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Advances in ammonite biostratigraphy of the marine Atacama basin (Lower Cretaceous), northern Chile, and its relationship with the Neuquén basin, Argentina

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Abstract

Preliminary results about the Lower Cretaceous ammonite biostratigraphy of northern Chile reveal eight fossiliferous levels: Lower–Upper Valanginian neocomitid and olcostephanid faunas in the Punta del Cobre and Abundancia Formations and Upper Hauterivian–Barremian crioceratid in the Nantoco, Totoralillo, and Pabellón Formations. The faunal affinities with the Neuquén are strong during the Valanginian and Hauterivian. In contrast, during the Barremian and Aptian, the ammonites show affinities with Austral, California, and Tethys basinal faunas. The Lower Valanginian–lower Upper Aptian series in northern Chile comprises two sedimentary cycles separated by a regressive pulse of Upper Hauterivian–Lower Barremian age. This pulse may be equivalent to the regression that ended the Early Cretaceous marine cycle in central Chile and central west Argentina, where the second marine sedimentary cycle observed in northern Chile is not represented.

Keywords: Ammonites; Biostratigraphy; Lower Cretaceous; Northern Chile; Paleogeography

Resumen

Los resultados preliminares de las actuales investigaciones acerca de la bioestratigrafía de ammonites del Cretácico Inferior del norte de Chile, revelan ocho niveles fosilíferos a través de la secuencia: neocomítidos y olcostefánidos valanginianos provenientes de las formaciones Punta del Cobre y Abundancia y criocerátidos de edades hauteriviano superior-barremianas provenientes de las formaciones Nantoco, Totoralillo, y Pabellón. Las afinidades faunísticas con la Cuenca de Neuquén son fuertes durante el Valanginiano-Hauteriviano, sin embargo, durante el Hauteriviano superior-Barremiano, se registran afinidades con las cuencas Austral, de California y Tethysiana. Las series del Valanginiano-Aptiano superior bajo comprenden dos ciclos sedimentarios con un pulso regresivo en el Hauteriviano superior-Barremiano inferior. Este último podría ser equivalente a la regresión que puso fin al ciclo marino en Chile Central y el Centro oeste de Argentina, donde no está representado el segundo ciclo sedimentario marino observado en el norte de Chile.

1. Introduction

The biostratigraphy of the Lower Cretaceous from the Atacama region, northern Chile, was established in the 1960s and 1970s (Tavera, 1956; Corvalán, 1974). Current geological surveys in this zone enable the reevaluation of the faunas and reassessment of their ages. New material has been collected from several localities in the Lower Cretaceous sequences from Copiapó to Vallenar (Atacama basin). In this paper, we present preliminary results about biostratigraphic investigations on the Valanginian–Aptian levels of the Chañarcillo Group in the Precordillera of northern Chile (27–29°S). We aim to provide preliminary updated information on the ammonite biostratigraphy of the Atacama basin on the basis of current research, along with comments on faunal affinities and possible correlations. Fossil identifications are based on both the available published literature and preliminary unpublished reports (SERNAGEOMIN).

The illustrated specimens are housed in the Colección Paleontología, Geological and Mining Survey of Chile, Santiago (SNGM).

2. Regional setting

Lower Cretaceous sedimentation in northern Chile is characterized by a regional facies change, with volcanic

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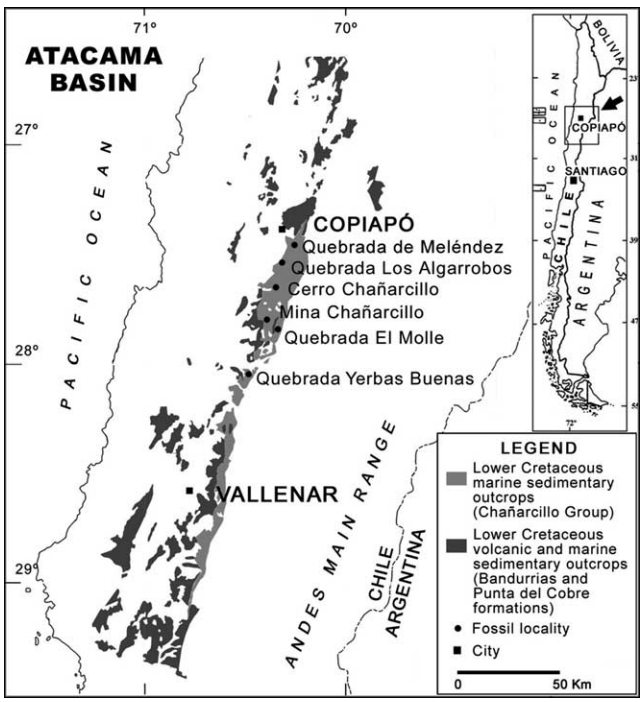

Fig. 1. Distribution of the major facies of the Lower Cretaceous Atacama basin (SERNAGEOMIN, 1982). The main fossil localities are indicated.

and volcanogenic facies to the west and carbonate marine facies to the east (Fig. 1). This characterization has been interpreted as a transition from an eastern backarc basin to a magmatic arc setting (Coira et al., 1982).

