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The Lower Cretaceous Chañarcillo and Neuquén Andean basins: ammonoid biostratigraphy and correlations

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The Chañarcillo and Neuquén basins of the Central Andes shared a common geological history in the earlier part of the Early Cretaceous but from Barremian times onward their evolution began to diverge, probably due to an increasing activity of an intervening volcanic arc. The Berriasian to Lower Barremian sequences were mainly marine and include rich ammonoid faunas, with many taxa in common to both the basins. They include both Andean and near-pandemic forms, the latter providing some good correlation levels with the 'standard' Mediterranean sequence. Marine conditions persisted in the Chañarcillo Basin till Early Albian times; the associated ammonoid faunas include pandemic, Pacific and Antarctic genera. In contrast, in the Neuquén Basin evaporites and continental clastics of the Huitrín Formation mark the beginning of a long disconnection with the Pacific Ocean, though a short-lived marine incursion is represented by the carbonates of La Tosca Member of the Huitrín Formation. The ammonoid faunas of the two basins are compared here, and a detailed biostratigraphic division of the sequences is discussed and compared with the Mediterranean succession. Copyright © 2007 John Wiley & Sons, Ltd.

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1. INTRODUCTION

The Andean system along the western margin of Gondwana records the development of a complex series of fore-arc, intra-arc, and retro-arc basins of distinctive evolution during the Jurassic and Cretaceous (Ramos and Alemán 2000). The northern part of South America, mainly Colombia and Equador, has a different palaeogeography, due to the presence of oceanic deposits and mafic sequences, associated with the collision and accretion of island arcs and oceanic plateaux during the Cretaceous (Alemán and Ramos 2000; Jaillard *et al*. 2000). On the other hand, in the Central Andes from Northern Perú to Southern Chile, the basins are characterized by a similar palaeogeography during the Early Cretaceous, where in the western domains volcaniclastic sequences are interfingered with shelf deposits (Jaillard *et al*. 2000; Ramos and Alemán 2000). The best known basins are in the central and southern parts of the continent, where several intra- and retro-arc basins record mostly marine

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sedimentation (Charrier 1984), encompassing six depocentres: Tarapacá (18°–24°S), Chañarcillo (formerly Atacama) (26°45′–31°20′S), Aconcagua-Central Chile (32°–35°S), Neuquén Embayment (35°–40°S), Río Mayo Embayment (44°–46°S) and Austral or Magallanes Basin (47°–51°S) (Figure 1).

It has generally been accepted that the Chañarcillo Basin shared a common evolution with the Neuquén Basin during the Early Cretaceous. However, modern detailed studies (Mourgues 2004, 2007) are showing quite different geological and biostratigraphic histories for part of that interval.

The period of minimum connection coincides with a stage of rapid convergence rate between the Farallón Plate and South America during the Aptian-Albian, characterized by widespread volcanic arc activity and the accumulation of thick sequences of volcanic products. Thicknesses of up to several thousand metres of andesitic lavas and pyroclastic flows, produced an effective barrier between the intra-arc basins in the western Chilean region, and the retro-arc basins in the Argentine foreland (Mpodozis and Ramos 1990). This barrier was only sporadically flooded by restricted seas in Aptian times, as recorded by thin marine carbonates observed in some retro-arc basins and known as the La Tosca Member of the Huitrín Formation (Legarreta 1985).

Thus, the objectives of this paper are to outline the stratigraphy and ammonoid biostratigraphy of both basins showing the similarities and differences, to compare the ammonoids of both basins, and to correlate their ammonoid biozones with the Mediterranean standards.

2. REGIONAL SETTING AND STRATIGRAPHY

2.1. Chañarcillo Basin

The infill of the Chañarcillo Basin comprises more than 2000 m of marine carbonate rocks and minor volcaniclastics at the base and in the top of the sequence, which range in age from Late Berriasian to Early Albian (Mourgues 2007). This Lower Cretaceous succession crops out in the southern Atacama region as a NNE-trending belt from south of Vallenar (29°15′S) to Copiapó (27°15′S), parallel to the current plate margin (Figure 2). Southward of this belt, there are only isolated outcrops. Another belt crops out in the high Andes at the latitude of Ovalle (30°20′–31°20′S) (Rivano and Sepúlveda 1991). Northward from Copiapó isolated and discontinuous outcrops extend up to Inca de Oro (26°45′S).

The sequence is represented by the upper sedimentary part of the Punta del Cobre Formation (Segerstrom and Ruiz 1962), identified as the Los Algarrobos Member (Marschik and Fontboté 2001) in the Copiapó valley, and the Chañarcillo Group (Segerstrom and Parker 1959).

The Chañarcillo Group lies on and partially interfingers with the Punta del Cobre Formation, the latter representing the deposits associated with the Upper Jurassic–Valanginian magmatic arc. The lower section of the Punta del Cobre Formation is named the lower Geraldo Negro Member, which is composed of massive andesitic and dacitic volcanic rocks, while the Los Algarrobos Member is made up of volcaniclastic sediments with lenses of massive volcanic rocks and fine-grained ammonite-bearing sediments (Marschik and Fontboté 2001). The transgressive nature of the sedimentary part of the Punta del Cobre Formation marks the onset of the subsidence that initiated the Early Cretaceous marine Chañarcillo retro-arc basin.

From the base to the top, the Chañarcillo Group includes four formations (Figure 3): Abundancia, Nantoco, Totoralillo and Pabellón, all defined by Biese (in Hoffstetter *et al.* 1957).

2.1.1. Abundancia Formation

This unit crops out well in Quebrada de Meléndez as an approximately 200 m-thick series, that is composed of well-laminated grey mudstones interbedded with green greywackes. These rocks represent the accumulation of fine-grained volcaniclastic mid-fan turbidites that accompanied the deposition of carbonate muds (Arévalo 1999). This unit passes vertically and laterally into limestones of the overlying Nantoco Formation.

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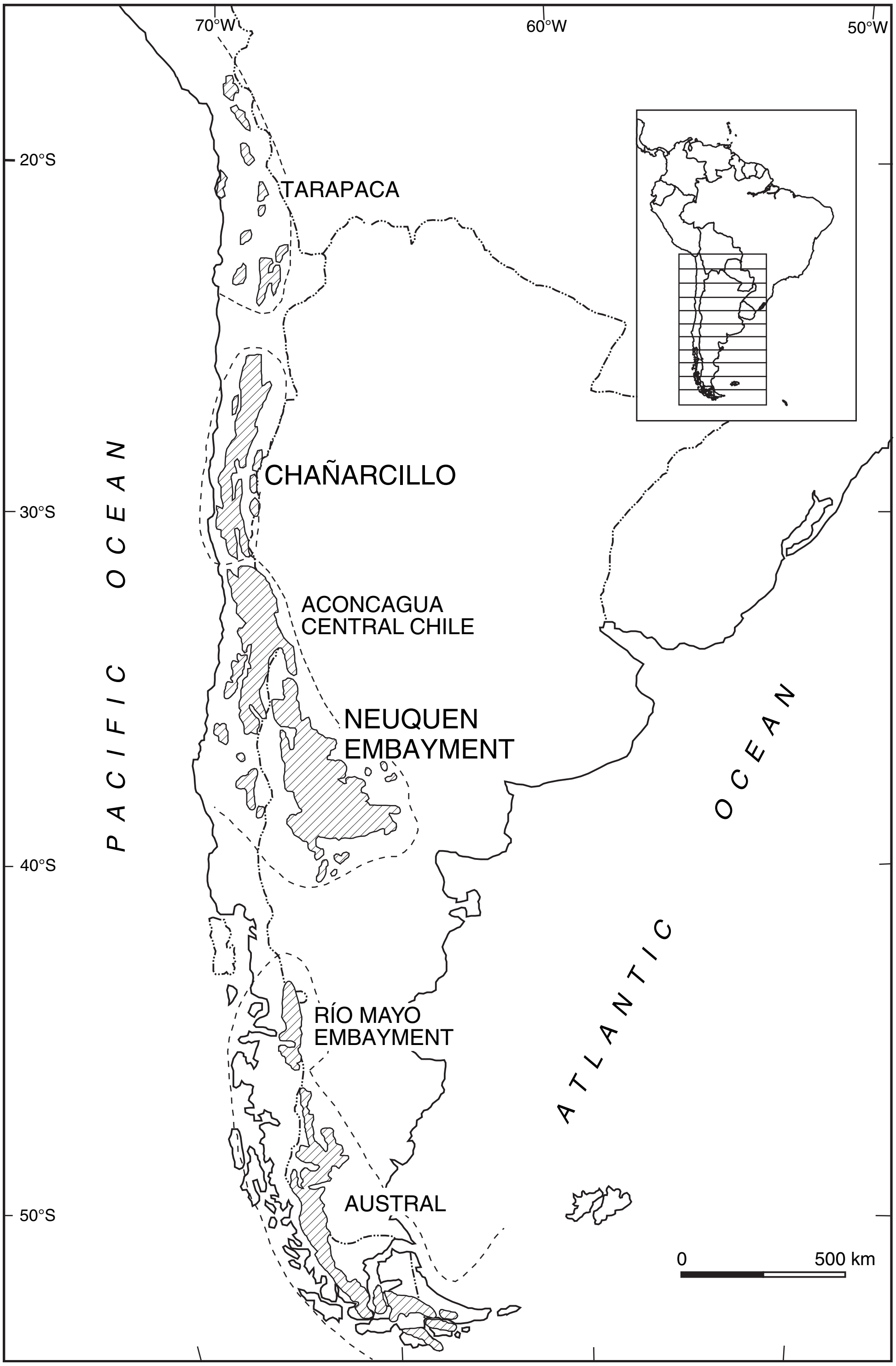

Figure 1. The southwestern margin of Gondwana with the location of Lower Cretaceous basins (modified from Aguirre-Urreta 1993).

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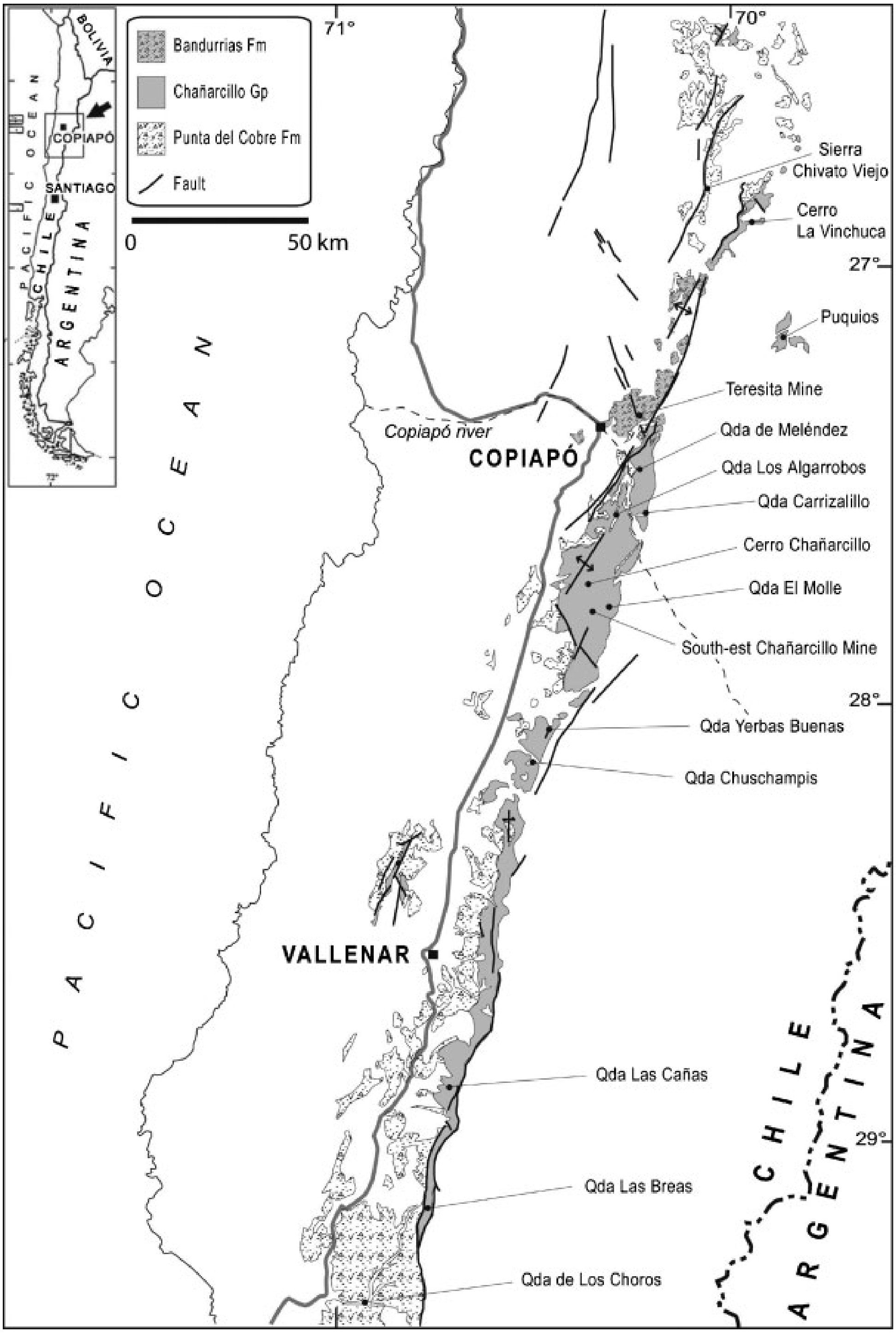

Figure 2. The Lower Cretaceous Chañarcillo Basin in Northern Chile (based on SERNAGEOMIN 2002). Abbreviation: Qda = Quebrada.

