern Chile and the Río Atuel region, Argentina. Equivalent to the upper part of the “*Dubariceras* Assemblage Zone” of Riccardi et al. (1990a, 2000), with *E. meridianus* Hill., *E. parameridianus* Hill. (Figures 4.16–17), *E. paraovatus* Hill., *E. multicostatus* Hill., *E. ovatooides* Hill., *E. intermissus* Hill., *E. blancoensis* Hill., *E. arayaensis* Hill., *Calliphylloceras* cf. *bicicola* (Meneg.), *Juraphyllites* cf. *planispira* (Reynes). Early Pliensbachian, Latest Ibex and Early Davoei Zones.

12. ***Austromorphites behrendseni* Assemblage Zone.** Introduced by Hillebrandt (1987, 2006) for west-central Argentina. Is equivalent to the lower part of the “*Fanninoceras* Assemblage Zone” of Riccardi (Riccardi et al., 1990a, 2000), with *A. behrendseni* (Jaworski, incl. *A. spinatus* Leanza and Blasco, 1990) (Figures 4.18–19), *A. volkheimeri* (Hill.), *A. multiformis* (Hill.), *A. prorsiflexus* (Hill.), *A. carinatus* (Hill.), *A. piutrinensis* (Hill.), *Zetoceras* cf. *indicarensis* (Haas), *Fanninoceras* sp. A, *Liparoceras* (*Bechei*) cf. *bechei* (J. Sow.). Late Early Pliensbachian, Davoei Zone.

13. ***Fanninoceras fannini* Assemblage Zone.** Introduced by Hillebrandt (1987, 2006) for northern Chile. In west-central Argentina is equivalent to the middle part of the “*Fanninoceras* Assemblage Zone” of Riccardi (Riccardi et al., 1990a, 2000), with *F. fannini* McLearn, *F. leptodiscus* (Behr.), *F. cf. latum* McLearn (Figure 4.20), *F. carlottense* McLearn. Late Early and Early Late Pliensbachian, Late Davoei and Early Margaritatus Zones.

14. ***Fanninoceras disciforme* Assemblage Zone.** Introduced by Hillebrandt (1987, 2006) for northern Chile. Equivalent to the upper part of the “*Fanninoceras* Assemblage Zone” of Riccardi (see Riccardi et al., 1990a, 2000), in west-central Argentina includes *F. disciforme* Hill., *Canavaria* (C.) cf. *finitima* (Fucini), *C. (C.) cf. naxensis* (Gemm.), *C. (C.) cf. pulcherrima* (Fuc.), *C. (Taoumeniceras)* sp. (Figure 4.21), *Neolioceratoides* sp., *Arietoceras* sp., *Protogram-*

moceras sp. Late Pliensbachian, Late Margaritatus and Spinatum Zones

Toarcian

Toarcian ammonites are widespread, but poorly known in west-central Argentina (see Riccardi et al., 1990a).

15. ***Tenuicostatum Standard* Zone.** This European Standard Zone was extended to the Andes (see Hillebrandt, 1987). In Argentina appears to be present with *Dactylioceras* (*Eodactylites*) sp., *D. (Orthodactylites)* sp. Early Toarcian.

16. ***Dactylioceras hoelderi* Assemblage Zone.** Introduced for Chile, is present in Argentina (see Hillebrandt, 1987; Riccardi et al., 1990a, 2000; Hillebrandt et al., 1992), with *D. hoelderi* Hill. and Schm.-Eff., *Nodicoeloceras* sp., *Harpoceratoides* cf. *alternatus* (Simps.), *Hildaites* cf. *murleyi* (Moxon). Early Toarcian, Serpentinum Zone.

17–19. ***Peronoceras largaense*, *P. pacificum*, and *Collina chilensis* Assemblage Zones.** Introduced for Chile, are present in Argentina (see Hillebrandt, 1987; Riccardi et al., 1990a, 2000; Alvarez, 1996) with *Peronoceras* cf. *subarmatum* (Y. and B.), *P. cf. vortex* (Simps.), *P. pacificum* Hill. and Schm.-Eff. (Figure 4.22), *Harpoceras* cf. *subexaratum* Bon., *H. subplanatum* (Oppel) (Figure 5.23), *Frechiella* cf. *helvetica* Renz, *Collina chilensis* Hill. and Schm.-Eff. (Figures 4.24–25), *Maconiceras* sp., *Polyplectus* sp. Late Early and Early Late Toarcian, Bifrons and Early Variabilis Zones.

20. ***Phymatoceras* Assemblage Zone.** Equivalent to the *P. toroense*, and *P. copiapense* zones of Hillebrandt (1987). In Argentina (Riccardi et al., 1990a, 2000) with *P. copiapense* (Morice), *P. ex gr. lilli* (Hauer), *P. ex gr. erbaense* (Hauer), *P. cf. pseudoerbaense* (Gab.) (Figures 4.26–27). Late Toarcian, latest Variabilis and Thouarsense Zones.

21. ***Phlyseogrammoceras* (?) *tenuicostatum* Assemblage Zone.** Well represented in Argentina (Riccardi et al., 1990a, 2000; Alvarez, 1996), with *P. (?) tenuicostatum* (Jaw.) (Figure 4.28), “*Witchellia*” *obscurecostata* Jaw., *Hammatoceras insigne* (Schubler), *Sphaero-coeloceras* cf. *brochiiiforme* Jaw. Late Toarcian, Dispansum Zone.