The Atacama basin (Fig. 1) is a backarc basin formed on a convergent continental margin and one of the five discrete Early Cretaceous basins identified by Aguirre-Urreta (1993) in the southern central Andes. During the Valanginian–Aptian marine cycle, up to 2000 m of sediment accumulated, interfingered with volcaniclastics to the west and northwest (Segerstrom, 1963).

The sedimentary sequences have been classified in the Chañarcillo Group (Segerstrom and Parker, 1959). Their outcrops extend as a NNE-trending belt from Vallenar (28°25′S) to Copiapó (27°20′S), parallel to the Andean main range (Fig. 1). The clastic input increases to the south (Corvalán, 1974). From base to top, the sequence is made up of the following formations, defined by Biese (in Hoffstetter et al., 1957) (Fig. 2): Abundancia, Nantoco, Totoralillo, and Pabellón. The Abundancia Formation consists of well-laminated gray mudstones interbedded with arkoses that pass vertically and laterally into limestones of the Nantoco Formation, which includes a lower member formed by homogeneous gray mudstones and wakestones and an upper

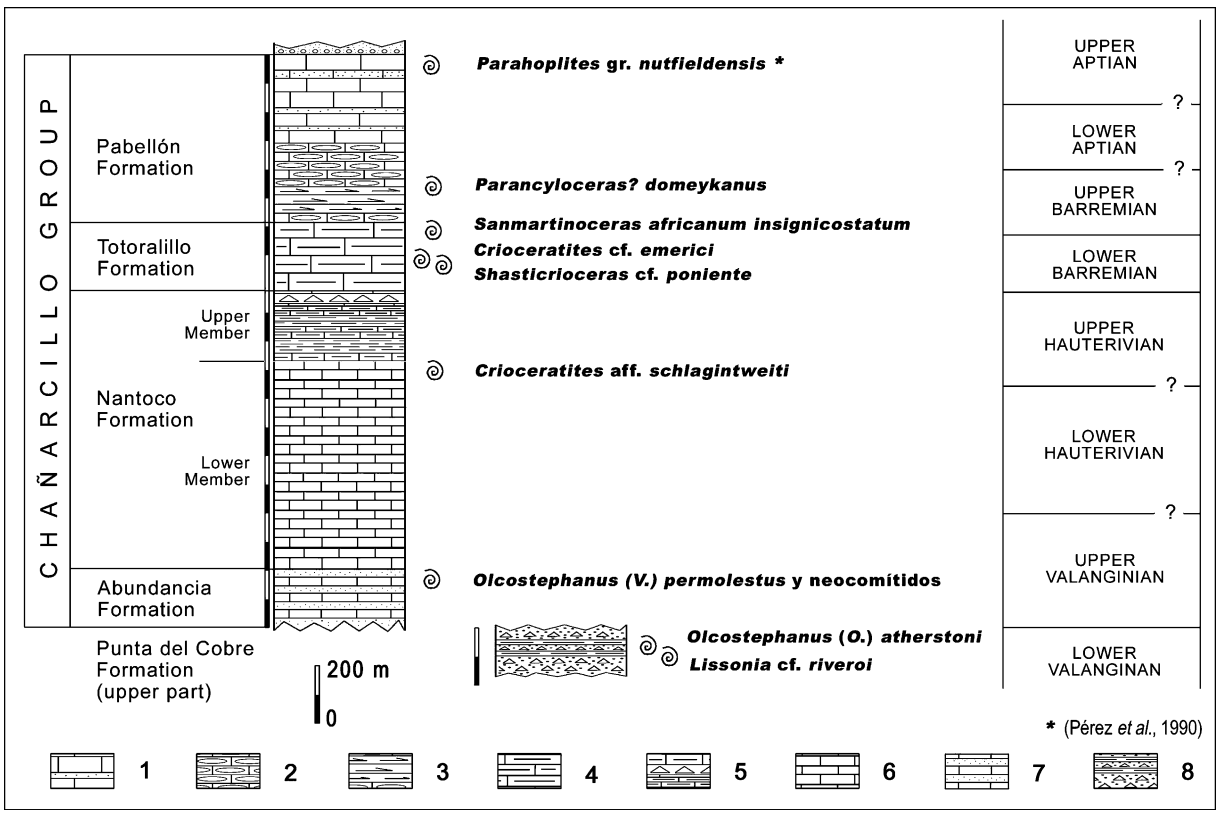

Fig. 2. Schematic stratigraphic section of the Chañarcillo Group and upper part of the Punta del Cobre Formation. The occurrence of the main ammonites are indicated. (1) Calcareous sandstones, (2) cherty limestones, (3) chert, (4) laminated marls, (5) mudflat facies, limestones, and calcareous breccia with evaporitic matrix, (6) homogeneous gray mudstones and wakestones, (7) well-laminated grey mudstones interbedded with arkoses, and (8) volcaniclastic breccia with sedimentary layers.