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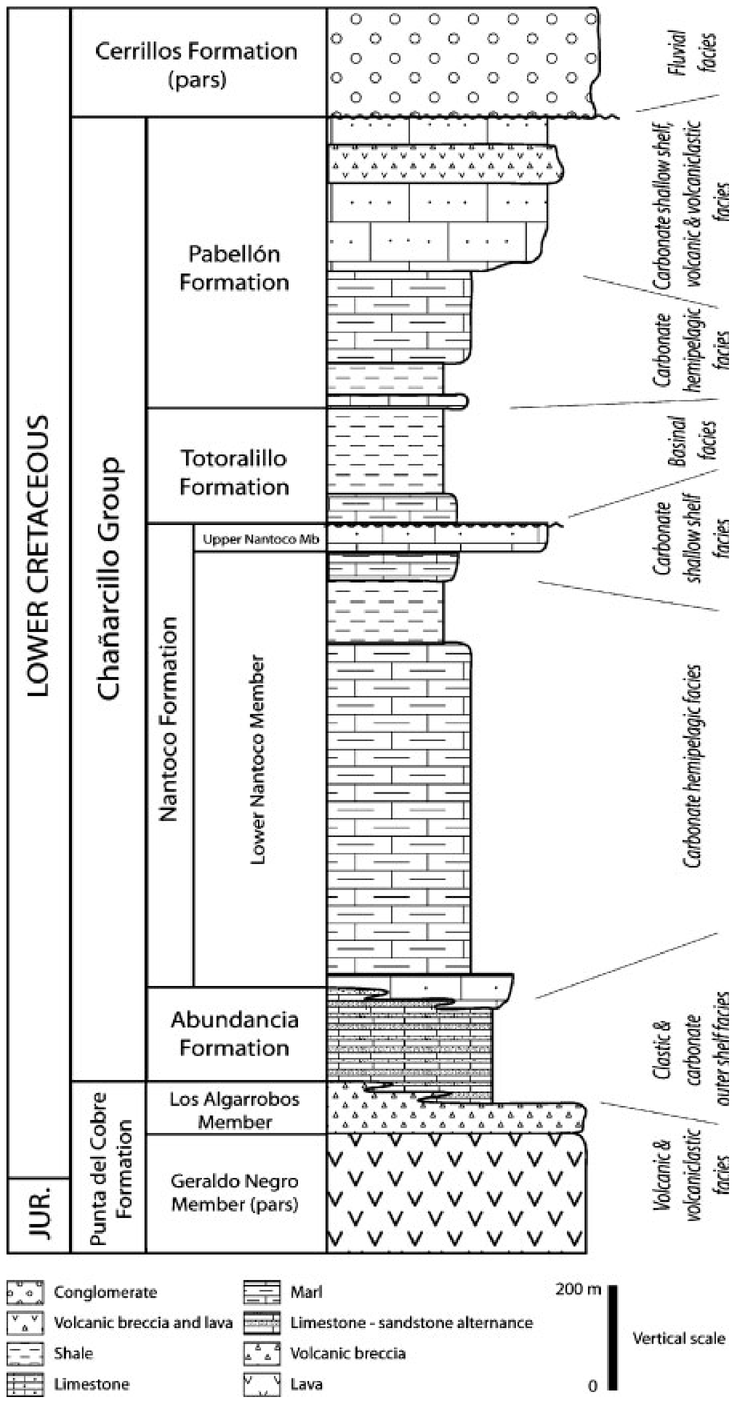

Figure 3. A stratigraphic column of the Chañarcillo Group (based on Mourgues 2007).

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2.1.2. Nantoco Formation

This unit includes two members which were defined by Corvalán (1974). The Lower Nantoco Member is a monotonous succession, approximately 800 m thick, composed of homogeneous grey mudstones and wackestones that in its upper part contains Late Hauterivian ammonites. The Upper Nantoco Member is a thin succession, approximately 100 m thick, formed of shallow-water shelf limestone, evaporites and calcareous breccias, which has been interpreted as associated with an important regression (Cisternas and Díaz 1990; Mourgues 2004, 2007). This member constitutes a characteristic horizon in the basin which can be recognized over 180 km from Quebrada de Meléndez to Quebrada Las Breas (Figure 2).

2.1.3. Totoralillo Formation

This is a thin, very uniform succession (100–200 m thick) of well-bedded, pale-grey to yellow marls interbedded with bioclastic wackestones, which bears Early Barremian ammonites. The thickest section of this unit is recorded at Quebrada de Meléndez from where it decreases northward and southward. Since it has a large extension, and the ammonite content allows a good stratigraphic control, this unit is regarded as a regional marker horizon in the basin.

2.1.4. Pabellón Formation

This is a thin succession, approximately 450 m in thickness, which overlies conformably the Totoralillo Formation and is covered through discordance by the Cerrillos Formation (Segerstrom and Parker 1959). Although no signs of discordance can be recognized at the outcrop scale, the lack of the upper part of the succession in Quebrada de Meléndez documents an erosive unconformity at the base of the Cerrillos Formation. The succession starts with well-bedded bioclastic wackestones and laminated mudstones alternating with cherts and cherty limestones (Mourgues 2007). The series continues with volcaniclastic breccias alternating with two thin carbonate platform deposits with Early Aptian ammonites. These deposits represent the increase of the episodic volcanic activity in the marine environment. To the north of the basin the volcaniclastic and carbonate deposits are covered by a 300 m-thick sequence of lava flows. At Quebrada Carrizalillo, the upper part of the Pabellón Formation is composed of a prograding, shallow-water carbonate shelf sequence, which was dissected by a set of synsedimentary normal faults limiting grabens infilled by lavas and volcanic debris flows. At Quebrada El Molle this tectonic-linked unit is correlated with a thick olistostrome that includes pieces of shallow-water shelf limestones and volcanic debris flows, which overlies Upper Aptian ammonite-bearing transgressive limestones. Finally, coarse-grained, volcaniclastic fan delta deposits, are overlain by shallow shelf limestones with Early Albian ammonites. These important synsedimentary tectonic events, recorded in the upper part of the Pabellón Formation, announce the closure of the Early Cretaceous marine sedimentary cycle in the basin.

The upper part of Chañarcillo Group interfingers toward the northwest with marine and continental volcanic rocks and conglomerates of the Bandurrias Formation (Segerstrom 1960; Segerstrom and Ruiz 1962). The Chañarcillo Group is covered eastwards by the Cerrillos Formation (Segerstrom and Parker 1959), a thick subaerial volcaniclastic sequence ascribed to the Albian-Turonian (?).

2.2. Neuquén Basin

The Neuquén Basin of central Argentina and Chile extends from 32° to 40° S latitude and encompasses two major depocentres, the Aconcagua-Central Chile in the north and the Neuquén Embayment in the south (Figure 1).

The Neuquén Basin shows a nearly continuous marine sedimentary record from Late Triassic to Early Cretaceous times. The outcrops form a narrow belt along the Andes in the north, covering part of the Chilean and Argentine Principal Cordillera. The Aconcagua area has a complex history with diverse marine and continental facies mainly controlled by the variable tectonic setting through Late Jurassic to Early Cretaceous times (Mpodozis and Ramos 1990). This northern part (31°–36°S) has a different palaeogeography with a larger component of volcanic rocks, but similar stratigraphic cycles to those in the Neuquén embayment in its Late Jurassic to Early Cretaceous evolution. These retro-arc deposits are represented by the Mendoza Group in Argentina and the San

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José, Lo Valdés and Baños del Flaco formations in Chile. These last three units, predominantly calcareous, are partially equivalent to each other.

2.2.1. San José Formation

This unit was defined by Aguirre Le Bert (1960) to characterize a 150 m-thick pile of marine rocks exposed in the Cajón San José (Figure 4). It comprises shallow carbonate shelf deposits capped by a 50 m-thick calcareous breccia interpreted as related to a rapid sea-level fall (Aguirre-Urreta and Lo Forte 1996). The San José Formation is covered by the continental clastics of the Cristo Redentor Formation and is equivalent in age to the Agrio Formation.

2.2.2. Lo Valdés Formation

The name was proposed by González (1963) for a section cropping out in the valley of Río Volcán. This thick sequence, more than 1300 m-thick, comprises two transgressive carbonate sections, separated by an episode of clastics and evaporites representing a regressive phase. The Lo Valdés Formation spans from the Tithonian to the Hauterivian based on its ammonite succession and can be correlated with the Mendoza Group.

2.2.3. Baños del Flaco Formation

Proposed by Klohn (1960), with its type area near Baños del Flaco in the valley of Río Tinguiririca. It embraces a sequence varying in thickness from 700 to 1000 m, composed of carbonates, sandy carbonates and calcareous sandstones, interbedded with conglomerates, glauconitic sandstones, shales and scarce volcanic rocks. This unit was deposited in a typical carbonate platform developed on the eastern side of the active volcanic arc. It is time equivalent to the northern Lo Valdés Formation.

The Mendoza Group in the Aconcagua depocentre is represented by the shales and bituminous marls of the Vaca Muerta Formation and the carbonates of the Quintuco Formation (Figure 5) during Tithonian-Berriasian times. The Lower Valanginian beds show some lithological variations but are mostly greenish to reddish clastics of the Mulichinco Formation. The upper Lower Valanginian-Hauterivian Agrio Formation is represented by carbonates and calcareous sandstones (Aguirre-Urreta and Lo Forte 1996). In general terms, those sequences are less fossiliferous than their equivalents on the Chilean side (Ramos and Aguirre-Urreta 1992), most probably related to a shallower environment, which was dominated by bivalves and gastropods.

South of 36°S latitude, the Neuquén Basin expands towards the eastern foreland forming a large embayment (Figure 4). It is a retro-arc basin flooded by marine influxes from the Pacific, where several thousand metres of mainly marine sediments accumulated during Jurassic and Early Cretaceous times. The first stratigraphic work was done by Bodenbender (1892), followed by Windhausen (1918), and mostly the fundamental studies of Groeber (1946, 1953). Modern studies are by Gulisano *et al.* (1984), Legarreta and Gulisano (1989) and Legarreta and Uliana (1991, 1999).

The latest Jurassic-Early Cretaceous in the Neuquén Basin is represented by a major sedimentary cycle: the Andean cycle of Groeber (1953). This cycle comprises both marine and continental deposits that are assembled in the Mendoza Group (Figure 5).

2.2.4. Vaca Muerta-Quintuco Formations

Both units were defined by Weaver (1931) in the Sierra de Vaca Muerta in west-central Neuquén. The marine Tithonian-Lower Valanginian deposits are represented by rich, organic dark shales with calcareous nodules of the Vaca Muerta Formation. This unit is divided into three members; the middle or Los Catutos Member is interesting as it contains lithographic limestones deposited on open shelves with a well-preserved fauna (Leanza and Zeiss 1990). The Vaca Muerta Formation grades upwards or interfingers with thinly laminated carbonates of the Quintuco Formation (Berriasian-Lower Valanginian).