22. ***Dumortieria* Assemblage Zone.** Equivalent to the *Pleydellia lotharingica* and *P. fluitans* zones of Hillebrandt (1987). In Argentina (Riccardi, 2000; Riccardi et al., 1990a, 2000) with *D. pusilla* Jaw. (Figure 4.29), *Pleydellia* spp. (Figure 4.30), *Sphaero-coeloceras brochiiiforme* Jaw., *Hammatoceras* sp. Late Toarcian, Late Pseudoradosa and Aalensis Zones.

Middle Jurassic

Middle Jurassic ammonite assemblages are widespread in west-central Argentina. Ammonoid biozones were previously summarized by Hillebrandt et al. (1992) and Riccardi et al. (1994), and are updated below.

Aalenian

23. ***Bredyia manflasensis* Assemblage Zone.** Poorly represented in west-central Argentina (see Riccardi et al., 1990b, 2000; Riccardi, 2000). With *B. cf. manflasensis* West. (Figure 6.1), *B. delicata* West., *Westermanniceras groeberi* (West. and Ricc.), *?Leioceras* sp. Early to Middle Aalenian, Opalinum and Early Murchisonae Zone.

24. ***Westermanniceras groeberi* Assemblage Zone.** Introduced by Westermann and Riccardi (see Riccardi et al., 1990b, 2000; Riccardi, 2000), and represented throughout west-central Argentina, with *W. groeberi* (West. and Ricc) (Figure 6.2), *Planammatoceras* cf. *planiforme* Buck., *Podagrosiceras athleticum* Maub. and Lamb., *Tmetoceras* spp. Middle Aalenian, Murchisonae Zone.

25. ***Malarguensis Standard* Zone.** Introduced by Westermann and Riccardi (see Riccardi et al., 1990b, 2000; Hillebrandt et al., 1992), includes from below, the Subzones of *Puchenquia compressa* and *P. mendozana* and the *Podagrosiceras maubeugei* Horizon. Widespread in west-central Argentina, with *Puchenquia* (*P.*)

STAGES	STANDARD ZONES	ARGENTINA	
CALLOVIAN	U	LAMBERTI	
		ATHLETA	
	M	CORONATUM	36. <i>R. patagoniensis</i>
		JASON	35. PROXIMUM
	L	GRACILIS / CALLOVIENSE	34. BODENBENDERI
		BULLATUS	33. VERGARENSIS
BATHONIAN	U	DISCUS	
		RETROSTATUM	
	M	BREMERI	31. <i>Cadomites - Tulitidae</i>
		MORRISI	
		SUBCONTRACTUS	
		PROGRACILIS	
	L	AURIGERUS	30. <i>M. gulisanoi</i> <i>Lobosphinctes</i>
		ZIGZAG	
BAJOCIAN	U	PARKINSONI	
		GARANTIANA	
		NIORTENSE	
	L	HUMPHRIESIANUM	28. HUMPHRIESIANUM
		PROPINQUANS	27. GIEBELI
		LAEVIVUSCULA	26. SINGULARIS
		DISCITES	
U	CONCAVUM	25. MALARGUENSIS	
AALENIAN	M	MURCHISONAE	
	L	OPALINUM	

Figure 5 Correlation chart for the Middle Jurassic of west-central Argentina.

malarguensis (Burck.) (Figure 6.3), *P. (Gerthicerias) compressa* West. and Ricc., *P. (G.) mendozana* West. and Ricc., *Planammato-ceras (Pseudaptetoceras) klimakomphalum* (Vacek), *P. (P.) tricolore* West. and Ricc., *P. gerthi* (Jaw.), *Eudmetoceras amplexens* (Buckman), *Csernyeiceras moerickei* (Jaw.), *Euhoplloceras amosi* West. and Ricc., *Podagrosiceras athleticum* Maub. and Lamb., *Praeleptosphinctes jaworskii* West. Late Aalenian to earliest Bajocian, Concavum to Early Discites Zones.

Bajocian

26. **Singularis Standard Zone.** Widespread in west-central Argentina. With *Pseudotoites singularis* (Gottsche) (Figure 6.4), *P. sphaeroceroideis* (Tornq.), *P. crassus* West. and Ricc., *P. transatlanticus* (Tornq.), *P. argentinus* Arkell, *Sonninia (Euhoplloceras) amosi* West. and Ricc., *S. (Fissiloboceras) zitteli* (Gott.), *S. (Papilliceras) espinazitensis altecostata* Tornq. Early Bajocian, Late Discites and Early Laeviuscula Zones. The regional Bajocian stratotype was defined (Westermann and Riccardi, 1989) at the base of this zone at Cerro Puchenque, Mendoza province.

27. **Giebeli Standard Zone.** Widespread in west-central Argentina, it includes, from below, the subzones of *E.g. submicrostoma* and *E. multiformis*, and the *Dorsetensia blancoensis* Horizon. With *E. (E.) multiformis* (Gott.), *E. (E.) aff. brochii* (Sow.), *E. (E.) vagabunda* Buck., *E. (Chondromileia) giebeli* (Gott.) (Figures 6.5–6), *Chondroceras recticostatum* West. and Ricc., *Stephanoceras (Skirroceras) cf. macrum* (Quenst.), *Sonninia (P.) espinazitensis* Tornq., *Witchellia* sp., *Dorsetensia mendozai* West. and Ricc., *D. blancoensis* West. and Ricc. Early Bajocian, Late Laeviuscula and Propinquans Zones.

28. **Humphriesianum Standard Chronozone.** The originally European standard zone was extended to northern Chile (see Riccardi et al., 1990b, 2000) where it includes, from below, the sub-

zones of *Dorsetensia romani*, *Stephanoceras chilense* and *Duashnoceras chilense*. It is rare in west-central Argentina, with *Stephanoceras (S.) pyritosum* (Qu.) (Figure 6.7), *S. (Stemmatoceras) aff. frechi* (Renz), *Duashnoceras paucicostatum chilense* (Hill.), *Teloceras crikmayi chacayi* West. and Ricc., *Dorsetensia romani* (Oppel), *D. liotraca* (Buckman).