member formed by calcareous breccias with an evaporitic matrix. The upper member of the Nantoco Formation constitutes a conspicuous unit within the Atacama region that can be recognized over approximately 180 km, from Quebrada de Meléndez (27°29′S) to Quebrada Las Breas (29°07′30″S). The presence of mudflat facies, the existence of evaporitic minerals in the breccia matrix, and the fragmentation of the limestones have been interpreted as subtidal to supratidal deposits that evince an important regression phase in the basin (Segerstrom, 1960; Cisternas and Díaz, 1990). The Nantoco Formation is overlain by well-laminated, pink to yellow marls of the Totoralillo Formation. The last unit is the Pabellón Formation, which consists of chert, cherty limestones, calcareous sandstones, and mudstones; the upper strata consist of a sequence of shallow marine sediments, which represent the regressive stage closing the last Early Cretaceous marine sedimentary cycle in the basin.

The Chañarcillo Group interfingers to the north and west with marine and continental volcanic rocks and conglomerates of the Bandurrias Formation (Segerstrom, 1960; Segerstrom and Ruiz, 1962). Elsewhere, the Chañarcillo Group lies on the Punta del Cobre Formation (Segerstrom and Ruiz, 1962), which is compounded by a pile of andesitic to basaltic andesitic lava flows, conglomerates, sandstones, tuffs, and dacitic dome complexes with sedimentary layers in its upper levels. The contact between this unit and the overlying Abundancia Formation is transitional and has been defined by the first occurrence of a continuous bed of massive limestone or its metamorphosed equivalent. The transgressive nature of the sedimentary part of the Punta del Cobre Formation marks the onset of increased subsidence that eventually culminated in the Early Cretaceous marine backarc basin south of Copiapó (Marschik and Fontboté, 2001). In agreement with Arévalo (1994, 1995, 1999), we consider that the Punta del Cobre and Abundancia Formations are separated by a structural discontinuity.

3. Biostratigraphy

3.1. Biostratigraphic background

Biostratigraphic knowledge of the Atacama basin is based on paleontological and stratigraphical work initiated in the nineteenth century (Bayle and Coquand, 1851; Hupé in Gay, 1854a,b; Paulcke, 1903; Fritzsche, 1923; Tavera, 1956; Corvalán, 1974; Pérez et al., 1990).

Ammonites, which are abundant at the top of the Abundancia and Punta del Cobre Formations, are Lower–Upper Valanginian olcostephanid and neocomitid faunas and represent the oldest ammonites in the succession. Among these, *Olcostephanus curacoensis* (Weaver) was identified from the Abundancia Formation (Tavera, 1956; Corvalán, 1974) (= *O. atherstoni* (Sharpe) in agreement with Riccardi et al., 1971; Aguirre-Urreta and Rawson, 1997). Corvalán (1974; see also Segerstrom et al., 1963) mentions its presence in the Abundancia Formation. Segerstrom (1960) and Arévalo (1995) report it in Quebrada Los Algarrobos from the Punta del Cobre Formation. These authors also report *Lissonia riveroi* (Lisson) from the same locality and formation, and Tilling (1962) and Marschik and Fontboté (2001) report the Berriasian ammonite *Cuyaniceras* sp. Tavera (1956) and Corvalán (1974) propose a Valanginian age for the beginning of the marine deposition in the basin (Punta del Cobre–Abundancia Formations boundary), in agreement with Weaver's (1931) interpretations of the Lower Cretaceous of central west Argentina.

Specimens of *Crioceras andinum* Gerth was reported in the lower part of the upper Nantoco Formation and the middle Totoralillo Formation, thus establishing a correlation with the Upper Hauterivian beds of the Neuquén basin (Tavera, 1956; Corvalán, 1974). Corvalán (1974) cites *Crioceras diamantense* Gerth and *Ancyloceras* sp. from the Totoralillo Formation. Jurgan (1977) reports *Crioceratites* cf. *hildesiense* (von Koenen), *Shasticrioceras inflatum* Anderson, *Shasticrioceras whitneyi* Anderson, *Shasticrioceras* sp. and *Menuthicrioceras* sp. juv. from beds of the Totoralillo Formation.

Until Pérez et al. (1990), the estimate of the minimum age of the Pabellón Formation (top of Chañarcillo Group) was Late Barremian-Aptian (Tavera, 1956), based on corals and bivalves, or Late Barremian (Corvalán, 1974), based on the presence of the rudist *Agriopleura blumenbachi* (Studer), characteristic of that stage in Europe (Fritzsche, 1923). The discovery of the ammonite *Parahoplites* gr. *nutfieldiensis* (J. Sowerby) in the upper part of the Pabellón Formation indicates an early Late Aptian minimum age for the unit, which enabled Pérez et al. (1990) to postulate the same age for the top of the Lower Cretaceous marine sedimentary cycle in the Andean basin of Chile and Argentina.