The shales of the Vaca Muerta Formation are representative of slope and basin centre facies, and the overlying carbonates of the Quintuco Formation correspond to shelf sediments. In the carbonate complex of the Quintuco and Vaca Muerta formations, three different sections can be defined which could be correlated with regional eustatic

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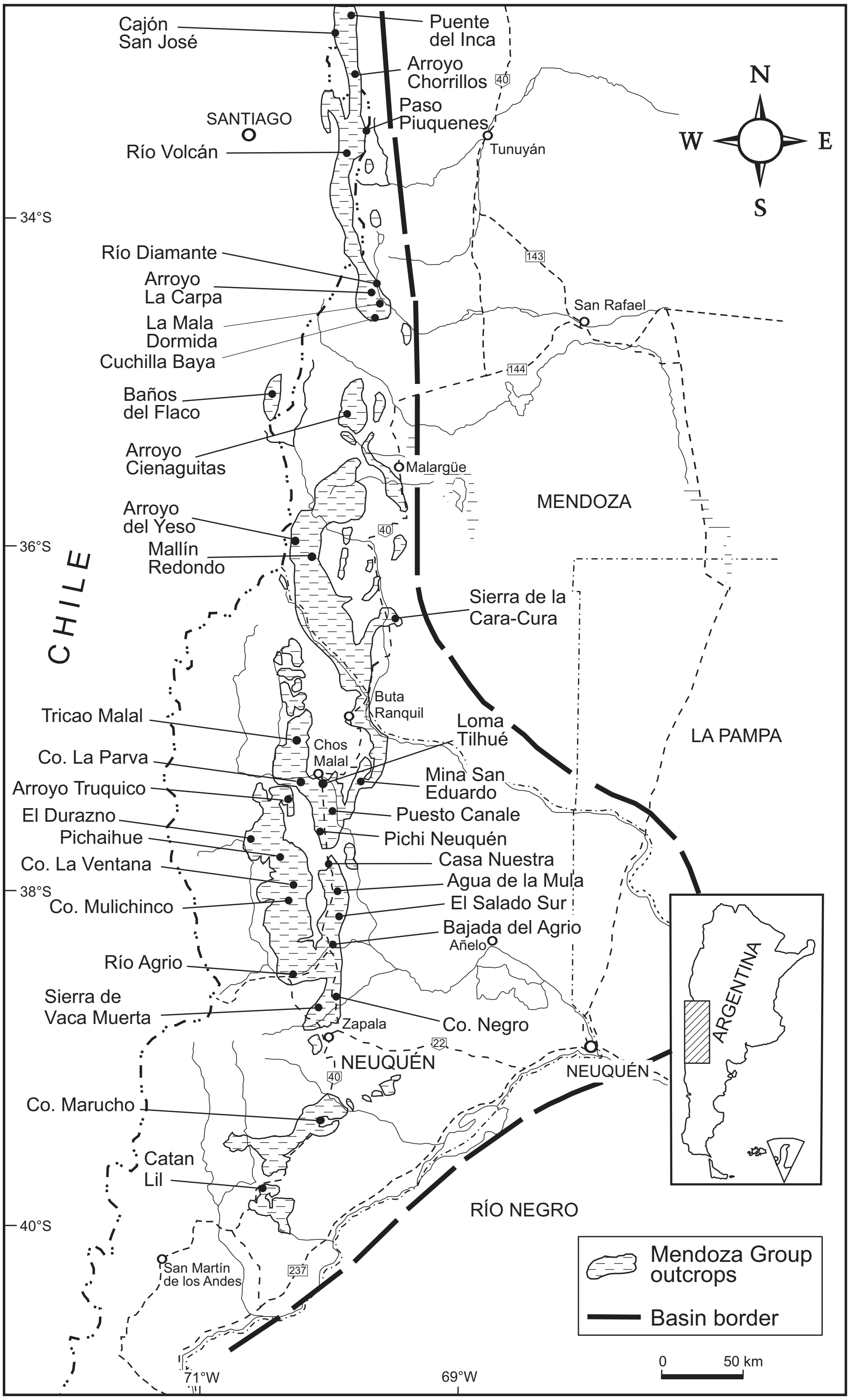

Figure 4. The Lower Cretaceous Neuquén Basin in west-central Argentina and Chile (modified from Gulisano *et al*. 1984 and Riccardi 1988). Abbreviation: Co. = Cerro.

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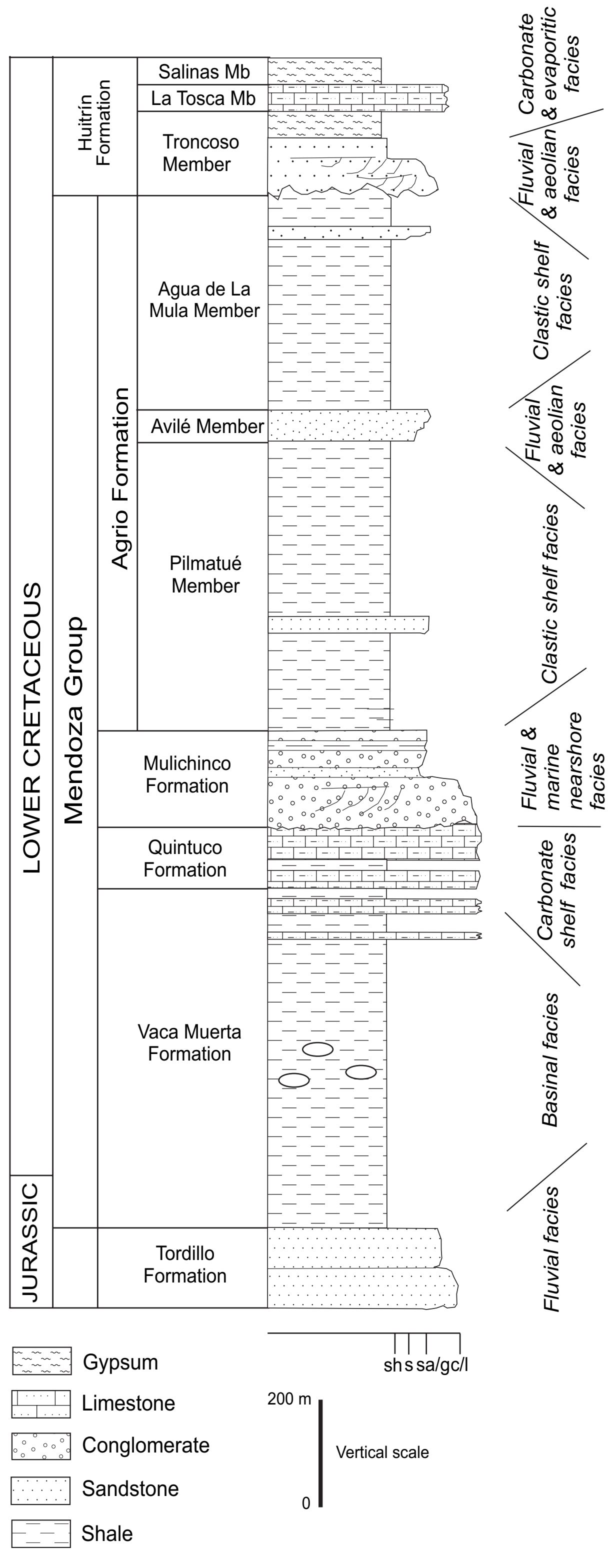

Figure 5. Stratigraphic column of the Mendoza Group.

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events. The basal section has an arrangement of prograding sequences from southeast to northwest, where it is possible to distinguish the offlap break and the associated facies. The mid sequence in the Quintuco Formation is represented by flood deposits on a shallow-water carbonate shelf, with tidal bars in a northwest-southeast direction, where the greatest carbonates thicknesses are located. The upper section is aggradational and shallow, in the internal shelf (Verzi *et al*. 2002). In the southern part of Neuquén, beds equivalent to the Quintuco Formation are known as the Picún Leufú Formation (Leanza 1973).

2.2.5. Mulichinco Formation

This lithostratigraphic unit was defined by Weaver (1931) in the region of Cerro Mulichinco (38°S) where it reaches more than 200 m in thickness. The palaeogeography was complex during the Early Valanginian, when an episode of partial desiccation of the basin took place, with the depositional systems shifing towards the basin centre (Gulisano and Gutiérrez Pleimling 1994). The Mulichinco Formation is represented by fluvial conglomerates and sandstones in central Neuquén and shallow shelf sandstones and shales with interbedded oyster coquinas in northern Neuquén. Contemporaneously with the deposition of the Mulichinco Formation, thick carbonate deposits of the Chachao Formation accumulated in southern Mendoza (Legarreta and Uliana 1999).

2.2.6. Agrio Formation

A transgressive phase occurred in the late Early Valanginian with the deposition of the shales and limestones of the Agrio Formation (Lower Valanginian-Lower Barremian). This unit, defined by Weaver (1931) in the Río Agrio section within the Neuquén embayment, corresponds to the upper part of the Mendoza Group. In the type area, the section reaches 1178 m and is divided into three members (Figure 5): the lower one or Pilmatué Member (Leanza and Hugo 2001) is mainly composed of massive clay shales interbedded with thin layers of packstones and wackestones. Towards the top of the lower member the clay shales are dominant. The middle member or Avilé Member, 25 to 30 m thick, is represented by yellowish brown coarse-grained sandstones, often cross-bedded, and provides an excellent marker horizon, generally forming a distinct topographic feature. It contains no marine fossils and in most areas, the Avilé Member comprises aeolian and fluvial facies (Gulisano and Gutiérrez Pleimling 1988; Veiga *et al.* 2002). The upper, Agua de La Mula Member (Leanza and Hugo 2001) is composed largely of massive clay shale in the lower part and grey calcareous clay shales interbedded with sandy limestones and sandstones in the upper part.

The Agrio Formation extends northwards to the Río Diamante in south-central Mendoza, and southwards to Catán Lil, in southern Neuquén. Towards the east it is known in subsurface up to the central part of the embayment while to the west, the boundary of the present outcrops coincides with the foothills of the Andes (70°30′ W).

2.2.7. Huitrín Formation

The Agrio Formation, the upper unit of the Mendoza Group, is followed by the fluvial and aeolian sandstones and evaporites of the Huitrín Formation which marks a regression and the disconnection of the Neuquén Basin with the Pacific Ocean during Barremian times. Within this unit there is a package of intertidal to marine limestones, known as the La Tosca Member, that has foraminifers and other fossils indicative of a short period of anomalous marine conditions (Legarreta 1985) of probably Aptian age. This limited facies is developed within a general evaporitic sequence, which indicates a restricted connection with the other Pacific basins.

3. BIOSTRATIGRAPHY

3.1. Chañarcillo Basin

The first published biostratigraphy of the Lower Cretaceous, based on ammonites from the Atacama region, was established in the 1960s and 1970s (Tavera 1956; Corvalán 1974); however, only an outline biozonation was proposed. Recent studies have allowed the distinction of many ammonite biozones and biohorizons in the

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Chañarcillo Basin (Mourgues 2004, 2007; Mourgues and Bulot in press). These encompass the Upper Berriasian to the Lower Albian stages. Some of the ammonite biozones have been proved in only one locality so far, and thus have only a local stratigraphic significance. There are also significant stratigraphic intervals where no ammonites are preserved, and thus there are gaps in the zonation (Figures 13 and 14).

3.1.1. The Malbosiceras Range Biozone

This zone was proposed and dated as early Late Berriasian by Mourgues (2007). In the Sierra Chivato Viejo the outcrops of the Punta del Cobre Formation bear *Malbosiceras* of the *malbosi* group (Figure 6A). These are the oldest Cretaceous ammonites known in the region.

3.1.2. The Parandiceras Horizon

This horizon was proposed by Mourgues (2007) for a thin bed containing *Parandiceras* cf. *groeberi* Weaver at Cerro La Vinchuca (Figure 6B), where a barren interval occurs between the *Malbosiceras* Zone and the *Parandiceras* Horizon. The index species was assigned in Chile (Mourgues and Bulot in press) to the Early Valanginian based on its stratigraphic location in the Neuquén Basin (Weaver 1931).

3.1.3. The Lissonia n. sp. Range Biozone

This zone was recognized by Mourgues (2004) in the Chañarcillo Basin as the northernmost extension of the *Lissonia riveroi* Zone of Argentina (Aguirre-Urreta and Rawson 1999a). New detailed studies (Mourgues and Bulot in press) show that the Chilean *Lissonia* is a new species (Figure 6F). It occurs in the upper part of the Punta del Cobre Formation at Quebrada Los Algarrobos, and also in the lower part of the Abundancia Formation at Puquios.

3.1.4. The Olcostephanus (Olcostephanus) atherstoni Range Biozone

This name was proposed by Aguirre-Urreta and Rawson (1997) as a replacement name for the former *O. curacoensis* Zone of the Neuquén Basin, named by Leanza (1945). It was recognized in the Chañarcillo Basin by Mourgues (2004), in the upper part of the Punta del Cobre Formation and in the upper part of the Abundancia Formation. Only the index species is known (Figure 6C,G).

3.1.5. The Olcostephanus (Viluceras) permolestus Range Biozone

In the Neuquén Basin, this is regarded as the highest subzone of the *Olcostephanus (O.) atherstoni* Biozone (Figure 13), but in the Chañarcillo Basin, the *O.* (*Viluceras*) *permolestus* fauna is taken to mark a separate biozone (Mourgues 2004). Here, *O.* (*Viluceras*) *permolestus* (Leanza) (Fig. 6D-E) occurs near the top of the Abundancia Formation (Mourgues 2004), in association with several neocomitids which Mourgues and Bulot (in press) identify as *Neocomites* sp. juv. gr. *neocomiensis* (d'Orbigny), *N. (Varlheidites) peregrinus* Rawson and Kemper, *N. (Sabbaiceras)* aff. *N. beaumugnensis* (Sayn) and *Rodighieroites cardulus* Company (Figure 7B-C).

3.1.6. The Crioceratites diamantensis Range Biozone

This biozone corresponds to the fauna formerly identified by Mourgues (2004) as *C. schlagintweiti*. The first appearance of the index species *C. diamantensis* (Gerth) (Figure 7E) defines the base of the biozone. Within the Quebrada de Meléndez section this fauna is well represented in the upper part of the Nantoco Formation, and it appears associated with *Crioceratites* aff. *C. bederi* (Gerth) and *Sornayites* sp. Southward from Quebrada Yerbas Buenas, *Pseudothurmannia* sp. (Figure 7A), *C.* aff. *C. bederi* (Gerth) and *C.* cf. *C. perditum* (Gerth) are recorded from these same stratigraphic levels.