29. **Rotundum Standard Chronozone.** Introduced for North America, was recognized in the Andes by Westermann and Riccardi (see Riccardi et al., 1990b, 2000), is rare in west-central Argentina, where it is present with *Megaspaheroceras magnum* Ricc. and West. (Figure 6.8), *Cadomites cf. daubenyi* (Gemm.), *C. aff. deslongchampsii* (d'Orb.), and *Leptosphinctes* sp. Late Bajocian, Niortense to Garantiana Zones. Beds correlative to the Parkinsoni Zone are probably present as indicated by the presence of *Lobosphinctes intersertus* Buck., a species typical of the English Upper Bajocian Parkinsoni Zone, but extending into the Lower Bathonian.

Bathonian

30. **Morphoceras gulisanoi Assemblage Zone.** This assemblage, defined by Riccardi and Westermann (1999) and Riccardi et al. (2000), is typically developed in Sierra de Reyes (c. 37° S, 69° 45' W), and probably occurs in Chacay Melehue (c. 37° 15' S, 70° 30' W), above the Rotundum Zone. The *M. gulisanoi* assemblage is characterized by *M. gulisanoi* Ricc. and West. (Figures 6.9–10), *Procerites cf. schloenbachi* (de Grossouvre), *Oxycerites cf. aspidoideis* (Rollier). Early Bathonian, Zigzag Zone.

31. **Cadomites-Tulitidae Mixed Assemblage.** Defined by Riccardi et al. (see 1990b) for a partially reworked fauna found in Chacay Melehue. Includes *Cadomites* ex gr. *orbignyi* (De Gross.) and *bremeri* Tsereteli, *C. ex gr. rectelobatus* (Hauer) (Figure 6.11), occurring with *Tulites (Rugiferites?) cf. davaiacensis* (Liss.), a species known from the Middle Bathonian, and *Bullatimorphites (Kheraicerias) cf. bullatus* (Orb.), and *Choffatia (Homoeoplanulites) ex gr. aequalis* (Roem.), indicating the Upper Bathonian. Similar ammonites were reported from northern Chile by Gröschke and Hillebrandt (1994) and placed in the Middle Bathonian *Rugiferites sofanus* Assemblage Zone. Middle to Late Bathonian.

32. **Steinmanni Standard Zone.** Defined by Riccardi et al. (see 1990b) at Chacay Melehue, Neuquen province. The lower part is characterized, besides the index species (Figure 6.12), by *Choffatia (Homoeoplanulites) ex gr. aequalis* (Roem.), *Iniskinites crassus*, *I. gulisanoi*, Ricc. and West., and the upper part, i.e. the *Stehnocephalites gerthi* Horizon, by *S. gerthi* (Spath), *L. australis* Ricc. and West. *Xenocephalites cf. araucanus* (Burck.), *Neuquenicerias (N.) steinmanni* Stehn, *N. (N.) biscissum* (Stehn), *Oxycerites obsoletoides* Ricc. et al., *Choffatia jupiter* (Stein.). Late Bathonian, Retrocostatum and Discus Zones. A possible distinction (see Parent 1998) of two additional horizons, of *I. gulisanoi* and *I. crassus*, for the lower and middle part of the zone respectively, is not adequately substantiated as the stratigraphic ranges of several species are wrongly quoted.

Callovian

Callovian ammonite assemblages of the Andes were defined, described and figured (see Riccardi et al. 1990b, 1994). The age of the Bathonian - Callovian boundary was directly dated in Chacay Melehue, from a level between the Steinmanni and Vergarensis zones. A tuff layer located at this boundary yielded a zircon date of 160.5 ± 0.3 (Odin et al., 1992).

33. **Vergarensis Standard Zone.** Typically represented in Chacay Melehue, with *Eurycephalites vergarensis* (Burck.) (Figures 6.13–14), *Neuquenicerias (N.) steinmanni* Stehn, *Xenocephalites gottschei* (Tornq.). Earliest Callovian. The alleged inclusion of *E. vergarensis* and *X. gottschei* in a single dimorphic pair and a change in the name of this zone (see Parent, 1998), is questionable, as raw data were not given, relationships between macro- and microconch phragmocones are not evident, stratigraphic ranges differ for both species, and material from type localities was not considered. The