The Atacama ammonite assemblages are comparable to those of the Neuquén region and the ammonite faunas of southeastern France and California. However, a continuous zonation hitherto has not been possible because the ammonite record is present only at some levels in the sequence.

3.2. Ammonite succession

The ammonite sequence recognized in this work comprises the following taxa in stratigraphic order (Fig. 3):

- *Lissonia* cf. *riveroi* (Lisson) (Fig. 5). In the Neuquén basin, Aguirre-Urreta and Rawson (1999a) define the *Lissonia riveroi* zone at the top of the Vaca Muerta Formation and its equivalents. It is present in the upper part of the Punta del Cobre Formation in Quebrada Los Algarrobos (Fig. 1), has been found below *Olcostephanus* (*O.*) *atherstoni* (Sharpe), and is separated from the latter by approximately 50 m of volcanic

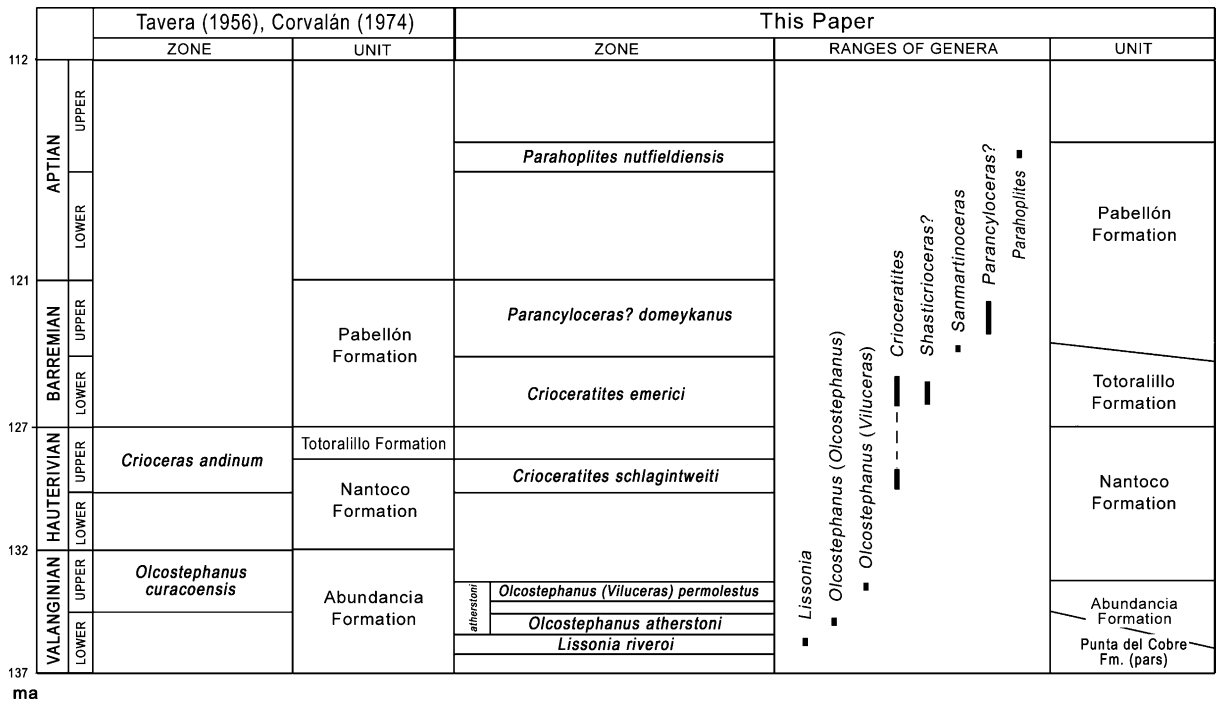

Fig. 3. Present and former zonations of the Valanginian–Aptian of the Atacama basin. The stratigraphic ranges of all genera present are indicated. The numerical timescale is based on Gradstein et al. (1996).

breccias and volcanic sandstones. We associate the Chilean specimens to the middle Lower Valanginian on the basis of their affinities with Argentinean faunas (Aguirre-Urreta and Rawson, 1999a,b).