Figure 6. Characteristic Berriasian-Early Valanginian ammonoids from the Chañarcillo Basin. (A) *Malbosiceras* gr. *malbosi* SNGM 1843. Sierra Chivato Viejo. (B) *Parandiceras* cf. *groeberi* SNGM 1844. Cerro La Vinchuca. (C) *Olcostephanus (Olcostephanus) atherstoni* SNGM 1022. Quebrada Los Algarrobos. (D, E) *Olcostephanus (Viluceras) permolestus* SNGM 1538, SNGM 1023. Quebrada de Meléndez. (F) *Lissonia* n. sp. SNGM 1025. Quebrada Los Algarrobos. (G) *Olcostephanus (Olcostephanus) atherstoni* SNGM 1021. Quebrada Los Algarrobos. All specimens natural size, except A $\times$ 0.5. SNGM: Repository of the Geological Survey of Chile.

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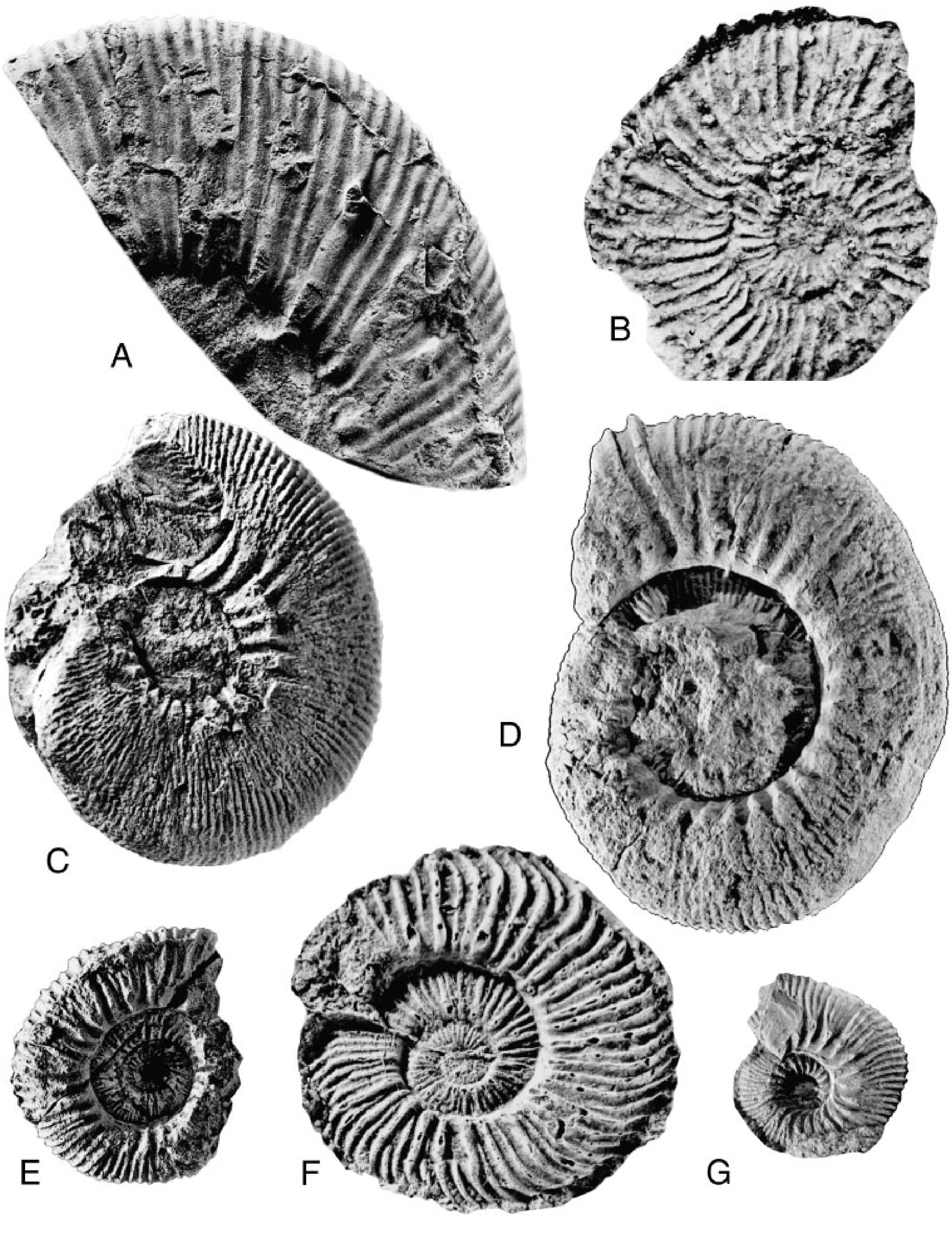

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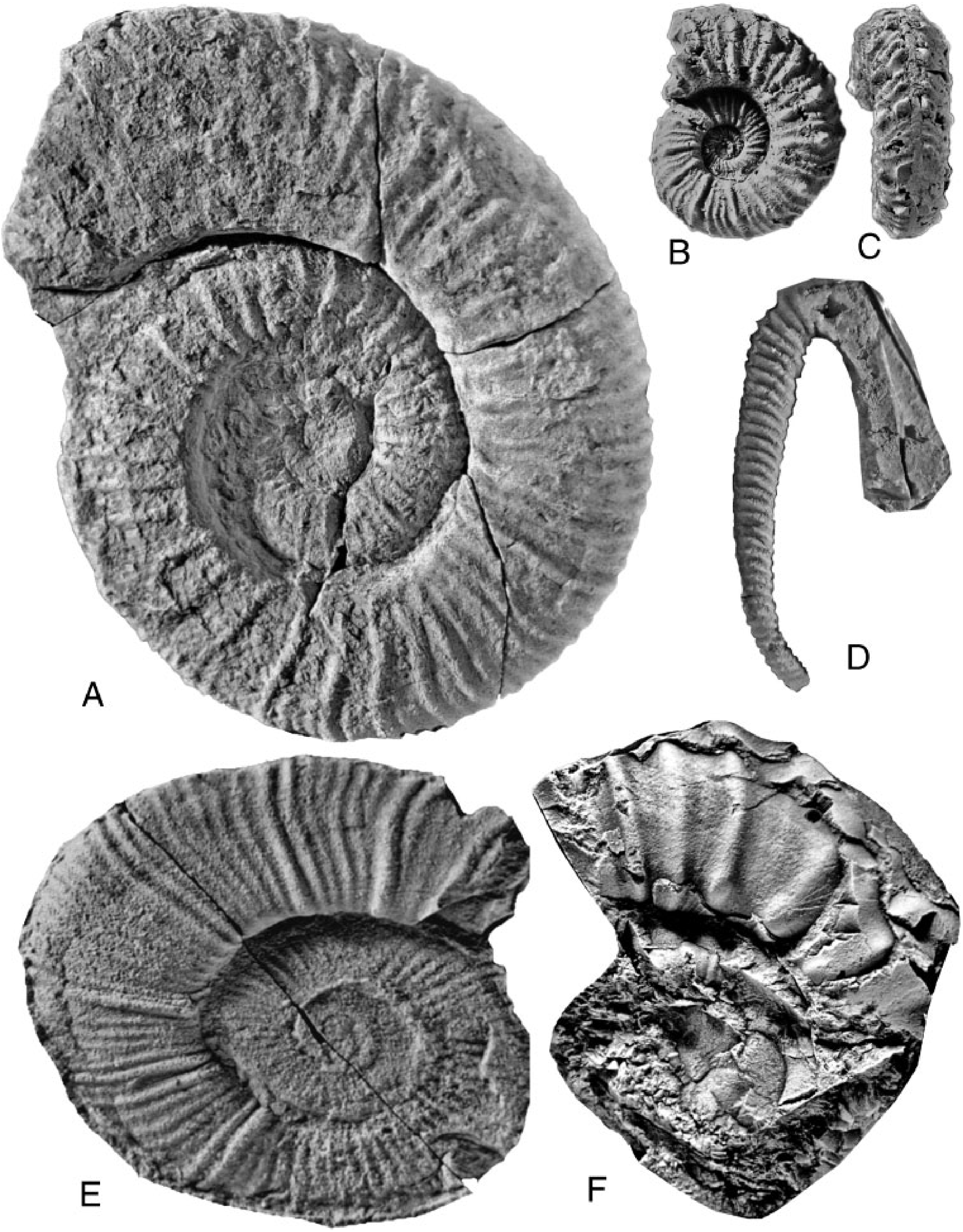

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3.1.7. The Paraspiticeras groeberi Range Biozone

Above the last crioceratitids of the *C. diamantensis* Biozone the *Paraspiticeras* fauna appears, mainly in the south of the basin. From many localities isolated fragments of *P. groeberi* (Figure 7F) were collected, always between the *C. diamantensis* Zone beds and the Nantoco and Totoralillo formations boundary. From Quebrada Las Cañas, Tavera (in Neuenschwander and Tavera 1942) erected '*Crioceras*' *vallenarense* which is regarded here as a species of *Paraspiticeras*. Recent collecting at the type locality shows that this form occurs near the top of the Nantoco Formation, just below the regressive breccias marker level (Mourgues 2007). Northward from this locality and from the same stratigraphic level, other specimens of *Paraspiticeras* were collected associated with *Sabaudiella simplex* Busnardo (in Busnardo *et al*. 2003) (Figure 7D).

3.1.8. The Shasticrioceras Interval Biozone

The base of this biozone is marked by the first appearance of *Shasticrioceras* and the top by the first record of *Emericiceras*. The acme of *Shasticrioceras* clearly occurs below *Emericiceras*, though the *Shasticrioceras* fauna was formerly included in the '*Crioceratites*' *emerici* biozone by Mourgues (2004). The zone is characterized by three species: *Shasticrioceras* aff. *S. patricki* Murphy (Figure 8G-H), *Shasticrioceras* sp. nov. and *Shasticrioceras* sp. At Quebrada de Meléndez it also contains '*Crioceratites*' aff. *C. australis* Klinger and Kennedy and '*Crioceratites*' sp. It is also recorded in the south-east Chañarcillo Mine and Quebrada Las Cañas (Figure 2). The biozone occurs in the upper half of the Totoralillo Formation, and is dated as Early Barremian (Mourgues 2004, 2007).

3.1.9. The Emericiceras Range Biozone

This biozone was recognized formerly as the '*Crioceratites*' *emerici* biozone, and originally included the *Shasticrioceras* fauna (Mourgues 2004). The base is now defined by the first appearance of *Emericiceras*. This zone has a wide geographic extension in the basin, occurring at several localities from Quebrada de Meléndez to Quebrada de Los Choros (Figure 2). The biozone starts with the *Emericiceras* aff. *E. otto-haasi* biohorizon (Figure 8F) and the first *Emericiceras* sp. 1. Another species of this zone is *E*. aff. *E. emerici* (Figure 8A). The biozone is present in the upper half of the Totoralillo Formation and is of Early Barremian age (Mourgues 2004, 2007).

3.1.10. The Moutoniceras? sp. Range Biozone

Above the *Emericiceras* Biozone and separated by a barren interval a very distinctive but not well-preserved fauna was distinguished as the *Moutoniceras* sp. Biozone by Mourgues (2007). It includes the *Sanmartinoceras africanum insignicostatum* Horizon in the highest part (Figure 14).

The *Moutoniceras* sp. Biozone is known only at Quebrada de Meléndez, in the upper part of the Totoralillo Formation. The base is marked by the first appearance of *Moutoniceras* sp. Biozone (Figure 8D), while in the upper half of this biozone *Nicklesia* cf. *N. communis* (Brugl) and *Nicklesia* sp. occur. *Moutoniceras* appears in Europe in the upper part of the Lower Barremian (Busnardo 1984; Company *et al*. 1995), while *Nicklesia communis* (Bürgl) is also characteristic of the upper Lower Barremian (Vermeulen 1996; Patarroyo 2004). In agreement with this, a late Early Barremian age is assigned to the bulk of the *Moutoniceras* Zone (Mourgues 2007).

Figure 7. Characteristic Late Valanginian, Hauterivian and Early Barremian ammonoids from the Chañarcillo Basin. (A) *Pseudothurmannia* sp. SNGM 1870. Quebrada Yerbas Buenas. (B, C) *Rodighieroites cardulus* SNGM 1847. Quebrada de Meléndez. (D) *Sabaudiella simplex* SNGM 1871. Quebrada Las Cañas. (E) *Crioceratites diamantensis* SNGM 1028. Quebrada de Meléndez. (F) *Paraspiticeras groeberi* SNGM 1872. Quebrada Chuschampis. All specimens natural size, except A × 0.5.

Figure 8. Characteristic Barremian ammonoids from the Chañarcillo Basin. (A) *Emericiceras* aff. *emerici*. SNGM 1874 (× 0.5). Quebrada de Meléndez. (B, C) *Antarcticoceras domeykanum* SNGM 1039 (× 0.5). Cerro Chañarcillo. (D) *Moutoniceras*? sp. SNGM 1882 (× 0.5). Quebrada de Meléndez. (E) *Sanmartinoceras africanum insignicostatum* SNGM 1020 (× 0.75). Quebrada de Meléndez. (F) *Emericiceras* aff. *otto-hassi* SNGM 1873 (× 0.5). South-east of Chañarcillo Mine. (G, H) *Shasticrioceras* aff. *patricki* SNGM 1037 (× 1). South-east of Chañarcillo Mine.