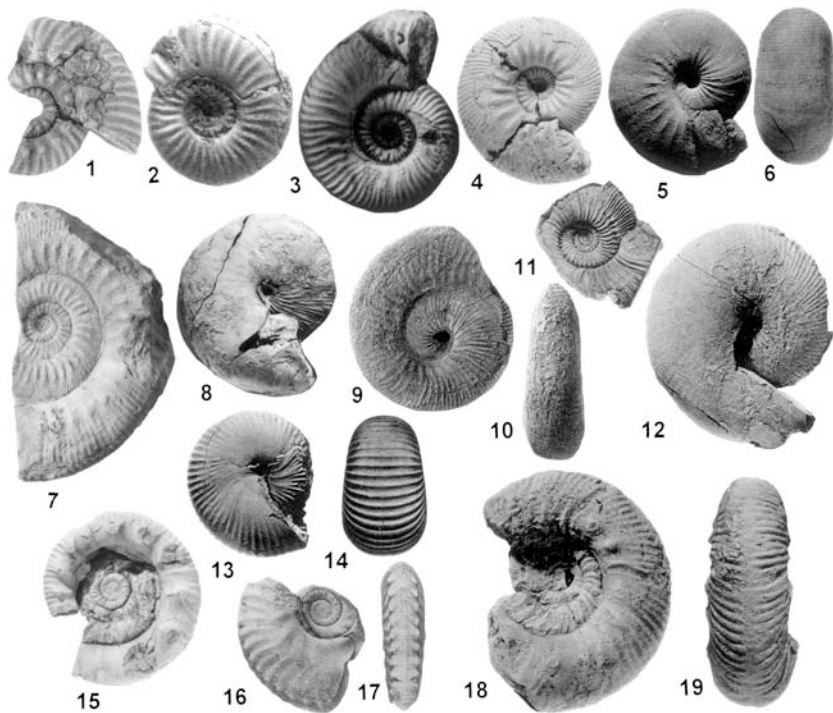


Figure 6 Middle Jurassic ammonites. Aalenian: 1, *Bredya* cf. *manflasensis* West. (MLP 24502), 2, *Westermanniceras groeberi* (West. and Ricc.) (MLP 25536), 3, *Puchenquia malarguensis* (Burck.) (MLP12228); Bajocian: 4, *Pseudotoites singularis* (Gottsche) (SEGEMAR 349b), 5–6, *Emileia* (*Chondromileia*) *giebelsi* (Gottsche) (MLP 12547), 7, *Stephanoceras* (*S.*) *pyritosum* (Quenstedt) (MLP 10666), 8, *Megaspaheroceras magnum* Ricc. and West. (MLP 23931); Bathonian: 9–10, *Morphoceras gulsanoi* Ricc. and West. (MLP 20043), 11, *Cadomites ex gr. rectelobatus* (Hauer) (MLP 21166), 12, *Lilloettia steinmanni* (Spath) (MLP 12703); Callovian: 13–14, *Eurycephalites vergarensis* (Burck.) (MLP 12658), 15, *Neuquenicer* (*Frickites*) *bodenbenderi* (MLP 23997), 16–17, *Hecticoceras* (*H.*) *proximum* Elmi (MLP 12808), 18–19, *Rehmannia* (*Loczyceras*) *patagoniensis* (Weaver) (MLP 23986). Repositories: MLP, Museo de la Plata; SEGEMAR, Argentine Geological Survey. All figures $\times 0.28$, except 2, 3, $\times 0.56$, 8, $\times 0.176$ and 15, $\times 0.215$.

regional Callovian stratotype was defined (Westermann and Riccardi, 1989) at the base of this zone at Chacay Melehue.

34. **Bodenbenderi Standard Zone.** Defined at Chacay Melehue, Neuquen province, with *Neuquenicer* (*Frickites*) *bodenbenderi* (Tornq.) (Figure 6.15), *Eurycephalites rotundus* (Tornq.), *E. extremus* (Tornq.), *Xenocephalites stipanicici* Ricc. et al., *X. involutus* Ricc. and West. Early Callovian, latest Bullatus and Gracilis Zones.

35. **Proximum Standard Zone.** Defined at Chacay Melehue, with *Hecticoceras* (*H.*) *proximum* Elmi (Figures 6.16–17), *H.* (*H.*) cf. *hecticum* (Rein.), *H.* (*H.*) *boginense* (Pet.), *H.* (*Chanasia*) *navense* Román, *H.* (*Ch.*) *ardescicum* Elmi, *Xenocephalites stipanicici* Ricc. et al., *X. involutus* Ricc. and West., *Neuquenicer* (*Frickites*) cf. *antipodum* (Gott.), *Rehmannia* (*R.*) cf. *paucicostata* (Tornq.), *R.* (*R.*) *brancoi* (Stein.), *R.* (*R.*) *stehni* (Zeiss), *Oxyerites* (*Paroxyerites*) *oxynotus* (Leanza). Early Callovian, late Gracilis Zone.

36. **Rehmannia patagoniensis Horizon.** Horizon with abundant *R.* (*Loczyceras*) *patagoniensis* (Weaver) (Figures 6.18–19), typically represented in near-shore facies along the eastern margin of the Neuquen Basin. The presence (Parent et al., 2006b, p. 309; Parent, 2006) in Chacay Melehue of this and other supposedly associated taxa, needs to be adequately substantiated, as it is in contradiction with a well documented biostratigraphy (see Riccardi et al., 1994), and could be due to a misconception of the species. Middle Callovian, Jason and Coronatum Zones.

Upper Jurassic

Oxfordian

Marine Oxfordian is well represented in west-central Argentina, although with a relatively poorly preserved ammonite fauna (see Riccardi et al., 1990c), mostly restricted to Middle Oxfordian levels of La Manga Formation. Late Callovian - Early Oxfordian and Late Oxfordian faunas are not usually present, due to regional hiatus, or are geographically restricted and poorly preserved. This situation and frequent absence of precise information on stratigraphic precedence has hindered most attempts to refine the Late Callovian-Oxfordian stratigraphy (cf. Parent, 2006).

37. **Peltoceratoides-Parawedekindia Assemblage Zone.** Defined in Riccardi et al. (1990c), is present (unpublished) in part of the Neuquen Basin, with *Peltoceratoides* sp. (Figure 8.1) and *Parawedekindia* sp. As “*P. pressulus* Biozone” in Parent (2006). Latest Callovian to Early Oxfordian, latest Lamberti to Early Cordatum Zones.