- *Olcostephanus* (*Olcostephanus*) *atherstoni* (Sharpe) (Fig. 5). This species appears in the upper levels of the Punta del Cobre Formation, Quebrada Los Algarrobos, where we assign it to the upper Lower Valanginian, in agreement with Aguirre-Urreta and Rawson (1997, 1999a,b). This taxon also is present in the upper part of the Mulichinco Formation and the basal beds of the Agrio Formation in the central part of the Neuquén basin (Fig. 4).
- *Olcostephanus* (*Viluceras*) *permolestus* (Leanza) (Fig. 5). This taxon is associated with *Acanthodiscus* (?) sp. and *Neocomites* (?) sp. and appears in the upper levels of the Abundancia Formation, Quebrada de Meléndez. The *Olcostephanus* (*Viluceras*) *permolestus* subzone occurs higher in the *Olcostephanus atherstoni* zone in the Neuquén basin (Aguirre-Urreta and Rawson, 1999a,b). The base of the *Olcostephanus* (*Viluceras*) *permolestus* subzone is defined by the first appearance of evoluted olcostephanids and is just beneath the *Pseudofavrella angulatiformis* fauna. We ascribe the material from the Atacama basin to the lower–middle Upper Valanginian, *Olcostephanus* (*Viluceras*) *permolestus* subzone (Aguirre-Urreta and Rawson, 1999a,b).
- *Crioceratites* aff. *schlagintweiti* (Giovine) (Fig. 5). The *Crioceratites schlagintweiti* zone was proposed by Aguirre-Urreta and Rawson (1997) for the lower part of the former *Crioceratites andinus* zone, in the lower part of the Upper Hauterivian of the Neuquén basin. In the Atacama basin, the specimens are located in upper beds of the lower member of the Nantoco Formation, Quebrada de Meléndez.
- *Shasticrioceras* cf. *poniente* Anderson (Fig. 6). This ammonite appears slightly below *Crioceratites* cf. *emerici* Léveillé in the middle part of the Totoralillo Formation, in the Mina Chañarcillo locality (Fig. 1). Anderson (1938) describes the species for the Lower Barremian in California. More recent studies cite *Shasticrioceras poniente* Anderson in the Upper Barremian of the same region (Murphy, 1975) and suggest that it could reach the Lower Aptian. We preliminarily propose an Early Barremian age.

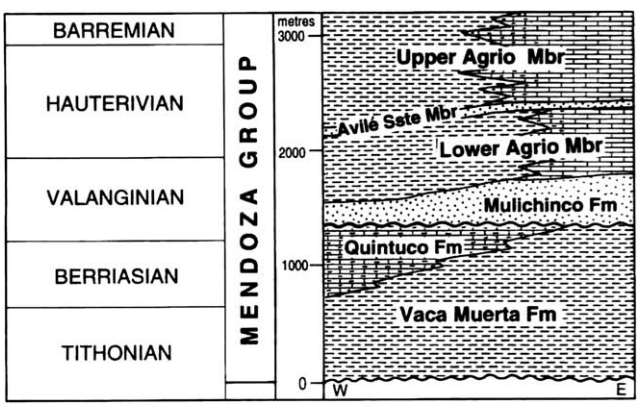

Fig. 4. Schematic stratigraphic section of the Mendoza Group (Aguirre-Urreta and Rawson, 1997).