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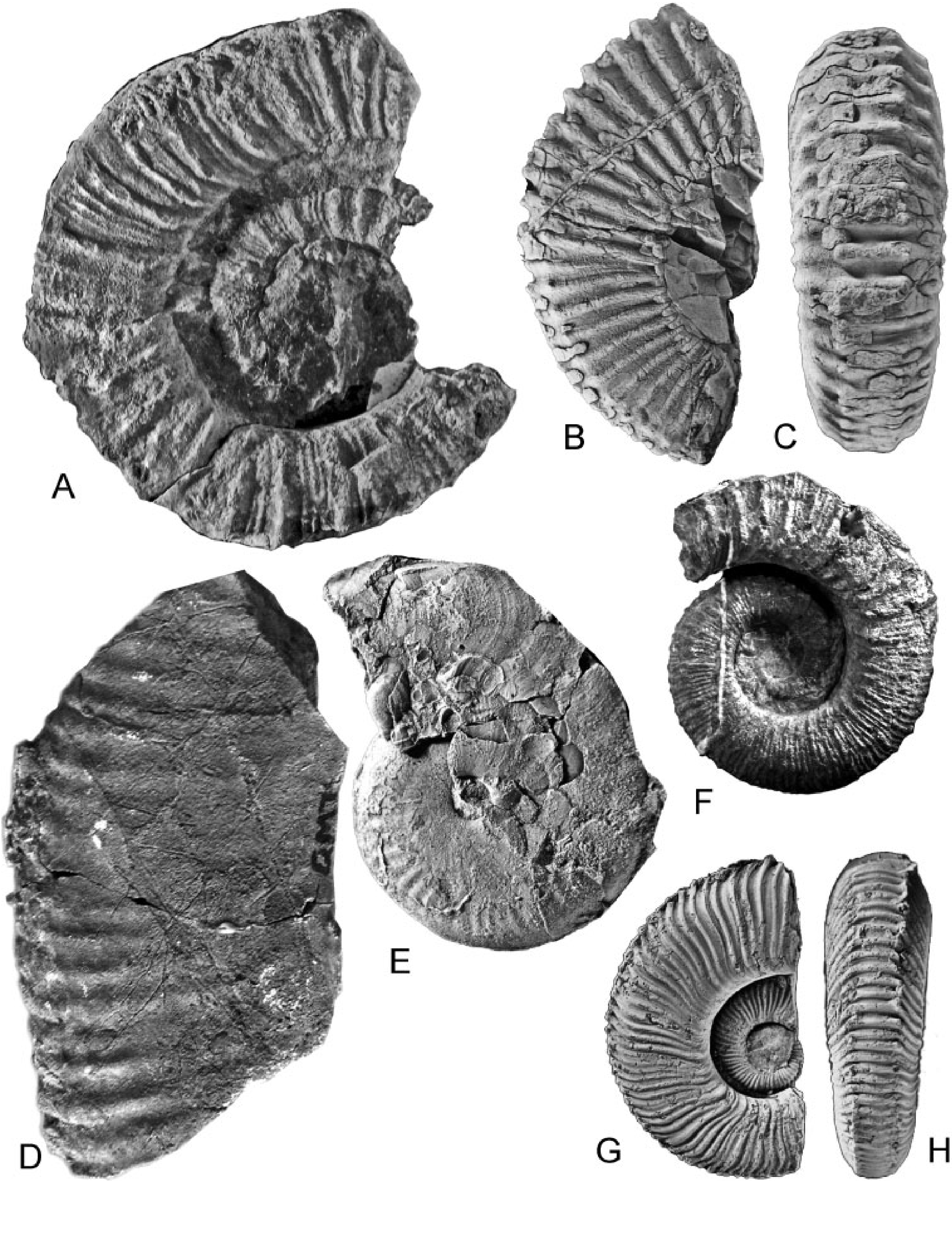

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3.1.11. The Sanmartinoceras africanum insignicostatum Horizon

At the top of the *Moutoniceras* sp. Biozone a thin bed with abundant *Sanmartinoceras africanum insignicostatum* Kennedy and Klinger (Figure 8E) was recognized at Quebrada de Meléndez, occurring in the upper part of the Totoralillo Formation. *S. africanum insignicostatum* was cited from the Upper Barremian in the Austral Basin (Riccardi *et al*. 1987), and in South Africa (Kennedy and Klinger 1979).

3.1.12. The Antarcticoceras domeykanum Range Biozone

This zone was recognized formerly as the *Parancyloceras domeykanum* Zone (Mourgues 2004). However, a systematic revision enabled reassignment of the index species to the genus *Antarcticoceras* (Mourgues 2007). The base of this biozone is defined by the first appearance of *A. domeykanum* (Figure 8B-C). The biozone has an extensive geographic distribution, occurring in several localities from Puquios to Quebrada Las Breas (Figure 2), always at the base of the Pabellón Formation. As in the Chañarcillo Basin, *Antarcticoceras* was found in Antarctica above a *Sanmartinoceras* fauna. The Antarctic forms are not well preserved, and the age of the *Antarcticoceras* fauna does not have reliable biostratigraphic constraints. However, Thomson (1982) tentatively dated it as Late Aptian-Early Albian, although he mentioned the association of this fauna with Barremian-like ancyloceratids. According to its relative position in the Chañarcillo Basin, the *Antarcticoceras domeykanum* Biozone is Late Barremian.

3.1.13. The Hemihoplites perezi Range Biozone

This zone was created for a particular fauna that is stratigraphically constrained to the lower to middle part of the Pabellón Formation, just above the *Antarcticoceras domeykanum* Biozone (Mourgues *et al*. submitted). The base is defined by the first appearance of *H. perezi* Mourgues (Figure 9B). This biozone occurs at Quebrada de Meléndez and northward from Mina Teresita. The *H. perezi* Biozone also contains other ancyloceratids which unfortunately are not well preserved. An Early Aptian age was preliminarily assigned to this biozone (Mourgues 2007).

3.1.14. The Ancyloceras (Adouliceras) sp. Horizon

At Quebrada de Meléndez, above the first volcaniclastic deposit of the middle part of the Pabellón Formation, a thin marl bed that contains several specimens of *Ancyloceras* (*Adouliceras*) sp. (Figure 9D) was recently recorded (Mourgues *et al*. 2005; Mourgues 2007). This species has been found only at this locality, and there are no associated ammonites. The Chilean material has strong similarities with the South African *Adouliceras* fauna such as *A. mozambiquense*, *A. cooperi* and *A.* of the *mozambiquense-cooperi* group, all from the South African Lower Aptian (Kennedy and Klinger 1977). Therefore, this horizon was attributed to the Lower Aptian (Mourgues 2007).

3.1.15. The Hypacanthoplites sp. Horizon

This horizon lies just under the olistostrome unit in the upper part of the Pabellón Formation at Quebrada El Molle (Figure 2), where it underlies the *Neodeshayesites* sp. Horizon (Figure 14). The Chilean *Hypacanthoplites* sp. (Figure 9A) has many similarities with *Hypacanthoplites evolutus* (Scott) from the Upper Aptian of Southern Texas (Young 1974). Also, the historic collection of SERNAGEOMIN (Pérez collection) contain *Sinzowiella* sp. (Deshayesitidae indet., in Cichowolski *et al*. 2004) recorded from stratigraphic levels near to the *Hypacanthoplites* Horizon, which was attributed by its affinities with the southern Texas fauna (Stoyanow 1949) to the Upper Aptian (Mourgues 2007).

3.1.16. The Neodeshayesites sp. Horizon

The minimum age of the Pabellón Formation was based on the discovery of a single ammonite originally assigned to *Parahoplites* of the *nutfieldiensis* (J. Sowerby) group, which indicates an early Late Aptian age (Pérez *et al*.

Figure 9. Characteristic Aptian-Albian ammonoids from the Chañarcillo Basin. (A) *Hypacanthoplites* sp. SNGM 1875 (× 0.33). Quebrada El Molle. (B) *Hemihoplites perezi* SNGM 1842 (× 0.75). Northward from Teresita Mine. (C) *Neodeshayesites* sp. SNGM F56c-6889 (× 0.75) (From Pérez *et al*. 1990, fig. 2a.) Quebrada El Molle. (D) *Ancyloceras* (*Adouliceras*) sp. SNGM 1876 (× 0.33). Quebrada de Meléndez.

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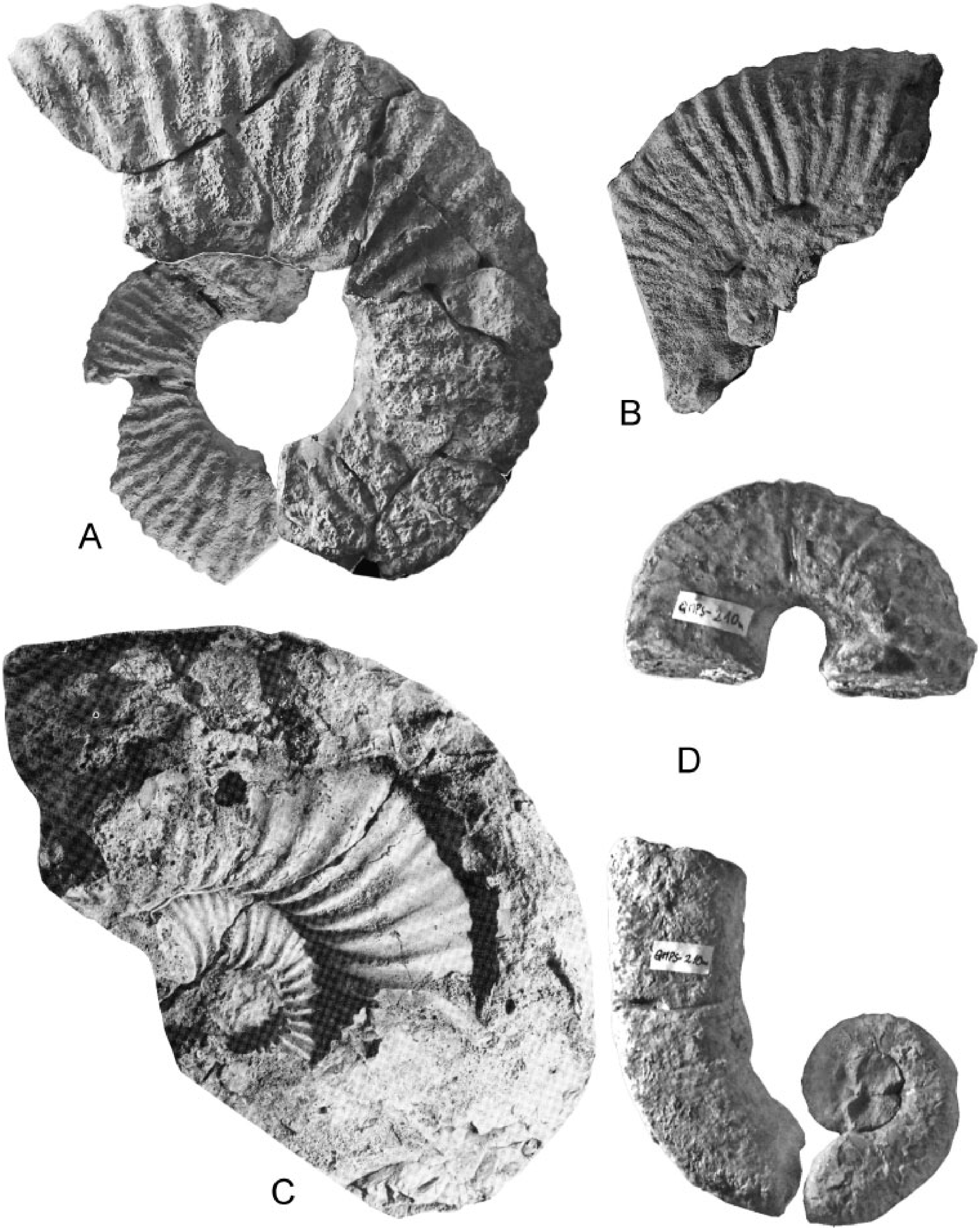