38. **Perisphinctes-Araucanites Assemblage Zone.** This assemblage (Riccardi et al., 1990c) is widespread throughout the Neuquen Basin, and is equivalent to the “*Subvinalesphinctes pseudokranaus*, *Passendorferia* and *Euaspidoceras tarapacaense* Biozones” of Parent (2006). It includes *P.* (*Kranaosphinctes*) spp., *P.* (*Arisphinctes*) spp. (Figure 8.4), “*Perisphinctes*” spp., *Araucanites mulai*, *A. reyesi*, *A. stipanicici* (Figures 8.2–3), West. and Ricc., *Euaspidoceras ajax* Leanza, *E. aff. waageni* Spath. Latest Early and Middle Oxfordian, Latest Cordatum to Transversarium (?and Bifurcatum) Zones.

39. **Lithacosphinctes Horizon.** Representatives of *Lithacosphinctes* Oloriz were first described from northern Chile and used (Parent, 2006) to define a “*L. desertorum* Biozone”, and appear to be present (Figure 8.5) in basal facies of the Neuquen Basin (Parent et al., 2006b). Late Oxfordian, Bimammatum (to Planula) Zone(s).

Kimmeridgian

In west-central Argentina the uppermost Oxfordian and Kimmeridgian consists of continental facies. Only in the Austral Basin, southern Argentina, some poorly preserved ammonites have been tentatively dated as Late Kimmeridgian.

Tithonian

In west-central Argentina, the base of the Mendoza Group has yielded a rich Tithonian ammonite fauna (see Riccardi et al. 1990c). A poorly preserved fauna of similar age is also present in southern Patagonia (see also Kraemer and Riccardi, 1997). A detailed zonal scheme (see below) was developed for west-central Argentina. Successive changes (Parent, 2001, 2003; Parent et al., 2006a) to the ammonite systematics and biostratigraphy await substantiation on a thorough systematic study of new and extensive field collections.

40. **Virgatosphinctes mendozanus Assemblage Zone.** Zone proposed by Burckhardt (see Leanza, 1980), characterizes the base of the Vaca Muerta Formation and marks the initiation of a new marine sedimentary cycle following the Kimmeridgian continental facies of the Tordillo Formation. With: *V. mendozanus* (Burck.), *V. andesensis* (Douv.), *V. denseplicatus rotundus* Spath, *V. evolutus* Leanza, *V. mexicanus* (Burck.), *V. burckhardti* (Douv.), *Pseudinvoluceras douvillei* Spath, *P. windhausenii* (Weav.), *P.* (?) *wilfridi* (Douv.), *Choicensisphinctes choicensis* (Burck.) (Figures 8.6–7), *Ch. erinoides* (Burck.), *Subplanites malarguensis* Spath. Latest Early to Middle Tithonian, Darwini to Semiforme Zones.

STAGES	STANDARD ZONES	ARGENTINA	
TITHONIAN	U	DURANGITES	45. <i>S. koeneni</i>
		MICROCANTHUM	44. <i>C. alternans</i>
	M	PONTI	43. <i>W. internispinosum</i>
		FALLAUXI	42. <i>A. proximus</i>
		SEMIFORME	41. <i>P. zitteli</i>
	L	DARWINI	40. <i>V. mendozanus</i>
HYBONOTUM			
KIMMERIDGIAN	U	BECKERI	
		EUDOXUS	
		ACANTHICUM	
	L	DIVISUM	
		HYPSELOCYCLUM	
		PLATYNOTA	
OXFORDIAN	U	PLANULA	?
		BIMAMMATUM	39. <i>Lithacosphinctes</i>
		BIFURCATUM	?
	M	TRANSVERSARIUM	38. <i>Perisphinctes</i> - <i>Araucanites</i>
		PLICATILIS	
	L	CORDATUM	
MARIAE		37. <i>Peltoceras</i> - <i>Parawedekindia</i>	

Figure 7 Correlation chart for the Upper Jurassic of west-central Argentina.

41. *Pseudolissoceras zitteli* Assemblage Zone. Zone introduced by Burckhardt (see Leanza, 1980). Widespread in west-central Argentina. With *P. zitteli* (Burck.) (Figures 8.8–9), *P. pseudoolithicum* (Haupt), *Glochiceras steueri* Leanza, *Hildoglochiceras wiedmanni* Leanza, *Parastreblites comahuensis* Leanza, *Aspidoceras cieneguitense* (Steuer), *Pseudhimalayites steinmanni* (Steuer), *Simocoscoceras adversum andinum* Leanza and Oloriz. Early Middle Tithonian, Semiforme to Fallauxi Zones.

42. *Aulacosphinctes proximus* Assemblage Zone. Zone proposed by Burckhardt (see Leanza, 1980). Widespread in west-central Argentina, with *A. proximus* (Steuer) (Figures 8.10–11), *Subdichotomoceras* sp., *Pseudhimalayites steinmanni* (Steuer), *Aspidoceras andinum* (Steuer), *A. neuquensis* Weaver. The proposed inclusion (Parent, 2003) of *A. proximus* (Steuer) in *Torquatisphinctes* Spath is ill-founded, as are several other related assumptions which require re-examination, e.g. the supposed presence of tubercles in the inner whorls of *Aulacosphinctes* Uhlig, the resemblance of *A. proximus* to some Mexican material, compared with *Subdichotomoceras inversum* (Spath) and *Aulacosphinctoides lauri* (Aguilera) and *A. potosinus* (Aguilera), and included by Parent (2003) in *Torquatisphinctes*. Middle Tithonian, Fallauxi to Ponti Zones.