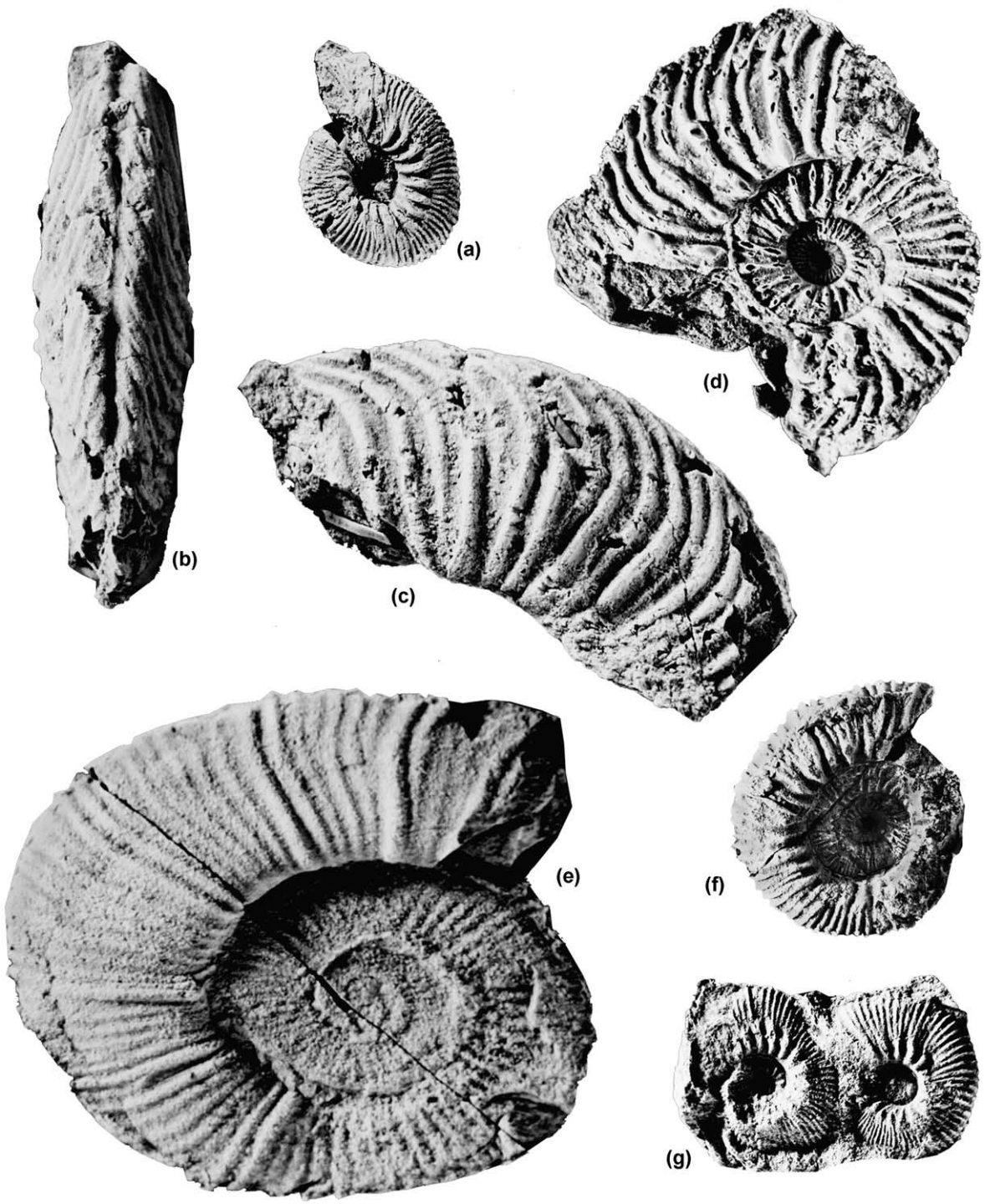

Fig. 5. Valanginian–Hauterivian faunas from the Atacama basin. All specimens are deposited in the paleontological collection of the SERNAGEOMIN (SNGM), Santiago, Chile. All photographs × 1. (a, g) *Olcostephanus* (*Olcostephanus*) *atherstoni* (Sharpe), SNGM-1021 [14,10,11], Quebrada Los Algarrobos (27°34′20″S, 70°17′35″W), upper Lower Valanginian. (b-d) *Lissonia* cf. *riveroi* (Lisson), SNGM-1025[17], Quebrada Los Algarrobos (27°34′20″S, 70°17′35″W), middle Lower Valanginian. (e) *Crioceratites* aff. *schlagintweiti* (Giovine), SNGM-1028[2], Quebrada de Meléndez (27°29′S, 70°13′20″W), lower Upper Hauterivian. (f) *Olcostephanus* (*Viluceras*) *permolestus* (Leanza), SNGM-1023[2], Quebrada de Meléndez (27°28′10″S, 70°14′15″W), lower Upper Valanginian.

- *Crioceratites* cf. *emerici* Léveillé (Fig. 6). Presenting a wide regional extension in the middle part of the Totoralillo Formation, this taxon has a coiling looser than *Crioceratites andinus* (Gerth), which was mentioned in these levels by Tavera (1956); Corvalán (1974). We compare the ammonites with the Mediterranean species and assign them to the Lower Barremian (Sarkar, 1955; Thomel, 1964).