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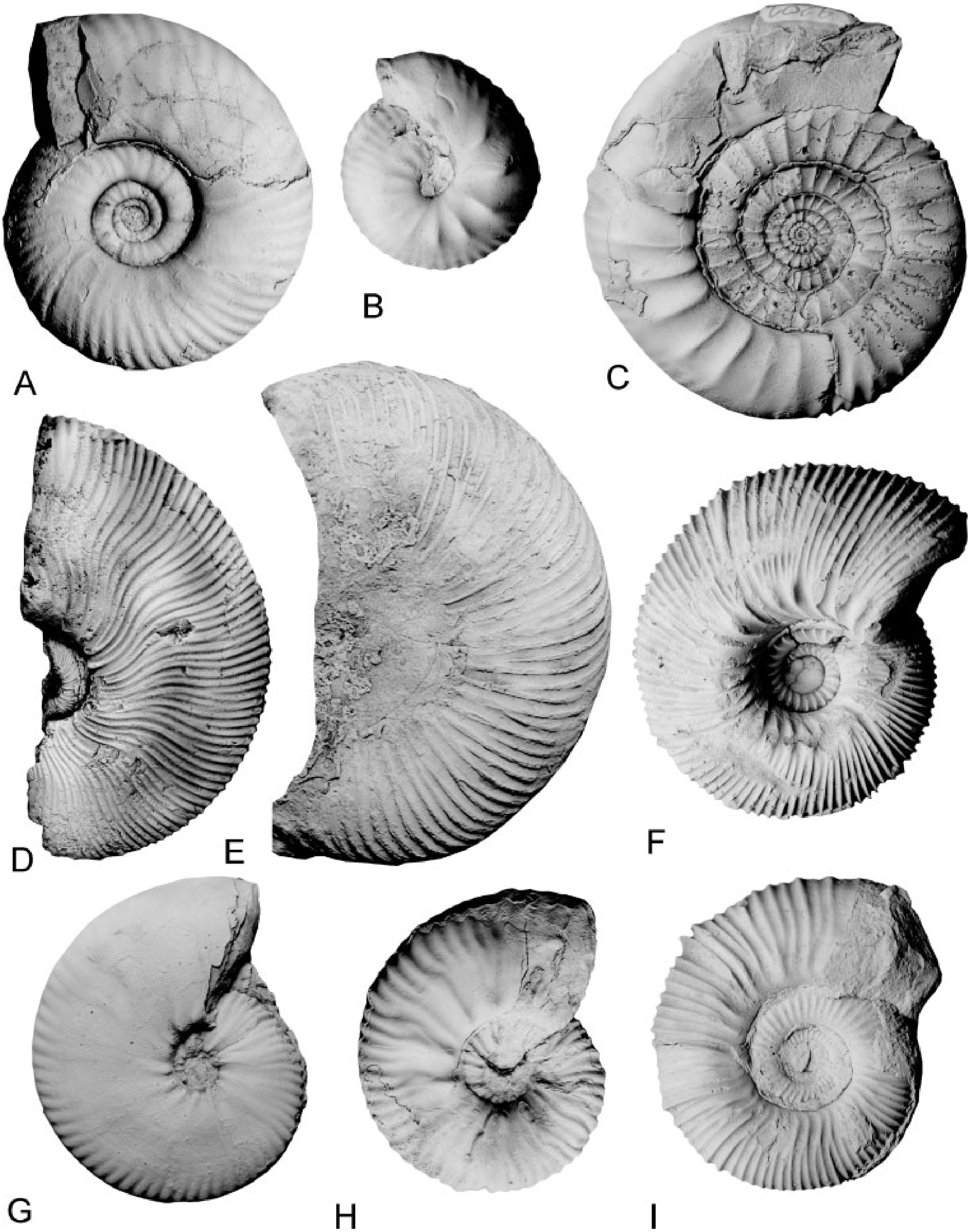

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1990). The specimen has been reidentified as *Neodeshayesites* sp. (Figure 9C) and consequently its age reassigned to the Early Albian (Mourgues 2007). This horizon occurs only at Quebrada El Molle and no additional specimens have been found.

3.2. Neuquén Basin

Windhausen (1918) provided one of the first biostratigraphic schemes of the Neuquén Basin. Since then, several proposals were published including those of Gerth (1921, 1925), A. Leanza (1945), H. Leanza (1981a,b), Riccardi (1984, 1988) and Aguirre-Urreta (1993). Meticulous collecting bed by bed, mostly in the Agrio Formation, allowed production of a more refined ammonite zonation (Aguirre-Urreta and Rawson 1997). Revision of the systematics of key genera together with the correlation with nannofossils resulted in modifications which are summarized in a recent biostratigraphic review (Aguirre-Urreta *et al*. 2005). One new horizon is formally defined below.

3.2.1. The Argentiniceras noduliferum Assemblage Biozone

This biozone was proposed by Leanza (1945) for ammonites recovered from the Vaca Muerta Formation in southern Mendoza. It is documented from northern Mendoza to southern Neuquén, where it is present in the Picún Leufú Formation. Components of the assemblage include species of *Argentiniceras*, *Groebericeras* (Figure 10A), *Frenguelliceras*, *Hemispiticeras*, *Berriasella* and '*Thurmanniceras*'. Only part of this fauna has been revised recently (Aguirre-Urreta and Alvarez 1999). Although Riccardi *et al*. (2000) placed it in the middle Berriasian, it is classically considered to be Early Berriasian in age.

3.2.2. The Spiticeras damesi Assemblage Biozone

The biozone was proposed by Gerth (1921) for ammonites of southern Mendoza and originally placed in the Valanginian. It is recorded in Mendoza and northern and central Neuquén in the Vaca Muerta Formation. The association is quite diverse and includes species of *Spiticeras* (Figure 10C), *Neocosmoceras*, *Cuyaniceras*, *Neocomites*, *Pseudoblanfordia* and *'Thurmanniceras'*. Burckhardt (1930) placed it in the Berriasian and presently its age is considered as Late Berriasian.

3.2.3. The Neocomites wichmanni Assemblage Biozone

The biozone was named by Leanza (1945) for ammonites of the Vaca Muerta Formation of southern Mendoza. It is also recorded in west-central Neuquén. Besides the nominal species, *N. wichmanni* (Figure 10D), several forms of *'Thurmanniceras'* sp. have been identified (Aguirre-Urreta and Rawson 1999a) but are in need of a systematic revision. Leanza (1981a,b) placed it in the Early Valanginian.

3.2.4. The Valanginites argentinicus Horizon (New)

Just beneath the boundary between the *Neocomites wichmanni* and the *Lissonia riveroi* zones there is a thin horizon with *Valanginites argentinicus* Leanza and Wiedmann (Figure 10B) in the black shales of the Vaca Muerta Formation. This horizon has been recorded in only two localities of Central Neuquén: Cerrito La Ventana and Cordillera El Salado (Figure 4). A single *Olcostephanus* sp. in Cerrito La Ventana, most probably from the *Valanginites* Horizon, represents the earliest Argentine record of this genus (Aguirre-Urreta and Rawson 1999a).

Figure 10. Characteristic Berriasian-Valanginian ammonoids from the Neuquén Basin. (A) *Groebericeras bifrons* CPBA 7609. Mallín Redondo. (B) *Valanginites argentinicus* CPBA 18145. Cerro La Ventana. (C) *Spiticeras damesi* CPBA 9201. Cuchilla Baya. (D) *Neocomites wichmanni* DNGM 7260. Arroyo del Yeso. (E) *Lissonia riveroi* CPBA 19294. Cerro La Parva. (F) *Olcostephanus (Olcostephanus) atherstoni* CPBA 17008.52. Cerro La Parva. (G) *Karakaschiceras attenuatum* CPBA 13962.3. Arroyo Truquico. (H) *Neohoploceras arnoldi* CPBA 13958. Arroyo Truquico. (I) *Olcostephanus (Viluceras) permolestus* CPBA 19144.2. El Durazno. CPBA: Repository of the University of Buenos Aires, Argentina. DNGM: Repository of the Geological Survey of Argentina. All specimens natural size.

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3.2.5. The Lissonia riveroi Range Biozone

This biozone was proposed by Aguirre-Urreta and Rawson (1999a); its base is defined by the first appearance of the index species which co-occurs with *Acantholissonia gerthi* (Weaver) in the highest part of the Vaca Muerta Formation in Neuquén (Aguirre-Urreta and Rawson 1999a). *Lissonia riveroi* (Figure 10E) is also present in the Chachao Formation of southern Mendoza. The age of the biozone is Early Valanginian.

3.2.6. The Olcostephanus (Olcostephanus) atherstoni Assemblage Biozone

This was named by Leanza (1945) as the *O. curacoensis* Zone and its age was considered as encompassing the Valanginian-Hauterivian boundary (Riccardi *et al*. 1971; Leanza 1981a,b; Riccardi 1984, 1988). Aguirre-Urreta and Rawson (1997) proposed the new name because the original index species is regarded as a junior subjective synonym of *O. atherstoni* (Sharpe) as provisionally suggested by Riccardi *et al*. (1971), and placed it in the late Early to early Late Valanginian. The base of the biozone is defined by the first appearance of *Olcostephanus (O.) atherstoni* (Figure 10F), which is in the upper part of the Vaca Muerta Formation or in the Chachao Formation in southern Mendoza, and in the Mulichinco Formation in Neuquén.

The biozone has been divided in three subzones (Figure 13). The first is the *Olcostephanus (Olcostephanus) atherstoni* Subzone which only contains abundant dimorphic pairs of the index species. It has a widespread geographic distribution, from the Aconcagua region in northern Mendoza (Lo Forte and Pérez 1991; Aguirre-Urreta and Sagasti 1999) to Pichaihue valley in Central Neuquén. The overlying subzone is the *Karakaschiceras attenuatum* Subzone and is characterized by the appearance of *Karakaschiceras*. The lower part also bears *O. (O.) atherstoni*, while the rest of the subzone contains, besides the nominal species *Karakaschiceras attenuatum* (Figure 10G), *K. neuymari* (Beherendsen), *K. lycoris* (Leanza) and *Neohoploceras arnoldi* (Sayn) (Figure 10H) (Aguirre-Urreta 1998). Most records are from northern Neuquén, but *Karakaschiceras* sp. is also recorded in Cajón San José (Chile) in the Aconcagua area and near Río Diamante in Mendoza (Figure 4). The third and last subzone is the *Olcostephanus (Viluceras) permolestus* Subzone. The subzone of *Olcostephanus (V.) permolestus* (Figure 10I) is also characterized by *Olcostephanus (V.) araucanus* (Leanza), *O. (V.) duraznoensis* Aguirre-Urreta and Rawson and *O. (Olcostephanus) mingrammi* (Leanza). Elements of this subzone are common in several localities of northen Neuquén (Aguirre-Urreta and Rawson 1999b), and there are also two isolated records of *O. (V.) permolestus* in southern Mendoza (Arroyo Cienaguitas) and central Mendoza (Arroyo Chorrillos, near Tupungato volcano).

3.2.7. The Pseudofavrella angulatiformis Assemblage Biozone

The name was proposed by Aguirre-Urreta and Rawson (1995) as a replacement for the '*Lyticoceras*' *pseudoregale* Zone of Gerth (1925). The substitute name was due to the fact that '*Lyticoceras*' *pseudoregale* is a poorly understood and poorly known species (Burckhardt 1903; Leanza and Wiedmann 1980) while *Pseudofavrella angulatiformis* (Beherendsen) is a distinctive element of the lower part of the zone. Its base is defined by the first appearance of another *Pseudofavrella* species: *P. garatei* Leanza and Wiedmann (Figure 11A), sometimes associated with the last *O. (V.) permolestus*. The biozone characterizes the upper part of the Late Valanginian and it has also been divided in three subzones (Aguirre-Urreta and Rawson 1997) (Figure 13). The first is the *Pseudofavrella angulatiformis* Subzone. The fauna is widely distributed though often flattened in dark shales. The index species is reported from the Aconcagua area (Aguirre-Urreta and Lo Forte 1996), Río Diamante and Arroyo Cienaguitas in Mendoza (Aguirre-Urreta and Sagasti 1999; Tunik *et al*. 2005), and in several localities of central Neuquén, including Arroyo Truquico, its type locality (Figure 4). In Pichaihue, bed-by-bed collecting has shown that *P. garatei* is the first species to appear and soon is replaced by *P. angulatiformis,* and then '*Besaireiceras*'

Figure 11. Characteristic Valanginian-Early Hauterivan ammonoids from the Neuquén Basin. (A) *Pseudofavrella garatei* CPBA 13961. Pichaihue. (B) *Chacantuceras ornatum* CPBA 18380. Pichaihue. (C) *Neocomites* sp. CPBA 19295. Casa Nuestra. (D, E) *Holcoptychites magdalenae* CPBA 19821.6. Pichaihue. (F, G) *Hoplitocrioceras giovinei* CPBA 19234. El Salado Sur. (H, I) *Holcoptychites neuquensis* EM 2001. Cerro Negro.? (J) *Olcostephanus (Olcostephanus) laticosta* CPBA 19296. Bajada del Agrio. EM: Repository of the University Claude Bernard, Lyon, France. All specimens natural size.