43. *Windhauseniaceras internispinosum* Assemblage Zone. Zone introduced by Weaver (see Leanza, 1980), Vaca Muerta Formation, widespread in west-central Argentina. With *W. internispinosum* (Krantz) (Figures 8.12–13), *Wichmanniceras mirum* Leanza, *Pachysphinctes americanensis* Leanza, *Hemisphinctes* aff. *steinmanni* (Steuer), *Subdichotomoceras araucanense* Leanza, *S. windhauseni* (Weaver), *Parapallasiceras* aff. *pseudocolubrinoides* Oloriz, *P.* aff. *recticosta* Oloriz, *Aulacosphinctoides* aff. *hundesianus* (Uhlig), *Aspidoceras euomphalum* Steuer, *Corongoceras lotenoense* Spath (Figures 8.14–15). In the Los Catus Member, Leanza and Zeiss (see 1992, 1994) recognized, from below, the *Catutosphinctes rafaeli* Leanza and Zeiss and *Zapalia fascipartita* Leanza and Zeiss Subzones, the latter including the

Aspidoceras aff. *altum* Biro and the *Djurjuriceras catutosense* Leanza and Zeiss horizons. Latest Middle Tithonian, Ponti Zone.

44. *Corongoceras alternans* Assemblage Zone. Zone proposed by Leanza (see Leanza, 1980). It is known in the Vaca Muerta and equivalent formations and is well represented in west-central Argentina. With *C. alternans* (Gerth), *C. mendozanum* (Behr.), *C. rigali* Leanza, *Aulacosphinctes mangaensis* (Steuer), *Lytohoplites burckhardti* Spath, *Micracanthoceras tapiai* Leanza, *M. lamberti* Leanza, *Berriasella australis* Leanza, *B. pastorei* Leanza, *B. krantzi* Leanza, *B. bardensis* Krantz, *Chigaroceras gerthi* (Krantz). Late Tithonian, Microcanthum and Durangites spp. Zones.

45. *Substeueroeras koeneni* Assemblage Zone. Proposed by Gerth (see Leanza 1981). With the same geographic extension than the underlying zones. With *S. koeneni* (Steuer) (Figures 8.16–17), *S. exstans* Leanza, *Aulacosphinctes azulensis* Leanza, *A. mangaensis* (Steuer), *Pectinatites* (?) *striolatus* (Steuer), *Berriasella fraudans inflata* Leanza, *B. inaequicostata* Gerth, *Parodontoceras calistoides* (Behr.), *Aspidoceras longaeuvum* Leanza, *Blanfordiceras vetustum* (Steuer), *Himalayites andinus* H. Leanza, *Spiticeras acutum* Gerth, Traditionally ascribed to the Upper Tithonian (see Leanza, 1981), probably reaches the lower Berriasian as indicated by the occurrence at its top of *Schaireria longaeva* Leanza and “*Spiticeras*” *acutum* Gerth, a probable forerunner of *Groebiceras* Leanza (see Zeiss, 1986; Leanza, 1996). Late Tithonian–early Middle Berriasian, Durangites spp.–Jacobi/Grandis and earliest Occitanica Zones).

Neuquen Basin: major paleogeographic, sedimentary and faunal patterns

The origin of Mesozoic rocks in southern South America is related to the Late Triassic and Early Jurassic extensional tectonics which affected the western margin of Gondwana, and formed a series of fault-bounded, NNW-striking grabens. In these grabens volcanic and volcanoclastic rocks were accumulated, together with continental and, locally, marine sediments. In the Rio Atuel area a Rhaetian-Sinemurian Pacific marine corridor opened, and subsequent widespread subsidence lead to full development of a back-arc basin, i.e. the Neuquén Basin.

Changes in sea level related to eustatic subsidence and sediment influx resulted in a succession of depositional sequences (see Legarreta and Gulisano 1989), bounded by discontinuities, associated with important paleogeographic changes. These sequences have been grouped in several “mesosequences”, i.e. Cuyo (max. thick. c. 3000 m, incl. sequences C1-7), Lotena-Chacay (max. thick. c. 800 m, incl. sequences L1-5), and Lower Mendoza (max. thick. c. 3800 m, incl. sequences M1-6). There is an apparent relationship between sequences and the distribution and abundance of ammonites (see Riccardi et al., 1994). Thus ammonite faunas are more widespread and diverse in the middle to upper part of the sequences, whilst geographic restriction and low diversity occur close to their boundaries (Figure 9).

The first Jurassic marine encroachment occurred north of 40°S (Figure 1), where the Rhaetian-Hettangian-Sinemurian sea covered coastal areas of Chile reaching as far east as the Río Atuel area (see Riccardi et al. 2004; Lanes, 2005). As a result basinal to shelf pelites and sandstones were deposited, which are absent toward the south, where marine deposition began in the Pliensbachian. The maximum expansion eastward of the Early Jurassic sea was attained in the late Early Pliensbachian. With sea-level lows turbiditic deposits (Los Molles Formation) were formed in the basinal area, and with sea-level highs, outer-shelf pelites (Los Molles Formation), littoral sandstones (Puesto Araya Formation), and continental facies (El Freno Formation). A Late Pliensbachian-Toarcian sea-level fall was punctuated by a late Early Toarcian rise.

This pattern agrees quite well with changes in ammonite diversity (considered as a simple measure of genera number) (Figure 9). Thus diversity is quite low in the Hettangian, and shows a rise in the