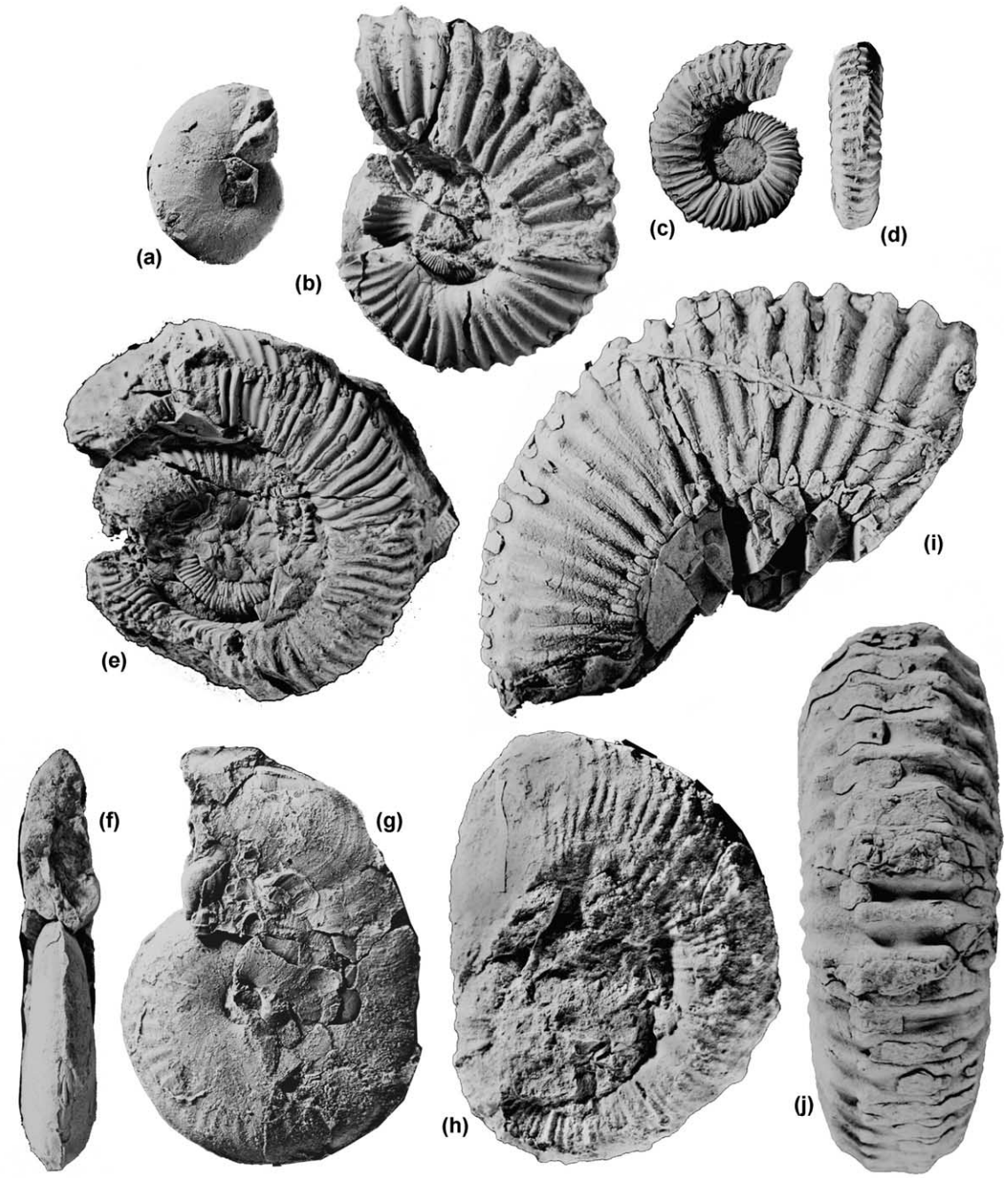

Fig. 6. Barremian faunas from the Atacama basin. All specimens are deposited in the paleontological collection of the SERNAGEOMIN (SNGM), Santiago, Chile. Photographs × 0.6, except (a, b, and h) (× 0.8) and (e) (× 0.4). (a, f, g) *Sanmartinoceras africanum insignicostatum* Riccardi, Aguirre-Urreta and Medina, SNGM-1021[1,2], Quebrada de Meléndez (27°29′20″S, 70°12′35″W), lower Upper Barremian. (b) *Parancyloceras? domeykanus* (Bayle and Coquand), SNGM-1039[34], Quebrada El Molle (27°53′S, 70°21′30″W). (c–e) *Shasticrioceras* cf. *poniente* Anderson, SNGM-1035 [1,2], Mina Chañarcillo (27°49′-50′S, 70°21′-23′W), Lower Barremian. (h) *Crioceratites* cf. *emerici* Léveillé, SNGM-1235[7], Quebrada Yerbas Buenas (70°27′42″W; 28°03′21″S), Lower Barremian. (i, j) *Parancyloceras? domeykanus* (Bayle and Coquand), SNGM-1039 [8], Cerro Chañarcillo (27°43′15″S, 70°19′15″W), Upper Barremian (?).

- *Sanmartinoceras africanum insignicostatum* Riccardi, Aguirre-Urreta and Medina (Fig. 6). We have found it in a single horizon close to the top of the Totoralillo Formation, Quebrada de Mélendez, and in agreement with Riccardi et al. (1987) we assign it to the Upper Barremian.
- *Parancyloceras? domeykanus* (Bayle and Coquand) (Fig. 6). This taxon is very common in the basin and appears in several localities at the base of the Pabellón Formation (e.g. Quebrada de Meléndez, Cerro Chañarcillo, Quebrada El Molle) (Fig. 1). It is assigned to the Upper Barremian (?), but a Early Aptian age cannot be discarded.