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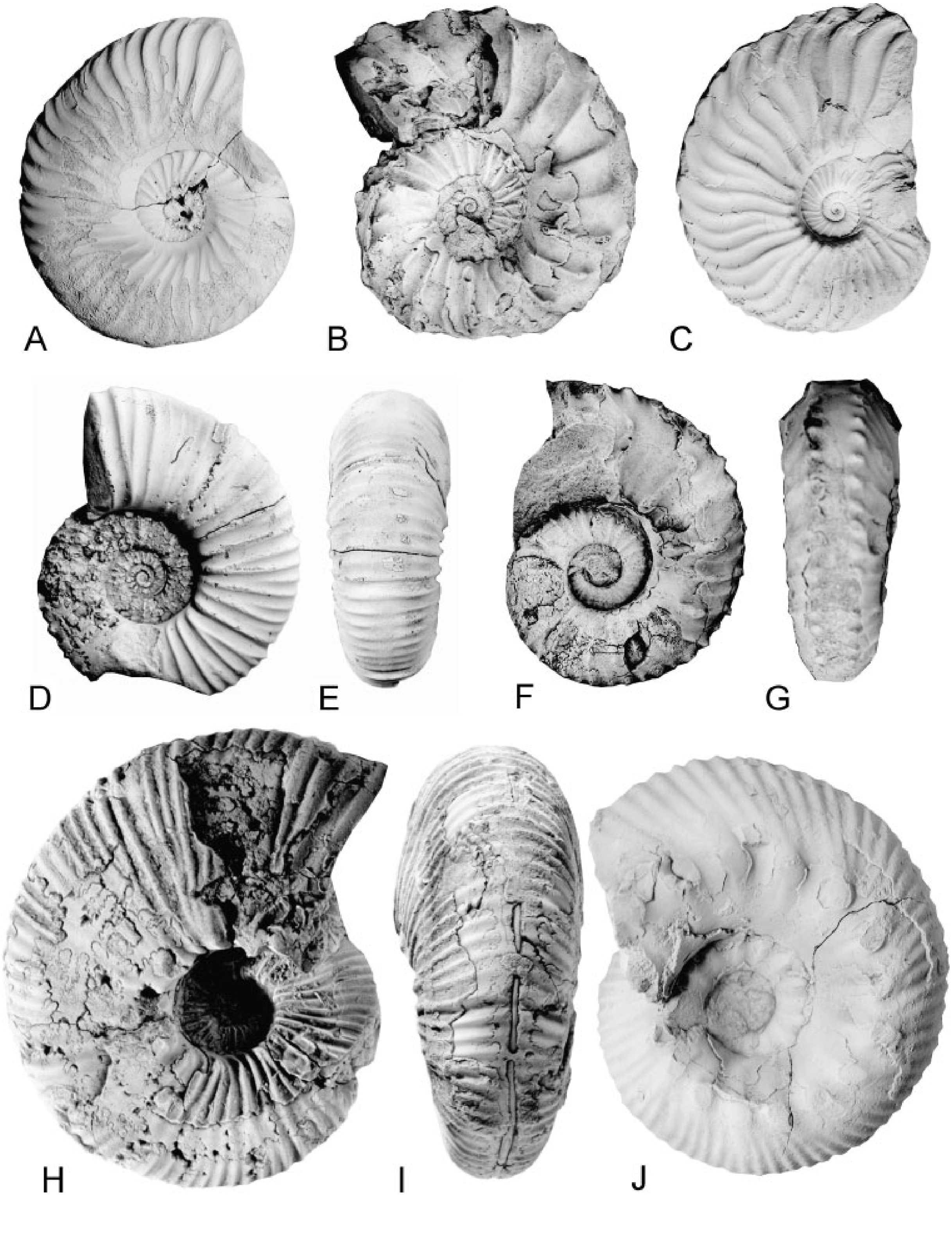

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australe (Leanza and Wiedmann) appears a little higher. The whole fauna is under revision now, but the three species have been described by Leanza and Wiedmann (1980).

The second subzone is the *Chacantuceras ornatum* Subzone. The index species (Figure 11B), initially recorded only from black shales facies in many localities in the central part of the Neuquén Basin (Aguirre-Urreta and Rawson 1999c), has since been found in yellowish limestones at La Mala Dormida (Río Diamante area) and Arroyo Chorrillos in Mendoza (Aguirre-Urreta and Sagasti 1999; Figure 2) and northwards in the Aconcagua region (Aguirre-Urreta 2002). This species seems to be endemic to the Aconcagua-Neuquén Basin and the Río Mayo embayment of Argentina (Figure 1).

The third subzone is the *Neocomites* sp. Subzone which records several forms of involute and compressed neocomitids (Figure 11C) which are presently under revision. Some are similar in lateral view to European forms of the *Neocomites (Teschenites) pachydicranus* group and characterizes the highest Valanginian beds of the basin (Aguirre-Urreta *et al*. 2005).

In the highest part of this subzone and in the lower part of the overlying *Holcoptychites neuquensis* Biozone few and poorly preserved specimens of *Oosterella* sp. have been identified in four different localities of central Neuquén (Cerro Negro, Pichaihue, Pichi Neuquén and Agua de La Mula; Figure 4) (Aguirre-Urreta and Rawson 1996, 2003).

3.2.8. The Holcoptychites neuquensis Assemblage Biozone

This biozone was originally proposed by Gerth (1921) to include the ammonoid assemblages between the top of his '*Acanthodiscus radiatus* Zone' and his '*Crioceras andinum* Zone'. It was later used in a more restricted way to include *Holcoptychites* and *Weavericeras* by Leanza (1981a,b) who placed it in the mid Hauterivian or late Early Hauterivian if a bipartite division is used, and by Riccardi (1984, 1988) who located it mostly in the Late Hauterivian, and later on spanning the later part of the Early Hauterivian and the earlier part of the Late Hauterivian (Riccardi *et al*. 1993). Aguirre-Urreta and Rawson (1997) and Aguirre-Urreta *et al*. (2005) restricted it to the *Holcoptychites* and *Olcostephanus (O.) laticosta* beds of the Lower Hauterivian and recognized three subzones (Figure 13).

The base of the zone, and of the *Holcoptychites neuquensis* Subzone, is marked by the appearance of the genus *Holcoptychites*. The first recorded species, *Holcoptychites* sp. cf. *H. recopei* (Douvillé) and *Holcoptychites* sp. nov., are not well preserved, but higher in the subzone abundant and beautifully preserved specimens of *H. magdalenae* (Douvillé) (Figure 11D-E) appear, followed by *H. neuquensis* (Douvillé) (Figure 11H-I). This subzone is documented from Puente del Inca in the Aconcagua region (Aguirre-Urreta and Lo Forte 1996), in Arroyo La Carpa near Río Diamante in central Mendoza (Tunik *et al*. 2005) and in many localities of Neuquén (Aguirre-Urreta and Rawson 2003).

The middle subzone is characterized only by the index species, the more compressed *Holcoptychites agrioensis* (Weaver), and its geographic distribution is restricted to central Mendoza to central Neuquén (Aguirre-Urreta and Rawson 2003).

The highest subzone is marked by the abrupt replacement of *Holcoptychites* by *Olcostephanus*. Together with the index species, *Olcostephanus (Olcostephanus) laticosta* (Gerth) (Figure 11J), a single *O*. (*O*.) *boesei* (Riedel) has been recorded, and *O*. (*Jeannoticeras*) *agrioensis* Aguirrre-Urreta and Rawson also occurs in the upper part of the subzone (Aguirre-Urreta and Rawson 2003). The distribution of the fauna is similar to that of the preceding subzone, but extends southwards to Cerro Marucho, south of Zapala (Figure 4). This subzone may be coincident with the upper division of the '*Olcostephanus curacoensis* zone' (=*O. O.) atherstoni* Zone) of Riccardi *et al*. (1993) who placed it in the latest Valanginian and earliest Hauterivian.

Fragments of an indeterminate neocomitid that may be the predecessor of the genus *Hoplitocrioceras* of the following biozone, are recorded in the highest part of the subzone in Agua de La Mula and El Salado Sur sections of central Neuquén (Aguirre-Urreta and Rawson 2001a).

3.2.9. The Hoplitocrioceras gentilii Assemblage Biozone

This biozone was erected by Aguirre-Urreta and Rawson (1997) and placed in the Lower Hauterivian. Its base is marked by *Hoplitocrioceras* replacing *Olcostephanus*. *Hoplitocrioceras* has not been recorded yet outside of the

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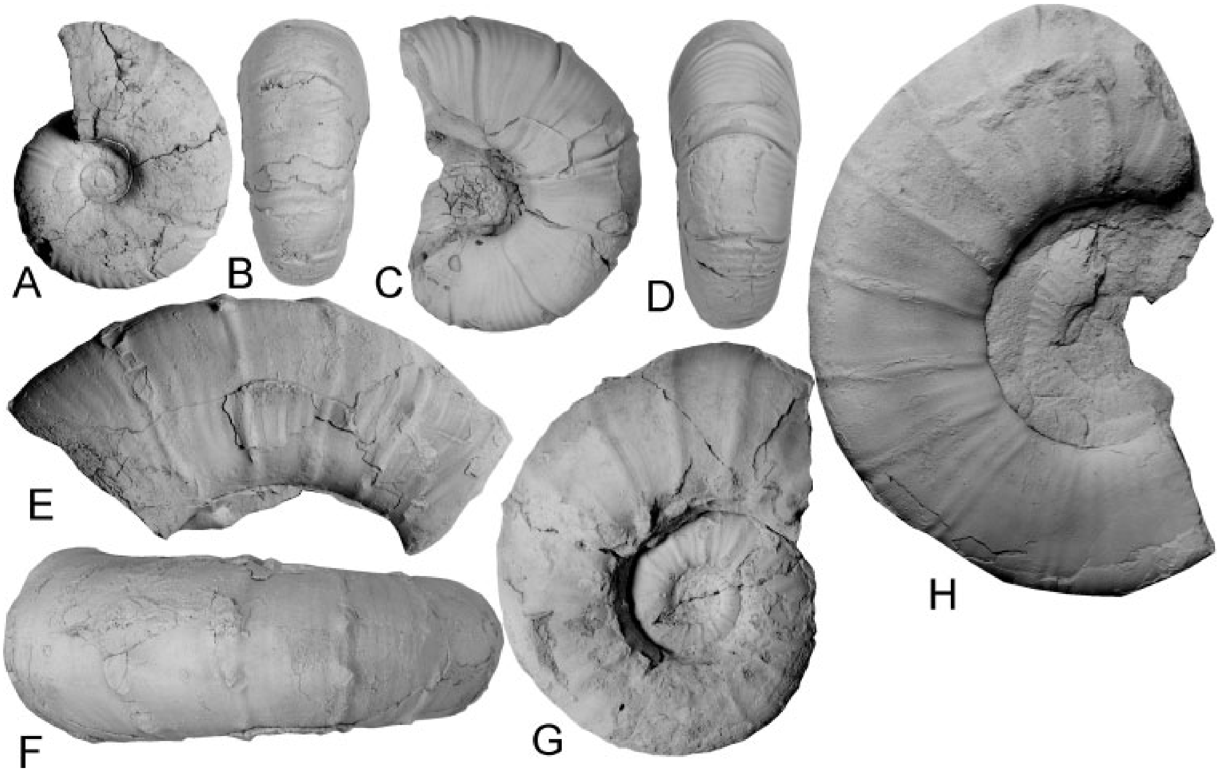

Figure 12. Characteristic Early Hauterivan-Early Barremian ammonoids from the Neuquén Basin. (A, B) *Weavericeras vacaense* CPBA 19297. Bajada del Agrio. (C, D) *Spitidiscus* sp. CPBA 20032.7. El Salado Sur. (E, F) *Crioceratites apricus* CPBA 19298. Mina San Eduardo. (G) *Paraspiticeras groeberi* CPBA 18378. Agua de la Mula. (H) *Crioceratites diamantensis* CPBA 19299. Mina San Eduardo. All specimens natural size.

Neuquén Basin, though one of us (MBA-U) has seen undescribed specimens from Colombia that may belong to *Hoplitocrioceras*.

The biozone is divided into a lower *Hoplitocrioceras giovinei* Subzone (Figure 11F-G) and an upper *H. gentilii* Subzone (Figure 13). The fauna was monographed by Aguirre-Urreta and Rawson (2001b) from many localities of Neuquén, but since then it has also been found in Mendoza (Tunik *et al*. 2005).

The nominal species of the biozone was placed in the *Crioceratites andinum* Assemblage Zone of the Upper Hauterivian and Lower Baremian by Riccardi (1988).

The only other ammonites so far recorded from the biozone are just two specimens of *Olcostephanus* (*Olcostephanus*) *variegatus* (Paquier) from the upper part of the *giovinei* Subzone, both from central Neuquén (El Salado Sur and Bajada del Agrio) (Aguirre-Urreta and Rawson 2001a).

3.2.10. The Weavericeras vacaense Assemblage Biozone

This biozone was proposed by Aguirre-Urreta and Rawson (1997) and its base is marked by the appearance of the genus *Weavericeras* (Figure 12A-B) which is associated at several localities with the very last occurrence of *Hoplitocrioceras*. The genus *Weavericeras* extends through the upper part of the Pilmatué Member of the Agrio Formation, up to the base of the Avilé Member. *Weavericeras* seems to be endemic to the Neuquén Basin; it occurs in many localities in Neuquén and has been recorded recently in Mendoza (Tunik *et al*. 2005).

3.2.11. The Spitidiscus riccardii Assemblage Biozone

This biozone was proposed by Aguirre-Urreta *et al*. (1993) for a sequence of shales with *Spitidiscus*, at the base of the Agua de la Mula Member of the Agrio Formation. These bluish-black shales represent a maximum flooding

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surface and are widespread in the basin, but at many localities *Spitidiscus* is either absent or flattened in the shales and can be easily missed.

Originally, Leanza and Wiedmann (1992) described *Spitidiscus riccardii* Leanza and Wiedmann, *S*. sp. aff. *S. gastaldianus* (d'Orbigny) and *Plesiospitidiscus coccai* Leanza and Wiedmann, and placed them in the top of the Agrio Formation, assigning them a late Early to early Late Barremian age. This was later changed by Aguirre-Urreta *et al*. (1993) who showed the correct stratigraphic position of the fossils, while Aguirre-Urreta (1995) merged them all into *Spitidiscus riccardii*, a single, variable species.