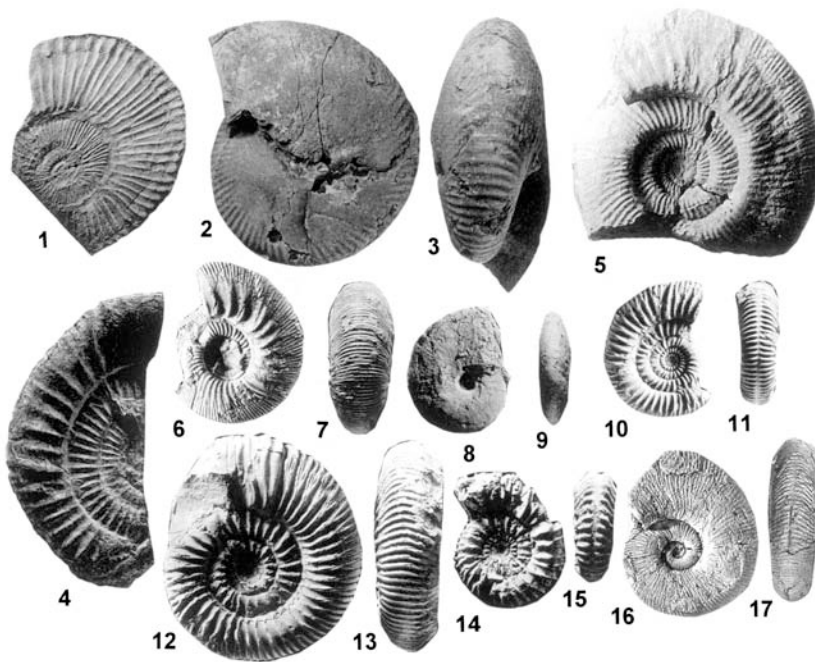


Figure 8 Upper Jurassic ammonites. Oxfordian: 1, *Peltoceratoides pressulus* (Leanza) (SEGEMAR s/n), 2–3, *Araucanites stipanicici* West. and Ricc. (MLP 12240); 4, *Perisphinctes* (*Arisphinctes*) sp., 5, *Lithacosphinctes* aff. *janus* (Choffat) (LPB 426); Tithonian: 6–7, *Choicensisphinctes choicensis* (Burck.) (SEGEMAR 8905/3); 8–9, *Pseudolissoceras zitteli* (Burck.) (SEGEMAR 7333/1); 10–11, *Aulacosphinctes proximus* (Steuer) (GPIT 1545/3); 12–13, *Windhausenicerias internispinosum* (Krantz) (SEGEMAR 8941/1); 14–15, *Corongoceras lotenoiense Spath* (SEGEMAR 8940/1); 16–17, *Substeueroeceras koeneni* (Steuer) (MLP 3362). Repositories: GPIT, Institut Geologie Paläontol. Tübingen; LPB, Universidad Nacional de Rosario; MLP, Museo de la Plata; SEGEMAR, Argentine Geological Survey. 1, modified from Leanza 1947; 4, modified from Stipanovic, 1951; 5, modified from Parent et al., 2006b; 6–15, modified from Leanza, 1980. All figures $\times 0.28$.

early Sinemurian—although this rise could also be an artifact due to a poorly defined biostratigraphy. Subsequently there was a progressive increase in diversity from the late Sinemurian to the early Pliensbachian (*M. externum* Zone, Late Jamesoni and Early Ibex Zones), with a maximum, characterized by high endemism (calculated as 40% with, or 80% without cosmopolitan taxa), coinciding with the middle part of sequence C2, followed by a sharp fall to the early-late Pliensbachian boundary (*F. fannini* Zone, late Davoei to early Margaritatus Zones), punctuated by a slight rise in the *A. behrendseni* Zone (middle Davoei Zone). Thereafter there is a further rise at the end of the Pliensbachian (*F. disciforme* Zone, Spinatum Zone), followed by a pronounced fall at the beginning of the Toarcian (*Tenuicostatum* Z), and a final rise to a maximum at the end of the early Toarcian (*P. largae*-*C. chilense* Zones, Serpentinum to Bifrons Zones), coinciding with the middle part of sequence C3. Subsequently there is a marked fall, with a slight intervening rise, across the Toarcian-Aalenian boundary.

During the Middle Jurassic parts of the western volcanic arc became continental, with subaerial volcanism. To the east, marine sedimentation was continuous in the back-arc basin. During the Aalenian the shelf-margin moved basinward, and the area of turbidite deposition was reduced to a brief, low-sea-level stage, with low ammonite diversity, in the early Aalenian. A transgressive maximum occurred during the Bajocian, when a sea-level rise expanded the shelf area and high clastic input from the south and east resulted in deltaic progradation (Lajas Formation; sequence C4). Ammonite diversity (Figure 9) shows a marked rise throughout the Aalenian, to reach a maximum in the Malarguensis Zone (\approx Concavum-Discites Zones), Aalenian-Bajocian boundary, followed by a slight fall at the boundary between the Malarguensis and Singularis zones (\approx Laeviuscula Zone) and a further slight rise in the Giebeli A.Z. (\approx Propinquans Zone). Both maxima coinciding with the middle part of sequence C4.

As a result of an important sea-level fall a regional regression occurred during most of the Bathonian in west-central Argentina, so that in marginal areas between 26°S and 37°S the Callovian rests directly on Bajocian or older strata. Ammonite diversity (Figure 9) shows a sharp drop across the Bajocian-Bathonian boundary, followed by a marked rise to a late Bathonian maximum in the Steinmanni Zone, in coincidence with the middle part of sequence C5.

The Bathonian regressive phase extended into the early Callovian when the basin became strongly restricted, and evaporites were deposited (sequences C6–7). Ammonite diversity (Figure 9) shows a decline across the Bathonian-Callovian boundary, followed by a slight rise at the end of the early Callovian. During the late Callovian there was a sharp sea-level fall, the shelf areas were partially eroded, and in the deepest areas fluvial and aeolian continental sandstones and conglomerates were deposited (sequence L1), although a short sea-level rise occurred during the middle-late Callovian producing a renewed short transgression with a marked expansion of the area of marine sedimentation which, however, did not reach the extent of the earlier Bajocian sea. The *Rehmannia patagoniensis* Horizon thus transgresses over evaporites, deltaic, and even continental facies of different ages of the Lower-Middle Jurassic.