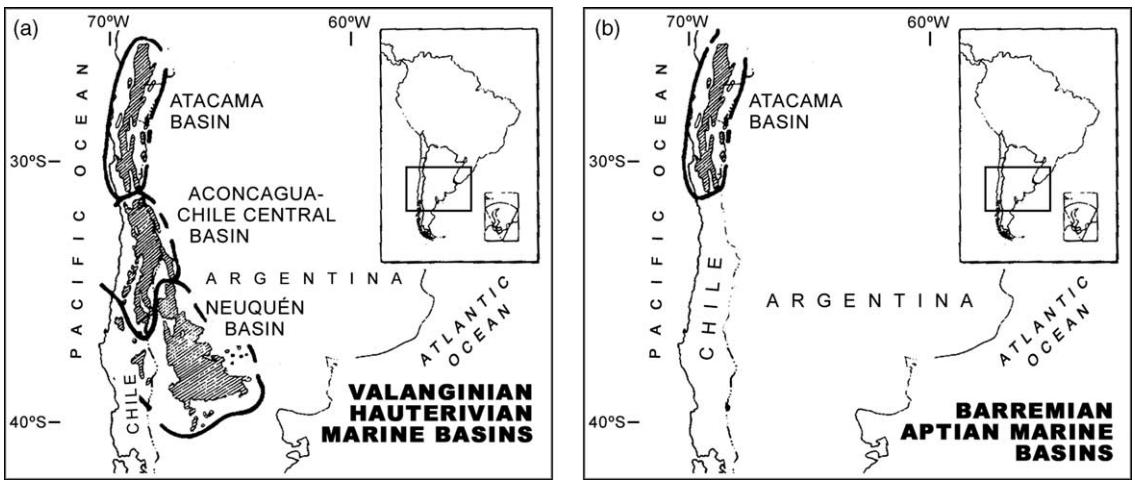

Fig. 7. Paleogeographic evolution of Lower Cretaceous marine basins in the southern central Andes (modified from Aguirre-Urreta, 1993).

This species was described by Bayle and Coquand (1851), and *Ammonites verrucosus* Hupé (in Gay, 1854a,b) may be a synonym. Tavera (1956) and Corvalán (1974) mention *Crioceras* sp. at the base of the Pabellón Formation, which also could correspond to the same taxon.

- *Parahoplites* gr. *nutfieldiensis* (J. Sowerby). This specimen was found at the top of the Pabellón Formation (Pérez et al., 1990). The *Parahoplites nutfieldiensis* zone, present in southern England and northern Germany, is correlated with the *Epicheloniceras subnodosocostatum* zone of southeast France (Rawson, 1983). This zone corresponds to the lower Middle Aptian in the Mediterranean realm (Rawson et al., 1999).

4. Relationships with the Neuquén and other Early Cretaceous basins: Paleogeographic implications

The Valanginian-Upper Hauterivian ammonite faunas of the Atacama basin have common elements with those of the Neuquén basin (*Lissonia* cf. *riveroi*, *Olcostephanus* (*O.*) *atherstoni*, *Olcostephanus* (*V.*) *permolestus*, *Crioceratites* aff. *schlagintweiti*). However, the associations from the Lower Barremian also show affinities with the California (*Shasticrioceras* cf. *poniente* Anderson) and Mediterranean (*Crioceratites* cf. *emerici* Léveillé) domains. Paleogeographically, sporadic discoveries of exceptionally well-preserved shells of *Sanmartinoceras africanum insignicostatum* Riccardi, Aguirre-Urreta and Medina are very interesting because of their relationship with the Austral basin. As the northernmost record of the austral genus *Sanmartinoceras* in South America, this relationship suggests a connection between the Atacama and Austral basins during the Late Barremian–Early Aptian.

Marine deposition in the Copiapó-Vallenar area started in the Early Valanginian and finished in the Late Hauterivian–Early Barremian (?) with a regressive pulse represented by the upper member of Nantoco Formation (Cisternas and Díaz, 1990). According to its evaporitic lithology and stratigraphic position above the *Crioceratites schlagintweiti* zone, this unit could be equivalent to the Huitrín Formation in west central Argentina, which lies on the Mendoza Group (Fig. 4). In the Atacama region, marine deposition started again during the Early Barremian (Fig. 2), whereas in the Neuquén basin, the sedimentation during this time is mainly represented by continental and marine-continental successions (Legarreta and Uliana, 1999). In addition, the youngest level of the Mendoza Group in the Neuquén basin consists of *Paraspiticeras* fauna, assigned to the base of the Lower Barremian (Aguirre-Urreta and Rawson, 1997); in the Aconcagua area, it corresponds to the crioceratid fauna of the Upper Hauterivian *Crioceratites diamantensis* zone (Aguirre-Urreta and Lo Forte, 1996). Until now, there have been no reports of ammonites younger than Late Hauterivian–Early Barremian in west central Argentina. Therefore, we postulate the same age for the regressive pulse in the Atacama basin of northern Chile and the end of the Lower Cretaceous marine sedimentary cycle in the Neuquén basin of Argentina and other marine basins of central Chile. Moreover, the Totoralillo and Pabellón Formations represent a second marine sedimentary cycle that developed during the Barremian-Aptian in northern Chile. This cycle is not represented in the Neuquén or central Chile regions (Fig. 7).

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