Besides the index species, there is also an undescribed form of *Spitidiscus* (Aguirre-Urreta and Rawson 1997, p. 456, fig 6e-g; Figure 12C-D), but the order of occurrence of both species remains uncertain.

There is only one record of *Spitidiscus riccardii* from Mendoza, from the Paso Piuquenes in central Mendoza (Aguirre-Urreta 2001), and in Neuquén it is known from Tricao Malal in the north to El Salado Sur in central Neuquén (Figure 4).

3.2.12. The Crioceratites schlagintweiti Consecutive-Range Biozone

Aguirre-Urreta and Rawson (1993) proposed this biozone for the lower part of the former *Crioceratites andinum* Zone (Gerth 1925; Leanza 1981a,b; Riccardi 1984, 1988). It includes those beds immediately above the *Spitidiscus riccardii* Biozone in which the earliest Crioceratitinae, *Crioceratites schlagintweiti* (Giovine) and *C. apricus* (Giovine) (Figure 12E-F) (Giovine 1950, 1952), appear, initially overlapping with the last *Spitidiscus*. Both species closely resemble the European species *C. nolani* (Kilian) and *C. duvalii* (Léveillé) which are regularly open coiled forms that are characteristic of the European 'mid' Hauterivian. The biozone is geographically restricted to central Neuquén.

3.2.13. The Crioceratites diamantensis Consecutive-Range Biozone

This biozone was proposed by Aguirre-Urreta and Rawson (1993) for the upper part of the former *Crioceratites andinus* Zone. The nominal species *Crioceratites diamantensis* (Gerth) (Figure 12H) is the more common, and its first appearance defines the base of the biozone. Vermeulen (2004) has recently erected the new genus *Diamanticeras* for this species, but the authors are dubious about this new generic status.

C. diamantensis is usually associated with *Crioceratites andinus* (Gerth). This biozone is widespread in the basin from northern Mendoza to southern Neuquén.

At Pichaihue and a few other localities, some strongly tuberculate *Crioceratites* occur higher in this biozone, but are different from the *diamantensis-andinus* group and are associated with other unidentified crioceratitids with umbilical bundling ribs. This fauna may correspond to the *Crioceratites emerici*? Biozone of Leanza (1981a,b).

3.2.14. The Paraspiticeras groeberi Local Range Biozone

This zone, created by Aguirre-Urreta and Rawson (1993), has its base marked by the first appearance of *Paraspiticeras* (Figure 12G). The stratigraphic position is equivalent to the beds with *Silesites* aff. *S. vulpes* (Coquand) and *Holcodiscus seunesi* Kilian from the Sierra de la Cara-Cura (southern Mendoza) assigned to the Barremian by Groeber (1933). This biozone may encompass the latest Hauterivian to earliest Barremian interval.

At Mina San Eduardo, Pichaihue, Puesto Canale and Loma Tilhué (Figure 4), a few fragments of open coiled and hooked heteromorph ammonoids have been recovered from the highest beds of the Agua de La Mula Member, above *Paraspiticeras*.

3.3. Correlation with the Mediterranean 'standard' zonation

As shown in Sections 3.1 and 3.2, the Berriasian to earliest Barremian faunal successions of the Chañarcillo and Neuquén basins are closely comparable and easily correlated (Figure 13), though the Chañarcillo record is very incomplete. Figure 13 also shows the suggested correlation with the 'standard' Early Cretaceous zonation of the Mediterranean area (Hoedemaeker *et al*. 2003; Reboulet *et al*. 2006). This correlation is based essentially on the Neuquén succession. Aguirre-Urreta and Rawson (1997) first proposed a detailed correlation between the two areas, but subsequent taxonomic work coupled with new ammonite records from Neuquén led to some modifications to the initial correlations (Aguirre-Urreta *et al*. 2005).

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AGE		Chañarcillo Basin	Neuquén Basin		Tethys/Mediterranean (Reboulet *et al.* 2006)	
		Zones/Horizons	Zones	Subzones/ Horizons	Zones	Subzones/Horizons
BA.		*Paraspiticeras groeberi*	*Paraspiticeras groeberi*		*Taveraidiscus hugii*	
HAUTERIVIAN	Late				*Pseudothurmannia ohmi*	*Pseudothurmannia picteti*
						Pseudothurmannia catulloi
		Crioceratites diamantensis	*Crioceratites diamantensis*			*Pseudothurmannia ohmi*
					Balearites balearis	
			Crioceratites schlagintweiti		*Plesiospitidiscus ligatus*	
			Spitidiscus riccardii		*Subsaynella sayni*	
	Early		*Weavericeras vacaense*		*Lyticoceras nodosoplicatum*	
			Hoplitocrioceras gentilii	*Hop. gentilii*		
				Hop. giovinei		*Olcostephanus (O.) variegatus*
			Holcoptychites neuquensis	*Olcostephanus (O.) laticosta*	*Crioceratites loryi*	*O.(Jeannoticeras) jeannoti*
						Crioceratites loryi
				Hol. agrioensis	*Acanthodiscus radiatus*	
				Hol. neuquensis		
VALANGINIAN	Late		*Pseudofavrella angulatiformis*	*Neocomites* sp.	*Criosarasinella furcillata*	*Teschenites callidiscus*
				Chacantuceras ornatum		*Criosarasinella furcillata*
				P. angulatiformis		
		O. (Viluceras) permolestus	*Olcostephanus (O.) atherstoni*	*O. (Viluceras) permolestus*	*Neocomites peregrinus*	*Olcostephanus (O.) nicklesi*
		Olcostephanus (O.) atherstoni		*Karakaschiceras attenuatum*		*Neocomites peregrinus*
					Saynoceras verrucosum	*Karakaschiceras pronecostatum*
						Saynoceras verrucosum
	Early				*Busnardoites campylotoxus*	*Karakaschiceras biassalensis*
				O. atherstoni		*Busnardoites campylotoxus*
		Lissonia n.sp.	*Lissonia riveroi*		*Thurmanniceras pertriansiens*	
			Neocomites wichmanni	*Valanginites argentinicus*		
		Parandiceras				
BERRIASIAN	Late		*Spiticeras damesi*		*Subthurmannia boissieri*	*Thurmanniceras otopeta*
		Malbosiceras				*Tirnovella alpillensis*
						Berriasella picteti
						Malbosiceras paramimounum
	Mid		*Argentiniceras noduliferum*		*Subthurmannia occitanica*	*Dalmasiceras dalmasi*
						Berriasella privasensis
						Subthurmannia subalpina
	E.				*Berriasella jacobi*	

Figure 13. Correlation chart of the ammonoid biostratigraphy of the Chañarcillo, Neuquén and Mediterranean regions in the Berriasian-Early Barremian. Abbreviation: BA = Barremian.

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AGE		Chañarcillo Basin Zones	Chañarcillo Basin Horizons	Tethys/Mediterranean (Reboulet *et al.* 2006) Zones
ALBIAN	Early		*Neodeshayesites* sp.	*Douvilleiceras mammillatum*
ALBIAN	Early			*Leymeriella tardefurcata*
APTIAN	Late		*Hypacanthoplites* sp.	*Hypacanthoplites jacobi*
APTIAN	Late			*Acanthohoplites nolani*
APTIAN	Middle			*Parahoplites melchoris*
APTIAN	Middle			*Epicheloniceras martini*
APTIAN	Early			*Dufrenoya furcata*
APTIAN	Early		*Ancyloceras (Adouliceras)* sp.	*Deshayesites deshayesi*
APTIAN	Early	*Hemihoplites perezi*		*Deshayesites weissi*
APTIAN	Early	*Hemihoplites perezi*		*Deshayesites oglanlensis*
BARREMIAN	Late	*Antarcticoceras domeykanum*		*Martelites sarasini*
BARREMIAN	Late	*Antarcticoceras domeykanum*		*Imerites giraudi*
BARREMIAN	Late	*Antarcticoceras domeykanum*		*Hemihoplites feraudianus*
BARREMIAN	Late	*Antarcticoceras domeykanum*		*Gerhardtia sartousiana*
BARREMIAN	Late	*Antarcticoceras domeykanum*		*Toxancyloceras vandenheckii*
BARREMIAN	Late			*Holcodiscus uhligi*
BARREMIAN	Early	*Moutoniceras* sp.	*S. africanum insignicostatum*	*Coronites darsi*
BARREMIAN	Early			*Kotetishvilia compressissima*
BARREMIAN	Early	*Emericiceras*		*Nickesia pulchella*
BARREMIAN	Early	*Emericiceras*	*E.* aff. *E. otto-hassi*	*Kotetishvilia nicklesi*
BARREMIAN	Early	*Shasticrioceras*		*Taveraidiscus hugii*

Figure 14. Correlation chart of the ammonoid biostratigraphy between the Chañarcillo and Mediterranean regions in the Barremian-Albian.

Some ammonites recorded from the Berriasian to earliest Barremian of the Chañarcillo Basin have not been found in the Neuquén Basin and provide some additional clues for long-distance correlation. The earliest Chañarcillo ammonites, *Malbosiceras* of the *malbosi* group, show close affinities with the Mediterranean species *Malbosiceras malbosi*, which was recorded by Le Hégarat (1980) and Nikolov (1982) from the base of the

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Subthurmannia boissieri Zone of the Mediterranean zonation (Hoedemaeker *et al*. 2003). Hence the *Malbosiceras* Zone of the Chañarcillo Basin could correspond to the lower Upper Berriasian.

The occurrence of neocomitid ammonites in the *Olcostephanus* (*Viluceras*) *permolestus* Subzone is of particular interest, as so far, none have been found at that level in the Neuquén Basin. Although they have yet to be described, the identification of *Neocomites peregrinus* as one of the components would suggest that the *permolestus* Zone/Subzone, currently provisionally correlated with the *Olcostephanus (O.) nicklesi* Subzone of the Mediterranean region, could equate also with at least part of the *N. peregrinus* Subzone. That is indicated on Figure 13.

The (undescribed) record of *Sabaudiella simplex* from the *Paraspiticeras groeberi* Biozone would strengthen the view that at least part of this zone is latest Hauterivian, according to the age of this taxon quoted by Busnardo (in Busnardo *et al*. 2003, p. 80).

The youngest ammonoids recorded from the Neuquén Basin are of earliest Barremian age, but in the Chañarcillo Basin faunas of later Barremian, Aptian and earliest Albian age occur. The suggested correlation of this part of the sequence with the Mediterranean one (Reboulet *et al*. 2006) is summarized in Figure 14, and is based mainly on data in Morgues (2007). Again, there are some significant gaps in the record, especially in the Aptian.

4. PALAEOBIOGEOGRAPHIC RELATIONSHIPS

The Berriasian to earliest Barremian faunas of the Chañarcillo and Neuquén basins are very similar and composed totally of Tethyan-derived taxa, some of which are endemic to the Andean Province. But it is noteworthy that at some levels there are additional elements in the Chañarcillo faunas that are not known from Neuquén. This may reflect the palaeogeographical setting, for the Chañarcillo Basin was closer to the mid-latitudinal belt where there was the greatest diversity of ammonite genera during the Early Cretaceous. The evolving biogeographical relationships of these faunas are discussed by Rawson (2007).

The Barremian to earliest Albian faunas of the Chañarcillo Basin are again of Tethyan origin, but there is much less evidence of biogeographically limited taxa and there is little hint of a distinctive 'Andean' fauna. They are thus reflecting a global trend in the breakdown of the previously strong pre-Aptian faunal differentiation across the Cretaceous world as the great sea-level rises of the mid Cretaceous commenced (Rawson 1981). Hence, some of the Chañarcillo heteromorph genera, such as *Emericiceras* and *Ancyloceras*, have an almost global distribution. On the other hand, *Shasticrioceras* is known mainly from other 'Pacific' areas, particularly California and Japan, while *Antarcticoceras* was previously recorded only from Antarctica. Among the normally coiled ammonites, *Sanmartinoceras* ranges from Antarctica to Greenland, though the species recorded from the Chañarcillo Basin is a form known mainly from the Austral basin and South Africa. *Nicklesia* is characteristic of the low latitude belt extending from Colombia to the Mediterranean region, while *Hypacanthoplites* follows a similar east-west trend, but spread further northwards onto the shallow seas from England eastward to Iran. Thus the Chañarcillo Barremian to earliest Albian faunas are a heterogeneous group dominated by very widely distributed taxa.

5. CONCLUSIONS

The Chañarcillo and Neuquén basins have a common geologic history from the Berriasian to the earliest Barremian and share many Andean genera, together with some pandemic taxa that provide good correlation points with the Mediterranean.

From the Barremian onwards the geological evolution of the two basins diverged: while in the Chañarcillo Basin marine conditions persisted till Early Albian times, in the Neuquén Basin evaporites and continental clastics of the Huitrín Formation witness the disconnection with the Pacific ocean, except for a short-lived marine invasion represented by the carbonates of the La Tosca Member of the Huitrín Formation. This disconnection seems to be related to the development of a robust volcanic arc during Aptian-Albian times.

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The knowledge of the Cretaceous Andean ammonoid faunas of both sides of the Andes has shed light in the evolution of the Cretaceous basins of the western margin of Gondwana and shows the importance of a systematic approach to the study of this fundamental group of Mesozoic fossils.

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