During the early Oxfordian, as a result of a sea-level rise, a turbiditic succession developed in the Andean area, followed by pelites that transgressed the shelf area (sequence L2). Toward the end of this stage,

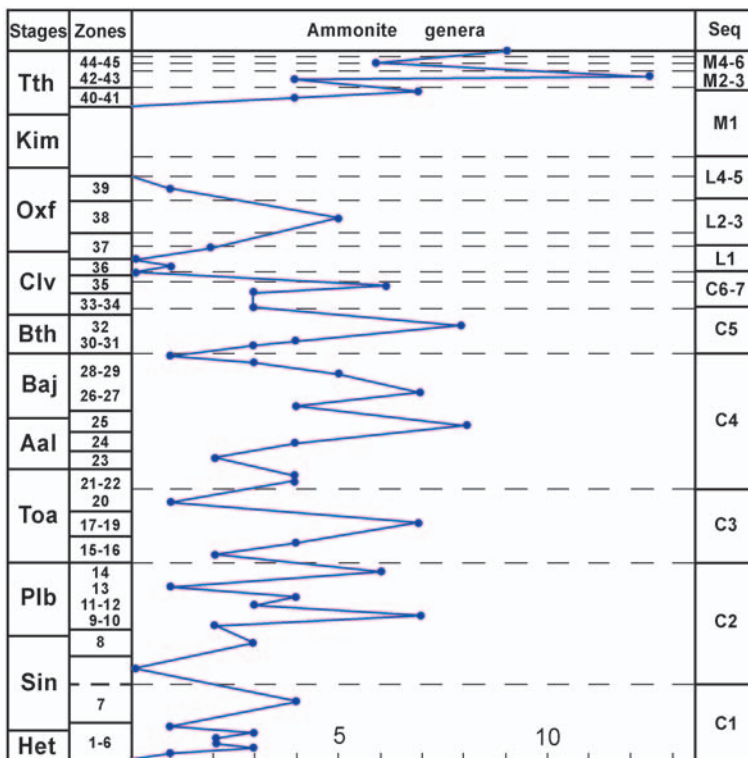


Figure 9 Jurassic ammonite diversity (genera) in the Neuquen Basin (For Zones 1–45 see Figs. 3, 5, and 7; for Seq. C1–C5, L1–L5 and M1–M6 see text).

prograding carbonates developed (La Manga Formation, sequence L3), followed in the late Oxfordian, by evaporitic sedimentation in the central parts of the basin (Auquilco Formation, sequences L4-5). Ammonite diversity (Figure 9) shows a more or less uniform increase from the beginning of the Oxfordian to reach a maximum in the *Perisphinctes-Araucanites* Zones (\approx Plicatilis and Tansversarium Zones), followed by a marked fall.

The progressive shallowing of basins of west-central Argentina during the Callovian-Oxfordian was due to a general sea-level fall related to marked uplift of the volcanic arc of the Coastal Cordillera of Chile, which acted as a source of clastics and volcanics. The resulting deposition from the west and displacement of the basin axis to the east climaxed during the Kimmeridgian, when the volcanism reached the Principal Cordillera. The marginal areas were sites of strong erosion, and deposition occurred in other parts of the basin. Thus, a complex setting of continental deposits was developed, i.e. Tordillo Formation and equivalents.

The area was again flooded during the Tithonian-Early Cretaceous by a new major transgression. In the middle early Tithonian, a sea-level rise caused fast submergence of the basin and strong expansion of the marine area, with deposition of marls and bituminous limestones (Vaca Muerta Formation). Deposition of littoral sandstones was restricted to some marginal areas. During the late Tithonian, as a result of strong progradation of clastic carbonates from the south and east, the area of marine sedimentation became restricted, and marginal and continental facies became widespread. Ammonite diversity (Figure 9) shows a sharp increase from the Early (*V. mendozanus* Zone \approx late Darwini Zone) to the Middle Tithonian (*W. internispinosum* Zone \approx Ponti Zone), with a slight fall in the *A. proximus* Zone, i.e. across the Fallauxi-Ponti boundary, followed by a sharp drop at the beginning of the late Tithonian, and another rise across the Tithonian-Berriasian boundary.

Acknowledgements

Financial support was provided by the Consejo Nacional de Investigaciones Científicas y Técnicas (PIP 5635) and Agencia Nacional de Promoción Científica y Tecnológica (PICT 07-26236), Argentina. B.A.P. Wimbledon and S. Turner made useful comments to improve this paper. This is a contribution to IGCP 506 "Jurassic Boundary Events".

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Hutchison 'Young Scientist' Fund

William Watt Hutchison, "Hutch" to his many friends around the world, was a Scots-born Canadian geologist who served Canada and the IUGS in myriad dynamic and creative ways. Most notably, he served as the IUGS Secretary General (1976–1980) at a pivotal time in its history, and as IUGS President (1984–1987). The same boundless energy, enthusiasm, skill in communications, and ability to foster teamwork that characterized his work with the IUGS also carried him to preeminent scientific administrative positions in the Canadian Government, where he served as Director General of the Geological Survey of Canada and as Assistant Deputy Minister of Earth Sciences. His distinguished career was terminated in 1987 by his untimely death at the age of 52, following a painful struggle with cancer.

One of Hutch's last wishes was to establish under IUGS auspices a memorial foundation intended to promote the professional growth of deserving, meritorious young scientists from around the world by supporting their participation in important IUGS-sponsored conferences. The first 3 beneficiaries of the *Hutchison "Young Scientist" Foundation* attended the 28th International Geological Congress (IGC) in Washington, D.C., in 1989.

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